WORLD ELECTRICITY CO-OPERATION

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ABSTRACT

This thesis evaluates the effect of electricity co-operation regarding import and export on electricity prices for OECD countries and on CO_2 emissions for the world. In addition, the study investigates which kinds of renewable energies provide the best economic future for Canada and the U.S. There are three main sections to the thesis.

Firstly, panel data analysis determines the electricity price functions, using 29 OECD countries' yearly data from 1980 to 2007. Membership of the European Union, used to investigate effect of high level co-operation on price, is seen to decrease household and industry prices, but is not significant for household price. The effect of electricity trading in OECD countries is not found to deliver cheaper electricity suggesting that these countries need to co-operate more closely to increase competition and improve efficiency in electricity markets.

Secondly, panel data analysis determines parameters of the CO_2 emissions function, using 131 countries' yearly data from 1971 to 2007. The world results show that electricity co-operation is highly significant in decreasing CO_2 emissions per unit of generation, thus supporting the hypothesis. At the continent level, Asia shows the highest CO_2 decrease from electricity import, with the lowest decrease being for Africa. Electricity export for North America, Latin America and Europe is found to be highly significant in decreasing CO_2 emissions.

Finally, time series analysis of yearly data for Canada and the U.S. from 1978 to 2009 is used to determine the electricity price functions. For Canada, electricity import is found to be highly significant in decreasing household electricity price, but not so for the U.S. Renewable energies such as wind and hydro are seen to be the future of electricity generation for Canada, but the results for the U.S. indicate that no type of renewable energy can reduce electricity price.

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CHAPTER ONE

WORLD ELECTRICITY CO-OPERATION

World electricity generation more than tripled from 5,256 terawatt-hours (TWh) in 1971 to 18,307 TWh in 2005, and it is forecasted to reach 63,000 TWh by 2050. Although developed economies generate the major part of the world's electricity, with the Organisation for Economic Co-operation and Development (OECD) countries responsible for 57% of world generation in 2005, most electricity demand growth arises from developing countries (The Treasury, Australian Government, 2011; IEA, statistic).[1] While electricity generation is predicted to increase, electricity demand is expected to grow more slowly than output (EIA, 2011), resulting in greater electricity surplus providing opportunity for international trade.

International electricity trade brings many advantages. Firstly, countries are able to more effectively utilize complementary resources, such as exporting hydro-generated electricity for peak demand and importing thermal power during off-peak times. Secondly, it makes it possible for countries to balance seasonal supply and demand variations, for example reduction of hydro reserves as a result of lower rainfall, or increased power usage as a result of colder weather. Thirdly, international electricity trade caters for discrepancies between anticipated and actual usage, for example underestimation of demand growth can be offset by imports. A further advantage is the availability of reserve capacity pooling which lessens the need for more power stations and reduces inefficient dispatch of power plants needed for the provision of spinning

[1] India and China are expected to account for 35% and 16% respectively of the growth from 2005 to 2050 (The Treasury, Australian Government, 2011; IEA, statistic).

reserve.[2] Therefore, international electricity exchange improves the efficiency of the electricity industry in the planning, operation and maintenance of generation facilities, lowers investment requirements, and optimizes system function by distribution of maintenance outages (Neuhoff, 2011).[3]

Electricity trading originated as the result of a search for more reliability in supply with local pooling by small, independent producers leading to regional and international systems. A connection between Canada and the United States (U.S.) in 1901 was the first recorded international electricity agreement while Europe's first was between Austria and Germany in 1929. Today, there exist many regional interconnected systems – in Western Europe (UCPTE), Scandinavia (NORDEL), the United Kingdom, Central Europe (CENTREL, formerly IPS), Eastern Europe (UPS), North America, Central and South America, southern Africa (SADC), and Asia (Charpentier, 1995).[4]

The different price levels across regions due to various demand and supply situations encourage systematic exploitation by cross-border trading and dictate the direction of the electricity traded (Scheepers et al., 2003). International exchange

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[2] Spinning reserve refers to more generation capacity made available by raising the power output of generators already part of the power system.

[3] Available at: http://scholar.googleusercontent.com/scholar?q=cache:ahT3jQG7FUsJ:scholar google.com/+electricity+trade&hl=en&as_sdt=0,5&as_vis=1

[4] Acronyms and abbreviations: UCPTE is an association of 22 Western European companies. NORDEL, formed in 1963, is an association of companies from Denmark, Finland, Iceland, Norway, and Sweden. CENTREL is an association of companies from Hungary, Poland, and the Czech and Slovak Republics. Before the collapse of the Soviet Union, the association was known as IPS. SADC, the Southern African Development Community, comprises 12 countries in southern Africa. A Southern African Power Pool (SAPP) has recently been formed (Charpentier, 1995).

affords the opportunity for traders to buy electricity in low-price markets and sell in higher-price markets thus reducing their outlay and allowing cheaper electricity for the consumer. Justus (1997) further states that electricity co-operation with regard to import and export causes market reform leading to reduced prices due to pressure of competition. Countries providing examples of such price reduction include Norway and the United Kingdom, among others. Furthermore, producers and consumers can protect themselves against risk from price volatility by reducing their dependence on individual or regional markets. The ability to be able to choose from the offerings of a wide, international electricity market is important in this regard.

As stated by Odgaard (2000), international electricity trade can exploit comparative resource advantages and lower costs.[5] Furthermore, the sharing of operational reserves and installed capacity reduces the need for additional investment in generation infrastructure (Economic Commission for AfricaSS, 2004). In addition, through markets, trade makes the sale of one type of output for other more highly valued goods possible (Samuelson and Nordhaus, 2004, Ch. 2). For electricity markets, this gives suppliers more incentive to export, thus allowing importing countries an increase in security, including emergency supply and reliability of electricity supply. Hence, trade in electricity leads to lower cost of production, reduced price for consumers, and security and reliability benefits.

However, applying trade theories to international electricity markets has to be of concern to policy makers because, as a commodity, electricity is unique in many ways.

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[5] The World Bank confirms that UCPTE, an association of Western European companies, saves between 3% and 10% overall as a result of regional interconnection. Similar savings are realized in the U.S. through interconnection (Charpentier, 1995). In the Nordic case, cross-border trade in electricity is shown to lower abatement cost by between 10% and 60% (Unger and Ekvall, 2003).

It possesses the quality of intangibility which has traditionally been associated with the classification of something as a service.[6] Whereas international trade involves countries exchanging different goods, for international electricity trading the exchange is a perfectly homogeneous commodity (Pennings and Heijman, 1995), with the end product being the same irrespective of its method or source of generation. Even though electricity is exchangeable and suitable for trading, it needs bounded conduction,[7] hence no global market for electricity trade exists (Barouti and Hoang, 2011).

In electricity markets there are generally two main categories of products. Those traded for actual physical delivery are known as *physical products*, as for example, when the traded amount of electricity is actually delivered to the buyer by the

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[6] Because of the unique characteristics of electricity, the General Agreement on Tariffs and Trade (GATT) has never considered it as a commodity since the late 1940s (Mattoo and Sauvé, 2003, p. 176). There is an argument about electricity's status. Some regard electricity as a good that can be stored in batteries and transferred from one place to another. Others say that it is not, because there is no way to see or touch electricity as a physical good, and that providing electricity is a service (Barouti and Hoang, 2011). This study sees electricity providers as selling a service which is not a good, in the meaning of an item that is bought and sold.

[7] Mill (1848) refers to network industries, such as electricity, as "practical monopolies" where "it is the part of the government, either to subject the business to reasonable conditions for the general advantage, or to retain such power over it that the profits of the monopoly may at least be obtained for the public". Furthermore, the monopolistic nature of the electricity sector arises where the largest supplier, in many cases the first supplier in the market, enjoys an overwhelming cost advantage over other actual or potential competitors. This is often the case in industries where fixed cost predominates, giving rise to economies of scale that are large compared to the size of the market, as is the case for electricity, resulting in high barriers to entry, thus reducing the number of likely entrants into the electricity industry. This is the main reason why, before or without international trade, electricity markets in many countries remained monopolies.

seller. In physical day-ahead markets, this occurs the following day, and is normally done for each hour of the day, although there can be grouping of hours into blocks. *Financial products* involve different power derivatives, such as options, contracts for differences, and futures, which relate to the underlying spot market price, and which function as risk management for price fluctuations. Financial products do not have to involve the physical delivery of electricity, since they are usually settled financially between the concerned parties. Products which combine both physical and financial aspects also exist (EURELECTRIC, 2003).

Unlike other fuels, electricity is delivered instantaneously as it is not currently able to be stored economically on a large scale. This storage problem gives rise to major concern with regard to reliability of supply (Goodman, 2010). Another feature is that electricity is provided to the consumer in a pure form for direct consumption without any energy conversion process as occurs in the case of coal, gas or other fuels. Electricity's existence depends on continued flow with associated distribution and transmission losses. Because of these characteristics that distinguish it from other commodities, e.g. storage difficulties, the balance requirement between generation and demand, the relative inelasticity of demand, the constraints of transmission, price relationship with other volatile commodities, and its importance for governments as a strategic asset, trade in electricity involves an element of risk (Bajpai and Singh, 2004).

Even though international exchange of electricity involves some risk, it brings many advantages for policy makers to consider. As pointed out by Bielecki and Desta (2004, p. 21), trade and investment planning in regard to wider integrated systems can lead to cost reduction through economies of scale, peak load reductions and postponement of the need for expansion, without compromising supply security. In addition, trade improves the efficiency of the electricity industry in the planning, operation and maintenance of generation facilities through competition, lowers investment requirements, and optimizes system function by distribution of maintenance outages. Furthermore, because of the growing concern over climate change and carbon dioxide (CO_2) emissions with associated abatement costs, electricity interconnections are seen as a means of developing more environmentally friendly energy supply resources and a way to decrease overall electricity generation (Sari-energy.org, 2001).[8] For decision makers' consideration, major benefits of international trading in electricity include greater security of supply, improved economic efficiency, and reduced environmental impact.

1.1 THE RESEARCH OBJECTIVE

Currently, policy makers are confronted by serious problems with regard to electricity. Not only is the price of electricity high worldwide, but, for more than 21% of the world's population (especially in developing countries), there exists an electricity shortage (IEA, 2010, pp. 237-238). In addition, the greater part of CO_2 emissions comes from the production of energy, especially electricity, which the world cannot do without. In order to meet targets aimed at tackling climate change and reduce price fluctuations associated with fossil fuels, many countries are increasing electricity generation from renewable energy sources and nuclear power.

However, renewable energy has problems with regard to economic costs and instability of supply, while nuclear power generation involves issues of safety and radioactive waste management. It seems that in the future we will still rely on fossil fuels. As a result, world electricity emissions are expected to nearly triple between 2005

[8] Available at: http://www.sari-energy.org/Publications/shean.pdf

and 2050 (The Treasury, Australian Government, 2012), so doing nothing is not an option.

Since 1990, growth in world net electricity generation, has outpaced growth in total electricity consumption, and this surplus is expected to make up one third of electricity generation by 2035 (EIA, 2011, Figure 72). This suggests that import and export of electricity may prove mutually beneficial for countries. Such international trade could not only increase electricity supply for excess demand countries while providing an economic gain for excess supply countries, but also decrease levels of CO_2 emissions from electricity generation.

This study investigates what effect electricity co-operation with regard to import and export has on electricity price and CO_2 emissions, as well as what types of renewable energies allow for future electricity generation capable of reducing not only CO_2 emissions but also the price of electricity. There are three main sections to the thesis.

Firstly, econometric methodology of panel data analysis determines the electricity price function for households and industry, using 29 OECD countries' yearly data from 1980 to 2007. Membership of the European Union (EU) is used to investigate the effect of high level co-operation on electricity prices.

Secondly, this study examines whether international co-operation can reduce CO_2 emission levels. Panel data analysis determines the CO_2 emissions function, using 131 countries' yearly data from 1971 to 2007. Because electricity involves international (but not global) markets, this study further divides electricity trade by continent before running panel data analysis to investigate the impact of such trade on CO_2 emissions.

Finally, the analysis focuses on the binary electricity trade of North America. Many studies show that this region enjoys the benefits of a shared electricity system which generates and transmits power over vast distances providing a reliable, secure and competitively priced supply. This section, then, looks at whether international co-operation regarding electricity import and export between Canada and the U.S. can help redress the problem of high electricity prices, using yearly data from 1978 to 2009. In addition, the study examines which renewable energies are the best options for both countries in the years ahead.

CHAPTER TWO

THE ROLE OF ELECTRICITY IMPORT AND EXPORT IN PRICE REDUCTION

Electricity plays an obvious role in improving our lives through increases in productivity, comfort, safety, health and economic prosperity.[9] Because of rising demand, world electricity generation more than tripled from 5,256 terawatt-hours (TWh) in 1971 to 18,307 TWh in 2005, and is forecasted to reach 63,000 TWh by 2050 (OECD/IEA, 2008). This increase in demand forces up the price of electricity, which not only has an effect on the expenditure of people who have to use electricity in their everyday lives, but also on the cost of industry and business.

In order to decrease the impact of high electricity prices and price fluctuations associated with fossil fuels,[10] many countries are trying to increase electricity generation from nuclear and renewable energy resources. However, high investment in renewable energy has resulted in major economic difficulty, and instability of energy supply in meeting consumer demand poses a significant problem,[11] while nuclear

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[9] American Nuclear Society (2012), available at http://www.aboutnuclear.org/view.cgi?fC=Electricity,Benefits_%5E_Effects

[10] Various methods of electricity production include generation from fossil fuels, nuclear reaction and renewable energies. An International Energy Agency (IEA) research paper points out that the traditional cost estimates for fossil fuel based electricity generation are significantly understated, and this has an implication of financial risk of fluctuations in the price of fossil fuels, especially oil and gas (Sauter and Awerbuch, 2003).

[11] Generation from renewable sources is usually more expensive than traditional generation, partly because of the recency of the technology and the restricted opportunity to exploit cost savings

power generation involves issues of safety and the complication of radioactive waste management. In order to circumvent such problems associated with electricity supply, another approach may be considered.

Energy Information Administration (EIA) reports that, since 1990, growth in world net electricity generation has outpaced growth in delivered electricity consumption and such surplus is expected to account for one third of electricity generation by 2035 (EIA, 2011, Figure 72). However, the International Energy Agency (IEA) estimated that "21 percent of the world's population did not have access to electricity in 2009 – a total of about 1.4 billion people" (IEA, 2010, pp. 237-238).[12]

As well as negatively impacting economic productivity, electricity shortages lower quality of life and impede the realization of the Millennium Development Goals.[13] Vijay Modi, who is researching alternative fuels for Africa, points out that lack

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through economies of scale most often associated with the more conventional fossil-fuel generation. In addition, renewable energy source fluctuations may impose a limit on output generation available from such sources (PB Power, 2004).

[12] Shortage of electricity exists in many countries of Africa and Asia. However, such shortage can occur, not only through lack of capacity or generation, like in Japan, but also because of high electricity prices that consumers cannot afford. Pakistan is a good example. The gap between supply and demand (electricity shortage) has been known to reach 7,500 megawatts or nearly 40% of national demand. A number of private power producers have had to severely cut or even stop production because the state-run power purchasing company hadn't paid them. The so-called "circular debt" currently runs at about $880m. (The Economist, 2012, available at http://www.economist.com/blogs/banyan/2012/05/ Pakistan % E2%80%99s-energy-crisis.)

[13] "The Millennium Development Goals (MDGs) are the world's time-bound and quantified targets for addressing extreme poverty in its many dimensions - income poverty, hunger, disease, lack of adequate shelter, and exclusion - while promoting gender equality, education, and environmental

of electricity means safety is compromised for night-time delivery of babies, children's study after dark is affected, businesses shut their doors at sunset and vaccines are unable to be safely refrigerated (Kimani, 2008). This electricity shortage in some areas co-existing with electricity surplus in others suggests that import and export of electricity between countries may prove mutually beneficial. When countries which have excess supply export electricity to countries which have excess demand,[14] the price in excess demand countries should decrease, and export countries will gain more income.

For OECD countries, IEA reports that, although there should be no problem with electricity supply investment because of the very high value placed on electricity and the ability to cover costs involved, there remains the serious issue of electricity supply security (OECD/IEA, 2003). Monopoly systems of the past worked but were not economically efficient.[15] By increasing competition, international trade improves the

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sustainability. They are also basic human rights - the rights of each person on the planet to health, education, shelter, and security" [Millennium Project (2012), available at: http://www. Unmillennium project.org/goals/index.htm].

[14] The system operator requires electricity generators to increase or decrease daily production according to demand. When there is excess demand, the highest price on offer is paid to all of the contributing plants in the system. If there is excess supply, the balancing units are required to cut back production and these companies purchase the gap between their actual production and demand from the system at the lowest balancing price on offer (Ada Mühendislik, 2009).

[15] Most OECD countries are introducing competition into their electricity markets bringing the benefits of increased reliability and reduced costs and avoiding the weaknesses of the vertically regulated monopoly. These include lack of external (market) incentives for efficiently setting consumer prices, investment risks being carried by end users rather than investors, and no day-to-day competition among generators. The risk for end users in the portfolio manager model involves being bound to long-term procurement contracts that may in the end prove to be too costly or otherwise inadequate (OECD, 2001).

efficiency of electricity markets and reduces price volatility (Justus, 1997; Bielecki and Desta 2004), promoting confidence in the market's ability to ensure a secure and reliable supply.

This chapter focuses on the economic problem of whether high electricity prices can be alleviated by the trading of electricity between countries. Yearly data from 29 OECD countries from 1980 to 2007 are considered, with parameters of the electricity price function determined by panel data models. This is followed, in Model 1, by investigation of the effects of electricity import and export on household electricity price, and, in Model 2, by investigation of the effects of electricity import and export on industry electricity price. The effect of membership of the European Union (EU) on electricity price is included in Model 1(a) and Model 2(a), but not included in Model 1(b) and Model 2(b).

The results show that electricity import is not significant in decreasing industry electricity price, while export is found to increase electricity prices for both household and industry by a tiny amount, with high significance. Membership of the EU is chosen to investigate whether political alliance, which assumes a high level of co-operation, can be of assistance in helping countries to decrease electricity prices. The results show that the close relationship among 19 countries in the EU is significant in reducing electricity price for industry, but not for households. However, Europe is far from being an internal market of open competition.[16] Furthermore, the focus of EU agreements is, not only on the free trade of electricity, but also on reduction of CO_2

[16] The European Commission noted, in 2007, that, for the original 15 EU member states, the top three European generation power companies held 60% of the market in ten different countries (Domanico, 2012).

emission levels which increases the cost of electricity generation. Such climate change policies put upward pressure on electricity prices.

The remainder of this chapter is organized as follows: section one, motivation; section two, co-operation causes competition; section three, increase trade to decrease price; section four, electricity price determinants; section five, methods and procedures; section six, empirical results; section seven, discussion; and section eight, conclusion.

2.1 MOTIVATION

Following Sauter and Awerbuch (2003), this chapter recognizes price of electricity as a major social welfare issue affecting everyday cost of living and consumer wealth. In addition, electricity price is an important factor in improving economic efficiency, i.e. basing investment decisions on economic rationality,[17] reducing costs and lowering prices in a macro-financial economy. Furthermore, countries need to maximise economic performance of the electricity sector in light of financial pressures on government budgets in part from electricity subsidies. However, as economies grow, demand for electricity will increase,[18] driving up the price.[19]

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[17] For the private sector, it is important to consider prices and costs together when appraising investments. Companies necessarily view the price of electricity as a major factor in any investment decision (Anderson, 2007).

[18] Many studies have looked at the causal relationship between electricity consumption and economic growth giving rise to some controversial results. Electricity restrictions may constrain economic growth while increase in electricity use may enhance economic growth (Altinay and Karagol, 2006; Shiu and Lam, 2004). A bi-directional causal relationship suggests that electricity consumption and economic growth are together determined and affected at the same time (Jumbe, 2004; Yoo, 2006). The long-run causality is significant in both directions between real GDP and electricity consumption. Also found is a uni-directional short-run causality from economic growth to electricity

Therefore, if international trade can help reduce electricity price, such policy would be instrumental for governments in improving social welfare.

When international trade occurs, due to an increase in electricity supply, there should be a decrease in the price in import countries along with a reduction in government subsidies for electricity generation. Electricity co-operation with regard to import and export decreases electricity generation subsidies from government revenue, i.e. taxes, and taxes come from people's income. So when governments subsidize, the people pay for electricity indirectly. Government subsidies of electricity impact different areas, particularly those which are energy intensive, affecting costs of production and, in turn, the prices of goods and services, so manipulating the consumer price index (CPI). In addition, electricity subsidies involve Moral Hazard (Harris, 2006, p. 131),[20] by discouraging efficiency of electricity generators while destroying market mechanism by decreasing competitiveness, resulting in the likelihood that electricity prices may not decrease in the long run.

Trade in electricity will allow export countries to gain more income, but at what effect on price? The economic model of market price determination shows that electricity price in export countries will increase because of a decrease in electricity

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consumption (Chen et al., 2007). For the long-run estimates, the relationship between PPP-GDP and residual electricity is significant in both OECD and non-OECD countries (Joyeux and Ripple, 2011).

[19] Herrden et al. (2005) state that there is a twofold relationship between inflation and increase in the price of electricity. Inflation and inflation projections have an input into electricity price determination, and the electricity price level has, conversely, an input into inflation.

[20] According to Justus (1997), impediments from subsidy to improving energy efficiency include turnover rate of electric equipment, insufficient information, lack of development in technology for efficient products and immature markets, all of which continue to stand in the way of realization of the high energy efficiency gains predicted by many studies.

supply. However, in trade theory, the domestic electricity price may decrease because of increased income from trading with neighbouring countries, lowered expense for electricity storage, and diminished cost per unit from economy of scale. This study examines whether international co-operation regarding electricity import and export between countries can help redress the problem of high electricity prices.

2.2 CO-OPERATION CAUSES COMPETITION

Even though countries face increasing demand for electricity, any decision regarding electricity trading requires careful consideration in view of certain factors. Stability of governments to ensure continued electricity supply for export, as well as on-going friendly relations between likely trading partners needs to be taken into account. Reliance on electricity supplied from another country involves benefits - but, also, risks. As a result, many countries have yet to make a decision with regard to electricity import and export.

Electricity is a vital commodity in all economies today being instrumental in the provision of basic needs and the infrastructures that serve them. Without electricity, businesses cannot operate and factories cannot produce. Therefore, uninterrupted maintenance of electricity supply is of major concern for governments. Because of the indispensability of electricity and the risks associated with its trading, governments need to be more careful with electricity exchange policy than with that for general international trade. Even when countries contract to export electricity, they usually include a condition in relation to electricity import as well.[21] Since electricity trading

[21] Of 29 OECD countries in this study, 24 trade electricity doing both import and export, while the other five countries have no import and no export of electricity.

between countries requires a high level of mutual trust, it involves more than just buying and selling - it is founded on co-operation.

Electricity co-operation can lead to developments in new technology for power generation and electricity end-use. For example, information exchange, joint funding of demonstration projects and collaboration on research and development (R&D) would assist countries to learn from each other's experiments and approach consensus on the best technology for possible standardisation where appropriate. Countries could also co-ordinate the incentives provided for new technology with a view to decreasing the cost of electricity generation, both private and social, e.g. CO_2 emissions. Hence, co-operation through interconnection of electricity can lead to a reduction in price.

In striving for a well-organised arrangement for competitive trading of electricity between countries, apart from *gentlemen's agreements*[22] among providers to supply emergency power, the European Union has considered open access and free transit within networks (Charpentier, 1995). However, the situation is quite different in Africa where there are a number of barriers to electricity trading as identified by Mkhwanazi (2003). Foremost among these is a hostile political climate between countries creating a serious impediment to co-operation. An absence of political will

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[22] Gentlemen's agreements have no legal status. They can be binding only if the participating companies conclude contracts that take these agreements into account. In Germany, for example, the three parties, Federal Association of Germany (BDI - Bundesverband der Deutschen Industrie e.V., Berlin), Association for the Industrial Energy and Power Industry (VIK - Verband der Industriellen Energie und Kraftwirtschaft e.V., Essen), and German Electricity Association (VDEW - Vereinigung Deutscher Elektrizita:tswerke e.V., Frankfurt/Main) represent mainly the industrial customers and the grid owners/operators, but not households or other diverse interests, especially newcomers to this market. The associations' agreements are private, voluntary framework agreements for the use of grid contracts (Ku, 2001, available at http://www.analyticalq.com/energy/germany/default.htm).

with regard to trade together with unstable economic policies in some countries is disruptive of long-term arrangements. The lack of trust between countries is a major stumbling block to progress in electricity co-operation.

Electricity co-operation through international trade is vital to the social and economic goal of a secure and competitive supply. It allows electricity providers protection for themselves and consumers against power outages and fluctuations in price. If local production of electricity is limited or not economically viable, the energy can be supplied by international markets. In a perfectly competitive market, no particular electricity provider is a price maker. Both suppliers and consumers are involved in a pool market model where competing transaction bids and offers determine the market clearing price (Bajpai and Singh, 2004).

However, wholesale electricity markets are often inefficient and not fully competitive, partly because retail-customer loads are not involved. Even though electricity costs can fluctuate markedly throughout the day, most consumers continue to pay prices set months or years before. As a result, consumers are protected against the volatility of these markets, reflecting the fact that wholesale electricity market movements cause minimal price variations at the retail level (Hirst and Kirby, 2001).

Electricity markets dominated by one or a small number of generators are susceptible to manipulation by the withholding of generating capacity at times when supply is not meeting demand, leading to higher prices. The likelihood of this happening is usually in inverse proportion to the number of electricity providers. For Cournot competition, the average price increase above marginal cost is as follows:

$$(\text{Price} - \text{Marginal Cost})/\text{Price} = \text{HHI}/\varepsilon \qquad (1)$$

where HHI (Herfindahl-Hirschman Index) = sum of the squares of the market share of each competitor,[23] and ε = demand-price elasticity.

This formula, which is frequently used to model competition in concentrated electricity markets, indicates that market price manipulation is more likely to occur in these types of markets with weak demand response. In many electricity markets, both these conditions are applicable (OECD/IAEE, 2003).

Equation (1) can be written as

$$\text{Price} = \text{Marginal Cost}/\ (1- (\text{HHI}/\varepsilon)) \qquad (2)$$

Equation (2) shows that increasing the number of firms through international trade will cause HHI to become smaller, thus the price of electricity will decrease when there is more competition.[24]

When international trade occurs, it increases competition in importing countries. However, as noted by OECD (2003), electricity market power depends not only on number of generators, but also on transmission network capacity.[25] In addition, if at any

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[23] The HHI index was initially put forward by Hirschman (1945) to measure the concentration of a country's trade in commodities (Hirschman, 1964).

[24] Bacon and Besant-Jones (2001) states that the Herfindahl-Hirschman Index (HHI) provides a simple measure of the degree of potential market power, which has been calculated for a series of countries (regions) that have experienced extensive restructuring and privatization. The index can value between unity for a monopoly and zero for perfect competition (a very large number of equal-size firms).

[25] At times when there is congestion on the transmission network, it is necessary to identify a specific localized market for electricity in different areas. It is possible for some generators to have substantial market influence in their local region, while other generators may hold significant market

one time, most generators are at or near maximum output, those remaining can achieve significant market power (OECD, 2003). Hence, number of generators alone is not a true representation of competition in the electricity market, and this paper does not include number of electricity generators per country in the models due to data limitation.

The opening of electricity markets to competition through international trade is pivotal in the treatment of electricity as any other commodity influenced by competitive forces. In international electricity exchange, when two systems are joined, electricity will transfer from the low price to the high price country. The resulting levels of production and consumption from international electricity co-operation will be more efficient because of increased market competition.[26]

2.3 INCREASE TRADE TO DECREASE PRICE

Neuhoff (2011) explains that, in a market that is perfectly competitive with the assumption of an infinite number of buyers and sellers, market prices will equal variable costs of the most expensive generator needed to meet demand. In a monopoly market, or when a small number of electricity generators have major market shares then, by executing market power, they can raise prices above competitive levels. Market power is increased by constraints on transmission and by the short-term price inelasticity of demand. In Europe, excluding the Nordic countries, market power appears to be so

power due to their ability to contribute to relief of congestion within the transmission network (OECD, 2003).

[26] For energy trade policy, abatement costs are found to be considerably lowered by all co-operative strategies, especially by the one involving full co-operation (Unger and Ekvall, 2003).

dominant that average prices are decided by the threat of new generators entering the market and the threat of regulatory intervention rather than trading in the spot market.

Villemeur and Pineau (2010), in a study addressing electricity trade, assume that two regions use the same type and the same technology for electricity generation, both markets are competitive, and electricity cannot be stored. Opposing the general view, they assume that price elasticity of demand for electricity is elastic, and there is no loss from generation (including transmission and distribution). This suggests that trade may decrease overall production costs.

This study employs the concept of Villemeur and Pineau (2010) to describe international electricity trade between two countries. In autarky (superscript A), price $\underline{p}^A$ is lower in country $\underline{T}$ compared to the other country $\overline{T}$ which has a higher price $\overline{p}^A$.[27]

$$\underline{p}^A = C'(\underline{Q}^A) < \overline{p}^A = C'(\overline{Q}^A), \tag{3}$$

where C(.), the production cost function, is increasing and convex, and C'(.) is the marginal cost function. The quantities of production and consumption are $\underline{Q}^A$ and $\overline{Q}^A$ in countries $\underline{T}$ and $\overline{T}$ respectively.

Trade in electricity between both countries results in

$$\underline{p} = C'(\underline{Q}^D + Q_X) = \overline{p} = C'(\overline{Q}^D - Q_X) \tag{4}$$

[27] In fact, there are a number of reasons to explain why the price of electricity in country $\underline{T}$ is cheaper than in the other country $\overline{T}$. These include lower demand, higher supply and higher technical efficiency. However, Villemeur and Pineau (2010) assume it is because of lower demand.

where Q_X is the quantity of electricity trade between two countries (+ Q_X represents exported quantity and - Q_X represents imported quantity), $\underline{Q}^D$ and $\overline{Q}^D$ are domestic demand in countries $\underline{T}$ and $\overline{T}$ respectively, while $\underline{Q}^S$ and $\overline{Q}^S$ are electricity supply in $\underline{T}$ and $\overline{T}$ respectively.

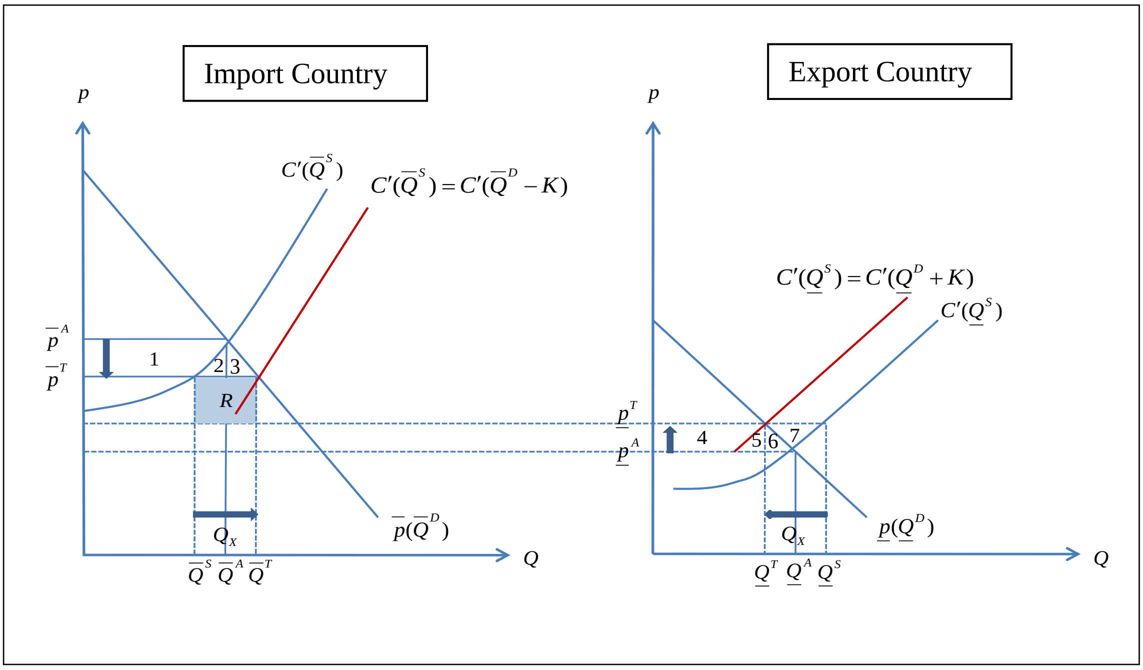
When the electricity systems of both countries are joined, energy will flow from the low price to the high price country. There is an increase in price in the exporting country because of the additional expense of more generators while, in the importing country, price decreases. In equilibrium, transmission increases to the point where cost of transmission equals the price difference between countries (Neuhoff, 2011). However, Villemeur and Pineau (2010) argue that, realistically, there is a limitation of transmission line capacity *K*, so that $Q_X \leq K$. Equation (5) shows there is a price difference between two countries because of transmission cost or total rent *R*, and $R = (\overline{p} - \underline{p})K$.[28]

$$\underline{p} = C'(\underline{Q}^D + Q_X) < \overline{p} = C'(\overline{Q}^D - Q_X) \tag{5}$$

Villemeur and Pineau (2010) assume that $Q_X = K$, hence the exporting country produces $\underline{Q}^S = (\underline{Q}^D + K)$ and sells electricity at price $\underline{p}$, while the importing country produces $\overline{Q}^S = (\overline{Q}^D - K)$ and sells electricity at price $\overline{p}$.

[28] Hence, the law of one price (LOP), which states that "identical goods in different countries should have identical prices, once the prices are expressed in common currency units" (Crucini et al., 2005), cannot apply to electricity.

Figure 2.1: Electricity Price Resulting from Trade Between Two Countries with Demand and Supply in Equilibrium



Original source image: Villemeur and Pineau, 2010

Notes: (1) *p* denotes price, *Q* denotes quantity, *D* denotes demand, *S* denotes supply, *A* denotes autarky, *T* denotes trade, *x* denotes quantity of trade and *K* denotes transmission.
(2) change in consumer surplus of import country = 1 + 2 + 3
(3) change in producer surplus of import country = -(1)
(4) change in consumer surplus of export country = -(4 + 5+ 6)
(5) change in producer surplus of export country = 4 + 5 + 6 + 7

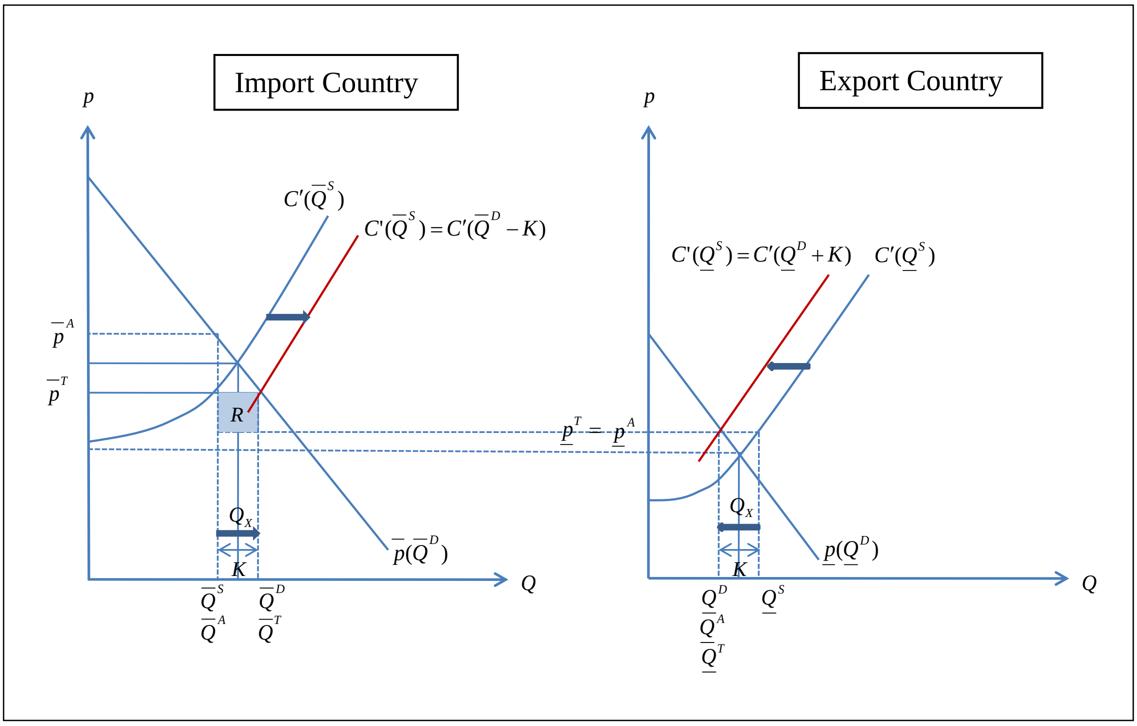
Figure 2.1 shows what is happening. Exporting country $\underline{T}$ generates $\underline{Q}^S$ and exports amount Q_X to importing country $\overline{T}$. This lowers price in country $\overline{T}$ from $\overline{p}^A$ to $\overline{p}^T$, but raises price in country $\underline{T}$ from $\underline{p}^A$ to $\underline{p}^T$, under the assumption that supply elasticities of both countries do not change. Both consumers and producers are impacted by these price changes, with rent R as transmission cost. Transmission constraint K between the two countries is pivotal in determining the profit level for the exporting country. Producers in exporting country $\underline{T}$ may not have direct control of the level of K but will obviously try to influence the transmission company to set a transmission capacity for their highest profit.

In exporting country $\underline{T}$, consumers and producers have somewhat conflicting interests as export increases the price from $\underline{p}^A$ to $\underline{p}^T$. As a result, trade causes a redistribution of wealth from consumers to producers (see Figure 2.1). However, Villemeur and Pineau (2010) suggest that producers and consumers in country $\underline{T}$ both gain from trade, and it is possible that some transfer arrangements could be designed to compensate consumers in country $\underline{T}$ for increased prices.

As reported by EIA, growth in world net electricity generation since 1990 has outpaced growth in total world electricity consumption and such surplus is expected to account for one third of electricity generation by 2035 (EIA, 2011: Figure 72). This study develops the model of Villemeur and Pineau (2010) for electricity trade between two countries when the economies of both countries are not at equilibrium. In this case, the import country has excess demand and the export country has excess supply - which is close to the real situation.

In regard to the situation where demand and supply are not in equilibrium (see Figure 2.2), the result for international trade is different from the equilibrium situation (see Figure 2.1). For the non-equilibrium situation, this study assumes that, in autarky (superscript A), price $\underline{p}^A$ is lower in country $\underline{T}$ which has excess electricity supply compared to the other country $\overline{T}$ which has excess electricity demand.

Figure 2.2: Electricity Price Resulting from Trade Between Two Countries with Demand and Supply not in Equilibrium



Note: *p* denotes price, *Q* denotes quantity, *D* denotes demand, *S* denotes supply, *A* denotes autarky, *T* denotes trade, *x* denotes quantity of trade and *K* denotes transmission.

Figure 2.2 illustrates the situation. Country $\underline{T}$ (exporting country) generates $\underline{Q}^S$ and exports amount Q_X to country $\overline{T}$ (importing country). This reduces electricity available in country $\underline{T}$ from $\underline{Q}^S$ to $\underline{Q}^T$, and increases electricity available in country $\overline{T}$ from $\overline{Q}^S$ to $\overline{Q}^T$ while prices do not change for either country. However, without trade, price in $\overline{T}$ will go up because of excess demand,[29] but price in $\underline{T}$ will

[29] Lafferty et al. (2001), in describing demand in the electricity market, note that, when there is electricity shortage with no market intervention, suppliers are able to capitalise on prices, resulting in significant transfer of wealth from buyers to sellers. Although such situations need not necessarily equate with short-run inefficiency, the fairness of this type of activity is called into question.

not go down, even though there is excess supply, because electricity cannot be stored under this model, as put forward by Bajpai and Singh (2004).[30]

It is always of benefit for countries with excess demand to import, and with excess supply to export. In Figure 2.2, as in Figure 2.1, if countries receive part of the transmission rent, it is never best practice to permit trade up to price equalization. However, international trade in electricity improves social welfare. For the importing country, trade interrupts price increase from excess demand, while in the exporting country, trade provides benefits for producers through exporting excess supply.

Environmental effects and transmission line construction costs aside, trade between two countries results in improved total welfare while prices are not equalized. Although trade always delivers improved welfare benefits for the importing country $\overline{T}$, where consumers gain, producers lose (see Figure 2.1 and Figure 2.2). The reduction in price through trade, which helps consumers but hurts producers, provides motivation for the latter to resist transmission lines allowing such trade, unless they gain their share of transmission capacity rent.

The equation below illustrates the combined welfare impacts (without environmental effects) for two countries.

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30 In reality, some countries use batteries to store electricity. However the cost is very high. As a result, electricity price may not decrease. Lafferty et al. (2001) further explain that suppliers are able to set prices in excess of the cost of the last unit produced. This ability to increase prices above costs becomes greater with lower demand responsiveness. As a result, the incentive of a supplier with market power to raise prices in this manner also becomes greater as the responsiveness of demand goes down. The unfortunate outcome of this pricing behaviour is a reduced market efficiency brought about by an increase in the gap between the real cost of electricity production and the value attributed to it by consumers.

$$\frac{dW}{dK} = C'(\overline{Q}^D - Q_X) - C'(\underline{Q}^D + Q_X) = \overline{p} - \underline{p} \geq 0 \tag{6}$$

Equation (6), in confirmation of Villemeur and Pineau (2010), shows the benefits of trading, and why it is considered good economic policy.[31] Using Adam Smith's (1776) terminology, international trade provides a win-win game or positive sum game, because electricity prices in import countries decrease and export countries gain more income.

The World Bank offers three main reasons for policy makers to consider trading in electricity with neighbouring countries. These include support in emergencies, operational cost savings due to structural differences in load profiles, and reduction in expenses relating to investment and operational costs from complementary means of production. There remains, however, an ever-present deterrent to achieving true electricity trade. Many governments have long considered electricity to be a specific strategic asset that, because of its vital nature to economies and the fact that it cannot be stockpiled, should remain under state control. As a result, governments have tended towards electricity self-sufficiency, mainly through vertically integrated, state-controlled systems. This concern provides an explanation for the somewhat limited spread of international trade in electricity (Charpentier, 1995).

[31] However, marginal cost functions $C'(.)$ which are private cost functions do not take into account the negative environmental effects of electricity production (Villemeur and Pineau, 2010). Electricity produced from fossil fuels (coal, natural gas and oil) gives rise to greenhouse gas (GHG) emissions, such that any welfare gain for consumers and producers carries an environmental cost.

2.4 ELECTRICITY PRICE DETERMINANTS

Lucia and Schwartz (2002) looked at electricity trading in the Nordpool market. They were in agreement that prices of general goods are determined by supply from existing production and demand for current consumption, as well as by the level of inventories. However, in the case of electricity, unlike other commodities, the buffering effect of inventories (i.e. excess supply) is not applicable. As opposed to natural gas, cereals or copper, electricity is difficult to store. Since there is no available technique to store power (outside of hydro), there can be no benefit from holding the commodity, nor a storage cost (Geman and Roncoroni, 2006). Electricity needs to be produced precisely when there is demand. As a result, all the factors that impact supply and demand have an immediate effect on the price on the spot market resulting in considerable fluctuation in the electricity price for the following day.

However, on the forward market, the price is more closely linked to long-term projections. With regard to supply, electricity price is greatly influenced by the cost of fuel (coal, gas and oil) and the CO_2 allowance price.[32] Also of relevance are wind and weather conditions which affect the amount of electricity generation from wind turbines and hydroelectric stations. In addition, supply is contingent on the capacities of power plants and their present technical condition, as well as disruption by scheduled overhauls and unforeseen outages.

With regard to demand, weather again has an input with its effect on consumer behaviour. Taylor (2003) points out that the accuracy of forecasts in electricity demand

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[32] The Office of Competition and Economic Analysis, U.S. Department of Commerce, in considering the impact that a reduction in U.S. CO_2 emissions has on the U.S. electricity producing sector, states that such reduction leads to GDP and electricity supply shrinkage, and a rise in the price of electricity (Anspacher et al., 2011).

may well be improved by the use of weather ensemble predictions. Also possibly affecting consumer behaviour are school and public holidays. Electricity demand is further influenced by the state of the local economy (Altinay and Karagol, 2005; Shiu and Lam, 2004; Jumbe, 2004; Yoo, 2006; Chen et al., 2006; Joyeux and Ripple, 2011) and, of course, fluctuations in the global economy. When high demand for energy greatly increases price, any resulting economic crisis leads to demand being markedly reduced. Following this, electricity prices on the exchanges go down, illustrating that market mechanism works.

Figure 2.3: The Representation of Electricity Market Framework

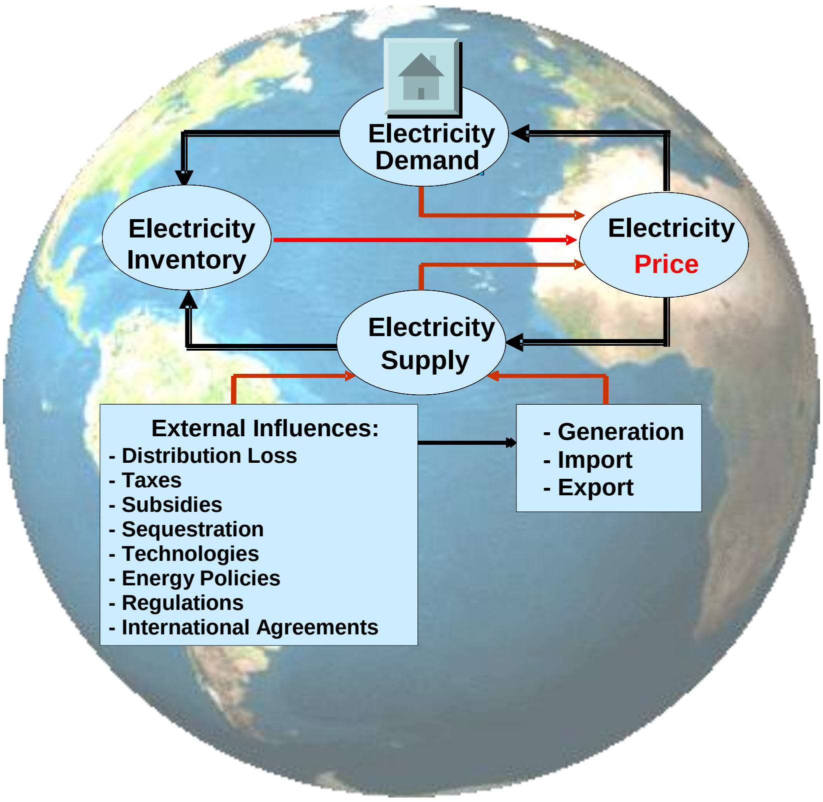

Figure 2.3 shows the Representation of Electricity Market Framework which is developed from the Representation of a Commodity Market model of Labys and Pollak

(1984, p. 48) and the Major Factors Affecting Supply Adequacy model of the California Energy Commission (Pryor et al., 2010). From this figure, price depends on demand and supply of electricity. As pointed out by Labys and Pollak (1984), for general commodities, price involves feedback effects where, as well as demand and supply being determined by prices, they also have an effect on prices. This applies to electricity.

The California Energy Commission describes electricity demand as dependent on the economy, demography, weather or season, demand response and interruptibles. On the supply side, electricity price depends on generation, import and export, together with the external influences of distribution loss, taxes, subsidies, sequestration, technologies, energy policies, regulations and international agreements. To avoid the problem of endogeneity when there is a correlation between demand and supply, this study focuses solely on electricity supply (California Energy Commission, 2010, p.12).

All of the external influences mentioned above are unobserved variables in this study. Inventory represents the difference between demand and supply of electricity, and the relationship between price and inventory (excess supply) should be negative. However, if supply and demand are out of balance, and electricity cannot really be held in inventory because of storage difficulties, a benefit from holding this commodity is not possible (Geman and Roncoroni, 2006).

Electricity transmission refers to the transfer of electricity from generation facilities to substations close to populated areas, and is separate from electricity distribution which involves the local connection between substations and consumers (Fogarty and Lamb, 2012). Villemeur and Pineau (2010) claim that transmission cost increases the price of electricity in importing countries more so than in exporting countries. However, Pusung (2012) argues that the cost of transmission is relatively low in comparison to distribution cost and all other costs faced by the customer. In this chapter, distribution loss includes transmission loss, and can be a proxy variable for transmission cost.[33] However, because of high correlation between generation and distribution loss (0.867), the models do not include this variable.

All around the world, governments are deregulating electricity markets to increase competition, lower costs and promote innovation. However, government subsidy of electricity generation has an effect on market mechanism such that decreased competition can result (Wohlgemuth, 2000). Because governments would like to encourage the use of renewable energies and also make electricity more affordable for lower-income people, subsidy remains part of the picture. In addition, any increase in the price of electricity puts upward pressure on inflation which has a direct effect on the consumer price index (CPI) (Herrden et al., 2005). This is especially the case with industrial electricity prices where producers can transfer the electricity cost to consumers. As a result, governments use subsidies as a means of controlling electricity prices, which is the reason why industry electricity price is lower than household electricity price.

Subsidies, whether to electricity producers or electricity consumers, provide benefits for the economy.[34] Producers gain higher profits and consumers gain by a

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[33] There are no data available for transmission cost.

[34] Electricity subsidy (negative tax) can have advantages in terms of encouraging renewable energy in order to reduce carbon dioxide emission levels, and distributing electricity to people who live in rural areas. As mentioned before, 1.4 billion people lack access to electricity services (IEA, 2010). Some 85% of these people live in remote communities. As a result, subsidy can be critical in ensuring access to modern energy services, including electricity, for the most economically deprived (IEA, OPEC, OECD and World Bank, 2010).

lowering in the price of electricity resulting in increased demand for electricity. However, subsidies pose a barrier to competition in a market (Justus, 1997),[35] and can lead economies into inefficient consumption and production, as well as involving moral hazard[36] by discouraging efficiency of electricity generation and electricity market systems - the result being price may not decrease in the long run. Unfortunately, no systematic recording of energy subsidies at the international level is available, while at the global level, measurements and estimations are incomplete (IEA, OPEC, OECD and World Bank, 2010). As a result, government subsidy is an unobserved variable in this study.

2.5 METHODS AND PROCEDURES

2.5.1 Data

This study looks at 29 Organisation for Economic Co-operation and Development (OECD) countries.[37] The data comprise electricity generation, electricity

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[35] Justus (1997) points out that impediments from subsidy to improving energy efficiency include turnover rate of electric equipment, insufficient information, lack of development in technology for efficient products and immature markets, all of which continue to stand in the way of realization of the high energy efficiency gains predicted by many studies.

[36] Moral hazard has been defined as, “The risk that a party to a transaction has not entered into the contract in good faith, has provided misleading information about its assets, liabilities or credit capacity, or has an incentive to take unusual risks in a desperate attempt to earn a profit before the contract settles” (Investopedia, 2012, available at: http://www.investopedia.com/terms/m/moralhazard.asp).

[37] Developed countries generate the major part of the world’s electricity, with the OECD responsible for 57% of world electricity generation in 2005 (OECD/IEA, 2008). The OECD represents

imports, and electricity exports from Energy Information Administration (EIA); household electricity price and industry electricity price from the International Energy Agency (IEA); inflation indicator (consumer price index [CPI] and producer price index [PPI]) from OECD; and membership of the European Union from the EU.[38]

Table 1 shows a summary of the key variables used in the analysis. This study employs yearly data of 29 OECD countries for 28 years from 1980 to 2007, with the total maximum observations being 812 (29 x 28). Because of a number of missing minor observations for some countries in household and industry electricity prices, the panel is unbalanced.

Table 2.1: Descriptive Statistics

29 OECD Countries, 1980-2007						
	Name	**Obs**	**Mean**	**Standard Deviation**	**Min**	**Max**
Household price (*$*)	PH	737	7.40	27.94	0.05	218.49
Industry price (*$*)	PI	414	6.53	20.59	0.31	110.42
Consumption (*MWh*)	C	812	238,412.40	561,580.60	2,862.00	3,921,929.00
Generation (*MWh*)	GC	784	274,491.80	638,322.10	3,184.00	4,298,444.00
Import (*MWh*)	M	812	8,103.28	10,299.04	0	56,861.00
Export (*MWh*)	X	812	8,687.36	14,243.64	0	80,739.00
Excess supply (*MWh*)	ES	812	31,749.25	104,526.60	52.92	560,748.00

Source: EIA, IEA and OECD

Note: (1) Generation (GC) denotes electricity generation for country, and equals total generation minus export.
(2) Obs denotes number of observations.

18% of the 2011 world population including: OECD Americas - United States, Canada, Chile, and Mexico; OECD Europe - Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom; and OECD Asia - Japan, South Korea, Australia, and New Zealand (EIA, 2011).

[38] Available at http://europa.eu/about-eu/countries/index_en.htm.

Table 2.1 indicates that the average electricity generation for country (274,491.80 MWh per country per year) is higher than the average electricity consumption (240,930.00 MWh per country per year), while the average values of electricity import and export are only 8,103.28 MWh and 8,687.36 MWh per country per year respectively. These numbers show that the 29 OECD countries export, on average, only about 21.48% of excess electricity supply per year.[39] As a result, further import and export between countries is possible and should benefit both trading partners.

A number of variables are employed for this chapter's research which looks at whether electricity trade between countries can reduce electricity prices. Household electricity prices, with a measure of average price per year in dollars, are adjusted in accordance with CPI with 2005 being the base year. Industry electricity prices, with a measure of average price per year in dollars, are adjusted in accordance with PPI with 2005 being the base year. Independent variables comprise electricity generation for country, electricity import, electricity export and excess supply, with each being measured for total MWh per year. In order to overcome the problem of different scales of measurement for dependent and independent variables, all variables are presented in the natural logarithmic form.[40]

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[39] In this study, there are five OECD countries which have no import and no export of electricity: Australia, Ireland, Japan, South Korea and New Zealand.

[40] This chapter use the natural logarithmic form for all variables, following which, data for countries having no import and no export will disappear (*ln*(0)). To solve this problem, variables are generated in STATA command by plus one before the natural logarithmic form is taken.

2.5.2 Statistical Analysis

- ***Panel Unit Root Tests***

The panel unit root test derives from the time series unit root test with the main difference being that asymptotic behaviour of the time-series dimension *T* and the cross-sectional dimension *N* must be included for consideration. How *N* and *T* converge to infinity is vital in determining the asymptotic behavior of estimators and tests employed for nonstationary panels (Nell and Zimmermann, 2011). Using the panel method noticeably increases the power of the test relative to the time series ADF tests (Levin et al., 2002). Because they allow for unbalanced panel, the following two panel unit root tests are employed for this study: the Im, Pesaran and Shin (IPS) test and the Fisher-ADF test.

1. Im, Pesaran, and Shin (IPS) Test

Im, Pesaran, and Shin (2003) begin by identifying, for each cross section, a separate ADF regression

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{pi} \beta_{ij} \Delta y_{it-j} + X'_{it}\delta_i + \varepsilon_{\text{it}} \qquad (7)$$

$$i = 1, 2 \,.....N \qquad t = 1, 2 \,.....T$$

where *i* denotes countries and *t* denotes years.

The null hypothesis is presented as

$$H_0: \rho_i = 0, \quad \text{for all } i$$

while the alternative hypothesis is given as

$$H_1: \begin{cases} \rho_i = 0, & \text{for all } i = 1, 2, \ldots, N_1 \\ \rho_i < 0, & \text{for all } i = N+1, N+2, \ldots, N_1 \end{cases}$$

where the *i* may be reordered as necessary, and *i* may be interpreted as a non-zero fraction of the individual process which is stationary.

The IPS test compares the null hypothesis that each series in the panel is nonstationary for all cross-section units against the alternative hypothesis that at least one of the series is stationary.

2. Fisher-ADF and Fisher-PP Tests

A different approach to panel unit root tests, using Fisher's (1932) results to derive tests that combine the p-values from individual unit root tests, has been suggested by Maddala and Wu (1999), and Choi (2001). Both the null and the alternative hypotheses are the same as for IPS. Under the null of unit root for all *N* cross-sections, if π_i is defined as the p-value from any individual unit root test for cross-section *i*, then the asymptotic result is

$$-2\sum_{i=1}^{N}\log(\pi_i) \rightarrow \chi^2_{2N}$$

In addition, Choi (2001) demonstrates that

$$Z = \frac{1}{\sqrt{N}}\sum_{i=1}^{N}\Phi^{-1}(\pi_i) \rightarrow N(0,1) \qquad (8)$$

where Φ^{-1} is the inverse of the standard normal cumulative distribution function.

The IPS and Fisher-ADF statistics reject the null hypothesis of non-stationarity or unit root at the 0.05 level of significance. Table 3 shows that the household electricity price for a constant term gives the result I(1) for the IPS test, but I(0) for the Fisher-ADF test, and both tests for a constant term plus a trend component give the result I(0). For industry electricity price, both tests for a constant term give the result I(1), and for a constant term plus a trend component give the result I(1).

The results show that the independent variables are non-stationary (except for excess supply), and that they are not cointegrated (see Table 2.2). In order to remedy the problem of non-stationarity, this paper estimates short run models with first differences.

Table 2.2: Panel Unit Root Tests Results

29 OECD Countries, 1980-2007						
	Im, Pesaran and Shin Test (IPS)			**Fisher-ADF Test**		
	Level	1st diff	Concl	Level	1st diff	Concl
	c	c		c	c	
ln Household price	-0.574	-25.705**	I(1)	81.809**		I(0)
ln Industry price	61.522	-11.503**	I(1)	61.521	238.881**	I(1)
ln Generation	-0.137	-20.255**	I(1)	79.526**		I(0)
ln Import	-1.182	-19.900**	I(1)	57.958	390.815**	I(1)
ln Export	-1.130	-25.131**	I(1)	59.076	494.875**	I(1)
ln Excess supply	-4.277**		I(0)	121.543**		I(0)
	c, t	c, t		c, t	c, t	
ln Household price	-3.876**		I(0)	120.684**		I(0)
ln Industry price	-0.742	-5.984**	I(1)	70.430	118.611**	I(1)
ln Generation	0.471	-18.834**	I(1)	66.885	368.581**	I(1)
ln Import	-2.863**		I(0)	77.399**		I(0)
ln Export	-3.883**		I(0)	89.068**		I(0)
ln Excess supply	-8.539**		I(0)	296.957**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic (** rejects at 5%).
(2) Generation denotes generation for country (GC). Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend component are included in the regression respectively.

- ***Pearson's Correlation Test***

This study uses the Pearson correlation test to avoid any problems of multicollinearity where there is high correlation between two or more independent variables (Blalock, 1963). The results show no high correlation among independent variables in both models and thus no multicollinearity problem (see Table 2.3).[41]

As mentioned by Goodman (2010), electricity has storage difficulties and, therefore, immediate generation is required to satisfy current demand. When electricity consumption (*C*) increases,[42] generation (*G*) and import (*M*) should increase, while electricity export (*X*) should decrease. When electricity consumption (*C*) decreases, generation (*G*) and import (*M*) should decrease, while electricity export (*X*) should increase. However, if any one of generation, import or export can be manipulated to ensure electricity supply meets consumption, control of all three is not necessary. This can help explain why there is no high correlation among generation, import and export.

There is high correlation between generation and excess supply (0.752), but after taking the natural logarithm (*ln*) and a first-difference operator (Δ) for the variables, the correlation decreases to an acceptable value of 0.588.

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[41] There is high correlation between generation and distribution loss (0.867**). To avoid multicollinearity, distribution loss is dropped in both models.

[42] Because electricity is a vital commodity in all economies, and electricity demand is inelastic (Bajpai and Singh, 2004), governments have to manage electricity supply to meet demand or consumption (*C*). As mentioned previously, this study focuses on supply side. Consumption is not included in the model to avoid the problem of endogeneity.

Table 2.3: Pearson's Correlation Test Results

29 OECD Countries, 1980-2007					
Model 1	(PH)	(GC)	(M)	(X)	(ES)
(PH): Household price	1.000				
(GC): Generation for country	-0.024	1.000			
(M): Import	-0.170**	0.587**	1.000		
(X): Export	-0.147**	0.179**	0.426**	1.000	
(ES): Excess supply	-0.025	0.752**	0.594**	0.221**	1.000
Model 2	(PI)	(GC)	(M)	(X)	(ES)
(PI): Industry price	1.000				
(GC): Generation for country	-0.034	1.000			
(M): Import	-0.213**	0.587**	1.000		
(X): Export	-0.176**	0.179**	0.426**	1.000	
(ES): Excess supply	-0.037	0.752**	0.594**	0.221*	1.000
Model 1	Δ*ln* (PH)	Δ*ln* (GC)	Δ*ln* (M)	Δ*ln* (X)	Δ*ln* (ES)
Δ*ln* (PH): Household price	1.000				
Δ*ln* (GC): Generation for country	0.235**	1.000			
Δ*ln* (M): Import	-0.138**	0.023	1.000		
Δ*ln* (X): Export	-0.010**	0.230**	0.582**	1.000	
Δ*ln* (ES): Excess supply	0.352**	0.588**	-0.098**	-0.016	1.000
Model 2	Δ*ln* (PI)	Δ*ln* (GC)	Δ*ln* (M)	Δ*ln* (X)	Δ*ln* (ES)
Δ*ln* (PI): Industry price	1.000				
Δ*ln* (GC): Generation for country	-0.586**	1.000			
Δ*ln* (M): Import	0.080	0.023	1.000		
Δ*ln* (X): Export	0.074	0.230**	0.582**	1.000	
Δ*ln* (ES): Excess supply	-0.273**	0.588**	-0.098**	-0.016**	1.000

Note: ** denotes significant level at 5%.

- ***A Lagram-Multiplier Test for Serial Correlation***

Before setting up the model, implementing serial correlation tests which apply to macro panels with long time series (28 years) is necessary for this study. Serial correlation[43] makes the standard errors of the coefficients smaller than they really are and gives them higher R-squared values (Wooldridge, 2002). A Lagram-Multiplier test for serial correlation is employed for this duty,[44] with no serial correlation being the null hypothesis. Running both the original models for household (*PH*) and industry (*PI*) electricity prices gives the following:

Model 1(a)

$$\Delta\ln(PH_{it}) = \alpha_0 + \beta_1\Delta\ln(GC_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + \beta_4\Delta\ln(ES_{it}) + \beta_5(EU_{it}) + u_{it} \quad (9)$$

$F(1, 25) = 56.041$

Prob > F = 0

Model 1(b)

$$\Delta\ln(PH_{it}) = \alpha_0 + \beta_1\Delta\ln(GC_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + \beta_4\Delta\ln(ES_{it}) + u_{it} \quad (10)$$

$F(1, 25) = 55.632$

Prob > F = 0

[43] Autocorrelation is sometimes known as "*lagged correlation*" or "*serial correlation*", which refers to the correlation between items in a series of observations arranged in temporal sequence.

[44] This study does not employ the Arellano-Bond autocorrelation test because it was designed for small-*T* and large-*N* panels. However, this paper employs yearly data from 1980 to 2007 (T = 28) of 29 OECD countries (N = 29). When N is small, like in this case, the Arellano-Bond autocorrelation test may be unreliable (Roodman, 2006).

Model 2(a)

$$\Delta\ln(PI_{it}) = \alpha_0 + \beta_1\Delta\ln(GC_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + \beta_4\Delta\ln(ES_{it}) + \beta_5(EU_{it}) + u_{it} \qquad (11)$$

$F(1, 24) = 221.647$

Prob > F = 0

Model 2(b)

$$\Delta\ln(PI_{it}) = \alpha_0 + \beta_1\Delta\ln(GC_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + \beta_4\Delta\ln(ES_{it}) + u_{it} \qquad (12)$$

$F(1, 24) = 218.710$

Prob > F = 0.

The results show that the null hypothesis is rejected in all models. The presence of first order autocorrelation (AR1) is detected by the Wooldridge test for autocorrelation in panel data (Lagram-Multiplier test for serial correlation). Therefore, lagged dependent variables, being household electricity price (Model 1) and industry electricity price (Model 2), are added on the right-hand side. In many instances, an autoregressive term takes on a sizeable coefficient of statistical significance improving the fit in a very effective manner when it is entered as a "control" (Achen, 2001).

However, arguing against the use of lagged dependent variables with OLS, Achen (2001) shows that their inclusion to free the residuals of autocorrelation is an unsafe option because of possible bias in coefficient estimates. On the other hand, Keele and Nathan (2006) maintain that, for autocorrelation problems or merely to control for some unspecified spurious correlation, insertion of lagged dependent variables is completely reasonable as a corrective procedure.

Dynamic model specifications that incorporate lagged dependent variables are often suggested by the modeling of dynamic relationships and availability of panel data in econometric applications. Since Nickell (1981) at least, it has been known that classical least squares estimators in dynamic panel models with fixed effects are strongly biased when panels comprise short time periods. However, this study employs yearly data encompassing 28 years from 1980 to 2007. Therefore, any bias should be minimal.

2.5.3 Empirical Models

This study employs panel data to confer two dimensions (year and country) upon the variables in two models of electricity price function. The cross-sectional unit of observation here is country, and the temporal reference is the year. The deterministic approach constrains the error term of electricity price function to be non-negative. According to Villemeur and Pineau (2010), electricity price depends on cost of generation, import and export [see Equation (4)]. The improved models with lagged dependent variables are shown as

Model 1(a)

$$\Delta \ln(PH_{it}) = \alpha_0 + \beta_1 \Delta \ln(PH_{i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(ES_{it}) + \beta_6 (EU_{it}) + \Delta u_{it} \quad (13)$$

$$i = 1, 2 \ldots\ldots N \qquad t = 1, 2 \ldots\ldots T$$

Model 1(b)

$$\Delta \ln(PH_{it}) = \alpha_0 + \beta_1 \Delta \ln(PH_{i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(ES_{it}) + \Delta u_{it} \quad (14)$$

$$i = 1, 2 \ldots\ldots N \qquad t = 1, 2 \ldots\ldots T$$

where i denotes countries, t denotes years, α_0 is a constant term, and u_{it} is the error term assumed to be independent over i, but may be correlated over t.

In Model l(a), the explained variable is household electricity price (*PH*) with average price per year ($). To negate the effect of inflation, electricity market price is adjusted in accordance with CPI with 2005 being the base year. The explanatory variables are: household electricity price of the previous period (PH_{t-1}), electricity generation for country (*GC*), electricity import (*M*), electricity export (*X*), excess supply (*ES*), and membership of the European Union (*EU*).[45] However, in Model 1(b), European Union (*EU*) is dropped. All of the explanatory variables have the same measure of total MWh per year per country, except *EU* which is a dummy variable with only two values, zero and one. The natural logarithm is *ln* and Δ is a difference operator.

Model 2(a)

$$\Delta \ln(PI_{it}) = \alpha_0 + \beta_1 \Delta \ln(PI_{i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(ES_{it}) + \beta_6 (EU_{it}) + \Delta u_{it} \quad (15)$$

$$i = 1, 2 \;.....N \qquad t = 1, 2 \;.....T$$

Model 2(b)

$$\Delta \ln(PI_{it}) = \alpha_0 + \beta_1 \Delta \ln(PI_{i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(ES_{it}) + \Delta u_{it} \quad (16)$$

$$i = 1, 2 \;.....N \qquad t = 1, 2 \;.....T$$

In Model 2(a), the explained variable is industry electricity price (*PI*) with average price per year ($). To negate the effect of inflation, electricity market price is adjusted in accordance with PPI with 2005 being the base year. The explanatory variables are: industry electricity price of the previous period (PI_{t-1}), electricity generation for country (*GC*), electricity import (*M*), electricity export (*X*), excess supply

[45] Membership of the European Union (EU) is one of a number of international agreements in the Representation of Electricity Market model (see Figure 1).

(*ES*), and membership of the European Union (*EU*). However, in Model 2(b), European Union (*EU*) is not included.[46]

To cope with the problems of non-stationarity and serial correlation, all models are transformed to be first-difference models with lagged dependent variables [see Equations (13), (14), (15) and (16)]. From the transformed models, we get the error term as

$$\Delta u_{it} = \Delta \mu_i + \Delta \varepsilon_{it} \tag{17}$$

where $u_{it} = \mu_i + \varepsilon_{it}$ stands for the composite errors $\mu_i \sim i.i.d\ (0, \sigma_\mu^2)$ and $\varepsilon_i \sim i.i.d\ (0, \sigma_\varepsilon^2)$.

Hence, Equation (17) can be written as

$$u_{it} - u_{i,t-1} = \mu_i - \mu_{i,t-1} + \varepsilon_{it} - \varepsilon_{i,t-1} = \varepsilon_{it} - \varepsilon_{i,t-1} \tag{18}$$

By transforming the regressors through first differencing, the fixed country-specific effects from unobserved variables (distribution loss, taxes, subsidies, sequestration, technologies, energy policies, regulations and international agreements [see Figure 2.3]) are removed, if they do not vary with time.

Cost of electricity production has a direct effect on prices (Villemeur and Pineau, 2010). According to market equilibrium of microeconomic theory, an increase in supply will create a surplus, which lowers the equilibrium price of electricity. Hence, (β_2) should be negative.

Import of electricity increases supply in domestic markets, and when electricity supply increases, price will go down (Neuhoff, 2011). Price and import of electricity

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[46] The initial forms of Model 2(a) and Model 2(b) include the difference of prices (*DP*) between household and industry, which is real household electricity price minus real industry electricity price, and is a proxy variable representing government electricity subsidy for the industry sector. However, the results show a positive relationship between difference of prices (*DP*) and industry electricity price (*PI*), which is unreasonable because subsidy should decrease price. Hence this variable is dropped.

have a negative relationship (see Figure 2.1 and Figure 2.2), so (β_3) is expected to be negative. However, because electricity price is inelastic (Bajpai and Singh, 2004), increase in supply might not be able to markedly decrease price. From Equation (2), Price = Marginal Cost/(1- (HHI/ε)), so when elasticity (ε) of electricity is very low or zero, it is difficult for price to decrease.

On the other hand, export decreases supply in the domestic market, and when electricity supply decreases, price will go up (Neuhoff, 2011). Price and export of electricity have a positive relationship, so (β_4) should be positive (see Figure 2.1). However, there are two factors which argue against this. Firstly, if exporting countries have excess supply, which cannot be stored, and export that amount, price will not increase (see Figure 2.2). Secondly, from trade theory, international trade can make markets more efficient by diminishing returns in the short run and by economy of scale in the long run causing lower costs,[47] and it is therefore possible to realise price decreases.[48] Exporting countries have to produce more electricity, thus affording an

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[47] According to microeconomic analysis of production, the short-run average total cost (SATC) curve at first will go down as fixed costs are spread over a larger number of units, but then will go up as marginal costs increase due to the law of diminishing returns. Furthermore, in the long run, when economies of scale occur, the long-run average total cost (LRAC) curve will be declining; while with diseconomies of scale, the LRAC curve will be rising (Schwartz, 2010). Both short and long-run average curves are U-shaped, but with the long-run curve flatter than the short-run. This shows that electricity cost of production and generation can have negative and positive relationships. The short run is defined in economic terms as a time period where at least one production factor is assumed to be in fixed supply, i.e. cannot be changed. In the long run, all production factors are variable. This study employs yearly data of 28 years from 1980 to 2007, representing a short run in electricity markets.

[48] For electricity, it is normally cheaper to build one large facility than a number of smaller units to an equivalent capacity, as it is similarly less expensive to construct multiple units at one location

opportunity for expansion of electricity firms. The bigger the firm, the lower its costs of electricity production will be (Christensen and Green, 1976). As a result, it is also possible that (β_4) can be negative.

As previously noted, electricity is a unique commodity due to storage problems and inelastic electricity demand (Bajpai and Singh, 2004). Because excess supply (β_5) is difficult to store, it will not decrease the price of electricity by more than a marginal amount. Furthermore, excess supply entails increased cost of generation with no sale benefit, putting upward pressure on price. Trade in electricity has increased significantly due, in large part, to the problem of storage (Geman and Roncoroni, 2006), requiring electricity to be available at the moment it is needed.

For international trade, bigger areas containing a greater number of electricity producers and consumers are more successful at maintaining this balance between demand and supply. This is borne out by the European Union's desire to liberalise electricity markets and increase competition by promoting open access and free transit within networks (Charpentier, 1995). In this study, membership of the European Union (EU) is selected as a dummy variable to represent high electricity trade co-operation[49] in both Model 1(a) and Model 2(a). The expectation is that the greater the co-operation,

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than to spread them over a number of sites. Such economies of scale come about through the common use of facilities including transformers, transmission lines and fuel-handling equipment. Through joint planning, these economies are available more often than through separate planning, by arranging utilities to share a common unit. Hydro production allows substantial scale economies, and there are considerable economic gains in coordinating the running of a joint hydro/fossil fuel generation system which utilizes hydro during high demand reducing the need for expensive peak-traffic combustion turbines (Bowen et al., 2003, available at: https://www.purdue.edu/discoverypark/energy/assets/pdfs/Dhaka-july23-2003.pdf).

[49] Domanico (2012), available at: http://www.worldenergy.org/documents/p001227.pdf

the lower the electricity prices. Hence, the relationship between EU membership (β_6) and both household and industry electricity prices should be negative.

However, the EU agreements focus, not only on electricity free trade, but also on decreasing CO_2 emission levels from electricity generation. Directives 2001/77/EC, 2003/30/EC and 2009/28/EC of the European Parliament and of the Council promoted electricity production from renewable energy sources in the internal electricity market to decrease CO_2 emissions (Official Journal of the European Union, 2009). In 2009, the body which regulates the electricity and gas markets in Great Britain estimated the UK's energy and climate change policies represented 7% of the total household electricity bill (Department of Energy & Climate change, 2009). Membership of the EU can, therefore, have a positive relationship with electricity prices.

2.5.4 Panel Data Analysis

For this paper, the problem of omitted variables is solved by the use of panel data which controls for unobserved cross section heterogeneity (Wooldridge, 2002, p. 169). The unobserved variables change over time but not across entities and account for individual heterogeneity. In addition, panel data investigates dynamics without relying on retrospective questions that may yield data subject to measurement error. Another advantage of using panel data is the involvement of large numbers of observations giving more informative data, more observation variability, less collinearity among variables, more degrees of freedom and more efficiency (Baltagi, 2005, pp. 4-9). This study estimates standard linear panel estimators with regard to pooled ordinary least squares (POLS), fixed effects (within) and random effects.[50]

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[50] Between estimation employs the simple mean in preference to the over-time information in the data, resulting in less efficiency. This study ignores the between effects estimator because of the

The POLS estimator makes use of variation of both time and cross sectional units to estimate β by stacking data over i and t into one long regression with NT observations, and estimating by ordinary least square (OLS). The natural logarithm (*ln*) and a difference operator (Δ) are taken for all variables. Hence the POLS model can be shown as

$$P_{it} = \alpha + \sum_{j=1}^{k} \beta_j x_{j,it} + \sum_{p=1}^{s} \gamma_p z_{p,i} + \varepsilon_{it} \quad (19)$$

where P stands for the dependent variable which is electricity price [both household and industry which takes the natural logarithmic and a first-difference form ($\Delta ln\ P$)]; x stands for observed variables which are electricity price of the previous period ($\Delta ln\ P_{t-1}$), electricity generation for country ($\Delta ln\ GC$), electricity import ($\Delta ln\ M$), electricity export ($\Delta ln\ X$), excess supply ($\Delta ln\ ES$), and membership of the European Union (EU); z stands for unobserved variables including taxes, government subsidies, national energy policies, regulations and international agreements (see Figure 1); α is the intercept which represents the individual-specific constants; β is a k-dimensional column vector of parameters; γ is an s-dimensional column vector of parameters; ε_{it} is an error term [($\Delta\varepsilon_{it}$) in Equation (17)]; i is country; and t is year.

Hence, (19) can be written in the regression model as

$$P_{it} = \alpha + x'_{it}\beta + \mu_i + \varepsilon_{it} \quad (20)$$

where $x'_{it}\beta = \sum_{j=1}^{k} \beta_j x_{j,it}$ and $\mu_i = \sum_{p=1}^{s} \gamma_p z_{p,i}$

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impossibility that there is only cross-sectional variation in the electricity price function, and that electricity generation, import, export, total trade and transmission loss, which are regressors, are constant over the time period 1980-2008.

Unobserved characteristics (μ_i) are ignored by POLS, and under the restriction $\sum \mu_i = 0$, there is a limited POLS estimation. Usually, POLS produces inefficient estimates and invalid standard errors due to the presence of the unobserved effect, even if this effect has no correlation with any of the explanatory variables (Dougherty, 2011, p. 411).

An important reason to use panel data is its ability to control for unobserved heterogeneity (Todd, 2007) which can be solved by fixed effects.[51] Under fixed effects assumption, the unobserved variables which are the country-specific effect (μ_i) and the intercept (α) are constant, hence they are both cancelled.

$$\ddot{P}_{it} = \ddot{x}'_{it}\beta + \ddot{\varepsilon}_{it} \tag{21}$$

where $\ddot{P}_{it} = P_{it} - \overline{P}_{it}$, $\ddot{x}_{itk} = x_{itk} - \overline{x}_{itk}$ and $\ddot{\varepsilon}_{it} = \varepsilon_{it} - \overline{\varepsilon}_{it}$.

Fixed effects regressions are not suitable when the variables to be examined are constant for each individual due to elimination of these variables.[52] For this reason, random effects regression will be used in this section because it includes time invariant variables which disappear under fixed effects. From regression Equation (20), the basic unobserved effects model (UEM) is given for a randomly drawn cross-section observation which, for this study, is country (i). Under certain assumptions, the POLS estimator for obtaining a consistent estimator of β in the model can be used. The random effect model is shown as

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[51] After taking first differences for all variables, POLS estimation in this study is equal to fixed effects (first differences) estimation before taking first differences for all variables. Hence, only within is employed for the analysis.

[52] Note that the within estimator cannot estimate the effect for time-invariant regressors (e.g. the constant) which is cancelled as $\ddot{x}_{itk} = x_{itk} - \overline{x}_{itk} = 0$.

$$P_{it} = \alpha + x'_{it}\beta + u_{it} \quad (22)$$

where $u_i = \mu_i + \varepsilon_{it}$, stands for the composite errors, μ_i ~ *i.i.d* $(0, \sigma_\mu^2)$ and ε_i ~ *i.i.d* (0, σ_ε^2), and μ_i is independent of ε_i (Baltagi, 2005, p. 14).

Hence, Equation (22) can be written in the regression model as

$$P_{it} = \alpha + x'_{it}\beta + \mu_i + \varepsilon_{it} \quad (23)$$

where μ_i is between-entity error and ε_{it} is within-entity error.

Equation (23) is similar to Equation (20) of POLS, but the different is that the variation across country (μ_i) is not assumed to be zero. Random effects assumes μ_i is random and uncorrelated with the independent variables (x_i). It is reasonable to assume that unobserved variables in this study, e.g. taxes, government subsidies, national energy policies, regulations and international agreements (see Figure 2.3), have some influence on the dependent variable ($\mu_i \neq 0$), so random effects is more applicable than POLS. However, if the fixed country-specific effects of unobserved variables do not vary with time, they will be eliminated for all estimation methods (POLS, fixed effects and random effects) after the transforming to first-difference models [see Equation (18)].

2.5.5 Hausman Test

The Hausman test (1978) is used to compare the preferred model which is random effects (RE) versus the alternative model which is fixed effects (within [WI]) (Green, 2008, Ch. 9), basically determining whether the unique errors (μ_i) are correlated with the regressors - the null hypothesis being that they are not.

The Hausman test statistic is given by

$$\mathrm{H} = \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)' \left[\hat{\mathrm{V}}\left[\hat{\beta}_{FE}\right] - \hat{\mathrm{V}}\left[\hat{\beta}_{RE}\right]\right]^{-1} \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right) \quad (24)$$

where S.E. = $\left[\hat{V}\left[\hat{\beta}_{FE}\right]-\hat{V}\left[\hat{\beta}_{RE}\right]\right]$. FE denotes fixed effects (within) and RE denotes random effects.

The null hypothesis is presented as

H_0: unique errors (u_i) are not correlated with the regressors.

Under H_0, β_{RE} is consistent and efficient,[53] while β_{FE} is consistent but inefficient. Under H_A, β_{RE} is inefficient but remains consistent (Schmidheiny, 2012). If the test result is not significant (P-value, Prob > χ^2 larger than 0.05), then the null hypothesis is not rejected and random effects can be used. However, if the P-value is significant, leading to rejection of the null hypothesis, then it is recommended that fixed effects be employed.

2.5.6 Testing for Random Effects: Breusch-Pagan Lagrange Multiplier Test

This chapter uses the Breusch-Pagan LM (B-P/LM) test to decide between a random effects regression and a simple OLS regression.[54] Breusch and Pagan (1980) devised a Lagrange multiplier test for the random effects model based on the OLS

[53] Under the null hypothesis, both fixed effects and random effects estimators are efficient. If we assume that the true model is the random effects model where μ_i are *iid* $\left[0, \sigma_{\mu}^2\right]$ and uncorrelated with regressors, and u_{ti} are *iid* $\left[0, \sigma_u^2\right]$, then $\hat{\beta}_{RE}$ is fully efficient (Green, 2008, Ch. 9).

[54] According to Baltagi (2005), in macro panel with long time series (over 20-30 years), there is concern about cross-sectional dependence. However, in micro panel, which is a small number of years and a large number of cases ($N > T$), the problem is not so prevalent. Even though, in this study, $N > T$ (29 > 28), the LM test is employed to check for cross-sectional dependence/contemporaneous correlation.

residuals. From Equation (22), the composite disturbances in panel data model are generated by $u_i = \mu_i + \varepsilon_{it}$, and the LM hypotheses are

$$H_0: \sigma_\mu^2 = 0$$

$$H_1: \sigma_\mu^2 \neq 0$$

For the LM test, the null hypothesis is that variances across countries (σ_μ^2) is zero. The LM test statistic is given by

$$LM = (NT/2(T-1)[(\sum_{i=1}^{N} e_i^2 / \sum_{i=1}^{N}\sum_{t=1}^{T} e_{it}^2) - 1]^2 \qquad (25)$$

where e_{it} denotes the POLS residuals, and e_i denotes their sum over t. This LM is distributed as a χ_1^2 statistic (with one degree of freedom) (Baltagi, 2011, p. 319).

Failure to reject the null hypothesis leads to the conclusion that random effects is not appropriate. There is no evidence of significant differences across countries, therefore POLS is the preferred option.

2.6 EMPIRICAL RESULTS

The methodology put forward in the previous section is used in this chapter to examine relationships between electricity prices (household in Model 1 and industry in Model 2), and the determined variables of electricity price of the last period, electricity generation, electricity import, electricity export, excess supply and EU membership. All variables in this study are in natural logarithms and take first differences.

2.6.1 Panel Data Analysis Results

This study focuses on whether co-operation between countries, with regard to import and export of electricity, can reduce electricity prices for both households and industry. Panel data analysis precedes comparison of electricity prices for generation and trading, using 29 OECD countries' yearly data from 1980 to 2007. The most suitable estimation method is determined by econometric testing for pool ordinary least squares (POLS), fixed effects (within) and random effects.

Table 2.4: Standard Linear Panel Model Estimator Results for Household Prices

Household Prices 29 OECD Countries, 1980-2007						
Model 1: $\Delta\ln(PH_{it}) = \alpha_0 + \beta_1\Delta\ln(PH_{i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(ES_{it}) + \beta_6(EU_{it}) + u_{it}$						
Model 1	**POLS**		**FIXED (WITHIN)**		**RANDOM**	
	(a)	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**
$\Delta ln(PH_{, t-1})$: Lag1 Household price	0.013 (0.223)	0.014 (0.022)	0.009 (0.023)	0.009 (0.023)	0.013 (0.223)	0.014 (0.222)
Δ*ln*(GC): Generation for country	-0.171*** (0.018)	-0.170*** (0.018)	-0.173*** (0.018)	-0.173*** (0.0180	-0.171*** (0.018)	-0.170*** (0.018)
Δ*ln*(M): Import	0.003 (0.006)	0.003 (0.006)	0.003 (0.006)	0.003 (0.006)	0.003 (0.006)	0.003 (0.006)
Δ*ln*(X): Export	0.031*** (0.006)	0.031*** (0.006)	0.031*** (0.006)	0.031*** (0.006)	0.031*** (0.006)	0.031*** (0.006)
Δ*ln*(ES): Excess supply	0.001 (0.012)	0.001 (0.012)	0.001 (0.012)	0.001 (0.012)	0.001 (0.012)	0.001 (0.012)
(EU): EU member	-0.008 (0.007)		0.010 (0.016)		-0.008 (0.007)	
α_0	0.006 (0.005)	0.002 (0.004)	-0.002 (0.008)	0.002 (0.004)	0.006 (0.006)	0.002 (0.004)
σ_μ			0.018	0.016	0	0
σ_ε			0.099	0.099	0.099	0.099
ρ			0.031	0.024	0	0
F-Statistics	23.63***	28.14***	23.21***	27.81***		
χ^2					141.78***	140.71***
Observations	632	632	632	632	632	632

Notes: (1) Standard errors in ( )
(2) *** denotes significance at 1% level.
(3) Intraclass correlation $\rho = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Table 2.4 shows the estimation results of household electricity price (Model 1) by three estimation methods. Standard linear panel estimators (POLS, fixed effects and random effects) all give similar results for Model 1(a) and Model 1(b). The results of both models show that the effect of electricity price of the previous period (β_1) is close to zero and not statistically significant. Because this study employs yearly data, it is possible that price of electricity in the previous year does have an effect on the current year price.[55]

Since (β_2) is negative, electricity generation increase is shown to lower household electricity prices with high significance, as expected. When supply increases, electricity price should decrease, and this can also apply for import. However, the results show that (β_3) is positive, although close to zero and not statistically significant. This might be attributed to electricity price inelasticity (Bajpai and Singh, 2004), with the amount of import not having enough effect on prices.

Export (β_4) has a highly significant positive relationship with household electricity price. However, the effect is marginal, probably because export countries sell much electricity from excess supply. Other possible reasons are that international electricity trade, through exploitation of comparative resource advantages, can reduce costs (Justus, 1997; Bielecki and Desta, 2004, p. 21), and electricity export can improve economic efficiency in lowering cost, e.g. through economies of scale (Christensen and Green, 1976).

The effect on household electricity price from excess supply (β_5) is close to zero and not statistically significant, following the expectation of this study from the inelasticity of the price of electricity as well as this commodity's storage difficulties.

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[55] Household electricity price of the previous period (PH_{t-1}) is included in the models in order to avoid serial correlation.

The EU member analysis in Model 1(a) gives a negative relationship between EU membership and household electricity price for POLS and random effects estimations, but a positive relationship for fixed effects estimation. However, the relationship degrees are tiny and all estimations are not statistically significant.

Table 2.5: Standard Linear Panel Model Estimator Results for Industry Prices

Industry Prices 29 OECD Countries, 1980-2007						
Model 2: $\Delta \ln(PI_{it}) = \alpha_0 + \beta_1 \Delta \ln(PI_{i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(ES_{it}) + \beta_6 (EU_{it}) + u_{it}$						
Model 2	**POLS**		**FIXED (WITHIN)**		**RANDOM**	
	(a)	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**
Δ*ln*($PI_{,t-1}$): Lag1 Industry price	0.051 (0.043)	0.055 (0.043)	0.037 (0.044)	0.036 (0.044)	0.051 (0.043)	0.055 (0.043)
Δ*ln*(GC): Generation for country	-0.285*** (0.022)	-0.284*** (0.022)	-0.290*** (0.023)	-0.289*** (0.023)	-0.285*** (0.022)	-0.284*** (0.022)
Δ*ln*(M): Import	-0.003 (0.009)	-0.003 (0.009)	-0.003 (0.009)	-0.003 (0.009)	-0.003 (0.009)	-0.003 (0.009)
Δ*ln*(X): Export	0.030*** (0.007)	0.030*** (0.008)	0.031*** (0.008)	0.031*** (0.008)	0.030*** (0.007)	0.030*** (0.008)
Δ*ln*(ES): Excess supply	-0.006 (0.013)	-0.006 (0.013)	-0.006 (0.013)	-0.006 (0.013)	-0.006 (0.012)	-0.006 (0.013)
(EU): EU member	-0.017* (0.010)		-0.012 (0.024)		-0.017* (0.010)	
α_0	0.016 (0.008)	0.006 (0.005)	0.012 (0.015)	0.006 (0.005)	0.016 (0.008)	0.006 (0.005)
σ_μ			0.019	0.020	0	0
σ_ε			0.093	0.093	0.093	0.093
ρ			0.038	0.044	0	0
F-Statistics	36.22***	42.56***	34.93***	25.75***		
χ^2					217.31***	212.80***
Observations	341	341	341	341	341	341

Notes: (1) Standard errors in ( )
(2) ***, ** and * denote significance at 1%, 5% and 10% levels respectively.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Table 2.5 gives the estimation results of industry electricity price (Model 2) by the three estimation methods (POLS, fixed effects and random effects). Model 2(a) and Model 2(b) both show that there is no effect from industry electricity price of the previous period (β_1) on the current year price. Electricity generation (β_2) shows a highly significant negative relationship with industry electricity price, following the expectation. The result for import (β_3) is negative, which follows the expectation that import increases electricity supply so reducing price for industry. However, the finding is not statistically significant under any estimation methods. As anticipated, export (β_4) has a significant positive relationship with industry electricity price, although the relationship degree is tiny.

For all estimation methods, the effect of excess supply (β_5) on industry price is negative, but the results are not statistically significant. Model 2(a) gives a negative relationship between EU membership and industry electricity price for all estimations. The results are significant for POLS and random effects estimations, but not for fixed effects estimation.

2.6.2 Hausman Test Results

From Table 2.6, the results for all models show that the null hypothesis, that unique errors (u_i) are not correlated with the regressors, is not rejected, hence random effects estimations are accepted. Because, under random effects, the regression model retains observed characteristics that remain constant for each country, this estimation method holds more appeal than does fixed effects where those characteristics are lost (Dougherty, 2011).

Table 2.6: Hausman Test Results

29 OECD Countries, 1980-2007			
Model 1: $\Delta\ln(PH_{it}) = \alpha_0 + \beta_1\Delta\ln(PH_{i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(ES_{it}) + \beta_6(EU_{it}) + u_{it}$			
	H	**Prob >** χ^2	**Random Effects**
(a)	2.99	0.810	accept RE
(b)	2.55	0.770	accept RE
Model 2: $\Delta\ln(PI_{it}) = \alpha_0 + \beta_1\Delta\ln(PI_{i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(ES_{it}) + \beta_6(EU_{it}) + u_{it}$			
	H	**Prob >** χ^2	**Random Effects**
(a)	4.22	0.648	accept RE
(b)	6.82	0.234	accept RE

Notes: (1) $\text{H} = \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)'\left[\hat{\text{V}}\left[\hat{\beta}_{FE}\right] - \hat{\text{V}}\left[\hat{\beta}_{RE}\right]\right]^{-1}\left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)$

(2) S.E. = $\left[\hat{\text{V}}\left[\hat{\beta}_{FE}\right] - \hat{\text{V}}\left[\hat{\beta}_{RE}\right]\right]$

(3) H < 0 indicates model fitted on these data fails to meet the asymptotic assumptions of the Hausman test.

2.6.3 Breusch-Pagan Lagrange Multiplier (LM) Test Results

In Table 2.7, the results show that all models for household and industry prices fail to reject the null hypothesis that variances across countries (σ_μ^2) is zero, with the conclusion that random effects estimations are not appropriate. Because there is no evidence of significant differences across OECD countries in this study, POLS is acceptable for all models.[56]

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[56] As mentioned previously, in principle, random effects is more applicable than POLS because random effects assumes that unobserved variables have some influence on the dependent variable ($\mu_i \neq 0$) while POLS assumes that there is no influence from unobserved variables ($\mu_i = 0$). However, the fixed country-specific effect from unobserved variables (μ_i) for all estimation methods is eliminated, if they do not vary with time, after the transforming to first-difference models [see Equation (18)]. Table 4 and

Table 2.7: Breusch-Pagan Lagrange Multiplier (LM) Test Results

29 OECD Countries, 1980-2007						
Model 1: $\Delta\ln(PH_{it}) = \alpha_0 + \beta_1\Delta\ln(PH_{i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(ES_{it}) + \beta_6(EU_{it}) + u_{it}$						
	Var Δ***ln(PH)***	**Var (*μ*)**	**Var (*ε*)**	**LM**	**Prob >** χ^2	**Random Effects**
(a)	0.012 (0.108)	0 (0)	0.010 (0.099)	0	1	not accept RE
(b)	0.012 (0.108)	0 (0)	0.010 (0.099)	0	1	not accept RE
Model 2: $\Delta\ln(PI_{it}) = \alpha_0 + \beta_1\Delta\ln(PI_{i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(ES_{it}) + \beta_6(EU_{it}) + u_{it}$						
	Var Δ***ln(PI)***	**Var (*μ*)**	**Var (*ε*)**	**LM**	**Prob >** χ^2	**Random Effects**
(a)	0.013 (0.116)	0 (0)	0.009 (0.093)	0	1	not accept RE
(b)	0.013 (0.016)	0 (0)	0.009 (0.093)	0	1	not accept RE

Notes: (1) $LM = (NT/2(T-1)[(\sum_{i=1}^{N} e_i^2 / \sum_{i=1}^{N}\sum_{t=1}^{T} e_{it}^2) - 1]^2$

(2) Standard errors in ( )

2.6.4 Results of Household Electricity Price

Hausman and LM tests determine the appropriate estimation methods, and Table 2.4 gives the results for household electricity price (Model 1) which are accepted under POLS. Model 1(a) with EU membership effect and Model 1(b) without EU membership effect both give similar results. The two models show that an increase of 1% in household electricity price of the previous period (β_1) raises electricity prices by about

Table 5 show that there is no difference between the coefficients of POLS and random effects estimations in both household and industry electricity prices.

0.01%, but the results are not statistically significant.[57] Following the expectation, a rise of 1% in electricity generation (β_2) gives a highly significant result of decreasing household electricity prices by about 0.17%.

A rise of 1% in import (β_3) is seen to increase household electricity prices by about 0.003%, which is close to zero and not statistically significant. This might be attributed to electricity price inelasticity (Bajpai and Singh, 2004), with the amount of import not enough to affect prices. As expected, for export (β_4), a rise of 1% shows a highly significant increase in electricity prices of about 0.03%, following the law of supply. The effect of excess supply (β_5) on household electricity price is close to zero (0.001%) and not statistically significant, following the expectation due to the inelasticity of the price of electricity and the fact that electricity is difficult to store. In addition, excess supply is associated with increased cost from electricity generation without the benefit of product sale, thus putting upward pressure on electricity price. Model 1(a), which includes the effect of EU membership, shows that being a member of the EU (β_6) decreases electricity prices by about 0.01%. However, this result is not statistically significant.

2.6.5 Results of Industry Electricity Price

Table 2.5 gives the results for industry electricity prices which are accepted under POLS for all models. Model 2(a) with EU membership effect and Model 2(b) without EU membership effect show similar results. Both models find that an increase of 1% in industry electricity price of the previous period (β_1) increases electricity

[57] Household electricity price of the previous period (PH_{t-1}) is included in the models in order to avoid serial correlation. Because this study employs yearly data, it is possible that price of electricity in the previous year does have an effect on the current year price.

prices by about 0.05%, but the result is not statistically significant. A rise of 1% in electricity generation (β_2) is shown to highly significantly decrease industry electricity prices by about 0.28%, as expected.

For import (β_3), a rise of 1% decreases industry electricity prices by about 0.003%, following the expectation. However, the result is close to zero and not statistically significant. As anticipated, a rise of 1% in export (β_4) produces a highly significant increase in electricity prices of about 0.03%, following the law of supply. A rise of 1% in excess supply (β_5) results in a non-significant decrease in industry electricity price of about 0.01%, which follows the expectation from electricity price inelasticity and electricity storage difficulties. Model 2(a), which includes the effect of EU membership, shows that being a member of the EU (β_6) significantly decreases industry electricity prices (-0.02%).

2.7 DISCUSSION

The results of this study show that electricity generation, for OECD countries, decreases electricity prices for both household and industry more so than electricity import and export. However, it must be remembered that the effect on electricity price from generation includes subsidy. The OECD has an estimation of 29 billion Euros in subsidies per year mostly for energy producers including electricity providers (Chomitz, 2009). Hence, an increase in generation is an increase in subsidy.[58] In fact, electricity from international trade is cheaper than the cost of generation plus subsidy.

Furthermore, government subsidy of electricity price is higher for industry than households, and when governments subsidize, it interferes with market mechanism, posing a barrier to competition from international trade (Harris, 2006, p. 131). For

[58] Subsidy is not included in the models because of data limitation.

OECD countries, subsidies in electricity for industry are more than for households. This might explain why the results of this study show that electricity generation decreases electricity price for industry (-0.20%) more than for households (-0.17%).

The results indicate that import increases household electricity prices by (0.003%), which is close to zero. However, because electricity import does not included subsidy, it can reduce the financial pressures on government budgets made, in part, from electricity subsidy. Conversely, for industry, the results show that a rise of 1% in import decreases electricity prices by about 0.003%, following trade theory assertion that import increases electricity supply, thus lowing price (see Figure 2.1). However, both results are not statistically significant.[59]

Many studies indicate that international electricity trade can reduce cost (Odgaard, 2000; Charpentier, 1995; Unger and Ekvall, 2003). However, the results of this study show that this benefit does not go to consumers as international trade, for OECD countries, is not found to decrease electricity prices for either households or industry. This may be due to the inelasticity of electricity price and the cost of transmission which increases the price for importing countries (see Figure 2.1). In addition, electricity markets are often inefficient and not effectively competitive due, in

[59] From Figure 2.2, international trade does not reduce electricity prices for the import country, however it can protect against price rise, especially when the import country is faced with the problem of electricity shortage and unable to generate more electricity. Sauter and Awerbuch (2003) maintain that price of electricity is a major social welfare issue which affects everyday cost of living and consumer wealth. Electricity price increase can cause inflation within domestic economies, with direct effect on the consumer price index (CPI) (Herrden et al., 2005). When electricity co-operation with regard to import and export occurs, it not only decreases household electricity prices directly to consumers, but also reduces industry electricity prices, negatively impacting the CPI, which is the target of national economic objectives, hence improving social welfare.

part, to the non-involvement of retail-customer loads. Electricity costs can fluctuate greatly during the day, but most consumers continue to pay prices set months or years ago. In fact, wholesale electricity market movements cause little price variation at the retail level (Hirst and Kirby, 2001).

Even though export is expected to increase price (see Figure 2.1), the benefits of international trade, which include promotion of specialization in production from division of labour and economy of scale as well as lower opportunity cost may explain why the increases here, although highly significant, are tiny for both household (0.03%) and industry (0.03%). It is possible that international electricity trade among OECD countries can exploit comparative resource advantages and lower costs resulting in no increase to electricity prices (Odgaard, 2000) (see Figure 2.2). In this way, electricity export can improve market efficiency.

Because electricity is a vital commodity, international electricity trade involves more than just buying and selling. It requires a high level of mutual trust between countries and is founded on co-operation. This study employs a dummy variable (membership of the EU) to represent high co-operation.[60] In 2008, countries linked to the Union for Coordination of the Transport of Electricity (UCTE) exchanged in the order of 300 terawatt-hours of electricity. However, the EU agreements focus, not only on electricity free trade, but also on decreasing CO_2 emission levels from electricity generation, and such climate change policies can increase electricity prices (Department of Energy & Climate Change, 2009). This can interfere with any price reducing effect of international electricity trade.

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[60] In 1995, the World Bank reported that the EU promotes open access and free transit within networks and has a certain amount of electricity trade under EU agreements, resulting in vast amounts of cross-border energy flow (Charpentier, 1995).

One reason why this close co-operation within the EU does not result in greater reduction of electricity prices could be because the real state of affairs in Europe is far from one of an internal market of open competition. This is reflected in the observation by the European Commission, in 2007, that, within the original 15 EU member states, the top three European generation power firms control 60% of the market in ten different countries (Domanico, 2012).[61] Neuhoff (2011) points out that monopolies will never seek more transmission capacity than what is available preferring to keep the economic rent of the transmission line. Since transmission is a natural monopoly, government policy here is needed in order to achieve social welfare maximization.

With a focus on economic strategy, when governments have to make a decision between increased domestic electricity generation or electricity trade with bordering countries, the latter is the better choice because international trade can reduce production costs, subsidies and CO_2 emissions from decrease in generation. However, the findings of this paper do not support the observation of Justus (1997) and Bielecki and Desta (2004, p. 21) that price reduction results from competition pressure following market reform caused by international trade. This suggests that OECD governments should improve co-operation to raise competition and efficiency in domestic markets. In addition, policy makers should implement regulations to help increase the elasticity of electricity price to allow retail prices to decrease when competition increases. In this way, consumers will benefit from electricity co-operation through price decreases.

[61] Available at: http://www.worldenergy.org/documents/p001227.pdf and http://ec.europa.eu/competition/antitrust/others/sector_inquiries/energy/.

2.8 CONCLUSION

This paper examines whether international co-operation regarding electricity import and export can reduce electricity household and industry prices. Econometric methodology of panel data analysis is employed to determine the electricity price functions for 29 OECD countries' yearly data from 1980 to 2007. The results show that electricity import has a tiny, but not significant, effect on decreasing both household and industry electricity prices. However, export gives a highly significant finding in increasing electricity prices a tiny amount for both households and industry. The effect of EU membership regarding close co-operation is seen to decrease electricity prices. For industry the result is significant, but not for households, leading to the speculation that trading countries need to co-operate more closely to improve efficiency in electricity markets. When countries which have excess supply export electricity to countries which have excess demand, the former gain more income while the latter pay less for electricity. International trade in electricity, by reducing the need of government subsidies for generation, can help redress the problem of high electricity prices. This will allow people to have a higher standard of living and also lower the cost of industry and business.

CHAPTER THREE

THE ROLE OF ELECTRICITY IMPORT AND EXPORT IN CO_2 REDUCTION

The greater part of carbon dioxide (CO_2) emissions comes from the production of energy, especially electricity, which the world cannot do without.[62] In order to meet targets aimed at tackling climate change, many countries are increasing electricity generation from renewable energy sources and nuclear power. However, renewable energy has problems with regard to economic costs and instability of supply,[63] while nuclear power generation involves issues of safety and radioactive waste management, as we can see from the very serious nuclear power situation in Japan, caused by the tsunami of 11th March, 2011. As a result, it would appear that, in the future, electricity generation by flue sources of coal, gas and oil will still be necessary, and these are the major players in the role of atmospheric carbonization.[64] Therefore, another approach is

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[62] The generation to supply our need for electricity is mostly derived from flue sources. In 2009, electricity production accounted for 32% of total global fossil fuel use and 41% of energy-related CO_2 emissions. Increasing the energy efficiency of electricity production would reduce the world's dependence on fossil fuels and as a result help to minimize climate change (Nezhad, 2009, p. 14).

[63] Conventional generation is usually cheaper than generation from renewable sources while, in addition, renewable energy source fluctuations may impose a limit on output generation available from such sources (PB Power, 2004).

[64] The Treasury Department of the Australian government forecasts that, after 2050, more than half of the planet's electricity generation will be coal based. In 2005, the percentage breakdown of world electricity generation by fuel was coal (41%), gas (22%), renewable (16%), nuclear (14%) and oil (7%). By 2050, the percentage breakdown is expected to be coal (53%), gas (17%), renewable (11%), nuclear (14%) and oil (8%) (The Treasury, Australian Government, 2011, Chart 3.11). Furthermore, because of

needed in the fight against global warming through CO_2 emissions from electricity generation.

Energy Information Administration (EIA) reports that, since 1990, increase in world net electricity generation has surpassed increase in total delivered electricity consumption and, by 2035, this surplus is anticipated to constitute one third of electricity generation (EIA, 2011, Figure 72). However, areas in many countries experience a situation of electricity shortage affecting a total of about 1.4 billion people in 2009 (IEA, 2010, pp. 237-238). This situation of co-existing surplus and shortage suggests that import and export of electricity may prove mutually beneficial for countries. Such international trading could not only increase electricity supply for excess demand countries while providing an economic gain for excess supply countries, but also decrease levels of CO_2 emissions from electricity generation.

This study examines whether international co-operation regarding electricity import and export between countries can help redress the problem of CO_2 emissions. The work covers 131 countries and also divides countries by continent with 37 yearly samples provided for the period 1971 to 2007. Panel data analysis determines the CO_2 emissions function for the world and each continent. The results show, with a level of high significance, that CO_2 emissions from electricity co-operation with regard to import and export are much lower than from generation. Such international co-operation can accelerate decarbonisation of the world's atmosphere, with a policy of electricity trading being a vital part of global warming solutions.

This chapter is organized as follows: section one, motivation; section two, electricity co-operation situation; section three, omitted social cost increases CO_2

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increased electricity demand causing a rise in supply, total electricity emissions by 2050 are expected to be more than triple those of 2005 (The Treasury, Australian Government, 2011, Chart 3.3).

impact; section four, increase in trade decreases CO_2; section five, model of CO_2 emissions; section six, methods and procedures; section seven, empirical results; section eight, discussion; and section nine, conclusion.

3.1 MOTIVATION

The current worldwide challenge confronting our planet is the issue of global warming.[65] This increase in the average temperature of the earth's near-surface air and oceans is caused by greater concentrations of greenhouse gases[66] trapping heat from the sun in the planet's atmosphere. An important consequence of this is a rise in sea levels. The Intergovernmental Panel on Climate Change (IPCC) expects that global sea levels will rise by up to 60 cm by the year 2100 (IPCC, 2007a). However, the recent accelerated decline of the polar ice sheet increases the likelihood of future sea level rise (SLR) being more than one metre over the same time span (Nicholls and Cazenave, 2010).[67]

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[65] The Intergovernmental Panel on Climate Change (IPCC, 2007a), describing the situation regarding global warming, states that over the last 100 years the earth has increased in temperature by 0.74°C, eleven of the twelve years from 1995 to 2006 rank among the twelve warmest years since 1850, and it is possible that, by the end of the 21st century, temperatures could rise by between 1.1°C and 6.4°C.

[66] The key greenhouse gases entering the atmosphere through human activity comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine) (IPCC, 2007b).

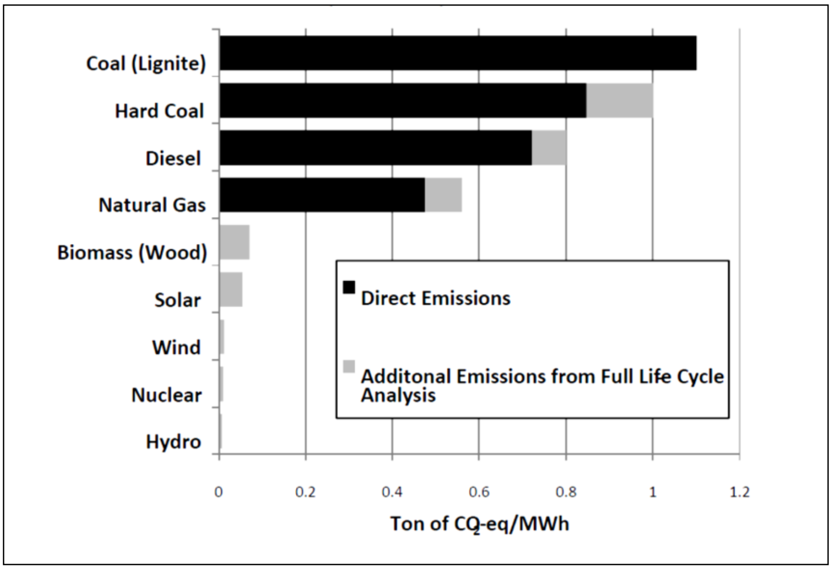
[67] Warming of the ocean not only melts polar ice and glaciers, but also expands the volume of water in oceans, and both these processes contribute to rising sea levels. Furthermore, there is an increased risk of the edges of ice shelves and coastal glaciers falling into the ocean, thereby causing greater sea level rise (IPCC, 2007a).

The World Bank research studies spatially-disaggregated global data on vital impact areas (land, population, agriculture, urban extent, wetlands, and GDP) with SLR inundation projected for 1-5 metres. The results show that, within this century, hundreds of millions of people in the developing world can expect displacement by SLR, and for many, the associated economic and ecological damage will be extreme (Dasgupta et al., 2007). In addition, the IPCC (2007a) states that, while mostly poor people will suffer the effects of global warming, no person will escape its impact. According to the Massachusetts Institute of Technology (MIT) scenario of a linear SLR of one metre over the next hundred years, where economically viable, cities around the world would adapt by building sea-wall defences. The resultant loss of wetlands, habitable land, and capital would be in the order of $2 trillion in present-day value, discounted at 3 to 4 percent (Sugiyama et al., 2008). Therefore, it is clear that climate change will affect every region and all levels of society.

Electricity generation involves the negative external factors of environmental destruction and release of greenhouse gases, especially CO_2, into the atmosphere causing global warming. Overall, 40% of the world's electricity is derived from coal and 20% from gas, but the figures vary widely across countries. For example, in South Africa and Poland, more than 90% of power generation comes from coal while, in China and Australia, it is close to 80%. For India, the figure is higher than 66%, for the UK 40% and for the US and Japan about 20%. With regard to CO_2 emissions, the age of a country's power plants plays an important role, since the efficiency of most coal-fired power plants is currently well below state of the art (Nezhad, 2009). Other generation technologies such as wind, photovoltaics (solar), hydro, biomass, wave/tidal and nuclear are often described as *low carbon* or *carbon neutral* because they do not produce CO_2 during generation (direct emissions). However, POST, UK, (2006) notes that CO_2

emissions do occur in other phases of their life cycle, e.g. during extraction, construction, maintenance, decommissioning and transport (additional emissions), thus indicating that all types of electricity-generating systems produce CO_2 emissions (see Figure 3.1).

Figure 3.1: Greenhouses Gas Emissions per MWh of Electricity from Different Sources



Source: Weisser, 2007

This study recognizes CO_2 emissions from electricity generation as a major factor in global warming and a social cost affecting the well-being of society by undermining economic development and altering the natural environment. Electricity, as the largest and fastest growing contributor to CO_2 pollution, is in a unique position with regard to tackling climate change, holding many of the solutions to a more efficient, less carbon-based economy (OECD/IEA, 2010, p. 7). However, such climate and energy policies have an impact on electricity bills,[68] putting upward pressure on inflation.[69] In response, Adams and Dixon (2007) compare cutting greenhouse gas emissions to buying an insurance policy in that a cost is incurred, as a loss in GDP, in order to reduce the risk of future catastrophic climate change. Even though global warming ranks as one of the most difficult major current problems in terms of solutions, doing nothing is not an option.

A study by Unger and Ekvall (2003) of Nordic countries shows that co-operative strategies, including cross-border electricity trade, can decrease both electricity cost and CO_2 emissions from electricity generation. This suggests that international electricity trade should be beneficial by not only helping to decrease the level of CO_2 emissions from electricity generation, but also by lowering electricity costs, both private and social, through increased market efficiency.

3.2 WORLD ELECTRICITY CO-OPERATION SITUATION

Electricity co-operation regarding import and export between countries has been common for many years ever since the first connection between Canada and the United States (U.S.) in 1901. There is an economic efficiency to be gained from trading based on differences in natural production costs between countries, while load fluctuations can be more easily managed through exchanges with neighbouring countries which have

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[68] Based on the analysis of Ofgem, which regulates the electricity and gas markets in Great Britain, energy and climate change policies are estimated to represent 7% of the total household energy bill (Department of Energy & Climate change, 2009).

[69] According to Herrden et al. (2005), there exists a twofold relationship between inflation and price increases in electricity. Inflation and inflation projections have an effect on electricity price determination, and the electricity price level has, conversely, an effect on inflation.

different demand profiles. Such co-operation decreases the size of reserve margins required by increasing the number of available supply sources. Excess capacity in a neighbouring country can arise simply from different load timings, or be the result of climate variation, difference in economic structure, or scheduled as well as unexpected unit outages (IEA, 2010).

As mentioned by the Treasury, Australian Government (2011) and IEA (statistic), most electricity demand growth arises from developing countries, especially China and India. Therefore, international electricity trade among developing countries in Asia is of interest as an instrument for governments in meeting increasing demand for electricity. China is involved in exporting electricity from nuclear and hydroelectric sources to Hong Kong, with net exports of 12.8 TWh in 2008, while India is known to import a significant amount of electricity, much of which is generated by hydro plants in Bhutan (IEA, 2010). Such trade in electricity involving non-fossil fuel sources reduces the need for conventional generation and so lessens the CO_2 emissions burden for this continent.

In Japan, assistance in regard to the serious issue of electricity supply since the tsunami of 2011 may be at hand from a study by Kanagawa and Nakata (2004). In their analysis of the impact of electricity grid interconnection between Korea and Japan, they find that not only can both countries increase electricity supply, but also a joint CO_2 emissions target achieves its desired result more efficiently than does individual effort.

Geography has, at times, linked or separated the Middle East and Asia. For the energy sector, the situation is one of separation demonstrated by an almost total lack of related infrastructure connecting the two areas. This is despite strong complementarities in energy resources, production and consumption which remain unexploited by electricity trade across these regions. In this study, therefore, the Middle East is separated from Asia.

Over the past 20 years, the Middle East has experienced dramatic growth in electricity demand and related infrastructure achieving a total generation capacity of 73,680 MW by 2002 with a large number of new generation plants being constructed and proposed within the area. However, it is expansion plans for the regional transmission grid that hold most significance from an electricity trade perspective (Bowen et al., 2003).

Although Africa has an abundance of rich natural resources,[70] in the sub-Saharan regions only 5 - 20% of the population have access to electricity, partly due to the unequal distribution of those resources among all countries. Across Africa, lack of local demand and suitable transport infrastructure leads to resources not being optimally accessed. The result is a wastage of energy, as evidenced by the vast hydro resources on the Congo River (in DR Congo) as well as the flaring of gas in Angola (Mkhwanazi, 2003).

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[70] As to be expected, a range of energy sources is used for power generation. Most electricity produced in Africa (82%) comes from thermal stations due to the dominance of the South African coal-fired plants, and the oil-fired units in Nigeria and North Africa. Hydro-electricity is most common in sub-Saharan Africa (excluding South Africa), accounting for 15% of Africa's installed capacity. One nuclear power station (Koeberg, in Cape Town, South Africa) supplies 3% of Africa's power needs. Natural gas plays an important role in supplying new power plants as a way of reducing dependence on expensive oil. This is particularly so in West Africa, but South Africa is also strongly interested in pursuing a natural gas sector, with the first gas flow from Mozambique expected within a year. Kenya has geothermal plants, and a small number of renewable plants (solar, wind etc.) are in operation in different countries (Mkhwanazi, 2003).

One of the most integrated and reliable electricity networks in existence is the North American system which interconnects U.S. and Canadian electricity markets. Both countries benefit from this two-way trading which involves a range of fuel sources and a vast transmission grid (CEA, 2005). As confirmed by the Canadian Electricity Association, this relationship between the two countries increases as trade and demand for energy continue to grow making close co-operation vital (CEA, 2010). Although the three North American countries (Canada, the U.S. and Mexico) in the North American Free Trade Agreement (NAFTA)[71] have moved towards trilateral trade in energy and electricity, three-way integration of the electricity sector remains at the initial stage. As noted by Pineau et al. (2004), in their review of transmission linkage development, electricity trading and national regulations, trade in electricity across this region remains bilateral, i.e. U.S./Mexico and U.S./Canada.

In Latin America,[72] MERCOSUR (Southern Common Market) which includes Argentina, Brazil, Paraguay, Uruguay and Venezuela (with Bolivia, Chile, Colombia, Ecuador and Peru as associate members) exists as a free trade agreement founded in 1991 and updated in 1994. Although it functions more as a co-ordinating mechanism than as a supra-national organization, its electricity sector has the potential to become a major force for integration provided movement towards macroeconomic policy co-ordination is first undertaken (Pineau et al., 2004).

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[71] CEC, 2011a.

[72] In Latin America, six countries are responsible for 84% of total electricity production in the LAC Region. The largest electricity producer is Brazil (36%), followed by Mexico (21%), Argentina (9%), Venezuela (9%), Colombia (5%), and Chile (4%). Paraguay contributes 5% through its share of production from the gigantic Itaipu hydrostation (The World Bank, 2010), however electricity from large hydroelectric projects in Paraguay is exported to Brazil and Argentina (IEA, 2010).

OECD Europe has a history of high levels of electricity co-operation as seen by the fact that electricity imports increased at an average annual rate of 7.0% between 1973 and 1990 although slowing to a rate of 1.8% after that period (IEA, 2010.[73] As well as encouraging free trade of electricity, EU agreements are focused on decreasing CO_2 emission levels from electricity generation (Official Journal of the European Union, 2009).[74] Outside of OECD Europe, there exists substantial electricity trade among Russia, Kazakhstan, Lithuania, Ukraine and other countries of the former Soviet Union, with significant export of electricity to net importing countries such as Belarus, Moldova, Latvia and Georgia, as well as to countries in Central and Western Europe (IEA, 2010).

In Australia, mainly fossil fuels are used to generate electricity. In 2005, the largest source of emissions in Australia was stationary energy that came mainly from electricity production (around 70%). About 95% of electricity comes from fossil fuels with coal being the main source, and only 5% comes from renewable energy (The Australia Institute, 2008a). Even though there is no international electricity trade in Australia, this study included data for this continent in comparing the effect of electricity generation on CO_2 emissions with other continents.

In reality, electricity can be traded across continents. For example, the study of Bowen et al. (2003) suggests that the Middle East could gain enormous economic benefits through significant electricity trading with Europe, North Africa, and Central Asia. However, in order to avoid a too-complicated analysis, this paper examines the effect of electricity trading by continent.

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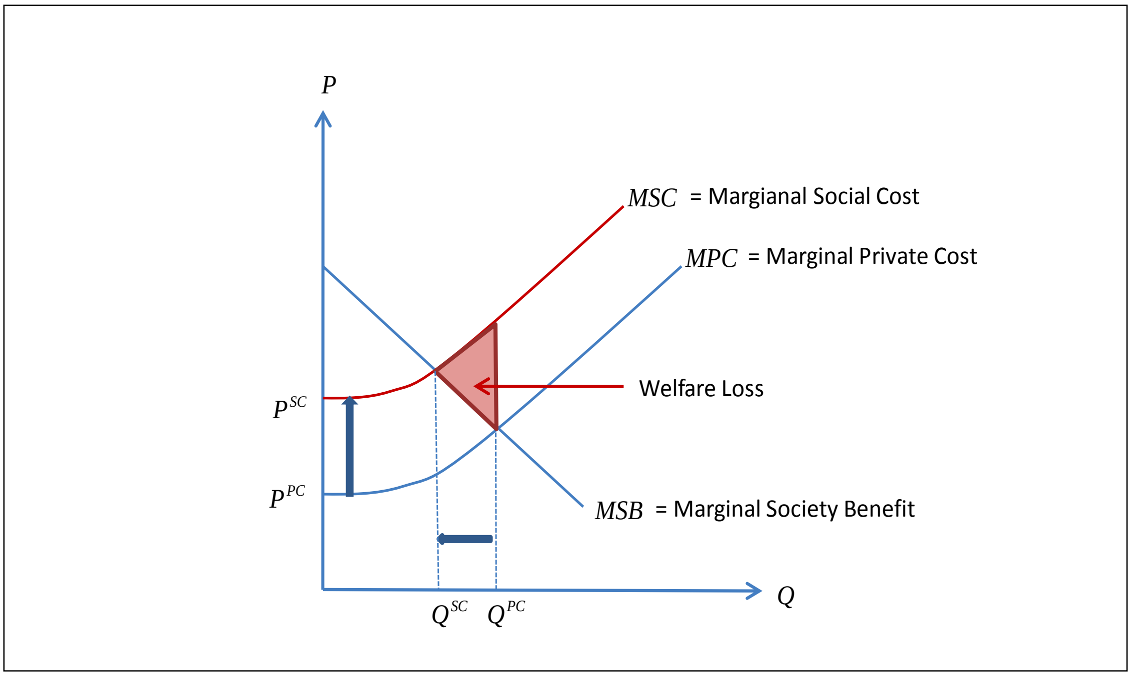
[73] The decline in the rate of electricity import for OECD Europe since 1990 is the result of decrease in demand (IEA, 2010).

[74] See Chapter 2, p. 46.

3.3 OMITTED SOCIAL COST INCREASES CO_2 IMPACT

Electricity generation involves the negative external factors of environmental destruction and release of greenhouse gases, especially CO_2, into the atmosphere causing global warming. These emissions come mainly from the use of coal, oil and gas, although all electricity generation technologies contribute (POST, UK, 2006). However, electricity generation costs do not normally include environmental costs. When these negative external factors are disregarded, the cost to society is the same as the private cost to the supplier but, in order to obtain the real social cost, the environmental impact needs to be added to the private cost.

Figure 3.2: Marginal Social Cost and Marginal Private Cost of Electricity Production



Original source image: Pettinger, (2011); The Australia Institute, 2008b

From Figure 3.2, when the market fails to include externality where marginal social cost exceeds marginal private cost (MSC > MPC), the result is a loss for society as electricity generation is over extracted. In relation to social welfare, the quantity of electricity output at the market equilibrium is greater than the optimum output for the situation where private and external costs are taken into consideration (The Australia Institute, 2008b). According to the law of demand, as price (*P*) goes up, the quantity demanded (*Q*) will go down, thus decreasing the extraction and consumption of electricity. In order to maximize social welfare, the socially efficient level of output and consumption is realized when social benefit equals social cost.

Global climate change has emerged as a major policy concern because it has the ability to undermine the well-being of society, interfere with economic development and damage the natural environment. Widespread agreement has been reached on the importance of greatly reducing greenhouse gas (GHG) emissions in the decades to come, finding ways to minimize climate change impact and providing adequate funding and technical support to assist developing countries to take part (OECD, 2011).[75] Economic instruments, called "market-based measures", are employed to have polluters incur a penalty for emitting greenhouse gases. They include carbon taxes, financial incentives (subsidies), and emissions trading schemes (Grattan Institute, 2011). However, the costs involved are disruptive to economic development (Adams and Dixon, 2007).

Carbon taxes are factored into the price mechanism by governments in trying to cope with a warming climate. The result is an increase in the private cost of producing goods and services meaning that producers and consumers pay extra because of the negative externalities arising from their actions. Carbon taxes can increase price and

[75] An international agreement to achieve these goals is being sought under the United Nations Framework Convention on Climate Change (UNFCCC) (OECD/IEA, 2011).

decrease quantity to compensate for welfare loss (see Figure 3.2).[76] In addition, through carbon taxes, innovation and new technology development are encouraged so that economic dependence on highly polluting inefficient forms of energy is reduced.

Another governmental intervention to encourage green energy in electricity generation through financial incentives is the use of subsidies (negative taxes). Energy subsidies involving government action to artificially force down the price of energy paid by consumers, or force up the price received by producers, or reduce the cost of production are extensive and pervasive. Properly planned subsidies to renewables and low-carbon energy technologies can achieve long-term benefits for the economy and the environment (IEA, 2011).

According to IEA (2011), increase in the proportion of energy subsidies allocated to renewable energy is set to continue with global renewable-energy subsidies rising from $39 billion in 2007 to $66 billion in 2010. However, in order to meet CO_2 reduction targets, there needs to be a further expansion of subsidies despite a projected reduction in unit production expenses due to cost reductions and increasing wholesale prices for electricity and transport fuels. On the other hand, subsidies for renewable energy production can mean a significant financial burden for public finances and for

[76] Policy makers have to concern themselves with a paradoxical element to carbon taxes. Even though these taxes do have a marginal effect in reducing CO_2 emissions from electricity generation, they reduce output and raise prices (Goulder, 2000), which might adversely affect consumer welfare. It may be possible for producers to pass on the tax to consumers if the demand for the good is inelastic (Bernstein and Grlffin, 2005; Paul et al., 2009), as is the case with electricity.

consumers, and may not be the most economically efficient path to emission reduction.[77]

Since the early 1990s, emissions trading has been seen as a way of combating greenhouse gas proliferation with such trading between countries forming part of the 1997 Kyoto Protocol agreement.[78] The Protocol puts forward many initiatives aimed at implementing emissions trading for greenhouse gas sources at national, state, local and corporate levels. These schemes are usually designed so that companies and government agencies may gain information and experience through actual participation in trading CO_2 equivalent emissions (OECD, 2004).

Putting a monetary value estimate on the social cost of carbon is no easy task, although some researchers have tried (Pearce, 2003; Atkinson et al., 1997).[79] The

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77 According to Pearce (2003), the Renewables Obligation has an implicit price which has been put at £310 tC (Utilities Journal, 2001). Obviously, if the marginal damage from carbon is £70 tC, renewables policy fails a cost–benefit test, as it is costing £310 tC in order to secure a benefit of £70 tC.

78 "The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions. These amount to an average of 5% against 1990 levels over the five-year period 2008-2012" (UNFCC, 2011, available at: http://unfccc.int/kyoto_protocol/items/2830.php).

79 Conventional accounting is a measure of gross and net national product (GNP, NNP) but does not deduct for any environmental damage. There exists now a substantial literature that provides these adjustments [see, for example, Atkinson et al. (1997)]. The essential result is shown by the identity:

$$gNNP = GNP - dM - dE$$

where *gNNP* denotes 'green' net national product, *dM* is depreciation on conventional 'man-made' capital assets, and *dE* is depreciation on environmental capital; *dE* would then be measured by the value of the economic rents from depleted natural resources and the value of pollution damage. Looking just at carbon author believes that, even though it is possible to evaluate with some degree of accuracy the environmental damage of CO_2 emissions from electricity generation in monetary terms, such amount of money will not buy a cleaner atmosphere for our planet. The better policy, therefore, is to minimize CO_2 emissions from electricity generation as much as possible.

3.4 INCREASE IN TRADE DECREASES CO_2

Economic theories of international trade indicate that import and export bring enormous benefits to countries and their citizens. Through trade, nations have been able to benefit from specialization and the efficiency gains from economies of scale. In addition, productivity has been increased, the spread of knowledge and new technologies assisted and consumer choice made more varied and extensive (WTO, 2008). These benefits also apply to international trade in electricity. Such trade increases competition which encourages efficiency as well as facilitating the introduction of new ideas and technologies. Innovation, according to Pomeda and Camacho (2003), acts as a further mechanism to enhance electricity market efficiency. In addition, technological innovations lead towards electricity generation through renewable energies (Scheepers et al., 2003), resulting in lower CO_2 emissions. Moreover, electricity trade directly reduces emissions from generation in importing countries. All of these reasons support the claim that electricity co-operation regarding import and export decreases CO_2 emissions.

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emissions, and selecting the £70/tonne of carbon (tC) figure for marginal social cost of carbon, gives these results for the UK: GNP in 2000 at 2000 prices = £890 billion, and CO2 emissions in 2000 = 145 million tC = £10.15 billion. The £70 tC figure gives rise to a total damage amount equal to 1.1% of GNP (Pearce, 2003).

Unger and Ekvall (2003) investigated the benefits from increasing cross-border co-operation (including electricity trade) under future CO_2 commitments in the Nordic countries. Their findings indicate that all co-operative strategies are successful in lowering abatement costs considerably, but more so if the full co-operation strategy is employed.

On the other hand, Villemeur and Pineau (2010) argue that, assuming reasonable demand and supply elasticities, trade in electricity can be damaging to the environment. It is their contention that trade results in higher levels of consumption with the likelihood of increased environmental impact. Whether there exists a positive relationship between overall consumption (and hence production) and trade is dependent on the price elasticity of demand in both import and export countries.

Let $\underline{\varepsilon}$ and $\underline{\eta}$ represent price elasticity of demand and supply respectively in lower price ($\underline{p}$) countries ($\underline{T}$), and $\overline{\varepsilon}$ and $\overline{\eta}$ represent price elasticity of demand and supply respectively in higher price ($\overline{p}$) countries ($\overline{T}$). From Equation (5) in Chapter 2, the capacity of the transmission line (*K*) is assumed to be the same amount as quantity of electricity trade (Q_X) (export of lower price country = import of higher price country).

$$\underline{p} = C'(\underline{Q}^D + K) < \overline{p} = C'(\overline{Q}^D - K) \qquad (26)$$

Total electricity consumption will increase because of international trade when

$$\frac{\overline{\varepsilon}}{\underline{\varepsilon}} > \frac{\overline{\eta}}{\underline{\eta}} \frac{(1 - K / \overline{Q}^D)}{(1 + K / \underline{Q}^D)}.$$

The effect of a marginal increase in transmission capacity (*K*) upon aggregate electricity demand (Q^D) writes as

$$\frac{dQ^D}{dK} = \left(\frac{dQ^D}{d\underline{p}}\right)\frac{d\underline{p}}{dK} + \left(\frac{d\overline{Q}^D}{d\overline{p}}\right)\frac{d\overline{p}}{dK}, \tag{27}$$

where

$$\frac{d\underline{p}}{dK} = \left[\left(\frac{dQ^D}{d\underline{p}}\right)\frac{d\underline{p}}{dK} + 1\right]C''(\underline{Q}^D + K) \text{ and } \frac{d\overline{p}}{dK} = \left[\left(\frac{d\overline{Q}^D}{d\overline{p}}\right)\frac{d\overline{p}}{dK} - 1\right]C''(\overline{Q}^D - K).$$

This rewrites directly as

$$\frac{d\underline{p}}{dK}\left[1 - \left(\frac{dQ^D}{d\underline{p}}\right)C''(\underline{Q}^D + K)\right] = C''(\underline{Q}^D + K) \quad \text{and}$$

$$\frac{d\overline{p}}{dK}\left[1 - \left(\frac{d\overline{Q}^D}{d\overline{p}}\right)C''(\underline{Q}^D - K)\right] = -C''(\overline{Q}^D - K).$$

Therefore,

$$\frac{d\underline{p}}{dK} = \frac{C''(\underline{Q}^D + K)}{1 + \left(\frac{-dQ^D}{d\underline{p}}\right)C''(\underline{Q}^D + K)} \geq 0 \text{ and } \frac{d\overline{p}}{dK} = \frac{-C''(\overline{Q}^D - K)}{1 + \left(\frac{-d\overline{Q}^D}{d\overline{P}}\right)C''(\overline{Q}^D - K)} \geq 0.$$

This gives the marginal change in total electricity demand as

$$\frac{dQ^D}{dK} = \frac{\left(\frac{-d\overline{Q}^D}{d\overline{p}}\right)C''(\overline{Q}^D - K)}{1 + \left(\frac{-d\overline{Q}^D}{d\overline{p}}\right)C''(\overline{Q}^D - K)} - \frac{\left(\frac{-dQ^D}{d\underline{p}}\right)C''(\underline{Q}^D + K)}{1 + \left(\frac{-dQ^D}{d\underline{p}}\right)C''(\underline{Q}^D + K)}. \tag{28}$$

Let $\underline{\varepsilon}$ and $\overline{\varepsilon}$ be the (absolute values of the) own-price demand elasticity in the exporting and importing countries respectively:

$$\underline{\varepsilon} = \frac{\underline{p}}{\underline{Q}^D}\frac{-d\underline{Q}^D}{d\underline{p}} \quad \text{and} \quad \overline{\varepsilon} = \frac{\overline{p}}{\overline{Q}^D}\frac{-d\overline{Q}^D}{d\overline{p}}.$$

Similarly, let $\underline{\eta}$ and be the supply elasticities in the exporting and importing countries respectively:

$$\underline{\eta} = \frac{C'(\underline{Q}^D + K)}{(\underline{Q}^D + K)C''(\underline{Q}^D + K)} \quad \text{and} \quad \overline{\eta} = \frac{-C'(\overline{Q}^D - K)}{(\overline{Q}^D - K)C''(\overline{Q}^D - K)}.$$

Supply elasticities in the exporting and importing countries respectively show

$$\underline{\eta} = \frac{\underline{p}}{\underline{Q}^S}\frac{d\underline{Q}^S}{d\underline{p}} \quad \text{and} \quad \overline{\eta} = \frac{\overline{p}}{\overline{Q}^S}\frac{d\overline{Q}^S}{d\overline{p}}.$$

where

$$\underline{p} = C'(\underline{Q}^D + K),\ \overline{p} = C'(\overline{Q}^D - K),\ \underline{Q}^S = \underline{Q}^D + K \quad \text{and} \quad \overline{Q}^S = \overline{Q}^D - K$$

This rewrites directly as

$$\underline{\eta} = \frac{C'(\underline{Q}^D + K)}{(\underline{Q}^D + K)}\frac{d(\underline{Q}^D + K)}{dC'(\underline{Q}^D + K)} \quad \text{and} \quad \overline{\eta} = \frac{-C'(\overline{Q}^D - K)}{(\overline{Q}^D - K)}\frac{d(\overline{Q}^D - K)}{dC'(\overline{Q}^D - K)}.$$

Hence,

$$\underline{\eta} = \frac{C'(\underline{Q}^D + K)}{(\underline{Q}^D + K)C''(\underline{Q}^D + K)} \quad \text{and} \quad \overline{\eta} = \frac{-C'(\overline{Q}^D - K)}{(\overline{Q}^D - K)C''(\overline{Q}^D - K)}.$$

The marginal change in total demand (28) thus rewrites as

$$\frac{dQ^D}{dK} = \frac{\overline{\varepsilon}\left(\frac{\overline{Q}^D}{\overline{p}}\right)C''(\overline{Q}^D - K)}{1 + \overline{\varepsilon}\left(\frac{\overline{Q}^D}{\overline{p}}\right)C''(\overline{Q}^D - K)} - \frac{\underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)}{1 + \underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)} \tag{29}$$

$$= \frac{\overline{\varepsilon}\overline{Q}^D}{\overline{\eta}(\overline{Q}^D - K) + \overline{\varepsilon}\overline{Q}^D} - \frac{\underline{\varepsilon}\underline{Q}^D}{\underline{\eta}(\underline{Q}^D + K) + \underline{\varepsilon}\underline{Q}^D} \tag{30}$$

$$= \left[1+\frac{\bar{\eta}}{\bar{\varepsilon}}\left(1-\frac{K}{\bar{Q}^D}\right)\right]^{-1} - \left[1+\frac{\underline{\eta}}{\underline{\varepsilon}}\left(1+\frac{K}{\underline{Q}^D}\right)\right]^{-1}. \qquad (31)$$

Proof . Equation (29) = Equation (31)

$$\frac{dQ^D}{dK} = \frac{\bar{\varepsilon}\left(\frac{\bar{Q}^D}{\bar{p}}\right)C''(\bar{Q}^D - K)}{1+\bar{\varepsilon}\left(\frac{\bar{Q}^D}{\bar{p}}\right)C''(\bar{Q}^D - K)} - \frac{\underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)}{1+\underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)}$$

$$= \frac{\bar{\varepsilon}\left(\frac{\bar{Q}^D}{\bar{p}}\right)C''(\bar{Q}^D - K)}{\frac{\bar{p}}{\bar{p}}\frac{C''(\bar{Q}^D - K)}{C''(\bar{Q}^D - K)}+\bar{\varepsilon}\left(\frac{\bar{Q}^D}{\bar{p}}\right)C''(\bar{Q}^D - K)} - \frac{\underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)}{\frac{\underline{p}}{\underline{p}}\frac{C''(\underline{Q}^D + K)}{C''(\underline{Q}^D + K)}+\underline{\varepsilon}\left(\frac{\underline{Q}^D}{\underline{p}}\right)C''(\underline{Q}^D + K)}$$

$$= \frac{\bar{\varepsilon}\bar{Q}^D}{\frac{\bar{p}}{C''(\bar{Q}^D - K)}+\bar{\varepsilon}\bar{Q}^D} - \frac{\underline{\varepsilon}\underline{Q}^D}{\frac{p}{C''(\underline{Q}^D + K)}+\underline{\varepsilon}\underline{Q}^D}$$

$$= \frac{\bar{\varepsilon}\bar{Q}^D}{\frac{C'(\bar{Q}^D - K)}{C''(\bar{Q}^D - K)}+\bar{\varepsilon}\bar{Q}^D} - \frac{\underline{\varepsilon}\underline{Q}^D}{\frac{C'(\underline{Q}^D + K)}{C''(\underline{Q}^D + K)}+\underline{\varepsilon}\underline{Q}^D}$$

$$= \frac{\bar{\varepsilon}\bar{Q}^D}{\frac{(\bar{Q}^D - K)}{(\bar{Q}^D - K)}\frac{C'(\bar{Q}^D - K)}{C''(\bar{Q}^D - K)}+\bar{\varepsilon}\bar{Q}^D} - \frac{\underline{\varepsilon}\underline{Q}^D}{\frac{(\underline{Q}^D + K)}{(\underline{Q}^D + K)}\frac{C'(\underline{Q}^D + K)}{C''(\underline{Q}^D + K)}+\underline{\varepsilon}\underline{Q}^D}$$

$$= \frac{\bar{\varepsilon}\bar{Q}^D}{\bar{\eta}(\bar{Q}^D - K)+\bar{\varepsilon}\bar{Q}^D} - \frac{\underline{\varepsilon}\underline{Q}^D}{\underline{\eta}(\underline{Q}^D + K)+\underline{\varepsilon}\underline{Q}^D}$$

$$= 1+\left[\frac{\bar{\varepsilon}\bar{Q}^D}{\eta(\bar{Q}^D - K)}\right] - 1+\left[\frac{\underline{\varepsilon}\underline{Q}^D}{\eta(\underline{Q}^D - K)}\right]$$

$$=1+\left[\frac{\bar{\varepsilon}}{\bar{\eta}}\left(\frac{\bar{Q}^D}{\bar{Q}^D}-\frac{\bar{Q}^D}{K}\right)\right]-1+\left[\frac{\underline{\varepsilon}}{\underline{\eta}}\left(\frac{\underline{Q}^D}{\underline{Q}^D}+\frac{\underline{Q}^D}{K}\right)\right]$$

$$=\left[1+\frac{\bar{\eta}}{\bar{\varepsilon}}\left(1-\frac{K}{\bar{Q}^D}\right)\right]^{-1}-\left[1+\frac{\underline{\eta}}{\underline{\varepsilon}}\left(1+\frac{K}{\underline{Q}^D}\right)\right]^{-1}$$

Rearranging, this gives $(dQ^D/dK) > 0$ if and only if $\frac{\bar{\varepsilon}}{\underline{\varepsilon}} > \frac{\bar{\eta}}{\underline{\eta}}\frac{(1-K/\bar{Q}^D)}{(1+K/\underline{Q}^D)}$.

Hence, international electricity trade increases consumption according to the concept of Villemeur and Pineau (2010). They maintain that emissions increase with total production, hence demand (consumption), so there exists then a necessary and sufficient condition for environmental damage to increase (see Figure 2.1). This study agrees with Villemeur and Pineau (2010) that electricity trade increases demand. When electricity price ($\bar{p}$) in import country ($\bar{T}$) decreases, the demand ($\bar{Q}^D$) of import country will increase.

However, opposing the view of Villemeur and Pineau (2010) of a resulting growth in emissions, there is little or no increase in damage to the environment because efficiency gains from specialization and economies of scale (WTO, 2008; Pomeda and Camacho, 2003; Unger and Ekvall, 2003) lead to a decrease in private and social costs, including CO_2 emissions. In addition, export countries do not usually use flue sources (coal, gas and oil) to generate electricity for export because of the financial risk of fluctuations in the price of fossil fuels.[80] This can further explain why electricity export does not increase CO_2 emissions.

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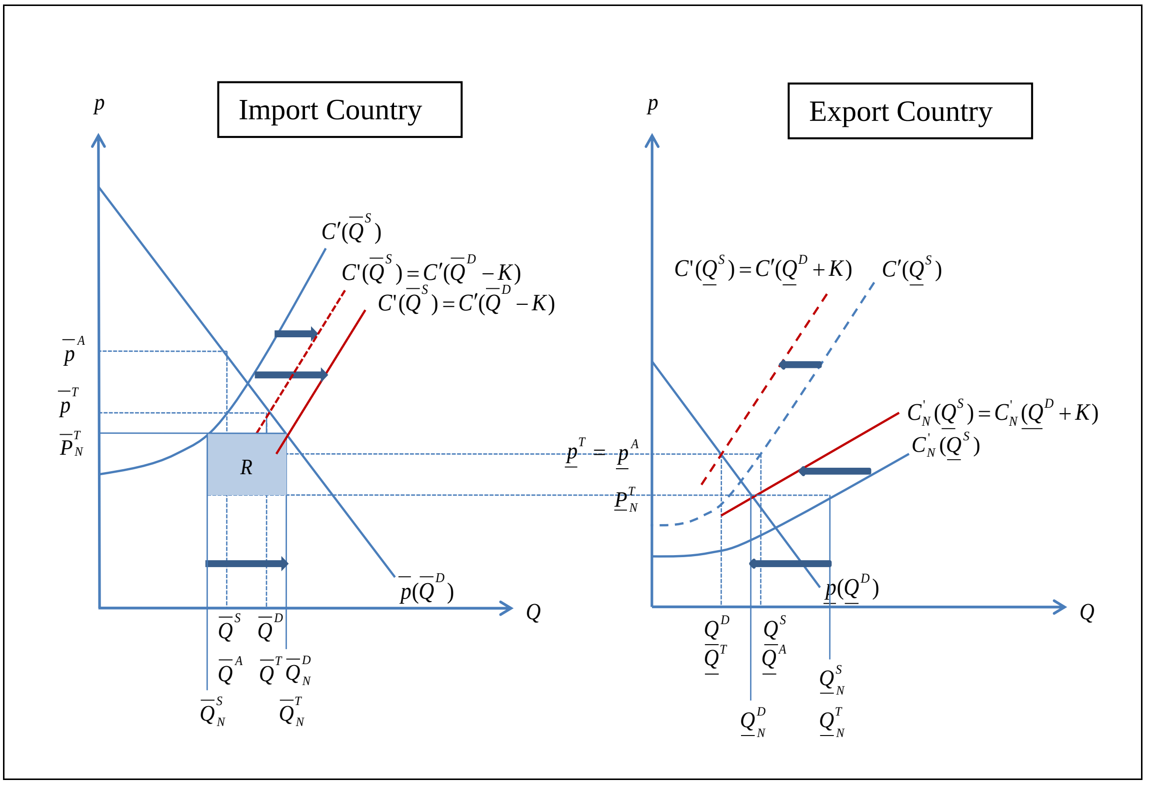
[80] For example, in North America, the U.S. imported 52,190,595 megawatt-hours (MWh) of electricity from Canada in 2009 (EIA, 2011), most of which came from Canadian hydroelectricity power at Niagara Falls. In Europe, Électricité de France (EDF), which manages the country's 58 nuclear power

According to Figure 2.2, international electricity trade does not increase the overall amount of electricity generation of both importing and exporting countries, so there is no risk of further environmental damage from increased generation in this situation. Furthermore, trade improves economic efficiency by gainful usage of electricity supply surplus in exporting countries while reducing electricity generation in importing countries meeting excess demand. All of this lends support to the view, which is in opposition to that of Villemeur and Pineau (2010), that international co-operation can lower CO_2 emission levels.

Figure 3.3: Effect on Prices by Electricity Trade Between Two Countries when Exporting Country Can Reduce the Cost of Generation and CO_2 Emissions



Note: *p* denotes price, *Q* denotes quantity, *D* denotes demand, *S* denotes supply, *A* denotes autarky, *T* denotes trade, *x* denotes quantity of trade, *K* denotes transmission and *N* denotes new technology which lowers cost of generation.

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plants, is the world leader in production of nuclear power by percentage, and the world's largest net exporter of electricity (World Nuclear Association, 2012).

Figure 3.3 shows that international trade is responsible for nations benefiting from specialization and the efficiency gains from economies of scale. Hence, the generation cost for the exporting country decreases from $C'(\underline{Q}^S)$ to $C_N^{'}(\underline{Q}^S)$ in preparation for trading and from $C'(\underline{Q}^S) = C'(\underline{Q}^D + K)$ to $C_N^{'}(\underline{Q}^S) = C_N^{'}(\underline{Q}^D + K)$ under trading. In opposition to the view taken by Villemeur and Pineau (2010), international trade lowers electricity prices and cost, as well as CO_2 emissions which represent the external cost. Even though, from this figure, trade can increase electricity demand by lowering prices in both trading countries, it reduces cost and CO_2 emissions in the exporting country, thus improving social welfare.

Such situations are possible where countries with nuclear (e.g. France) or hydro (e.g. Canada) power plants, which are associated with lower costs and possibly greater reliability of supply, are contracted to export electricity. They can select the size of electricity plant which has the highest efficiency from economies of scale, hence lowering costs as well as CO_2 emissions. Furthermore, the import countries will be able to reduce dependence on present and future conventional generation from coal, gas and oil, so further helping to decrease atmospheric pollutants.

Further evidence that import and export of electricity can play a major role in reducing global warming comes from the knowledge that trade encourages competition, competition increases efficiency (Justus, 1997; WTO, 2008), efficiency forces new technology (Pomeda and Camacho, 2003), and new technology decreases CO_2 emissions from electricity generation (Scheepers et al., 2003).

International electricity trade can exploit comparative resource advantages in order to lower costs (Odgaard, 2000). With regard to the external cost of CO_2 emissions, trade allows an importing country to obtain electricity generated from non-fossil fuel sources from an exporting country. Furthermore, while renewable energy has problems with regard to high investment and instability of supply in meeting consumer demand,[81] international electricity trade can lower the cost of generation and provide higher security of electricity supply through import by allowing access to a greater variety of energy sources creating a balance better than autarky. Therefore, when planning energy policies in relation to security of supply, environmental impact, national competitiveness and social concerns, governments should seriously consider electricity co-operation regarding import and export as a choice of preference.

3.5 MODEL OF CO_2 EMISSIONS

Electricity demand is the cause of electricity supply, so CO_2 emissions of electricity generation can be affected by both demand and supply. The demand side includes such factors as economy, demography, weather or season, demand response, and interruptibles. On the supply side, the factors are resource addition and retirement, local generation, generator outage, line outage, fuel availability and net electricity import (California Energy Commission, 2010: Figure 3).

Because of the interest generated by global warming, much effort is being put into investigating options for limiting CO_2 emissions resulting from human activity, especially electricity generation, and managing the consequences of global warming and climate change. Karakaya and Ozcag (2005) analyse human involvement in

[81] Generation from renewable sources is usually more expensive than traditional generation, partly because of the recency of the technology and the restricted opportunity to exploit cost savings through economies of scale most often associated with the more conventional fossil-fuel generation. In addition, renewable energy source fluctuations may impose a limit on output generation available from such sources (PB Power, 2004).

environmental change. They study energy-linked carbon emissions which are structured by using Kaya Identity (1990) outlined by

$$CO_2\ Emissions = Population \times \frac{GDP}{Person} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \qquad (32)$$

The CO_2 emissions depend on of population, income (GDP per capita), energy intensity (units of energy/GDP), and carbon intensity (CO_2 emissions per unit of energy). Their study is focused on demand side, and demand for electricity is responsible for electricity supply.

McFarland and Herzog (2006) specify that production functions comprise determining the cost (*C*) of electricity from the technology, the factor shares of capital, labour, and energy needed for electricity production. They view the full cost of electricity as including the unit costs of electricity generation, transmission and distribution (*T&D*), sequestration, and value of carbon released to the atmosphere, in Equation (33).

$$C_{electricity} = C_{generation} + C_{T\&D} + C_{sequestration} + K(P_{carbon}) \qquad (33)$$

where *K* is a technology-specific emissions constant.

Hence, by subtraction, carbon price can be shown as

$$P_{carbon} = (C_{electricity} - C_{generation} - C_{T\&D} - C_{sequestration})/K \qquad (34)$$

This chapter analyses the literature on CO_2 emissions from electricity generation with a focus on the impact of international electricity trade on those emissions. Because of supply-side concentration, the concept of McFarland and Herzog (2006) is employed to create the CO_2 emissions function since CO_2 emissions depend on electricity supply (E_{supply}) and distribution losses ($E_{distribution\ loss}$).[82]

$$CO_2 = f(E_{supply}, E_{distribution\ loss}) \tag{35}$$

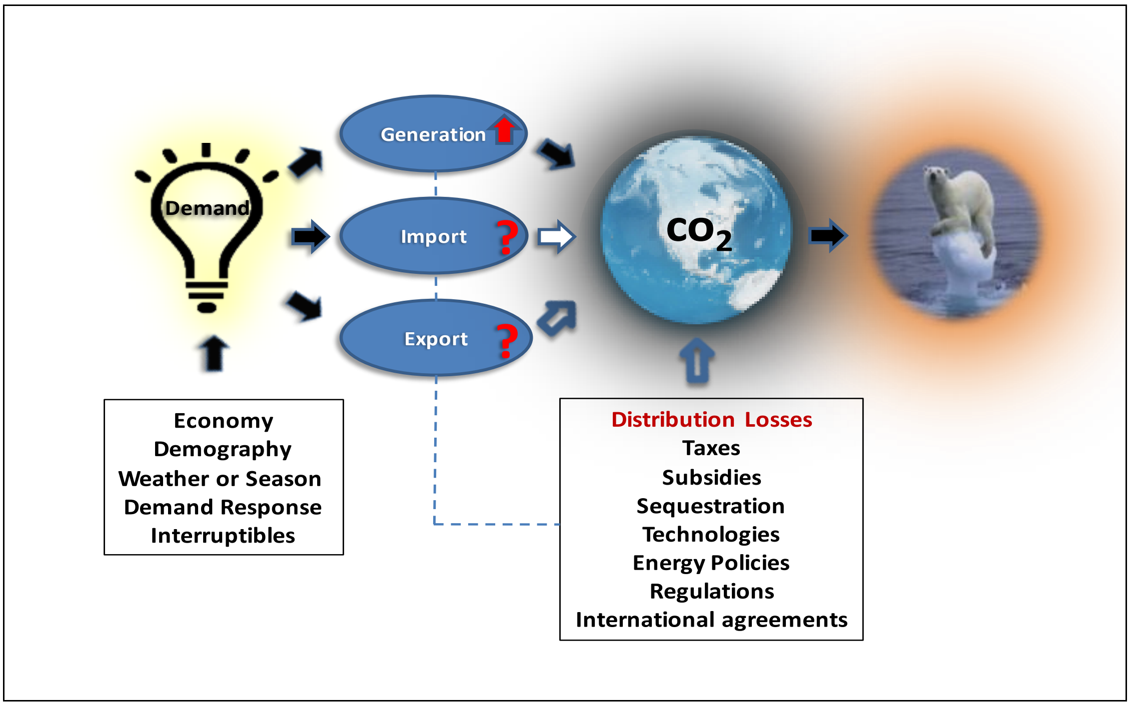
where $E_{supply} = f(E_{generation\ for\ country}, E_{import}, E_{export})$

Hence, the CO_2 emissions function can be written as

$$CO_2 = f(E_{generation\ for\ country}, E_{import}, E_{export}, E_{distribution\ loss}) \tag{36}$$

illustrating that the CO_2 emissions depend on electricity generation for country, electricity import, electricity export and distribution loss.

Figure 3.4: Conceptual Framework



82 Distribution loss in this study includes transmission loss.

Figure 3.4 shows the conceptual framework of this study. Our need for electricity causes electricity generation which is mostly produced from flue sources - about 68%. This increases CO_2 in our atmosphere - in 2008, about 9,300 million tons of CO_2, which was about 32% of the overall total in that year, and the highest by sector (IEA, statistic).[83] Some countries have decided to import electricity instead of producing more themselves, thus decreasing CO_2 from electricity generation. With regard to export, if countries have excess electricity supply, export will not increase generation and CO_2 levels, but if those countries do not have excess supply, then, of course, electricity export will increase CO_2 if they use flue sources.

In this study, distribution loss includes transmission loss,[84] and can be a proxy variable for transmission cost. The level of distribution loss depends not only on size of the electricity network, but also on technical and operational factors (OFGEM, 2003). According to IEA reports, in 2008, distribution loss for 131 countries was 16,841 gigawatt-hours (GWh), making up about 6.55% of total gross electricity production (IEA, statistic). The Office of Gas and Electricity Markets (OFGEM), UK (2003) reports that the major part of environmental damage attributable to electricity losses is caused by the release of emissions, especially CO_2, during generation. Because distribution loss leads to more electricity production, any reduction in such loss would save on power generation, thus lessening the environmental impact (Wijaya and Limmeechokchai, 2009).

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[83] Available at http://www.iea.org/stats/index.asp

[84] Electricity transmission refers to the transfer of electricity from generation facilities to substations close to populated areas, and is separate from electricity distribution which involves the local connection between substations and consumers (Fogarty and Lamb, 2012).

Concentrating on supply side, the main influences on CO_2 emissions that result from electricity generation include type of energy source for generation and thermal efficiency of the generation process (Department of Energy and Environmental Protection Agency, 2000). The focus of new technologies is on improving the efficiency of this process as well as isolating and storing the CO_2 rather than releasing it to the atmosphere (National Academics, 2012). However, promotion of new energy technologies has not been a feature of the emergence of electricity sector reforms of the 1990s, that aimed to improve operational and investment efficiency.[85] This, and the fact that changing to a low-carbon system involves a major impact on energy budgets, may explain the lack of evidence of technology change from 1971 to 2007 for the 131 countries in this study.

There remain unobserved variables of sequestration, technology, taxes, government subsidies, national energy policies, regulations and international agreements, all of which can change over time but not across countries, and these account for individual heterogeneity (see Figure 3.4).

3.6 METHODS & PROCEDURES

Econometric methodology of panel data analysis is employed to determine the effects of electricity import and export on CO_2 emissions. The analysis covers 131 countries and also division of countries by continent. Even though electricity is

[85] Electricity sector reforms began in many countries during the 1990s with the major objective being to improve operational and investment efficiency by way of regulatory reform, competition, restructuring and privatization (OECD, 2003). However, technical progress has had little involvement with the forces behind liberalisation reform, and new energy technology promotion has not featured in any major way (Russell and Bunting, 2002).

exchangeable and suitable for trading, it needs bounded conduction, hence no global market for electricity trade exists (Barouti and Hoang, 2011). Therefore, this study analyses the effect of electricity trading by continent. However, geography has, at times, linked or separated the Middle East and Asia. For the energy sector, the situation is one of separation demonstrated by an almost total lack of related infrastructure connecting the two areas. This is despite strong complementarities in energy resources, production and consumption which remain unexploited by electricity trade across these regions. Hence, in this study, the Middle East is separated from Asia.

3.6.1 Data

The data of all variables in this study are sourced from the International Energy Agency (IEA). The IEA data series typically provide for consistency across time and countries and are therefore very suitable for analysing panel techniques. The dataset involves 131 countries' yearly data for 37 years from 1971 to 2007. The total maximum observations are 4,847 (131 x 37). However, because of a number of missing observations for some countries, the panel is unbalanced.[86] There are 4,458 observations for CO_2 emissions from electricity generation, which is the explained variable, and 4,454 observations for all explanatory variables (see Table 3.1).

The dependent variable of this study is CO_2 emissions from main activity electricity plants with a measure of million tons (MT) of CO_2 per year. Independent variables are electricity generation for countries, import, export and distribution loss, all

[86] There are missing observations for the following countries: Bosnia, Croatia, Serbia, Slovenia, Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Latvia, Lithuania, Russia, Tajikistan, Ukraine and Uzbekistan (1971-1989), Botswana (1971-1980), Eritrea (1971-1991), Namibia (1971-1990), Cambodia (1971-1994) and Mongolia (1971-1984).

having the same measure of total MWh per year. To overcome the problem of different scales of measurement between dependent and independent variables, all variables are in the natural logarithmic form.[87]

Table 3.1: Descriptive Statistics

World (131 countries) 1971-2007 (Unbalanced Panel)						
	Name	**Obs**	**Mean**	**Standard Deviation**	**Min**	**Max**
CO_2 emissions (*MT*)	CO_2	4,458	41.30	189.56	0	2635.61
Generation for country (*MWh*)	GC	4,454	87,158.38	326,244.10	0	4,329,697
Generation minus DL (*MWh*)	GD	4,454	79,669.85	303,665.40	-345	4,062,654
Import (*MWh*)	M	4,454	2,637.77	6,791.82	0	56,861
Export (*MWh*)	X	4,454	2,529.06	7,804.95	0	80,739
Distribution loss: DL (*MWh*)	DL	4,454	7,488.53	24,224.42	0	310,036

Source: IEA
Note: For descriptive statistics for each continent, see Appendix: Table A-3.1.

3.6.2 Statistical Analysis

- ***Panel Unit Root Tests***

Before conducting tests of panel data on these variables, it is necessary to perform unit root tests. This study considers two panel unit root tests: the Im, Pesaran and Shin (IPS) test and the Fisher-ADF test.[88] The two tests show the combining of

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[87] Using logarithms of variables enables coefficients to be interpreted easily when variables are measured on different scales, as well as being an effective method of shrinking the distance between values. After taking the natural logarithmic form, data of some countries which have no import and no export will disappear (*ln*(0)). Then variables are generated by plus one before taking the natural logarithmic form.

[88] See details on pp. 34-36.

individual unit root tests to derive a panel-specific result, and allow for unbalance panel (Levin et al., 2002).

The IPS test compares the null hypothesis that each series in the panel is nonstationary for all cross-section units against the alternative hypothesis that at least one of the series is stationary. A different approach to panel unit root tests, using Fisher's (1932) results to derive tests that combine the p-values from individual unit root tests, has been suggested by Maddala and Wu (1999), and Choi (2001). Both the null and the alternative hypotheses are the same as for IPS.

The results for panel unit root tests are shown in Table 3.2. With regard to unit root tests with a constant term (*c*), the world results provide strong evidence of panel unit roots for the independent variables of electricity generation for country, import, export, and distribution loss, i.e. the series are all I(0). However, for the CO_2 emissions variable, which is the dependent variable, IPS and Fisher-ADF unit root tests give the result I(1).

At the continent level, for Asia, the Middle East, Africa, Latin America, Europe, and Australia, the results for CO2 emissions show non-stationarity I(1). For North America, CO2 emissions, generation for country and generation minus distribution loss show stationarity I(0), however import, export and distribution loss show non-stationarity I(1).

For both unit root tests with a constant term plus a trend components (*c*,*t*), the results show nonstationarity I(1) in some variables for the world and for all continents. This suggests that, for the world and all continents, first differences should be taken for all variables before running panel regression to avoid nonstationary process (see Appendix: Table A-3.2).

Table 3.2: Panel Unit Root Tests Results

Panel Unit Root Tests Results																
	Im, Pesaran and Shin Test								**Fisher-ADF Test**							
	W	AS	ME	AF	NA	LA	EU	AU	W	AS	ME	AF	NA	LA	EU	AU
	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
ln CO_2 emissions	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)
ln Generation for country	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)
ln Generation minus DL	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)
ln Import	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)	I(0)	-	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)	I(0)	-
ln Export	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)	I(0)	-	I(0)	I(0)	I(0)	I(0)	I(1)	I(1)	I(0)	-
ln Distribution loss (DL)	I(0)	I(1)	I(0)	I(1)	I(1)	I(0)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(1)	I(0)	I(0)	I(1)
	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t	c, t
ln CO_2 emissions	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)	I(0)	I(1)	I(0)	I(0)	I(1)	I(1)	I(1)	I(0)
ln Generation for country	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(0)	I(1)	I(1)	I(1)	I(1)
ln Generation minus DL	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(0)	I(1)	I(1)	I(1)	I(1)
ln Import	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)	I(0)	-	I(0)	I(1)	I(1)	I(0)	I(1)	I(1)	I(0)	-
ln Export	I(0)	I(0)	I(0)	I(0)	I(1)	I(1)	I(0)	-	I(0)	I(0)	I(0)	I(0)	I(1)	I(1)	I(0)	-
ln Distribution loss (DL)	I(0)	I(1)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)	I(0)	I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic (reject at 5%).

(2) W = World, AS = Asia, ME = the Middle East, AF = Africa, NA = North America, LA = Latin America, EU = Europe, and AU = Australia.

(3) *c* and *c, t* indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

- ***Pearson's Correlation Test***

Table 3.3: Pearson's Correlation Test Results

World (131 countries) 1971-2007 (Unbalanced Panel)					
Model 1	Δln (CO_2)	Δln (GD)	Δln (M)	Δln (X)	Δln (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.723***	1.000			
Δln (M): Import	0.207***	0.217***	1.000		
Δln (X): Export	0.189***	0.297***	0.286***	1.000	
Δln (DL): Distribution loss	0.558***	0.711***	0.218***	0.235***	1.000
Model 2	Δln (CO_2)	Δln (GC)	Δln (M)	Δln (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.719***	1.000			
Δln (M): Import	0.207***	0.221***	1.000		
Δln (X): Export	0.189***	0.291***	0.289***	1.000	

Note: *** denotes level of significance at 1%.

In order to avoid the problem of multicollinearity where high correlation exists between two or more independent variables (Blalock, 1963), this analysis employs the Pearson correlations test. The results show no high correlation among independent variables in Model 1 and Model 2, thus there is no multicollinearity problem (see Table 3.3).[89] However, at the continent level, there is high correlation between CO_2 emissions

[89] As mentioned by Goodman (2010), electricity has storage difficulties and, therefore, immediate generation is required to satisfy current demand. When electricity consumption (*C*) increases, generation (*G*) and import (*M*) should increase, while electricity export (*X*) should decrease. When electricity consumption (*C*) decreases, generation (*G*) and import (*M*) should decrease, while electricity export (*X*) should increase. However, if any one of generation, import or export can be manipulated to

and distribution loss for the Middle East, North America and Australia. Hence, care should be taken in interpreting the results for these continents (see Appendix: Table A-3.3).

- ***A Lagram-Multiplier Test for Serial Correlation***

For the study, before the model can be set up, serial correlation tests which have application to macro panels with long time series (37 years) must be implemented. The effect of serial correlation is in reducing the size of the standard errors of the coefficients and giving them higher R-squared values (Wooldridge, 2002). A Lagram-Multiplier serial correlation test is selected here,[90] with the null hypothesis being no serial correlation.[91] The following is given by running both the original models for CO_2 emissions.

Model 1

$$\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(GD_{it}) + \beta_2 \Delta \ln(M_{it}) + \beta_3 \Delta \ln(X_{it}) + \beta_4 \Delta \ln(DL_{it}) + u_{it} \tag{37}$$

Model 2

$$\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(GC_{it}) + \beta_2 \Delta \ln(M_{it}) + \beta_3 \Delta \ln(X_{it}) + u_{it} \tag{38}$$

---

ensure electricity supply meets consumption, control of all three is not necessary. This can help explain why there is no high correlation among generation, import and export.

[90] This study does not employ the Arellano-Bond autocorrelation test because it was designed for small-*T* and large-*N* panels. However, this paper employs yearly data from 1971 to 2007 (T = 37), and *N* is the number of countries (World = 131, Asia = 20, the Middle East = 13, Africa = 27, North America = 3, Latin America = 21, Europe = 45, and Australia = 2). When *N* is small, like in this case, the Arellano-Bond autocorrelation test may be unreliable (Roodman, 2006).

[91] See details on pp. 39-40.

Table 3.4: A Lagram-Multiplier Test for Serial Correlation Results

A Lagram-Multiplier Test for Serial Correlation								
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(GD_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + \beta_4\Delta\ln(DL_{it}) + u_{it}$								
	W	**AS**	**ME**	**AF**	**NA**	**LA**	**EU**	**AU**
F	132.119	56.083	13.814	48.064	0.959	26.941	75.503	17.030
Prob > F	0	0	0.003	0	0.431	0	0	0.151
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(GC_{it}) + \beta_2\Delta\ln(M_{it}) + \beta_3\Delta\ln(X_{it}) + u_{it}$								
	W	**AS**	**ME**	**AF**	**NA**	**LA**	**EU**	**AU**
F	141.171	63.582	11.103	53.678	1.591	27.106	75.451	12.427
Prob > F	0	0	0.006	0	0.334	0	0	0.176
Countries	131	20	13	27	3	21	45	2
Observations	4,376	696	479	905	110	775	1,328	72

Note: W = World, AS = Asia, ME = the Middle East, AF = Africa, NA = North America, LA = Latin America, EU = Europe, and AU = Australia

The results for North America and Australia fail to reject the null hypothesis with the conclusion that these data do not have first order autocorrelation (AR1) in Model 1 and Model 2. However, the results for the world, Asia, the Middle East, Africa, Latin America and Europe reject the null hypothesis in both models. As a result of the Wooldridge test for autocorrelation in panel data (Lagram-Multiplier test for serial correlation) detecting the presence of AR1, lagged dependent variables are added on the right-hand side for the world, Asia, the Middle East, Africa, Latin America and Europe (see Table 3.4).[92]

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[92] Dynamic model specifications that incorporate lagged dependent variables are often suggested by the modeling of dynamic relationships and availability of panel data in econometric applications. Since Nickell (1981) at least, it has been known that classical least squares estimators in

3.6.3 Empirical Models

This study constructs two models of panel data which confers two dimensions (year and country) upon the variables. There is a cross-sectional unit of observation, which in this case is country (*i*). There is a temporal reference (*t*), which in this case is the year. The deterministic approach constrains the error term of the CO_2 emissions function to be non-negative. The altered models with lagged dependent variables for the world, Asia, the Middle East, Africa, Latin America and Europe appear as

Model 1

$$\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(CO_{2,i,t-1}) + \beta_2 \Delta \ln(GD_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(DL_{it}) + \Delta u_{it} \quad (39)$$

$$i = 1,2.....N, \qquad t = 1,2.....T$$

where Δ is a difference operator, *ln* is the natural logarithm, *i* denotes countries, *t* denotes years, α_0 is a constant term and u_{it} is the error term assumed to be independent over (*i*) countries.

In Model l, the explained variable is CO_2 emissions from main activity electricity plants (CO_2). The explanatory variables are CO_2 emissions from main activity electricity plants of the previous period ($CO_{2,\ t-1}$), electricity generation for country minus distribution loss (*GD*), electricity import (*M*), electricity export (*X*) and distribution loss (*DL*).

---

dynamic panel models with fixed effects are strongly biased when panels comprise short time periods. However, this study employs yearly data encompassing 37 years from 1971 to 2007. Therefore, any bias should be minimal.

Model 2

$$\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(CO_{2,i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \Delta u_{it} \quad (40)$$

$$i = 1,2.....N, \qquad t = 1,2.....T$$

In Model 2, the explained variable is CO_2 emissions from main activity electricity plants (*CO_2*). The explanatory variables are CO_2 emissions from main activity electricity plants of the previous period (*$CO_{2,t-1}$*), electricity generation for country (*GC* = *GD* + *DL*), electricity import (*M*) and electricity export (*X*).

To cope with the problems of non-stationarity and serial correlation, all models are transformed to be first-difference models. From the transformed models, we get the error term as

$$\Delta u_{it} = \Delta \mu_i + \Delta \varepsilon_{it} \quad (41)$$

where $u_{it} = \mu_i + \varepsilon_{it}$ stands for the composite errors $\mu_i \sim i.i.d\ (0, \sigma_\mu^2)$ and $\varepsilon_i \sim i.i.d\ (0, \sigma_\varepsilon^2)$.

Hence, Equation (41) can be written as

$$u_{it} - u_{i,t-1} = \mu_i - \mu_{i,t-1} + \varepsilon_{it} - \varepsilon_{i,t-1} = \varepsilon_{it} - \varepsilon_{i,t-1} \quad (42)$$

By transforming the regressors through first differencing, the fixed country-specific effects from unobserved variables (taxes, subsidies, sequestration, technologies,[93] energy policies, regulations and international agreements (see Figure 3.4) are removed, if they do not vary with time.

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[93] As mentioned previously, promotion of new energy technologies only began in the 1990s, and changing to a low-carbon system has a major impact on energy budgets. As a result, there is little evidence of technology change from 1971 to 2007 for the 131 countries in this study. Therefore, it is possible that, after taking first differences, the effect of technology change on CO_2 emissions will disappear.

This study examines whether international co-operation regarding electricity import and export between countries can help redress the problem of CO_2 emissions. In all models, electricity generation (β_2) is expected to increase CO_2 emissions more than electricity import (β_3). Electricity export (β_4) is expected to increase CO_2 emissions when export countries do not have excess supply for export and use flue resources for generation (see Figure 1). However, if export countries have excess electricity supply and do not use flue resources for generation, international electricity trade is expected to reduce CO_2 emissions as well as lower the cost of electricity generation (WTO, 2008; Odgaard, 2000). Therefore, the effect of export (β_4) on CO_2 emissions can be negative. In Model 1, distribution loss (β_5) is expected to increase CO_2 emissions because it causes more electricity generation (Wijaya and Limmeechokchai, 2009).

3.6.4 Panel Data Analysis

This chapter estimates standard linear panel estimators with regard to pooled ordinary least squares (POLS), fixed effects (within) and random effects.[94] Panel data analysis is employed to solve the problem of unobserved variables since it allows control for unobserved cross section heterogeneity (Wooldridge, 2002; Baltagi, 2005). In this study, for example, taxes, government subsidies, national energy policies, regulations, and international agreements change over time but not across countries, and these unobserved variables account for individual heterogeneity. Another advantage of

[94] Between estimation employs the simple mean in preference to the over-time information in the data, resulting in less efficiency. This study ignores the between effects estimator because of the unlikelihood that there is only cross-sectional variation in the CO_2 emissions function, and that electricity generation, import, export and distribution loss, which are regressors, are constant over the study period 1971 to 2007.

panel data is that it involves very large numbers of observations, resulting in more informative data, more observation variability, less collinearity among the variables, more degrees of freedom and more efficiency (Baltagi, 2005).

The POLS estimator uses variation of both time and cross sectional units to estimate β by stacking data over *i* (country) and *t* (year) into one long regression with *NT* observations, and estimating by ordinary least square (OLS).

$$CO_{2,it} = \alpha + \sum_{j=1}^{k} \beta_j x_{j,it} + \sum_{p=1}^{s} \gamma_p z_{p,i} + \varepsilon_{it} \tag{43}$$

where $CO_{2,it}$ represents the dependent variable which is CO_2 emissions from main activity electricity plants; x_{it} represents observed variables which are explanatory variables (see Model 1 and Model 2); z_i represents unobserved variables including taxes, government subsidies, national energy policies, regulations, and international agreements (see Figure 1); α is the intercept which represents the individual-specific constants; β is a k-dimensional column vector of parameters; γ is an s-dimensional column vector of parameters; ε_{it} is an error term [($\Delta\varepsilon_{it}$) in Equation (41)]; *i* is country; and *t* is year.

Hence, Equation (43) can be written in the regression model as

$$CO_{2,it} = \alpha + x_{it}'\beta + \mu_i + \varepsilon_{it} \tag{44}$$

where $x_{it}'\beta = \sum_{j=1}^{k} \beta_j x_{j,it}$ and $\mu_i = \sum_{p=1}^{s} \gamma_p z_{p,i}$

Under the restriction, $\sum\mu_i. = 0$, of POLS estimation, Equation (44) can be written as

$$CO_{2,it} = \alpha + x_{it}'\beta + \varepsilon_{it} \tag{45}$$

POLS does not consider unobserved characteristics (μ_i), hence there is a limited POLS estimation under the restriction $\sum\mu_i. = 0$. The presence of the unobserved effect will usually cause POLS to give inefficient estimates and invalid standard errors, even if such effect is not correlated with any of the explanatory variables (Dougherty, 2011, p. 411).

If μ_i is constant, the initial model (43) can be written as

$$\ddot{C}O_{2,it} = \ddot{x}'_{it}\beta + \ddot{\varepsilon}_{it} \tag{46}$$

where $\ddot{C}O_{2,it} = CO_{2,it} - \overline{CO}_{2,it}$, $\ddot{x}_{it} = x_{it} - \bar{x}_{it}$ and $\ddot{\varepsilon}_{it} = \varepsilon_{it} - \bar{\varepsilon}_{it}$.

This model is called the fixed effects (within-groups) regression model because it explains the variations about the mean of the dependent variable in terms of the variations about the means of the explanatory variables for the group of observations relating to a given individual. A main attraction for using within in this study is the possibility of tackling unobserved heterogeneity bias (Todd, 2007). Because the individual-specific effect μ_i and the intercept α are constant, they are both cancelled.

A fixed effects regression is not an effective model when the variables of interest are constant for each individual, because such variables are eliminated as a result. In this section, an alternative approach known as a random effects regression will be considered. From Equation (44), the basic unobserved effects model (UEM) is written for a randomly drawn cross-section observation (*i*). It is possible, under certain suppositions, to use the POLS estimator for obtaining a consistent estimator of β in the model. The random effects model is shown as

$$CO_{2,it} = \alpha + x'_{it}\beta + u_{it} \tag{47}$$

where $u_i = \mu_i + \varepsilon_{it}$ stands for the composite errors $\mu_i \sim i.i.d\ (0, \sigma^2_\mu)$ and $\varepsilon_i \sim i.i.d\ (0, \sigma^2_\varepsilon)$, and μ_i is independent of ε_i (Baltagi, 2005, p. 14).

Hence, Equation (47) can be written in the regression model as

$$P_{it} = \alpha + x_{it}'\beta + \mu_i + \varepsilon_{it} \tag{48}$$

where μ_i is between-entity error and ε_{it} is within-entity error.

Equation (48) is similar to Equation (44) of POLS, but the different is that the variation across country (μ_i) is not assumed to be zero. Random effects assumes μ_i is random and uncorrelated with the independent variables (x_i). It is reasonable to assume that unobserved variables in this study, e.g. taxes, government subsidies, national energy policies, regulations and international agreements (see Figure 3.4), have some influence on the dependent variable ($\mu_i \neq 0$), so random effects is more applicable than POLS. However, if the fixed country-specific effects of unobserved variables do not vary with time, they will be eliminated for all estimation methods (POLS, fixed effects and random effects), after the transforming to first-difference models [see Equation (42)].

3.7 EMPIRICAL RESULTS

This study examines whether electricity co-operation regarding import and export can reduce CO_2 emissions. Panel data analysis is followed by comparison of CO_2 levels for electricity generation and trading (import and export), using 131 countries' yearly data from 1971 to 2007. Hausman and B-P/LM tests determine the appropriate estimation models.

3.7.1 Panel Data Analysis Results

Table 3.5 shows the world estimation results of Model 1 and Model 2 by three estimation methods (POLS, fixed effects and random effects), and it is evident that the findings appear similar. The results in both models show that the effects of CO_2

emissions of the previous period (β_1) on the current period are close to zero and not statistically significant except for fixed effects estimation method of Model 1.

Table 3.5: Standard Linear Panel Model Estimator Results for the World

World (131 countries)
1971-2007 (Unbalanced Panel)

Model 1: $\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(CO_{2,i,t-1}) + \beta_2 \Delta \ln(GD_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + \beta_5 \Delta \ln(DL_{it}) + u_{it}$

Model 2: $\Delta \ln(CO_{2,it}) = \alpha_0 + \beta_1 \Delta \ln(CO_{2,i,t-1}) + \beta_2 \Delta \ln(GC_{it}) + \beta_3 \Delta \ln(M_{it}) + \beta_4 \Delta \ln(X_{it}) + u_{it}$

Model	**POLS**		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
$\Delta ln(CO_{2,\ t-1})$: lag1_CO_2 emissions	-0.004 (0.010)	-0.003 (0.010)	-0.017* (0.011)	-0.016 (0.011)	-0.004 (0.010)	-0.003 (0.010)
Δln(GC): Generation for country		0.549*** (0.008)		0.545*** (0.009)		0.549*** (0.009)
Δln(GD): Generation minus DL	0.510*** (0.012)		0.507*** (0.012)		0.510*** (0.012)	
Δln(M): Import	0.021*** (0.004)	0.022*** (0.004)	0.021*** (0.004)	0.022*** (0.004)	0.021*** (0.004)	0.022*** (0.004)
Δln(X): Export	-0.017*** (0.004)	-0.014*** (0.004)	-0.017*** (0.004)	-0.014*** (0.004)	-0.017*** (0.004)	-0.014*** (0.004)
Δln(DL): Distribution loss	0.052*** (0.009)		0.052*** (0.009)		0.052*** (0.009)	
α_0	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)
σ_μ			0.041	0.041	0	0
σ_ε			0.265	0.267	0.265	0.267
ρ			0.023	0.023	0	0
F-Statistics	991.65***	1,196.06***	962.12***	1,159.98***		
χ^2					4,958.25***	4,784.23***
Observations	4,376	4,411	4,376	4,411	4,376	4,411

Notes: (1) Standard errors in ( )
(2) *** and ** illustrate significance at 1% and 5% levels respectively.
(3) Intraclass correlation $\rho = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

As anticipated, (β_2) of Model 1 (electricity generation minus distribution loss) and (β_2) of Model 2 (electricity generation for country) have a highly significant positive relationship with CO_2 emissions. For all models, electricity import (β_3) shows a highly significant positive relationship with CO_2 emissions, following the expectation. On the other hand, electricity export (β_4) has a highly significant negative relationship with CO_2 emissions for all models. This result may be due, in part, to countries exporting electricity from excess supply, and also since flue sources are not normally used to generate for export, through exploitation of comparative resource advantages (Justus, 1997; Bielecki and Desta, 2004, p. 21). In addition, through economies of scale (Christensen and Green, 1976), trade reduces social cost and, therefore, emissions. Distribution loss (β_5) of Model 1 is seen to have a highly significant positive relationship with CO_2 emissions, as expected.

3.7.2 Hausman Test Results

The decision of selection between fixed effects (FE) and random effects (RE) estimators can be determined by the (Durbin-Wu-) Hausman test.[95] Under H_0, β_{RE} is consistent and efficient, while β_{FE} is consistent but inefficient. Under H_A, β_{RE} is inefficient but remains consistent (Schmidheiny, 2012). If the test result is not significant (P-value, Prob > χ^2 larger than 0.05), then the null hypothesis is not rejected and random effects can be used. However, if the P-value is significant, leading to rejection of the null hypothesis, then it is recommended that fixed effects be employed.

Table 3.6 shows the results of the Hausman test for both models. Random effects estimation is accepted for Asia, the Middle East, North America, Latin America and Australia, but not accepted for Africa, Europe and the world. Under random effects, the regression model retains observed characteristics that remain constant for each country making it more attractive than fixed effects estimation where those characteristics have to be discarded (Dougherty, 2011).

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95 See details on pp. 49-50.

Table 3.6: Hausman Test Results

Hausman Test			
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$			
	H	**Prob >** χ^2	**Random Effects**
World	52.81***	0	not accept RE
Asia	8.13	0.149	accept RE
Asia: Middle East	3.41	0.638	accept RE
Africa	17.61***	0.003	not accept RE
North America	0.58	0.965	accept RE
Latin America	3.96	0.555	accept RE
Europe	23.37***	0	not accept RE
Australia	0.13	0.939	accept RE
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$			
	H	**Prob >** χ^2	**Random Effects**
World	54.30***	0	not accept RE
Asia	8.42	0.077	accept RE
Asia: Middle East	3.91	0.419	accept RE
Africa	21.48***	0	not accept RE
North America	0.27	0.965	accept RE
Latin America	3.96	0.411	accept RE
Europe	22.81***	0	not accept RE
Australia	0.15	0.698	accept RE

Notes: (1) $H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})' [\hat{V}[\hat{\beta}_{FE}] - \hat{V}[\hat{\beta}_{RE}]]^{-1} (\hat{\beta}_{FE} - \hat{\beta}_{RE})$

(2) H < 0 indicates model fitted on these data fails to meet the asymptotic assumptions of the Hausman test.

(3) *** denotes significance at the 1% level.

3.7.3 Breusch-Pagan Lagrange Multiplier Test Results

This study employs the Breusch-Pagan LM (B-P/LM) test of independence. The null hypothesis in the B-P/LM test of independence is that residuals across countries are not correlated.[96] In deciding between a random effects regression and a simple OLS

[96] See details on pp. 50-51.

regression, the LM test proves useful. With the LM test, only the estimation models which are accepted for random effects in Table 3.6 are tested.

Table 3.7: Breusch-Pagan Lagrange Multiplier (LM) Test Results

Breusch-Pagan Lagrange Multiplier (LM) Test						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$						
	Var $\ln(CO_2)$	**Var (μ)**	**Var (ε)**	**LM**	**Prob >** χ^2	**Random Effects**
Asia	0.432 (0.657)	0 0	0.187 (0.432)	0	1.00	not accept RE
Middle East	0.197 (0.444)	0 0	0.031 (0.177)	0	1.00	not accept RE
North America	0.093 (0.304)	0 0	0.006 (0.074)	0	1.00	not accept RE
Latin America	0.073 (0.270)	0 0	0.032 (0.179)	0	1.00	not accept RE
Australia	0.303 (0.551)	0 0	0.021 (0.144)	0	1.00	not accept RE
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	Var $\ln(CO_2)$	**Var (μ)**	**Var (ε)**	**LM**	**Prob >** χ^2	**Random Effects**
Asia	0.432 (0.657)	0 0	0.193 (0.440)	0	1.00	not accept RE
Middle East	0.197 (0.444)	0 0	0.032 (0.178)	0	1.00	not accept RE
North America	0.093 (0.304)	0 0	0.006 (0.079)	0	1.00	not accept RE
Latin America	0.073 (0.270)	0 0	0.032 (0.179)	0	1.00	not accept RE
Australia	0.303 (0.551)	0 0	0.021 (0.144)	0	1.00	not accept RE

Notes: (1) $LM = (NT/2(T-1)[(\sum_{i=1}^{N} e_i^2 / \sum_{i=1}^{N}\sum_{t=1}^{T} e_{it}^2) - 1]^2$

(2) Standard errors in ( )

In Table 3.7, the LM test results for Asia, the Middle East, North America, Latin America and Australia show failure to reject the null hypothesis that variances across countries (σ_μ^2) is zero. This leads to the conclusion that random effects estimation is not appropriate. Hence, POLS will be used for all unaccepted random effects estimation models.

3.7.4 World Results of Panel Data Analysis

For Model 1 in Table 3.8, the world results show that a rise of 1% in CO_2 emissions from electricity generation of the previous year leads to a decrease of CO_2 emissions for the current year by about 0.02%, but the finding is not statistically significant.[97] A rise of 1% in electricity generation minus distribution loss is highly significant in increasing CO_2 emissions by about 0.51%, while a rise of 1% in electricity import is highly significant in increasing CO_2 emissions by about 0.02%. Following expectation,[98] the results confirm that electricity import is a better choice than electricity generation in regard to environmental concerns. With regard to export, a rise of 1% is shown to highly significantly decrease CO_2 emissions by about 0.02%. A rise of 1% in distribution loss shows a highly significant increase in CO_2 emissions of about 0.05%.

In Model 2, all independent variables give the same results as Model 1, except electricity generation for country (GC = GD + DL). Table 3.9 shows that a rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.55%.

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[97] CO_2 emissions from electricity generation of the previous year ($CO_{2,\ t-1}$) is included in the models in order to avoid serial correlation.

[98] See detail on pages 83-86.

3.7.5. Continent Results of Panel Data Analysis

Table 3.8 and Table 3.9 give the continent results of the CO_2 emissions functions for Model 1 and Model 2 respectively, which are accepted under POLS for Asia, the Middle East, North America, Latin America and Australia, and under fixed effects (within) for Africa and Europe.

The results of Model 1 and Model 2 appear similar. However, in Model 1, the effects of distribution loss on CO_2 emissions for Asia, the Middle East and North America are negative, which is incorrect. This anomaly suggests estimates of the coefficients in these continents' results might be influenced by multicollinearity. To avoid this problem, Model 2, which does not include distribution loss, is used to explain the results for continents.

From Table 3.9, the results for Asia show that a rise of 1% in CO_2 emissions from electricity generation of the previous year leads to a decrease of CO_2 emissions for the current year by about 0.01%, but it is not statistically significant. A rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.90%, while a rise of 1% in electricity import is highly significant in decreasing CO_2 emissions by about 0.16%. With regard to export, a rise of 1% is shown to increase CO_2 emissions by about 0.03%, but it is not statistically significant.

The results for the Middle East show that a rise of 1% in CO_2 emissions from electricity generation of the previous year leads to an increase of CO_2 emissions for the current year by about 0.02%, but it is not statistically significant. A rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.60%, while a rise of 1% in electricity import decreases CO_2 emissions by about 0.01%, but it is not statistically significant. With regard to export, a rise of 1% is shown to increase CO_2 emissions by about 0.01%, but it is not statistically significant.

For Africa, a rise of 1% in CO_2 emissions from electricity generation of the previous year leads to a decrease of CO_2 emissions for the current year by about 0.01%, but it is not statistically significant. A rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.31%, while a rise of 1% in electricity import is highly significant in increasing CO_2 emissions by about 0.06%. With regard to export, a rise of 1% is shown to highly significantly increase CO_2 emissions by about 0.04%.

For North America, the model does not include a lagged dependent variable (electricity generation of previous year). The results show that a rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 1.02%, while a rise of 1% in electricity import is expected to increase CO_2 emissions by about 0.001%, which is close to zero and not statistically significant. With regard to export, a rise of 1% is shown to highly significantly decrease CO_2 emissions by about 0.06%.

The results for Latin America show that a rise of 1% in CO_2 emissions from electricity generation of the previous year leads to a decrease of CO_2 emissions for the current year by about 0.02%, but it is not statistically significant. A rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.48%, while a rise of 1% in electricity import is significant in increasing CO_2 emissions by about 0.01%. With regard to export, a rise of 1% is shown to highly significantly decrease CO_2 emissions by about 0.02%.

Table 3.8: Panel Data Analysis Appropriate Estimation Model 1 Results

Panel Data Analysis Appropriate Estimation Model 1								
	Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$							
	W	**AS**	**ME**	**AF**	**NA**	**LA**	**EU**	**AU**
	WITHIN	POLS	POLS	WITHIN	POLS	POLS	WITHIN	POLS
$\Delta ln(CO_{2,\,t-1})$: lag1_CO_2 emissions	-0.017* (0.011)	-0.002 (0.025)	0.018 (0.018)	-0.005 (0.024)	-	-0.014 (0.024)	-0.051** (0.025)	-
Δln(GD): Generation minus Distribution loss	0.507*** (0.012)	1.079*** (0.060)	0.611*** (0.021)	0.297*** (0.016)	1.070*** (0.055)	0.453*** (0.020)	0.334*** (0.041)	1.517*** (0.110)
Δln(M): Import	0.021*** (0.004)	-0.158*** (0.021)	-0.008 (0.008)	0.053*** (0.007)	-0.0003 (0.010)	0.012** (0.005)	0.031*** (0.011)	-
Δln(X): Export	-0.017*** (0.004)	0.025 (0.024)	0.006 (0.009)	0.030*** (0.008)	-0.52*** (0.010)	-0.021*** (0.006)	-0.022** (0.009)	-
Δln(DL): Distribution loss	0.052*** (0.009)	-0.188*** (0.056)	-0.008 (0.015)	0.075*** (0.015)	-0.107* 0.056)	0.019** (0.009)	0.158*** (0.040)	0.063 (0.138)
α_0	0.001 (0.004)	-0.002 (0.016)	-0.001 (0.008)	-0.001 (0.007)	0.008 (0.007)	-0.001 (0.006)	0.003 (0.009)	-0.022 (0.017)
σ_μ	0.041			0.034			0.057	
σ_ε	0.265			0.209			0.345	
ρ	0.023			0.025			0.026	
F-Statistics	962***	185***	514***	192***	436***	202***	81***	494***
Countries	131	20	13	27	3	21	45	2
Observations	4,376	696	479	905	110	775	1,328	73

Notes: (1) Standard errors in ( )

(2) ***, ** and * illustrate significance at 1%, 5% and 10% levels respectively.

(3) Intraclass correlation $\rho = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Table 3.9: Panel Data Analysis Appropriate Estimation Model 2 Results

Panel Data Analysis Appropriate Estimation Model 2								
	Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$							
	W	**AS**	**ME**	**AF**	**NA**	**LA**	**EU**	**AU**
	WITHIN	POLS	POLS	WITHIN	POLS	POLS	WITHIN	POLS
$\Delta ln(CO_{2,t-1})$: lag1_CO_2 emissions	-0.016 (0.011)	-0.006 (0.025)	0.016 (0.018)	-0.006 (0.024)	-	-0.010 (0.024)	-0.051** (0.025)	-
Δln(GC): Generation for country	0.545*** (0.009)	0.903*** (0.031)	0.595*** (0.012)	0.307*** (0.014)	1.019*** (0.041)	0.479*** (0.016)	0.492*** (0.028)	1.608*** (0.052)
Δln(M): Import	0.022*** (0.004)	-0.160*** (0.021)	-0.009 (0.009)	0.057*** (0.006)	0.001 (0.011)	0.013** (0.005)	0.031*** (0.011)	-
Δln(X): Export	-0.014*** (0.004)	0.034 (0.024)	0.006 (0.009)	0.042*** (0.008)	-0.057*** (0.010)	-0.022*** (0.006)	-0.021** (0.009)	-
α_0	0.001 (0.004)	-0.001 (0.017)	-0.001 (0.008)	0.001 (0.007)	0.008 (0.008)	-0.001 (0.006)	0.003 (0.009)	-0.021 (0.017)
σ_μ	0.041			0.035			0.056	
σ_ε	0.267			0.213			0.344	
ρ	0.023			0.026			0.026	
F-Statistics	1,160***	218***	636***	215***	515***	256***	98***	963***
Countries	131	20	13	27	3	21	45	2
Observations	4,411	696	479	905	110	775	1,328	73

Notes: (1) Standard errors in ( )

(2) ***, ** and * illustrate significance at 1%, 5% and 10% levels respectively.

(3) Intraclass correlation $\rho = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Surprisingly, in Europe, a rise of 1% in CO_2 emissions from electricity generation of the previous year is significant in decreasing CO_2 emissions for the current year by about 0.06%. This might be due to the efficiency of the green energy policy of the EU in setting targets to decrease CO_2 emissions from the previous period. A rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 0.50%, while a rise of 1% in electricity import is highly significant in increasing CO_2 emissions by about 0.03%. With regard to export, a rise of 1% is shown to significantly decrease CO_2 emissions by about 0.02%.

There is no international electricity trade in Australia, and the model does not include a lagged dependent variable for this country. The results show that a rise of 1% in electricity generation for country is highly significant in increasing CO_2 emissions by about 1.61%.

In Model 2, Australia (1.61%), North America (1.02%) and Asia (0.90%) have the highest production of CO_2 emissions per unit of electricity generation for country respectively, while Africa has the lowest (0.31%). For electricity import, Africa (0.06%) has the highest increase in CO_2 emissions, with Asia (-0.16%) having the highest decrease. For electricity export, Africa (0.04%) has the highest increase in CO_2 emissions, with North America (-0.06%) having the highest decrease.

3.8 DISCUSSION

Villemeur and Pineau (2010) maintain that increased electricity consumption as a result of trade is detrimental to the environment due to an increase in electricity generation. However, the empirical results of this study show that for the world, a rise of 1% in electricity generation for country is expected to increase CO_2 emissions by 0.55% which is much higher than for electricity import (0.02%), while a rise of 1%

in electricity export is expected to decreases CO_2 emissions by 0.02% (see Table 3.8). This supports the contention that international trade does not increase CO_2 emissions overall. Furthermore, when countries import electricity rather than produce more themselves, a decrease in CO_2 emissions from electricity generation in importing countries can be expected.

Electricity trade reduces electricity cost (private and social) by increasing market efficiency and encourages innovation in electricity generation through competition resulting in less CO_2 production (Pomeda and Camacho, 2003). Under free trade theories, trade allows each country to specialize in production of those products that it can produce most efficiently, thus electricity surplus should decrease. Not surprisingly, following this idea, the world results show that electricity import is expected to increase CO_2 emissions by about only 0.02% which is much lower than for electricity generation (0.55%) (see Table 3.8).

Emissions of CO_2 result not only from electricity generation, but also from activities surrounding the importing infrastructure e.g. construction, distribution, maintenance, decommissioning and transport, thus offering an explanation for the positive effect on CO_2 emissions from electricity import for Africa, North America, Latin America and Europe (see Table 3.9), as well as the world (see Table 3.8). For Asia and the Middle East, CO_2 emissions can also increase from importing activities. However, following trade theory, electricity import can decrease the social cost of CO_2 emissions outweighing any increase in emissions related to importing infrastructure, thus leading to a negative effect on CO_2 emissions in these continents, although the result is not statistically significant for the Middle East (see Table 3.9). Furthermore, because Asia and the Middle East rely heavily on flue sources for domestic electricity supply, any import of electricity may reduce generation from coal, gas and oil more so than for other continents. This may help explain why electricity import decreases CO_2 emissions in Asia and the Middle East.

Even though exporting countries export mostly excess supply which cannot be stored, there still may be small increases in CO_2 emissions due to related infrastructure as mentioned above. Such small increases are reflected in export results for Asia, the Middle East and Africa. On the other hand, North America, Latin America and Europe all show a decrease in CO_2 emissions for export, as predicted by trade theory (see Table 3.9). As mentioned before, export countries do not usually use flue sources to generate electricity for export, and electricity co-operation encourages innovation in electricity generation through competition resulting in less CO_2 production (WTO, 2008; Pomeda and Camacho, 2003; Unger and Ekvall, 2003).

According to the Treasury, Australian Government (2011) and IEA (statistic), most electricity demand growth arises from developing countries, especially India and China which are expected to account for 35% and 16% respectively of the growth from 2005 to 2050. The results indicate, with a level of high significance, that Asia (-0.16%) shows the highest decrease in CO_2 emissions from electricity import (see Table 3.9). This suggests that the more electricity trade there is in this continent, the more CO_2 emissions from electricity generation will decrease.

For the Middle East, electricity import and export have no impact on CO_2 emissions (see Table 3.9). This might be due to there being little electricity co-operation in this continent as a result of political issues. Data from IEA indicate that, from 1971 to 2007, the levels of import and export of electricity in the Middle East were the lowest when compared with other continents, except Australia which had no international electricity trade. Lack of trust between countries is a major stumbling block to progress in electricity co-operation in this continent.

With regard to Africa, the results show that electricity generation produces the lowest CO_2 emissions in comparison with other continents (see Table 3.9). However, for electricity trading, there exist a number of barriers as identified by Mkhwanazi (2003). Foremost among these is a hostile political climate between countries creating a serious impediment to co-operation. An absence of political will with regard to trade together with unstable economic policies in some countries is disruptive of long-term arrangements. Both import and export of electricity in this continent are found to increase CO_2 emissions with high significance. This paper supports the position put forward by Mbirimi (2010) that Africa is in need of infrastructure development in electricity including new generation capacity as well as the use of renewable technologies so that poor rural areas can be connected more quickly and cheaply. Increased co-operation in this continent will improve efficiency in the electricity sector with the view to decreasing CO_2 emissions.

The second highest producer of CO_2 emissions from electricity generation is shown to be North America (see Table 3.9),[99] and this might explain why the U.S. rejected the Kyoto agreement on global warming, and Canada announced that country's withdrawal from the Kyoto Protocol in December 2011, saying that the move would save Canada $14 billion in penalties for not achieving its Kyoto targets.[100] However, this paper sheds light on CO_2 reduction through international electricity trade in this

[99] In 2005, Canada and Mexico each contributed less than 2% to global greenhouse gas emissions while the U.S. contributed 16% (CEC, 2012, available at: http://www2.cec.org/site/PPE/united-states/power-plants-and-their-impact-climate-change).

[100] Mail Online News, 2011, available at: http://www.dailymail.co.uk/news/article-2073520/Canada-abandons-Kyoto-Protocol-save-14bn-penalties-missing-greenhouse-gas-targets.html

continent. Table 6 shows that, although there is no impact from electricity import, electricity export is highly significant in decreasing CO_2 emissions.

In Latin America, MERCOSUR (Southern Common Market) exists as a free trade agreement founded in 1991 and updated in 1994.[101] Although it functions more as a co-ordinating mechanism than as a supra-national organization, its electricity sector has the potential to become a major force for integration provided movement towards macroeconomic policy co-ordination is first undertaken (Pineau et al., 2004). The results for this region support the view that electricity co-operation has a positive impact on the environment. From Table 3.9, Latin America is seen to produce the second lowest CO_2 emissions from electricity generation. Electricity export is found to be highly significant in decreasing CO_2 emissions, while there is only a tiny impact from electricity import.

Surprisingly, in Europe, a rise of 1% in CO_2 emissions from electricity generation of the previous year is significant in decreasing CO_2 emissions for the current year by about 0.06%, while the results for other continents are not statistically significant (see Table 3.9). The European result might be due to the efficiency of the green energy policy of the EU in setting targets to decrease CO_2 emissions from the previous period. The EU agreements focus, not only on electricity free trade, but also on CO_2 reduction levels from electricity generation.[102] Directives 2001/77/EC, 2003/30/EC and 2009/28/EC of the European Parliament and of the Council promoted

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[101] MERCOSUR includes Argentina, Brazil, Paraguay, Uruguay and Venezuela (with Bolivia, Chile, Colombia, Ecuador and Peru as associate members) (Pineau et al., 2004).

[102] OECD Europe has a history of high levels of electricity co-operation as seen by the fact that electricity imports increased at an average annual rate of 7.0% between 1973 and 1990 although slowing to a rate of 1.8% after that period (IEA, 2010).

electricity production from renewable energy sources in the internal electricity market to decrease CO_2 emissions (Official Journal of the European Union, 2009).

Australia is an interesting case, and not only because it has no international electricity trade. In this country, from 1971 to 2007, around 95% of electricity generation came from fossil fuels with coal being the main source, and only 5% from renewable energy (IEA, statistic). This shows why Australia has the highest percentage of CO_2 increase from electricity generation per unit (see Table 3.9).

Even though the world results of this study show that electricity import is expected to increase CO_2 emissions by about 0.02%, the figure is far lower than for electricity generation (0.55%) (see Table 3.8). Since electricity is a vital commodity in all economies, uninterrupted maintenance of electricity supply is of major concern for governments. Because of this, electricity trading requires a high level of mutual trust, and involves more than just buying and selling – it is founded on co-operation. Any decision regarding such trade requires careful consideration in view of certain factors. Stability of governments to ensure continued electricity supply for export, as well as on-going friendly relations between likely trading partners needs to be taken into account.

3.9 CONCLUSION

This chapter examines whether international co-operation regarding electricity import and export can reduce CO_2 emission levels. The panel data analysis covers 131 countries and also division of countries by continent with yearly samples for the period 1971 to 2007. The world results show that electricity co-operation is highly significant in decreasing CO_2 emissions, thus supporting the hypothesis. At the continent level, Asia shows the highest CO_2 decrease from electricity import, with the lowest decrease being for Africa due to a number of barriers to electricity trading. Electricity export of

North America, Latin America and Europe is highly significant in decreasing CO_2 emissions. Australia has no international electricity trade and produces the highest CO_2 emissions per unit of electricity generation. The study reveals that electricity co-operation can have a positive impact on efficient management of decarbonisation of energy supply and be instrumental for governments in the fight against global warming. If more countries become involved in electricity co-operation, it will effectively decrease our planet's burden of CO_2 emissions.

CHAPTER FOUR

ELECTRICITY CO-OPERATION IN NORTH AMERICA: EFFECT ON PRICE

One of the most integrated and reliable electricity systems in the world is the North American network which connects the Canadian and U.S. electricity markets comprising a variety of fuel sources, vast transmission interconnections and reciprocal trading benefiting both countries (CEA, 2005). Such benefits, created from electricity co-operation regarding import and export, are economic as well as environmental. The combined assets of generation, transmission and distribution put this region among the most dynamic, robust and stable areas of economic growth anywhere (CEA, 2010). Fundamental to the system's cost effectiveness, reliability and security is access to a range of supply options involving different fuels and different technologies (Bradley, 2012;[103] Goodman, 2010; Bernard et al., (2003).

However, future growth in demand for electricity in Canada and the U.S. will need to be met by a corresponding growth in supply.[104] Increases in the order of 25% for generation capacity by 2025 are projected to satisfy the higher demand (CEA, 2005). This growth in electricity demand, in conjunction with the closing down of aging and environmentally unfriendly generation sites, will necessitate investment in new

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[103] Available at http://www.electricenergyonline.com/?page=show_article&ID=258.

[104] In the U.S., recent attempts to satisfy this need have focused mainly on natural gas. However, a number of factors have resulted in a substantial increase in the price of natural gas. Furthermore, the ability of Canada to meet projected increases in demand in the U.S. is of concern considering projected increases in Canadian demand for natural gas together with the realization that Canada's supplies of gas are finite (CEA, 2005), even though it is third in the world in production of natural gas (Centre for Energy, 2010).

electricity infrastructure and supply (CEA, 2006). Accordingly, both countries will face the problem of rising electricity prices from increased demand together with the need to reduce carbon dioxide (CO_2) emissions from electricity generation.

One important aspect of electricity management is sustainability in relation to economic, environmental and social interests which change over time in accordance with society's values and preferences. Does electricity co-operation with regard to import and export of electricity provide an effective means by which governments can address this challenge? This chapter focuses on electricity co-operation between the U.S. and Canada, investigating the effects of import and export on electricity price (both household and industry) while also examining which renewable energies are the best options for both countries in the years ahead. This bi-national electricity trading is subjected to time series analysis involving yearly samples for the period 1978 to 2009. This is followed, in Model 1, by investigation of the effects of electricity import and export on household electricity price, and, in Model 2, by investigation of the effects of electricity import and export on industry electricity price. The difference between household and industry prices, which is a proxy variable representing government electricity subsidy for the industry sector, is included in Model 2, but not included in Model 1.

The results for Model 1 reveal that electricity import is significant in decreasing household electricity price for Canada, but not for the U.S. With regard to export, the findings do not show a significant effect on household electricity price for Canada or for the U.S. From Model 2, import and export do not have an effect on industry electricity price for both countries. Looking at renewable energies for electricity supply into the future, this study shows that hydro and solar generation are significant in lowering household and industry electricity prices for Canada, but not for the U.S.

Section one of this paper deals with motivation; section two, overview of electricity trade between Canada and the U.S.; section three, methods and procedures; section four, empirical results; section five, discussion; and section six, conclusion.

4.1 MOTIVATION

The electricity trading system that has evolved between Canada and the U.S. since 1901 was the first recorded international electricity agreement, and the sheer volume of this trade in both import and export is without comparison, being valued at Canadian $5.13 billion in 2008.[105] Goodman (2010) attributes this success to an ability to meet the energy security and clean energy requirements of the U.S. while, at the same time, satisfying Canadian economic and societal objectives for energy exports beneficial to all regions of the country, showing a classical comparative advantage.

The overall demand for electricity in North America continues to rise with the majority of all daily activity consuming electricity, both household and industry. As the U.S. and Canadian economies develop into the future, they will require even more electricity with the inter-relationship between the two countries increasing as electricity generation as well as electricity trade continues to grow. The result of this is that the electricity industry in both countries faces mounting pressure to meet future demand as well as reduce atmospheric pollution from fossil-fuel based generation. This growing

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[105] In 2008, Canada's total electricity production peaked at 602 terawatt-hours (TWh), while Canadian exports to the United States were 55.7 TWh, with a value of Canadian $3.8 billion, at an average price of Canadian $64.91 per megawatt-hour (MWh). In addition, Canada imported 23.5 TWh of electricity from the United States, with a value of $1.33 billion, at an average price of $56.59 per MWh (Goodman, 2010).

focus on clean energy as a reflection of climate change concerns represents a major challenge confronting the North American power industry (IEA, 2010).[106]

Conversion to cleaner energy is a far greater challenge in the U.S. which relies on coal-fired generation for 48.4% of the energy industry's power. In Canada, it is much less of a problem since carbon-free hydro, nuclear, and renewable sources already generate 77% of current electricity supply. However, both countries are acting towards reducing CO_2 emissions from electricity generation by increasing the number of clean energy power plants. Such investment makes an already highly capital-intensive power business even more so, with the result that American and Canadian consumers face significantly higher electricity prices as being the cost of controlling greenhouse gas emissions (Goodman, 2010).

Even though there is no question that electricity trade between Canada and the U.S. is on the right path, there are some important issues that policy makers of both countries have to address. Can electricity trade achieve the economic and environmental objectives for a sustainable energy future? Can ongoing co-operation in international electricity trade policies assist the optimization of overall system efficiency while enabling the development of more renewable generation methods? These are the concerns of government and industry on both sides of the border, whose interests remain in co-operating to take full advantage of the system's potential to sustain

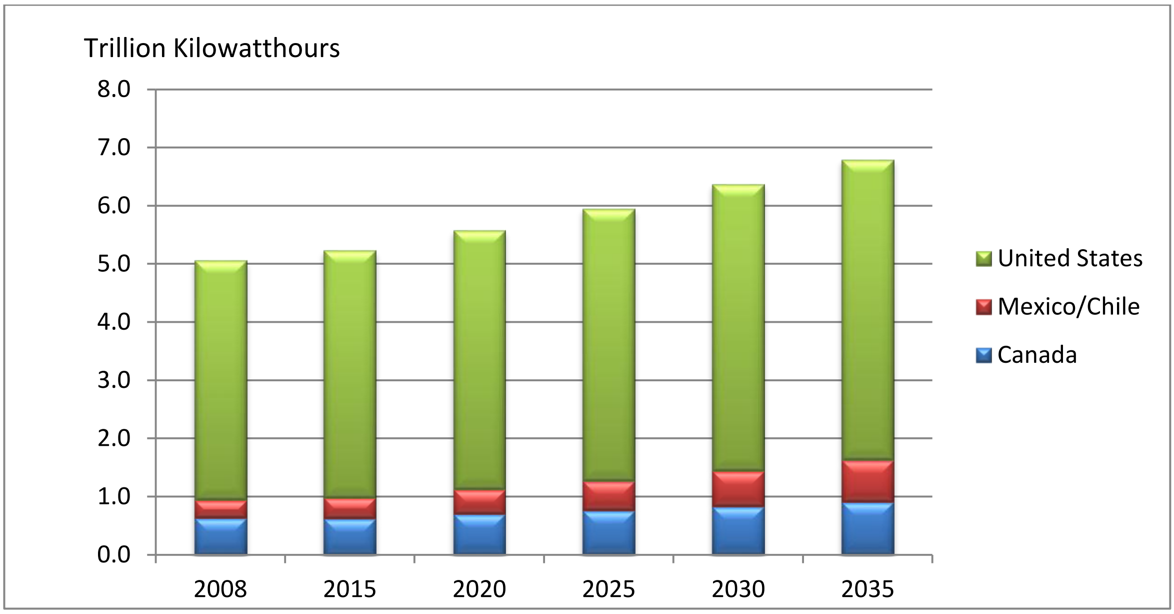
[106] The International Energy Agency's (IEA) 450 Scenario is a reference to the Scenario where governments are assumed to take strong action in reducing CO_2 emissions. These policy changes would limit the concentration of GHGs in the atmosphere to 450 parts/million of CO_2 equivalent and global temperature rises to 2^oC. Fossil-fuel demand reaches a peak by 2020, and zero-carbon fuels comprise one-third of the world's primary sources of energy demand by 2030. Actions, however, must be in place by 2020 (IEA, 2010).

economic development across both trading countries with the understanding that the economic and environmental issues involved need to be addressed in a sensitive and inclusive manner.

This paper focuses on electricity trade between Canada and the U.S. with the objective of determining whether such trade can reduce household and industry electricity prices. In addition, the study examines which forms of renewable energy best solve the future energy needs of both countries. The results may prove beneficial in indicating the way forward.

4.2 OVERVIEW OF ELECTRICITY GENERATION AND TRADE BETWEEN CANADA AND THE U.S.

Figure 4.1: North America Net Electricity Generation by Country from 2008 to 2035



Source: EIA, 2011, Figure 7.7[107]

107 Available at: http://www.eia.gov/forecasts/ieo/electricity.cfm

The U.S. is far and away the biggest electricity consumer of the region (see Figure 4.1). Both it and Canada have mature electricity markets with electricity generation continuing to increase. For the U.S. this increase, which includes generation by electric power producers as well as on-site generation, is expected to average a yearly rate of 0.8% between 2008 and 2035. The increase for Canada over the same period is put at 1.4% per year, while generation growth for other countries in the region is forecasted to be somewhat faster e.g. Mexico/Chile averaging 3.2% per year for the same time span reflecting a less developed electric power infrastructure with greater potential for expansion (EIA, 2011).

In 2009, Canada was the sixth highest electricity producer worldwide, generating 604.4 billion kWh, while the U.S. was the second highest, generating 3,953 billion kWh (CIA, World Fact Book, 2012).[108] In 2009, electricity in Canada was generated by hydroelectric facilities (63.2%), conventional steam (coal) (17.4%), nuclear (14.5%), combustion turbine (4.1%), wind (0.3%), internal combustion (0.2%) and tidal (0.01%) (Statistics Canada, Survey 2151, 2010). In contrast, electricity in the U.S. was generated by coal (44.7%), national gas (23.3%), nuclear (20.2%), hydro (6.8%), other renewables (3.6%), petroleum (1.0%) and other (0.6%) (EIA, Electric Power Monthly, 2012).[109]

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[108] Available at: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2038rank.html

[109] Available at: http://www.eia.gov/electricity/monthly/pdf/epm.pdf

In 2005, Canada and Mexico each contributed less than 2% to global GHG emissions while the U.S. contributed 16% (CEC, 2012).[110] Within the electricity industry, because almost two-thirds of the U.S. generating capacity is older than 20 years with almost one quarter being 30 years old, generation of CO_2 emissions is far greater than would be the case under new technologies. The Commission for Environmental Co-operation (CEC) suggests that the removal of existing regulatory subsidies would encourage competition through international trade in electricity, thus providing a strong incentive for the upgrading of old industrial infrastructure.

The trade relationship between Canada and the U.S. stands as a model of bilateral co-operation dating back to 1901. The breadth and depth of this expanding two-way traffic is unequalled across the globe with electricity currently a vital and growing part of the overall energy trade between the two countries (CEA, 2010). The Canadian Electricity Association (CEA) reports that, electricity trade between the two countries originates mainly from two sources. Canadian generators are of great importance in supplying certain U.S. markets, and generators in both countries make the most of the trading arrangement to maximize performance of their own asset portfolios, thus helping to reduce electricity costs and improve the overall efficiency and reliability of the system (CEA, 2006).

Looking at each country's proportion of total capacity available for export under present transmission capability indicates that Canada could export 17% of its electricity production while the U.S. could manage 2.5% (Pineau et al., 2004). However, in reality, Canada exported less than 9% and the U.S. less than 0.6% from 2000 to 2009

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[110] Available at: http://www2.cec.org/site/PPE/united-states/power-plants-and-their-impact-climate-change

(calculated from IEA data), indicating an opportunity for both countries to do more in this area.

4.2.1 Economic and Environmental Benefits of Electricity Trade

Electricity co-operation between Canada and the U.S. provides three main advantages - improved electricity supply, enhanced transmission infrastructure, and greater flexibility in addressing air quality issues and climate change (CEA, 2006). In addition, Goodman (2010) argues that, an increase in electricity trade gives countries important economic advantages (including economic growth), better international trade balance, more jobs, improved regional development, creation of carbon offsets, as well as greater flexibility and reliability of the electrical system.

In Canada, non-fossil fuels provide the main energy sources for electricity supply, while fossil fuels account for most U.S. generation. Cross-border electricity markets allow access to a variety of energy sources including hydro, coal, oil, natural gas, nuclear, and geothermal (among others) creating incentives for electricity trading. For instance, Canada can store hydro energy while buying low-cost electricity from nuclear or fossil-fuel sources in the U.S. in order to later run individual hydro generation units to satisfy peak hour demands when electricity is more expensive in the domestic or export market (Pineau et al., 2004). In addition, Natural Resources Canada observes that electricity trading reflects seasonal influence where peak demand occurs in winter for Canada but in summer for the U.S. when air-conditioning use is high and surplus electricity from Canada is available (Natural Resources Canada, 2012).[111] International electricity trade, therefore, allows optimization of generation resources for the benefit of consumers in both the U.S. and Canadian markets.

[111] Available at: http://www.nrcan.gc.ca/energy/sources/electricity/1387

For this situation to continue, the relationship between both countries is critical. With the benefits of cross-border trade in electricity evident, the way forward entails maximizing their advantage of supply diversity ensuring reliability in the North American electricity market. The resolution of concerns regarding electricity infrastructure, supply availability and environmental issues demands a close co-operation between both countries (Bradley, 2012).[112]

4.2.2 Limitations and Conflicts in Electricity Co-operation

Even though the Canada-U.S. bulk power system is arguably the best case of cross-border collaboration (Burney, 2009), electricity trade between them is restricted by a number of factors. There exists a limit in the compatibility of the two markets brought about by differences in regulation and ownership structure. In Canada, provincial governments are the owners of most vertically integrated utilities together with associated transmission lines, and are responsible for initiating exports. The ownership situation varies in the U.S. In about half the states, transmission lines are the property of vertically integrated investor-owned electric utilities which, in the main, are regulated by the state. This means that the retail power sales rates and the transmission and distribution rates of the utilities are set by state commissions (Pineau, 2004).[113]

Also of concern is that future increase in demand for electricity in this region will necessitate a similar increase in supply. Additional output capacity in the order of

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[112] Available at: http://www.electricenergyonline.com/?page=showarticle&mag=33 &article= 258

[113] However, a number of state commissions have begun to restructure their vertically integrated utilities shedding their generation assets and leaving them mainly with only state regulated distribution related functions (NAEWG, 2002).

25% by 2025 is projected to meet this growing demand (CEA, 2005). Studies by the OECD and the IEA show that, in North America, fossil fuels provide the main energy sources for electricity generation (IEA, 2010). Another study by Bernard et al. (2003) highlights upcoming problems as growing electricity demand applies pressure on available resources that face increasing restrictions because of environmental concerns.

Another consideration involves policy conflict between the U.S. and Canada in regard to action on climate change, which has a significant impact on generation investment decisions in both countries. When Canada was a signatory to the Kyoto Protocol, it was obliged to achieve certain reductions in greenhouse gas emissions while, by contrast, the U.S. had no such commitment. Any future action taken by the U.S. in this area will have an impact on investment in fossil-fuel generation technologies. Although the U.S. Congress did not include a renewable portfolio standard in the Energy Policy Act, a number of states have adopted renewable mandates (CEA, 2006).

The reduction of CO_2 emissions through international electricity co-operation is undermined by the free riding position adopted by the U.S. On 21st March 2009, the American Clean Energy and Security Act of 2009 was introduced in the U.S. House of Representatives. The objective was the reduction of greenhouse gas emissions by 17% by 2020, 42% by 2030, and 83% by 2050 - all relative to a 2005 baseline (Goodman, 2010).[114] The bill was approved by the House on 26th June 2009, but died in the Senate.

In 2011, Canada stated that they would not take on further Kyoto targets. Even though this country was one of the first to sign the Kyoto Protocol, on 29th April 1998, neither the current Conservative government nor their Liberal predecessors were able to

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114 American Clean Energy and Security Act of 2009, accessed 5th July, 2009.

meet commitments. In December 2011, the Canadian environment minister, Peter Kent, announced the country's withdrawal from the Kyoto Protocol, saying that the move will save Canada $14 billion in penalties for not achieving its Kyoto targets (Mail Online News, 2011).[115] This decision highlights the huge conflict, in energy policy, between economic development and environmental protection.

4.3 METHODS AND PROCEDURES

This chapter explores the effects of electricity trade for Canada and the U.S. in a number of aspects. Firstly, household and industry electricity price functions are determined in order to derive the effects of electricity import and export on both electricity prices. Secondly, comparisons of the effects on prices of various renewable energies (hydro, solar, tide wave and ocean, and wind) are made to determine the best solution for future energy needs of both countries.

4.3.1 Empirical Models

In a study involving two-country electricity trade, Villemeur and Pineau (2010) assume that two regions trade electricity and that both markets are competitive. There is no storage of electricity but there is demand heterogeneity indicating that trade may decrease overall production costs. They assume, with no loss of generality, that,

[115] The environment minister further stated, "It's now clear that Kyoto is not the path forward to a global solution to climate change. If anything it's an impediment. To meet the targets under Kyoto for 2012 would be the equivalent of either removing every car, truck, ATV, tractor, ambulance, police car and vehicle of every kind from Canadian roads or closing down the entire farming and agriculture sector and cutting heat to every home, office, hospital, factory and building in Canada." Mail Online News, 2011, available at: http://www. dailymail.co.uk/news/article-2073520/Canada-abandons-Kyoto-Protocol-save-14bn-penalties-missing-greenhouse-gas-targets.html

in autarky (superscript A), price $\underline{p}^{A}$ is lower in country $\underline{T}$ compared to another country $\overline{T}$ which has a higher price $\overline{p}^{A}$ giving

$$\underline{p}^{A} = C'(\underline{Q}^{A}) < \overline{p}^{A} = C'(\overline{Q}^{A}) \tag{49}$$

where C(.), the production cost function, is increasing and convex, and C'(.) is the marginal cost function, while $\underline{Q}^{A}$ and $\overline{Q}^{A}$ are the quantities produced and consumed in countries $\underline{T}$ and $\overline{T}$ respectively. Trade in electricity between both countries results in

$$\underline{p} = C'(\underline{Q}^{D} + Q_X) < \overline{p} = C'(\overline{Q}^{D} - Q_X). \tag{50}$$

The exporting country produces $\underline{Q}^{S} = (\underline{Q}^{D} + Q_X)$ and sells it at price $\underline{p}$, while the importing country produces $\overline{Q}^{S} = (\overline{Q}^{D} - Q_X)$ and sells it at price $\overline{p}$. Equation (50) shows that a price difference will continue to exist between the two countries because of transmission cost (Villemeur and Pineau, 2010).

Since electricity trade between Canada and the U.S. is a two-way affair, electricity prices in both countries depend on quantity from generation, import (*M*) and export (*X*), shown as

$$p = C'(Q^{D} - Q_M + Q_X). \tag{51}$$

Labys and Pollak (1984) pointed out that, for general commodities, price involves feedback effects where, as well as demand and supply being determined by prices, they also have an effect on prices. These effects apply to electricity.

To avoid the problem of endogeneity arising from a correlation between demand and supply,[116] this paper focuses solely on electricity supply, and follows the position

[116] According to the California Energy Commission model (2010, p.12), electricity demand depends on the economy, demography, weather or season, demand response and interruptibles. On the

taken by Villemeur and Pineau (2010) that electricity price depends on cost of generation, import and export.

However, in reality, electricity trade between Canada and the U.S. differs from the assumptions of Villemeur and Pineau (2010). Firstly, both markets are not perfectly competitive (Goodman, 2010; Rudkevich et al., 1998[117]); secondly, electricity can be stored, even though it is difficult and the cost is very high;[118] and, finally, there are losses of transmission and distribution. These factors can reduce the efficiency of electricity trade between the two countries at lowering electricity price.

The Organisation for Economic Co-operation and Development (OECD)/ International Energy Agency (IEA) lists electricity supply as generated from combustible fuels, chemical processing, hydro, geothermal, nuclear, solar, tide wave and ocean, and other sources (see Figure 4.2).

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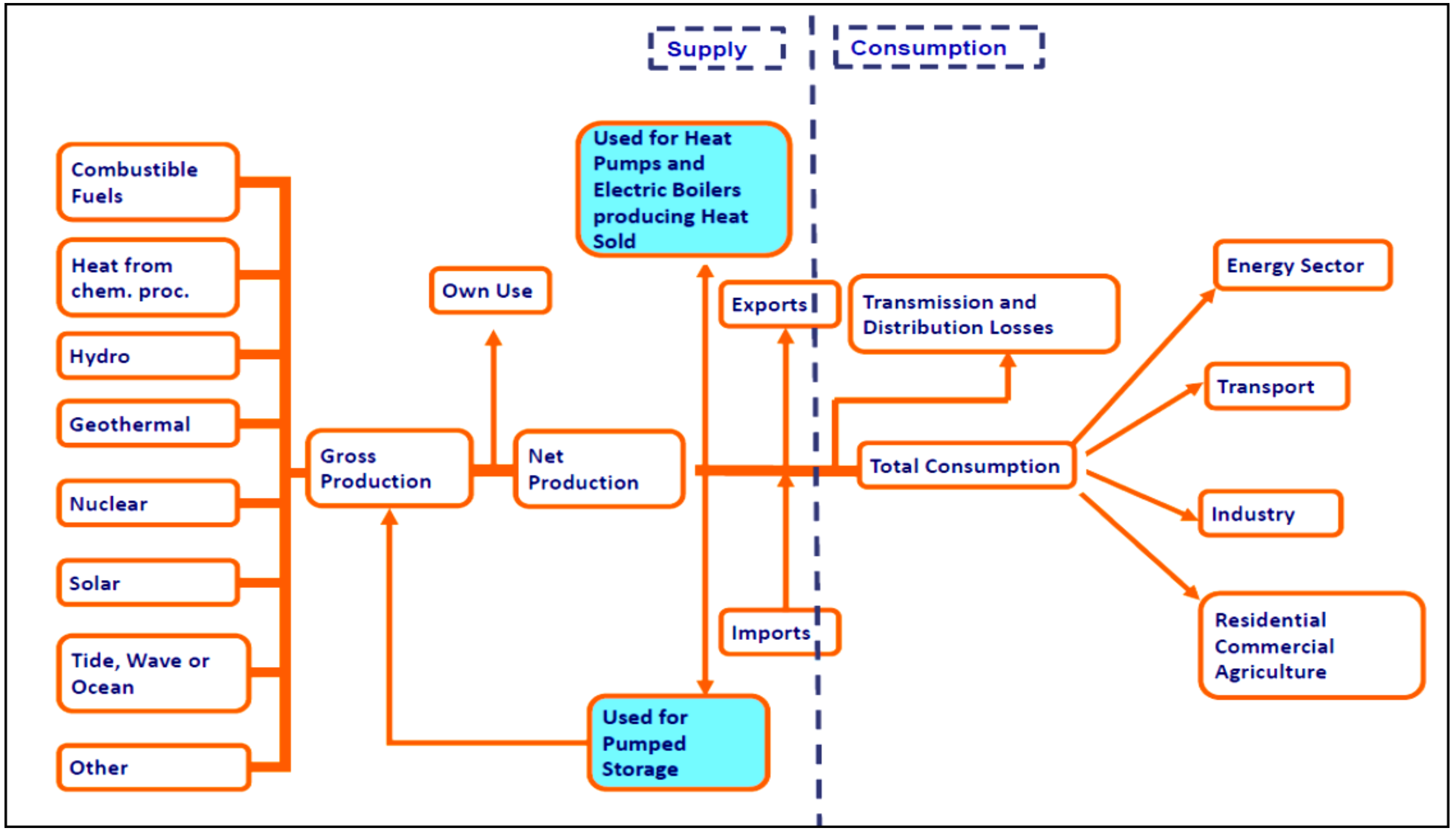
supply side, the factors are resource addition and retirement, local generation, generator outage, line outage, fuel availability and net electricity import.

[117] Available at: http://www.tellus.org/publications/files/e7-ar01.pdf

[118] Electricity is unique among fuels since it is delivered instantaneously and currently not able to be stored economically on a large scale (Goodman, 2010).

Figure 4.2: Electricity Supply and Demand (Consumption) Chain



Source: OECD/IEA, 2012[119]

119 Available at: http://www.iea.org/work/2012/training_moscow/Session6Schnapp.pdf

Gross electricity production is adjusted by own use consumption, import and export. Electricity lost during transfer from generators to consumers is referred to as distribution loss. On the demand side, electricity consumption is divided among the energy sector, transport, industry, residential consumption, commercial use and agriculture (OECD/IEA, 2012). For this study, only the supply side is considered in determining the electricity price functions.[120]

This paper uses time series analysis to construct models of household electricity price function (Model 1) and industry electricity price function (Model 2), all of which involve OLS with lagged dependent variables to control serial correlation. The models for Canada and the U.S. are the same except that the U.S. has no tide wave and ocean source for electricity generation, and, in addition, imports and exports electricity with Mexico.[121] Using *ln* as the natural logarithm and Δ as a difference operator, the models can be presented as below.

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[120] The three major subsystems which generally make up the electric power system in North America are generation, transmission, and distribution. In generation, electricity is produced from other forms of energy or processes that release energy. In transmission, the electric energy is conveyed from power plants to the distribution areas, and in distribution, a local system of low voltage lines, substations and transformers deliver the electricity to the consumer target. A portion of the electric energy is lost during transmission and distribution (CEC, 2011b). In this paper, distribution loss (including transmission loss) is dropped for Canada and the U.S. because of the problem of multicollinearity.

[121] In this study, the models of household and industry prices for Canada include a constant term, while the models of household and industry prices for the U.S. do not include a constant term.

Model C1(a): Household Electricity Price for Canada

$$\Delta\ln(PH_t) = \alpha_0 + \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(TW_t) + \beta_6\Delta\ln(WD_t)$$

$$+ \beta_7\Delta\ln(OG_t) + \beta_8\Delta\ln(M_t) + \beta_9\Delta\ln(X_t) + \beta_{10}\Delta\ln(ES_t) + \beta_{11}\Delta\ln(PH_{t-1})....$$

$$+ \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (52)$$

Model C1(b): Household Electricity Price for Canada

$$\Delta\ln(PH_t) = \alpha_0 + \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(TW_t) + \beta_6\Delta\ln(WD_t)$$

$$+ \beta_7\Delta\ln(OG_t) + \beta_8\Delta\ln(M_t) + \beta_9\Delta\ln(X_t) + \beta_{10}\Delta\ln(PH_{t-1})... + \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (53)$$

where *t* denotes years, α_0 is a constant term, ε_t is the error term, and the lagged first differences of *ln* household electricity prices (PH_{t-1},…, PH_{t-p}) account for the autoregressive effects of the previous years.[122]

In Model Cl(a) and Model C1(b), the explained variable is household electricity price (PH_t), being the average price per year in dollars. The explanatory variables are fossil fuel generation (*FF*), nuclear generation (*NC*), hydro generation (*HD*), solar generation (*SL*), tide wave and ocean generation (*TW*), wind generation (*WD*), other sources generation (*OG*), electricity import (*M*), electricity export (*X*) and excess supply (*ES*). All of the explanatory variables have the same measure of MWh per year. Excess supply is included in Model C1(a) but not in Model C1(b). This approach shows the

[122] The correlation in a time series between its own past and future values gives rise to autocorrelation. This analysis employs the Durbin–Watson statistic for detecting its presence (Durbin and Watson, 1950; 1951). When autocorrelation does occur, lags of the dependent variable may be added in the models.

effects of import, export and renewable energy generation on household electricity prices.

Model U1(a): Household Electricity Price for the U.S.

$$\Delta\ln(PH_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t) + \beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(M_t) + \beta_8\Delta\ln(X_t) + \beta_9\Delta\ln(ES_t) + \beta_{10}\Delta\ln(PH_{t-1})... + \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (54)$$

Model U1(b): Household Electricity Price for the U.S.

$$\Delta\ln(PH_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t) + \beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(M_t) + \beta_8\Delta\ln(X_t) + \beta_9\Delta\ln(PH_{t-1})... + \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (55)$$

In Model U1(a) and Model U1(b) of the U.S., all variables are as described in Model C1(a) and Model C1(b) of Canada respectively, except that the U.S. models do not include a constant term and do not include tide wave and ocean (*TW*).

Model U1(c): Household Electricity Price for the U.S.

$$\Delta\ln(PH_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t) + \beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(MC_t) + \beta_8\Delta\ln(MM_t) + \beta_9\Delta\ln(XC_t) + \beta_{10}\Delta\ln(XM_t) + \beta_{11}\Delta\ln(ES_t) + \beta_{12}\Delta\ln(PH_{t-1})... + \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (56)$$

Model U1(d): Household Electricity Price for the U.S.

$$\Delta\ln(PH_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t)$$

$$+\beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(MC_t) + \beta_8\Delta\ln(MM_t) + \beta_9\Delta\ln(XC_t) + \beta_{10}\Delta\ln(XM_t)$$

$$+\beta_{11}\Delta\ln(PH_{t-1})... + \beta_k\Delta\ln(PH_{t-p}) + \varepsilon_t \quad (57)$$

Model U1(c) and Model U1(d) of the U.S. are similar to Model U1(a) and Model U1(b) of the U.S. respectively. However Model U1(c) and Model U1(d) replace total electricity import (*M*) with import from Canada (*MC*) and import from Mexico (*MM*), and replace total electricity export (*X*) with export to Canada (*XC*) and export to Mexico (*XM*).

Model C2(a): Industry Electricity Price for Canada

$$\Delta\ln(PI_t) = \alpha_0 + \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(TW_t) + \beta_6\Delta\ln(WD_t)$$

$$+\beta_7\Delta\ln(OG_t) + \beta_8\Delta\ln(M_t) + \beta_9\Delta\ln(X_t) + \beta_{10}\Delta\ln\beta(DP) +_{11}\Delta\ln(ES_t) + \beta_{12}\Delta\ln(PI_{t-1})...$$

$$+\beta_k\Delta\ln(PI_{t-p}) + \varepsilon_t \quad (58)$$

Model C2(b): Industry Electricity Price for Canada

$$\Delta\ln(PI_t) = \alpha_0 + \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(TW_t) + \beta_6\Delta\ln(WD_t)$$

$$+\beta_7\Delta\ln(OG_t) + \beta_8\Delta\ln(M_t) + \beta_9\Delta\ln(X_t) + \beta_{10}\Delta\ln(DP) + \beta_{11}\Delta\ln(PI_{t-1})...$$

$$+\beta_k\Delta\ln(PI_{t-p}) + \varepsilon_t \quad (59)$$

where t denotes years, α_0 is a constant term, ε_t is the error term, and the lagged first differences of *ln* industry electricity prices (PI_{t-1},…, PI_{t-p}) account for the autoregressive effects of the previous years.

In Model C2(a) and Model C2(b), the explained variable is industry electricity price (*PI*), being the average price per year in dollars. The difference of prices (*DP*) between household and industry price, which is household electricity price minus industry electricity price, is a proxy variable representing government electricity subsidy for the industry sector. It is expected to have a negative relationship with industry electricity price. Excess supply is included in Model C2(a), but not in Model C2(b). This approach shows the effects of import and export, and of renewable energy generation on industry electricity prices.

Model U2(a): Industry Electricity Price for the U.S.

$$\Delta \ln(PI_t) = \beta_1 \Delta \ln(FF_t) + \beta_2 \Delta \ln(NC_t) + \beta_3 \Delta \ln(HD_t) + \beta_4 \Delta \ln(SL_t) + \beta_5 \Delta \ln(WD_t)$$

$$+ \beta_6 \Delta \ln(OG_t) + \beta_7 \Delta \ln(M_t) + \beta_8 \Delta \ln(X_t) + \beta_9 \Delta \ln(DP) + \beta_{10} \Delta \ln(ES_t) + \beta_{11} \Delta \ln(PI_{t-1}) \ldots$$

$$+ \beta_k \Delta \ln(PI_{t-p}) + \varepsilon_t \qquad (60)$$

Model U2(b): Industry Electricity Price for the U.S.

$$\Delta \ln(PI_t) = \beta_1 \Delta \ln(FF_t) + \beta_2 \Delta \ln(NC_t) + \beta_3 \Delta \ln(HD_t) + \beta_4 \Delta \ln(SL_t) + \beta_5 \Delta \ln(WD_t)$$

$$+ \beta_6 \Delta \ln(OG_t) + \beta_7 \Delta \ln(M_t) + \beta_8 \Delta \ln(X_t) + \beta_9 \Delta \ln(DP) + \beta_{10} \Delta \ln(PI_{t-1}) \ldots$$

$$+ \beta_k \Delta \ln(PI_{t-p}) + \varepsilon_t \qquad (61)$$

In Model U2(a) and Model U2(b) of the U.S., all variables are as described in Model C2(a) and Model C2(b) of Canada respectively, except that the U.S. models do not include a constant term and do not include tide wave and ocean (*TW*).

Model U2(c): Industry Electricity Price for the U.S.

$$\Delta\ln(PI_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t)$$

$$+\beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(MC_t) + \beta_8\Delta\ln(MM_t) + \beta_9\Delta\ln(XC_t) + \beta_{10}\Delta\ln(XM_t)$$

$$+\beta_{11}\Delta\ln(DP) + \beta_{12}\Delta\ln(ES_t) + \beta_{13}\Delta\ln(PI_{t-1})... + \beta_k\Delta\ln(PI_{t-p}) + \varepsilon_t \qquad (62)$$

Model U2(d): Industry Electricity Price for the U.S.

$$\Delta\ln(PI_t) = \beta_1\Delta\ln(FF_t) + \beta_2\Delta\ln(NC_t) + \beta_3\Delta\ln(HD_t) + \beta_4\Delta\ln(SL_t) + \beta_5\Delta\ln(WD_t)$$

$$+\beta_6\Delta\ln(OG_t) + \beta_7\Delta\ln(MC_t) + \beta_8\Delta\ln(MM_t) + \beta_9\Delta\ln(XC_t) + \beta_{10}\Delta\ln(XM_t)$$

$$+\beta_{12}\Delta\ln(DP) + \beta_{12}\Delta\ln(PI_{t-1})... + \beta_k\Delta\ln(PI_{t-p}) + \varepsilon_t \qquad (63)$$

Model U2(c) and Model U2(d) of the U.S. are similar to Model U2(a) and Model U2(b) of the U.S. respectively. However Model U2(c) and Model U2(d) replace total electricity import (*M*) with import from Canada (*MC*) and import from Mexico (*MM*), and replace total electricity export (*X*) with export to Canada (*XC*) and export to Mexico (*XM*).

The law of supply states that, "all other factors being equal, as the price of a good or service increases, the quantity of goods or services offered by suppliers increases",[123] while according to market equilibrium of microeconomic theory, increasing supply will create a surplus, which lowers the equilibrium price. As a result, all generation should have a negative relationship with electricity price. This study does not include taxes, subsidies and regulations which can destroy market mechanisms, making it possible for some generation sources mentioned to have a positive relationship with electricity price. For example, electricity generation from fossil fuels

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[123] Investopedia, 2012, available at: http://www.investopedia.com/terms/l/lawofsupply.asp#axzz2IIFp9NBn

might show a positive relationship with electricity price because of having the lowest rate of government subsidy for generation source in both Canada and the U.S.

Import of electricity increases domestic supply, and when electricity supply increases, price will go down. As a result, the relationship between import and household electricity price is expected to be negative (Villemeur and Pineau, 2010).

Export decreases domestic supply, and when electricity supply decreases, price will go up. Therefore, export and price of electricity should have a positive relationship. However, there are a number of factors which argue against this. If exporting countries have excess supply, which is difficult or unable to be stored, and export that amount, price will not increase. Also, from trade theory, international trade can improve market efficiency by diminishing returns in the short run and by economy of scale in the long run causing lower costs,[124] and so it is therefore possible to realise price decreases. All of this shows that export can have a negative effect on electricity price.

Electricity is a unique commodity due to storage problems and inelastic electricity demand (Bajpai and Singh, 2004). Because excess supply is difficult to store, it will not decrease the price of electricity by more than a marginal amount. Furthermore, excess supply entails increased cost of generation with no sale benefit, putting upward pressure on price. Trade in electricity has increased significantly due, in large part, to the problem of storage (Geman and Roncoroni, 2006), requiring electricity to be available at the moment it is needed.

[124] Because exporting countries generally have to produce more electricity, it affords an opportunity for expansion of electricity firms. The bigger the firm, the lower its relative costs of electricity production will be (Christensen and Green, 1976).

4.3.2 Data

In this empirical study, the data set for Canada and the U.S. comprises yearly data for the 32 years from 1978 to 2009 provided by the International Energy Agency (IEA).[125] This data set includes household electricity prices of Canada (Model C1), household electricity prices of the U.S. (Model U1), industry electricity prices of Canada (Model C2) and industry electricity prices of the U.S. (Model U2).

To eliminate the effect of inflation, household electricity prices are adjusted in accordance with the consumer price index (CPI), and industry electricity prices are adjusted in accordance with the producer price index (PPI).[126] Both CPI and PPI are provided by the OECD, with 2005 being the base year, thus deriving real household and real industry electricity prices. The measure is average price per year in U.S. dollars.

The explanatory variables of price functions comprise electricity generation from source type (fossil fuel, nuclear, hydro, solar, tide wave and ocean, wind and other generation), electricity import, electricity export and distribution loss, with each being measured for total megawatt-hours (MWh) per year. Table 1 shows a summary of the key variables used in the analysis. To overcome the problem of different measurement scales, the natural logarithms of all variables are taken.

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[125] Many studies forecasting electricity prices employ time series models analyzing daily data (Weron and Misiorek, 2008; Geman and Roncoroni, 2006; Lucia and Schwarts, 2002). This paper, however, uses yearly data because no other type is available in relation to renewable sources.

[126] The OECD does not provide PPI data before 1997, therefore this study forecasts PPI from 1978 to 1999 from regression ($PPI_t = \alpha + \beta(CPI_t) + \varepsilon_t$) and trend projection methods. The results show that trend projection gives less error, so it is employed in this study.

Table 4.1: Descriptive Statistics

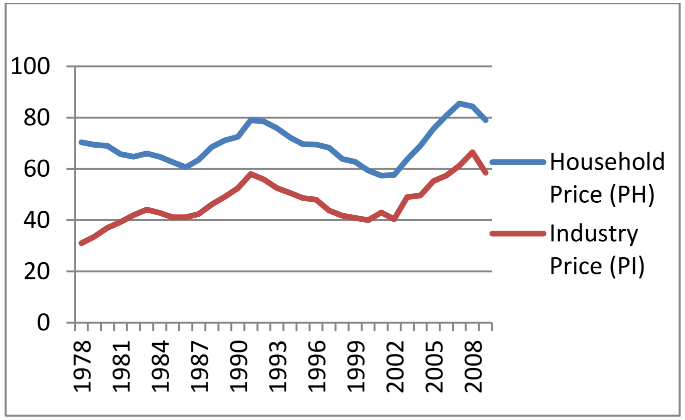
Descriptive Statistics (1978-2009)										
		CANADA					U.S.			
	Name	Mean	S.D.	Min	Max		Mean	S.D.	Min	Max
Household Price	PH	69.44	7.41	57.44	85.52		113.34	16.50	91.79	141.73
Industry Price	PI	47.00	8.24	31.00	66.58		67.17	13.42	45.73	96.42
Fossil Fuel	FF	77,049.84	14,458.87	49,674	97,238		1,575,825	319,716.60	924,044	2,078,932
Nuclear	NU	11,480.63	3,117.12	5,600	16,393		89,541.97	16,220.14	53,528	101,004
Hydro	HY	57,266.16	9,196.60	37,443	70,125		103,181.60	17,722.90	70,989	122,480
Solar	SO	8.34	17.89	0	95		147.06	209.94	0	618
Tide Wave and Ocean	TW	15.63	8.40	0	20		-	-	-	-
Wind	WI	342.88	782.11	0	3,319		3,778.25	7,883.58	0	34,295
Other Generation	OG	289.69	687.71	0	2,103		47,797.22	70,276.75	0	193,765
Total Import	M	10,859.47	7734.04	1,496	24,520		39,743.66	8,828.68	21,602	57,019
Import from Canada	MC	-	-	-	-		38,750.28	8,727.03	20,555	55,732
Import from Mexico	MM	-	-	-	-		993.38	864.85	0	2,257
Total Export	X	38,620.25	9,341.00	18,130	55,336		11,387.56	7,333.24	2,092	24,271
Export to Canada	XC	-	-	-	-		10,799.97	7,176.49	2,092	23,582
Export to Mexico	XM	-	-	-	-		587.59	492.68	0	1,993
Excess Supply	ES	15,780.19	4,205.74	6,390	21,472		19,6765.60	65,192.64	63,500	305,000
Difference of Prices	DP	22.44	5.10	14.43	39.41		46.16	6.22	36.37	64.22

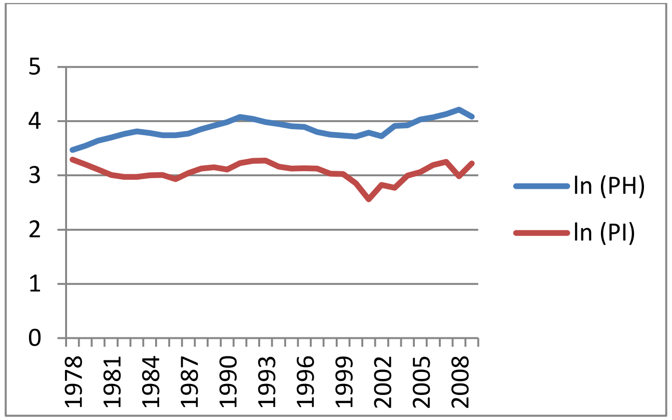
Sources: IEA and OECD

Notes: (1) S.D. indicates standard deviation.
(2) For Canada, total import = import from the U.S., and total export = export to the U.S.
(3) Difference of prices is the difference between household and industry price, which is a proxy variable representing government electricity subsidy for the industry sector.

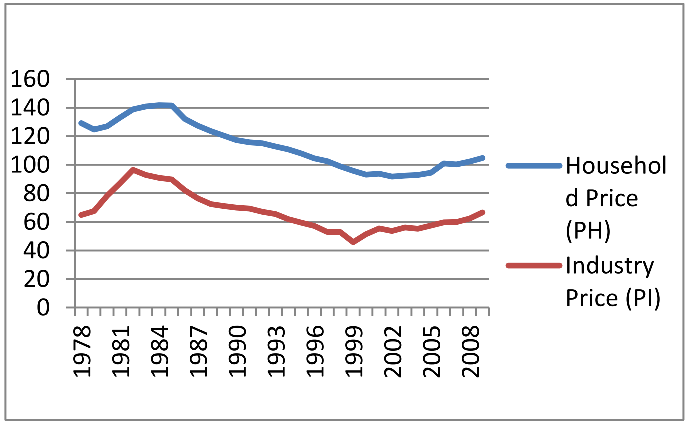
Figure 4.3: Household and Industry Electricity Prices for Canada and the U.S.

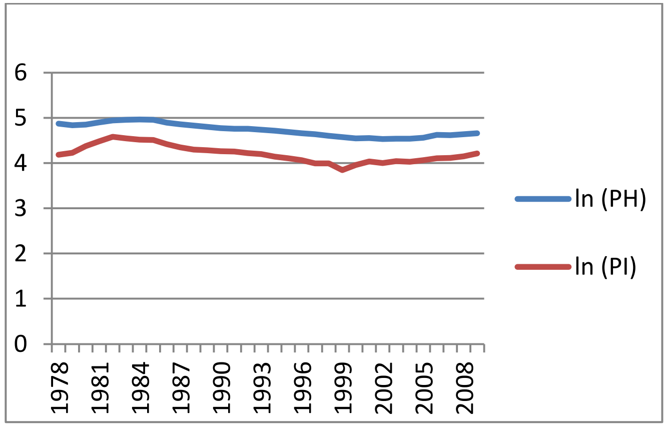
Canada





U.S.





A time series regression model is suitable for evaluating the effect of import and export of electricity on price for each country. However, in general, there is a problem of potential for confounding in short time series regression, which can reduce estimation efficiency.[127] Therefore, care must be taken for proper analysis. Because this chapter employs yearly data, there is no seasonal effect on the models. In addition, after taking natural logarithms to overcome the problem of different measurement scales of variables, the series can be fitted by linear time series regression (see Figure 4.3).

4.3.3 Statistical Analysis

- ***Unit Root Test***

Before conducting time series tests on the variables, this study employs the Augmented Dickey-Fuller (ADF) unit root test to check for stationarity. From Table 2, the ADF unit root test results for Canada provide strong evidence of stationarity (I(0)) for household price and industry price for constant term and constant term plus trend, but not for no constant term and no trend. The results show non-stationarity for the explanatory variables which are fossil fuel, nuclear, hydro, solar, tide wave and ocean, wind, other generation, electricity import, electricity export, excess supply and difference of prices. This suggests that taking first differences of all variables should be carried out before running regression to avoid the non-stationary process (see Table 4.2).

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[127] Because of short time series data availability, the data before taking natural logarithms have exponential trending, hence non-stationarity. However, if long time series data are available, these data can have stationarity by visual analysis (see Figure 4.2).

Table 4.2: Unit Root Test Results for Canada

Unit Root Test Results (Augmented Dickey-Fuller)									
	CANADA								
	no constant term and no trend			constant term			constant term plus trend		
	Level	1st diff	Conclusion	Level	1st diff	Conclusion	Level	1st diff	Conclusion
ln Household Price	0.03	-2.48**	I(1)	-3.33**		I(0)	-3.34*		I(0)
ln Industry Price	0.97	0.02**	I(1)	-3.31**		I(0)	-3.69**		I(0)
ln Fossil Fuel	0.53	-5.30**	I(1)	-2.43	-5.26**	I(1)	-2.57	-5.52**	I(1)
ln Nuclear	1.43	-3.36**	I(1)	-2.03	-3.48**	I(1)	-1.37	-3.67**	I(1)
ln Hydro	4.79	-2.74**	I(1)	-4.06**		I(0)	-3.04	-5.29**	I(1)
ln Solar	5.07	0.41	I(2)	3.06	-0.55	I(2)	-0.29	-4.97**	I(1)
ln Tide Wave and Ocean	near singular matrix								
ln Wind	3.47	-1.65*	I(1)	1.36	-5.65**	I(1)	-2.11	-6.43**	I(1)
ln Other Generation	5.32	-14.45**	I(1)	4.77	-14.58**	I(1)	3.36	-14.91**	I(1)
ln Import (from the U.S.)	0.83	-6.68**	I(1)	-1.53	-6.91**	I(1)	-3.33*	-3.33**	I(0)
ln Export (to the U.S.)	0.76	-5.04**	I(1)	-2.34	-4.96**	I(1)	-2.76	-4.86**	I(1)
ln Excess Supply	1.57	-4.90**	I(1)	-2.47	-5.39**	I(1)	0.70	-6.37**	I(1)
ln Difference of Prices	-1.09	-5.91**	I(1)	-3.37**		I(0)	-3.08	-6.17**	I(1)

Notes: (1) **and * illustrate significance at 5% and 10% levels respectively.
(2) For Canada, *ln* Tide Wave and Ocean is a near singular matrix. From 1978 to 1984, there is no electricity generation from Tide Wave and Ocean, while from 1985 to 2009, electricity generation from Tide Wave and Ocean is constant at 20 MWh per year.

Table 4.3: Unit Root Test Results for the U.S.

Unit Root Test Results (Augmented Dickey-Fuller)									
	U.S.								
	no constant term and no trend			constant term			constant term plus trend		
	Level	1st diff	Conclusion	Level	1st diff	Conclusion	Level	1st diff	Conclusion
ln Household Price	-0.36	-1.99**	I(1)	-0.87	-2.01	I(2)	-0.36	-2.79	I(2)
ln Industry Price	0.03	-3.73**	I(1)	-0.94	-4.46**	I(1)	-0.71	-4.43**	I(1)
ln Fossil Fuel	1.44	-4.88**	I(1)	-2.22	-2.22**	I(1)	-2.69	-5.01**	I(1)
ln Nuclear	0.76	-1.61*	I(1)	-4.17**		I(0)	-2.32	-2.32	I(2)
ln Hydro	2.45	-4.28**	I(1)	-1.90	-4.76**	I(1)	-1.42	-4.85**	I(1)
ln Solar	0.27	-5.29**	I(1)	-0.96	-5.45**	I(1)	-2.45	-5.35**	I(1)
ln Tide Wave and Ocean	-	-	-	-	-	-	-	-	-
ln Wind	1.29	-5.44**	I(1)	0.18	-6.05**	I(1)	-1.98	-6.24**	I(1)
ln Other Generation	0.43	-5.77**	I(1)	-2.91	-5.88**	I(0)	-3.62**		I(0)
ln Import	0.80	-5.49**	I(1)	-2.57	-5.41**	I(1)	-2.93	-5.30**	I(1)
ln Import from Canada	0.75	-5.44**	I(1)	-2.92**		I(0)	-2.99	-5.25**	I(1)
ln Import from Mexico	-0.14	-6.20**	I(1)	-2.57	-2.57**	I(1)	-2.32	-6.46**	I(1)
ln Export	1.03	-6.47**	I(1)	-1.80	-6.78**	I(1)	-2.92	-6.81**	I(1)
ln Export to Canada	1.03	-6.47**	I(1)	-1.78	-7.05**	I(1)	-3.06	-7.03**	I(1)
ln Export to Mexico	-0.12	-7.89**	I(1)	-2.95**		I(0)	-2.95	-8.64**	I(1)
ln Excess Supply	0.59	-8.23**	I(1)	-3.03**		I(0)	-4.42**		I(0)
ln Difference of Prices	-1.45	-5.08**	I(1)	2.47	-5.16**	I(1)	-3.01	-5.05**	I(1)

Notes: (1) **and * illustrate significance at 5% and 10% levels respectively.
(2) There is no Tide Wave and Ocean for the U.S.
(3) The unit root test results of Nuclear for constant term plus trend at level and 1st difference are the same (-2.32), however the standard deviations are different being 0.410 and 0.225 respectively.

For the U.S., ADF unit root test results offer evidence of non-stationarity for household price and industry price. For the explanatory variables, the results provide strong evidence of non-stationarity (see Table 4.3). This suggests that taking first differences of all variables should be carried out to avoid the non-stationary process.

- ***Pearson's Correlation Test***

This study employs the Pearson correlation test to check for multicollinearity which indicates strong correlation between two or more independent variables (Blalock, 1963). The results show no high correlation among independent variables in all models and thus no multicollinearity problem (see Appendix: Tables A-4.1, A-4.2, A-4.3, A-4.4, A-4.5 and A-4.6).

- ***Testing for Serial Correlation***

For results to be consistent, there is a requirement of no serial correlation in the error terms (Green, 2008; Wooldridge, 2009). This is tested by means of the Durbin-Watson statistic, after running the regression for every model. The statistic results of all models are substantially less than 2, thus indicating serial correlation (see Appendix: Table A-4.7).[128]

In addition to the Durbin-Watson statistic, this paper employs two Lagrange Multiplier tests for serial correlation, using Durbin's alternative test for autocorrelation and the Breusch-Godfrey test (Green, 2008). For both tests, the null hypothesis, that

[128] Serial correlation is an indication that OLS can no longer be considered an efficient linear estimator, standard errors are not correct and usually overstated, and bias and inconsistency occur in OLS estimates if, as in this paper, a lagged dependent variable is employed as a regressor (EViews User's Guide, 1996, p 273).

there is no serial correlation, is rejected at the 5% level of significance confirming that serial correlation is detected for all models (see Appendix: Tables A-4.8, and A-4.9).

In order to deal with the problem of serial correlation, this paper adopts the method of adding lagged values of the dependent variable. Table 4.4 and Table 4.5 show the results for household and industry electricity prices with the inclusion of lagged dependent variables. The Durbin alternative test for autocorrelation and the Breusch-Godfrey test show that there is no serial correlation for all models after adding lags of the dependent variable (see Appendix: Tables A-4.10 and A-4.11).[129]

4.4 EMPIRICAL RESULTS

This study focuses on whether co-operation of the U.S. and Canada, regarding import and export of electricity, can reduce electricity prices for both households and industry, as well as comparing various renewable energies with a view to determining the best solution for future energy needs. Ordinary least squares (OLS) estimation is employed to determine household and industry electricity price functions, using yearly data from 1980 to 2007 for both countries.

[129] Because the Durbin-Watson statistic is not valid in models with a lagged dependent variable, this study employs Durbin's alternative test for autocorrelation and the Breush-Godfrey test to check for serial correlation.

4.4.1 Household Electricity Price

Table 4.4 gives the results of household electricity price functions in the OLS models for Canada and the U.S. For Canada, Model C1(a) includes excess supply, but Model C1(b) does not. Both models give similar results. Following Villemeur and Pineau (2010), the results for import indicate a significant reduction in household electricity price of about 0.05% in both models, thus supporting the hypothesis. For export, the results provide affirmation for the proposition by Christensen and Green (1976) that generators of electricity can lower costs by increasing the size of firms (economy of scale), resulting in cheaper electricity prices. A rise of 1% in electricity export decreases household electricity price by about 0.04% in Model C1(a) and by about 0.03% in Model C1(b). However the results are not statistically significant.

For Canada, the results show that a rise of 1% in electricity generation from fossil fuel is significant in increasing household electricity price by about 0.18% and 0.21% for Model C1(a) and Model C1(b) respectively. On the other hand, a rise of 1% in electricity generation from hydro is shown to significantly decrease household electricity price by about 0.93% and 1.01% for Model C1(a) and Model C1(b) respectively. A similar rise in solar generation is highly significant in decreasing household electricity price by about 0.09% and 0.11% for Model C1(a) and Model C1(b) respectively. Nuclear, wind, and tide wave and ocean generation show no significant effect on price, while for other sources of generation there is only a tiny effect (0.004%) for both models.

For the U.S., the results of Model U1(a) and Model U1(b) are a little different. With regard to electricity import and export, there is no significant effect on price. The results further show that a rise of 1% in electricity generation from fossil fuel is significant in increasing household electricity price by about 0.18% and 0.19% for

Model U1(a) and Model U1(b) respectively. In Model U1(a), a rise of 1% in electricity generation from nuclear power is significant in decreasing household electricity price by about 0.30%, but the result is not statistically significant for Model U1(b). There is no significant effect from renewable energies (hydro, solar, tide wave and ocean, and wind) on household electricity price for both models. Other sources of generation show a significant tiny effect (0.004%) for Model U1(b), but for Model U1(a) the result (0.002%) is not statistically significant.

The U.S. results of Model U1(c) and Model U1(d) show some differences. A rise of 1% in electricity import from Canada is significant in decreasing household electricity price by a tiny amount (0.01%) for Model U1(d), but the result is not significant for Model U1(c). For electricity import from Mexico, there is no significant effect on price in both models. Electricity export to Canada and Mexico show only tiny effects on household electricity price of the U.S., and the results are not statistically significant in both models.

There is no significant effect from renewable energies (hydro, solar, tide wave and ocean, and wind) on household electricity price for both models. Other sources of generation show a significant tiny effect (0.004%) for Model U1(d), but the result (0.002%) for Model U1(c) is not significant. For Model C1(a), Model U1(a) and Model U1(c), there is no significant effect from excess supply on household electricity price, which follows the expectation because of electricity price inelasticity and electricity storage difficulties.

Table 4.4: Results of Time Series Analysis for Household Electricity Price

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
Δln Fossil Fuel	0.182* (0.092)	0.209** (0.084)	0.189*** (0.049)	0.180*** (0.051)	0.188** (0.057)	0.164*** (0.056)
Δln Nuclear	0.011 (0.075)	0.001 (0.073)	-0.299** (0.137)	-0.207 (0.129)	-0.291* (0.149)	-0.241 (0.149)
Δln Hydro	-0.925* (0.502)	-1.012** (0.482)	0.079 (0.118)	0.009 (0.114)	0.091 (0.128)	0.045 (0.127)
Δln Solar	-0.092** (0.037)	-0.107*** (0.031)	0.006 (0.008)	0.002 (0.008)	0.007 (0.009)	0.001 (0.008)
Δln Tide Wave and Ocean	-0.007 (0.011)	-0.006 (0.011)	-	-	-	-
Δln Wind	0.008 (0.018)	0.011 (0.018)	-0.002 (0.007)	6.11E-05 (0.007)	-0.001 (0.007)	0.002 (0.007)
Δln Other Generation	0.004* (0.002)	0.004** (0.002)	-0.002 (0.002)	-0.004* (0.002)	-0.002 (0.003)	-0.004* (0.002)
Δln Import	-0.050** (0.022)	-0.051** (0.021)	-0.003 (0.035)	0.020 (0.032)	-	-
Δln Import from Canada	-	-	-	-	-0.011 (0.036)	0.009* (0.034)
Δln Import from Mexico	-	-	-	-	-0.003 (0.004)	-0.002 (0.004)
Δln Export	-0.043 (0.051)	-0.026 (0.046)	0.014 (0.018)	0.015 (0.019)	-	-
Δln Export to Canada	-	-	-	-	0.011 (0.019)	0.013 (0.019)
Δln Export to Mexico	-	-	-	-	0.002 (0.005)	0.005 (0.005)
Δln Excess Supply	0.128 (0.166)	-	0.024 (0.015)	-	0.024 (0.017)	-
$\Delta ln\ PH_{t-1}$	0.924*** (0.172)	0.930*** (0.169)	0.477*** (0.177)	0.460* (0.184)	0.482** (0.186)	0.454** (0.190)
$\Delta ln\ PH_{t-2}$	-0.465* (0.237)	-0.502** (0.229)	0.332* (0.194)	0.233 (0.191)	0.385* (0.214)	0.314 (0.214)
$\Delta ln\ PH_{t-3}$	0.056 (0.202)	0.023 (0.194)	-	-	-	-
α_0	0.033** (0.014)	0.039*** (0.012)	-	-	-	-
DW	1.947	2.096	1.907	1.930	1.827	1.893
Mean VIF	2.00	1.87				

Notes: (1) Standard errors in ( )
(2) ***, ** and * illustrate significance at 1%, 5% and 10% levels respectively.
(3) DW indicates Durbin-Watson test, and VIF indicates variance inflation factor test.

4.4.2 Industry Electricity Price

Table 4.5 gives the results of industry electricity price functions in the OLS models for Canada and the U.S. For Canada, Model C2(a) includes excess supply, but Model C2(b) does not. Both models give similar results. For electricity import and export, there is agreement in no significant effect on industry electricity price. Looking at electricity generation, in Model C2(b), a rise of 1% from fossil fuel is significant in increasing industry electricity price by about 0.17%, while the result is not statistically significant for Model C2(a).

Focusing on renewable energies, a rise of 1% in electricity generation from hydro is shown to significantly decrease industry electricity price by about 1.58% and 1.56% for Model C2(a) and Model C2(b) respectively. A similar rise in solar generation is highly significant in decreasing industry electricity price by about 0.15% and 0.14% for Model C2(a) and Model C2(b) respectively. For nuclear, wind, and tide wave and ocean generation, there is no significant effect on price, while other sources of generation show only a tiny effect (0.01%) which is significant in both models. The difference in prices between household and industry, which is the proxy variable for industry subsidy, is found to decrease industry electricity price for both models by about 0.26% with high significance.

Table 4.5: Results of Time Series Analysis for Industry Electricity Price

Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
Δ*ln* Fossil Fuel	0.208 (0.127)	0.169* (0.093)	0.144 (0.103)	0.144 (0.100)	0.046 (0.134)	0.064 (0.124)
Δ*ln* Nuclear	0.086 (0.101)	0.104 (0.091)	-0.195 (0.236)	-0.181 (0.218)	-0.205 (0.250)	-0.228 (0.239)
Δ*ln* Hydro	-1.579** (0.673)	-1.560** (0.655)	-0.147 (0.191)	-0.156 (0.180)	-0.128 (0.198)	-0.115 (0.191)
Δ*ln* Solar	-0.146*** (0.050)	-0.135*** (0.043)	0.003 (0.014)	0.002 (0.013)	-0.005 (0.016)	-0.001 (0.014)
Δ*ln* Tide Wave and Ocean	-0.016 (0.016)	-0.017 (0.015)	-	-	-	-
Δ*ln* Wind	0.017 (0.025)	0.017 (0.024)	-0.017 (0.011)	-0.016 (0.010)	-0.012 (0.012)	-0.015 (0.011)
Δ*ln* Other Generation	0.007** (0.003)	0.007** (0.003)	-0.009** (0.004)	-0.009*** (0.003)	-0.011** (0.004)	-0.010** (0.004)
Δ*ln* Import	-0.046 (0.030)	-0.043 (0.029)	0.089 (0.056)	0.092* (0.051)	-	-
Δ*ln* Import from Canada	-	-	-	-	0.087 (0.056)	0.080 (0.052)
Δ*ln* Import from Mexico	-	-	-	-	0.001 (0.007)	0.001 (0.007)
Δ*ln* Export	-0.032 (0.064)	-0.041 (0.060)	0.029 (0.030)	0.029 (0.029)	-	-
Δ*ln* Export to Canada	-	-	-	-	0.031 (0.031)	0.030 (0.030)
Δ*ln* Export to Mexico	-	-	-	-	0.010 (0.009)	0.008 (0.008)
Δ*ln* Excess Supply	-0.068 (0.148)	-	0.004 (0.024)	-	-0.012 (0.029)	-
Δ*ln* Difference of Prices (Subsidy)	-0.261*** (0.080)	-0.255*** (0.077)	-0.699*** (0.120)	-0.699*** (0.117)	-0.761*** (0.134)	-0.749*** (0.127)
Δ*ln* PI_{t-1}	1.041*** (0.255)	1.019*** (0.244)	0.436*** (0.135)	0.434*** (0.131)	0.502** (0.157)	0.494*** (0.152)
Δ*ln* PI_{t-2}	-0.546* (0.284)	-0.494* (0.254)	-	-	-	-
α_0	0.055*** (0.019)	0.051** (0.016)	-	-	-	-
DW	2.281	2.238	1.930	1.937	2.041	2.012
Mean VIF	2.15	1.78				

Notes: (1) Standard errors in ( )
(2) ***, ** and * illustrate significance at 1%, 5% and 10% levels respectively.
(3) DW indicates Durbin-Watson test, and VIF indicates variance inflation factor test.

For the U.S., the results of Model U2(a) and Model U2(b) are similar. A rise of 1% in electricity import is significant in increasing industry electricity price by a tiny amount (0.01%) for Model U2(b), but the result is not significant for Model U2(a). For electricity export, there is no significant effect on price in both models. There is also no significant effect for all types of electricity generation, except other sources of generation. For both Model U2(a) and Model U2(b), a rise of 1% in other sources of generation shows a tiny, but significant effect of about 0.01%. The difference in prices between household and industry, which is the proxy variable for industry subsidy, is found to decrease industry electricity price by about 0.70% for both models with high significance.

The U.S. results of Model U2(c) and Model U2(d) are in agreement. For electricity import and export, there is no significant effect on industry electricity price, while other sources of generation show only a tiny effect (0.01%) which is significant in both models. The difference in prices between household and industry, which is the proxy variable for industry subsidy, is found to decrease industry electricity price by about 0.76% and 0.75% for Model U2(c) and Model U2(d) respectively with high significance. For Model C2(a), Model U2(a) and Model U2(c), there is no significant effect from excess supply on industry electricity price, following the expectation.

4.5 DISCUSSION

North America experiences the benefits of co-operation from a shared electricity arrangement that is able to generate and distribute power across great distances ensuring a secure, reliable and competitively priced supply (CEA, 2010). For Canada, the findings support CEA’s reference to competitive pricing, but not for the U.S. In Model C1(a) and Model C1(b), the result for Canada shows that a rise of 1% in import significantly decreases household electricity price (-0.05%), following trade theory assertion that import increases electricity supply, thus lowing price. For the U.S., Model U1(d) shows that electricity import from Canada significantly increases household electricity price by a tiny amount (0.01%). This lends support to the finding of Bernard et al. (2003) that electricity imports from the Canadian regions are not large enough to reduce the marginal costs of the U.S. regions, and as a result, electricity deregulation across the border is not expected to significantly decrease prices. The result for U.S. electricity import from Mexico is not statistically significant.

For industry electricity price, the Canadian results do not show any significant effect on price from electricity import and export. However, for the U.S., a rise in total import is found to be significant in lowering industry price by about 0.09% in Model U2(b). The price difference between household and industry (a proxy of subsidy for industry) gives an interesting finding for both Canada and the U.S. showing that it plays a highly significant role in reducing industry price. Even though this price difference is included in the model, there remain other subsidies and taxes which can compromise the market process. When governments subsidize, the result is market-mechanism interference which poses a barrier to competition from international trade (Harris, 2006, p. 131).

Even though an increase in export should cause a rise in price, the econometric analysis for Canada gives the opposite result for both household and industry electricity prices. An explanation for this may come from international trade, the benefits of which include promotion of specialization in production from division of labour and economy of scale as well as lower opportunity costs, thus reducing electricity prices (Odgaard, 2000). However, the results are not statistically significant. For the U.S., an increase in total export causes a tiny rise in both household and industry prices, with the results being not statistically significant.

A major challenge faced by the North American electricity industry relates to the increasing focus on clean energy brought about by climate change concerns. For Canada, disregarding the effects of subsidies and taxes, electricity generation from hydro is shown to be highly significant in decreasing household and industry electricity prices. In addition, solar is found to be significant in decreasing electricity price for both household and industry. Hydro and solar sources, therefore, shed light on the future direction of electricity generation in Canada under the increasing pressure to reduce greenhouse gas emissions in the industry.[130] The results for the U.S. indicate that no type of renewable energy reduces electricity price for household or industry, however nuclear energy shows a significant lowering of household electricity price in Model U1(a) and Model U1(c) by about 0.03% for both.

The Canadian Electricity Association (CEA) supports moving the integrated electricity markets of North America towards a more sustainable energy economy by focusing on clean technologies, infrastructure security and reliability, and sustainability

[130] The Government of Canada reports that the country is one of the world leaders in the production of clean, renewable hydroelectric power with an installed capacity of over 70,858 megawatts (MW), an annual average production of 350 terawatt-hours (TWh), and the potential to more than double output. Hydro power makes up 97% of Canada's renewable electricity generation and almost 13% of hydropower produced worldwide. Canada is increasing its production of solar energy. Solar thermal energy has increased by 17% per year since 1998, while solar photovoltaic (PV) capacity has grown by 27% per year since 1993. To date, the majority of the market for solar PV has been in off-grid applications, which in 2007 made up 89% of this capacity. Total installed PV capacity grew by 27% in 2008 to 32.7 MW with 84% of this increase being from stand-alone applications (The Government of Canada, 2012).

of cross-border trade. Such planning will help to ensure that the electric grid promotes economic development across the continent with the key to success being government and industry co-operation on both sides of the border (CEA, 2010). Increasing demand for electricity in both the U.S. and Canada requires investment in electricity infrastructure and supply for the years ahead. A major recommendation of this study is that close co-operation between Canada and the U.S. is essential in looking to the future, with electricity trade vital for economic efficiency, security of energy supply and containment of greenhouse gas emissions.

4.6 CONCLUSION

This chapter examines whether international co-operation regarding electricity import and export between Canada and the U.S. can reduce household (Model 1) and industry (Model 2) electricity prices. In addition, best options in relation to renewable energies for both countries into the future are explored. Using OLS, time series analysis of yearly samples from 1978 to 2009 is employed. From Model 1, the results show that, for Canada, electricity import is highly significant in decreasing household and industry electricity prices, but the results for export are not statistically significant. For the U.S., electricity import from Canada is significant in reducing household electricity price by a tiny amount, however import from Mexico is not statistically significant. With regard to industry (Model 2), electricity import of the U.S. shows a significant result in decreasing price. Looking at future electricity generation from green energy sources reveals that hydro and solar generation are significant in decreasing electricity price for Canada. For the U.S., nuclear generation gives better results than renewable energies for lowering electricity price. The challenge facing both countries lies in their ability to extract the maximum benefit from cross-border electricity co-operation in solving future problems of greatly increased electricity demand and generation.

CHAPTER FIVE

CONCLUSION

Currently, there exist serious concerns with regard to high electricity prices and the increase in CO_2 emissions from electricity generation. Electricity price impacts the standard of living for individuals as well as the cost of industry and business, while CO_2 emissions have adverse environmental effects contributing to global warming. This thesis examines how electricity co-operation with regard to import and export affects household and industry electricity prices in OECD countries, as well as what effect such trade in electricity has on CO_2 emissions for the world. The study further investigates which renewable energies promise the best economic outcome for Canada and the U.S. in the years ahead, thus providing three major sections to the thesis.

Since 1990, growth in world net electricity generation has surpassed growth in total electricity consumption, with the surplus anticipated to make up one third of electricity generation by 2035, presenting a situation that provides opportunity for international trade in electricity. The second chapter of the thesis looks into whether electricity co-operation regarding import and export between countries can help redress the problem of high electricity prices. The electricity price functions are determined by panel data analysis using 29 OECD countries' yearly data from 1980 to 2007. Membership of the European Union, employed to investigate the effect of high level co-operation on price, is found to decrease household and industry prices, but is not significant for household price. The effect of electricity trading in OECD countries is not seen to produce cheaper electricity suggesting that these countries need to co-operate more closely to increase competition and improve efficiency in electricity markets.

International trade in electricity could not only increase supply for excess demand countries while providing an economic gain for excess supply countries, but should also reduce CO_2 emissions from electricity generation. Chapter three examines whether electricity co-operation regarding import and export between countries can help redress the problem of CO_2 emissions. The work covers 131 countries and also divides countries by continent with 37 yearly samples provided for the period 1971 to 2007. Panel data analysis determines the CO_2 emissions function for the world and each continent. Empirical results for the world show that electricity co-operation is highly significant in decreasing CO_2 emissions, thus supporting the hypothesis. At the continent level, Asia shows the greatest CO_2 decrease from electricity import, with high statistical significance. Electricity export for North America, Latin America and Europe is found to be highly significant in decreasing CO_2 emissions. Such international trade in electricity can have a positive impact on efficient management of decarbonisation of energy supply and be instrumental for governments in the fight against global warming.

International electricity co-operation between the U.S. and Canada gives rise to one of the most integrated and reliable electricity systems in the world. The fourth chapter, in addressing both countries, investigates the effects of import and export on electricity price (both household and industry) while also examining which renewable energies are the best options economically into the future. Time series analysis of yearly data for each country from 1978 to 2009 is used to determine the electricity price functions. For Canada, electricity import is found to be highly significant in decreasing household electricity price, but not so for the U.S. Renewable energies such as wind and hydro are seen to be the future of electricity generation for Canada, but the results for the U.S. indicate that no type of renewable energy can reduce electricity price.

APPENDICES

SUPPLEMENT TO CHAPTER 3

Table A-3.1: Descriptive Statistics

Asia (19 countries) 1971-2007 (Unbalanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	702	49,208.98	187,470.80	0	1,135,718
Generation for country (*MWh*)	GC	702	133,829.90	324,776.50	86	3,296,608
Generation minus DL (*MWh*)	GD	702	122,160.10	302,448.30	55	3,095,344
Import (*MWh*)	M	702	403.75	1,763.18	0	16,287
Export (*MWh*)	X	702	282.54	1,676.37	0	18,602
Distribution loss: DL (*MWh*)	DL	702	11,669.86	28,041.45	11	201,264

Asia: Middle East (13 countries) 1971-2007 (Balanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	481	13.35	19.69	.01	115.52
Generation for country (*MWh*)	GC	481	20,789.77	33,276.69	13	201,466
Generation minus DL (*MWh*)	GD	481	18,692.57	29,523.96	11	175,074
Import (*MWh*)	M	481	64.14	281.42	0	2,540
Export (*MWh*)	X	481	90.89	342.45	0	2,775
Distribution loss: DL (*MWh*)	DL	481	2,097.21	4,391.06	0	38,714

Africa (27 countries) 1971-2007 (Unbalanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	948	7.65	26.79	0	211.05
Generation for country (*MWh*) [131]	GC	948	11,473.13	32,687.51	0	248,983
Generation minus DL (*MWh*)	GD	948	10208.02	30,077.35	-345	226,966
Import (*MWh*)	M	948	418.91	1,382.57	0	11,348
Export (*MWh*)	X	948	371.60	1,524.84	0	14,496
Distribution loss: DL (*MWh*)	DL	948	1,265.11	2,824.44	0	24,105

North America (3 countries) 1971-2007 (Balanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	111	632.97	812.48	12.87	2,275.49
Generation for country (*MWh*)	GC	111	1,204,045.00	1,401,789.00	31,039	4,329,697
Generation minus DL (*MWh*)	GD	111	1,115,191.00	1,312,220.00	26,766	4,062,654
Import (*MWh*)	M	111	14,416.98	16,540.72	5	52,230
Export (*MWh*)	X	111	14,379.15	15,994.06	0	50,983
Distribution loss: DL (*MWh*)	DL	111	88,854.03	92,664.69	4,273	310,036

Latin America (21 countries) 1971-2007 (Balanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	777	3.88	5.78	0	32.35
Generation for country (*MWh*)	GC	777	22,178.99	55,081.25	82	443,729
Generation minus DL (*MWh*)	GD	777	18,651.80	46,116.13	59	371,933
Import (*MWh*)	M	777	1,110.64	5,635.63	0	44,200
Export (*MWh*)	X	777	1,145.97	6,135.82	0	47,358
Distribution loss: DL (*MWh*)	DL	777	3,527.19	9,148.71	0	71,796

131 Between 1971 and 1972, there was no electricity generation in Benin.

Europe (45 countries) 1971-2007 (Unbalanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	1,365	24.00	50.68	0	282.55
Generation for country (*MWh*)	GC	1,361	85,165.19	145,393.00	47	1,038,802
Generation minus DL (*MWh*)	GD	1,361	77,940.29	133,586.10	45	954,541
Import (*MWh*)	M	1,361	6,299.74	8,545.15	0	56,861
Export (*MWh*)	X	1,361	6,012.93	11,008.06	0	80,739
Distribution loss: DL (*MWh*)	DL	1,361	7,224.90	12,829.90	0	112,591

Australia (2 countries) 1971-2007 (Balanced Panel)						
	Name	Obs	Mean	Standard Deviation	Min	Max
CO_2 emissions (*MT*)	CO_2	74	62.69	68.76	1.37	214.33
Generation for country (*MWh*)	GC	74	89,007.09	72,755.50	15,478	251,054
Generation minus DL (*MWh*)	GD	74	82,019.70	68,231.03	13,392	234,943
Import (*MWh*)	M	74	0	0	0	0
Export (*MWh*)	X	74	0	0	0	0
Distribution loss: DL (*MWh*)	DL	74	6,987.39	4,689.38	2,086	18,777

Table A-3.2: Panel Unit Root Tests at Continent Level Results

World (131 countries) 1971-2007 (Unbalance Panel)						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	23.285	-34.279**	I(1)	218.914	1,626.61**	I(1)
ln Generation for country	-3.302**		I(0)	445.106**		I(0)
ln Generation minus DL	-2.274**		I(0)	419.176**		I(0)
ln Import	-2.743**		I(0)	232.685**		I(0)
ln Export	-3.081**		I(0)	268.437**		I(0)
ln Distribution loss (DL)	-3.532**		I(0)	359.393**		I(0)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	-0.074	-30.605**	I(1)	287.760**		I(0)
ln Generation for country	-0.398	-24.653**	I(1)	381.856**		I(0)
ln Generation minus DL	-0.367	-24.954**	I(1)	304.521**		I(0)
ln Import	-4.289**		I(0)	275.761**		I(0)
ln Export	-4.473**		I(0)	319.113**		I(0)
ln Distribution loss (DL)	-4.943**		I(0)	669.954**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.
(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Asia: 20 countries Unbalanced Panel: 1971-2007						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	3.078	-12.494**	I(1)	23.624	232.359**	I(1)
ln Generation for country	1.595	-10.164**	I(1)	38.144	191.123**	I(1)
ln Generation minus DL	2.378	-10.295**	I(1)	34.171	196.975**	I(1)
ln Import	0.406	-7.300**	I(1)	11.367	83.611**	I(1)
ln Export	-1.253	-10.004**	I(1)	24.473**		I(0)
ln Distribution loss (DL)	0.338	-17.057**	I(1)	35.136	329.751**	I(1)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	1.480	-10.596**	I(1)	31.540	188.012**	I(1)
ln Generation for country	4.268	-9.845**	I(1)	19.674	181.437**	I(1)
ln Generation minus DL	3.570	-10.236**	I(1)	25.839	188.344**	I(1)
ln Import	0.006	-4.674**	I(1)	11.708	68.298**	I(1)
ln Export	-2.187**		I(0)	29.855**		I(0)
ln Distribution loss (DL)	-0.872	-15.754**	I(1)	58.269**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Middle East (13 countries) 1971-2007 (Balanced Panel)						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	0.362	-9.521**	I(1)	30.240	144.443**	I(1)
ln Generation for country	-3.647**		I(0)	65.794**		I(0)
ln Generation minus DL	-3.478**		I(0)	63.080**		I(0)
ln Import	1.513	-4.800**	I(1)	3.502	38.765**	I(1)
ln Export	-1.248	-7.388**	I(1)	16.475**		I(0)
ln Distribution loss (DL)	-3.552**		I(0)	65.005**		I(0)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	-1.755	-7.761**	I(1)	41.385**		I(0)
ln Generation for country	-1.095	-5.755**	I(1)	40.668**		I(0)
ln Generation minus DL	-0.799**	-6.033**	I(1)	36.811**		I(0)
ln Import	1.390	-4.018**	I(1)	3.187	30.729**	I(1)
ln Export	-1.633**		I(0)	15.890**		I(0)
ln Distribution loss (DL)	-3.510**		I(0)	77.651**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Africa (27 countries) 1971-2007 (Unbalanced Panel)						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	1.480	-15.970**	I(1)	43.820	354.780**	I(1)
ln Generation for country	-1.977**		I(0)	117.638**		I(0)
ln Generation minus DL	-1.373	-13.891**	I(1)	103.970**		I(0)
ln Import	-1.699		I(0)	64.150**		I(0)
ln Export	-2.648**		I(0)	73.673**		I(0)
ln Distribution loss (DL)	1.520	-16.658**	I(1)	35.199	366.557**	I(1)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	0.222	-14.716**	I(1)	71.843**		I(0)
ln Generation for country	-3.036**		I(0)	166.177**		I(0)
ln Generation minus DL	-2.383**		I(0)	95.008**		I(0)
ln Import	-2.909**		I(0)	78.221**		I(0)
ln Export	-2.925**		I(0)	99.772**		I(0)
ln Distribution loss (DL)	0.341	-14.370**	I(1)	48.705	295.066**	I(1)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

North America (3 countries) **1971-2007 (Balanced Panel)**						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	-1.698**		I(0)	15.445**		I(0)
ln Generation for country	-1.948**		I(0)	14.360**		I(0)
ln Generation minus DL	-2.099**		I(0)	15.177**		I(0)
ln Import	-0.918	6.921**	I(1)	9.137	51.833**	I(1)
ln Export	0.015	-5.557**	I(1)	4.982	40.460**	I(1)
ln Distribution loss (DL)	-0.351	-7.889**	I(1)	7.031	60.353**	I(1)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	-0.557	-7.779**	I(1)	8.822	56.421**	I(1)
ln Generation for country	0.564	-5.409**	I(1)	3.005	36.426**	I(1)
ln Generation minus DL	1.023	-6.126**	I(1)	2.749	42.215**	I(1)
ln Import	-1.386	-5.864**	I(1)	10.004	39.571**	I(1)
ln Export	-0.419	-4.456**	I(1)	7.168	29.722**	I(1)
ln Distribution loss (DL)	-3.297**		I(0)	22.179**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Latin America (21 countries) **1971-2007 (Balanced Panel)**						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	2.935	17.859**	I(1)	27.058	351.600**	I(1)
ln Generation for country	2.452	-11.720**	I(1)	35.827	220.341**	I(1)
ln Generation minus DL	3.339	-11.083**	I(1)	32.487	207.661**	I(1)
ln Import	-0.455	-14.000**	I(1)	24.381	225.230**	I(1)
ln Export	0.058	-12.667**	I(1)	29.075	188.079**	I(1)
ln Distribution loss (DL)	-4.058**		I(0)	80.208**		I(0)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	0.028	-16.605**	I(1)	39.799	316.014**	I(1)
ln Generation for country	-0.073	-9.939**	I(1)	40.455	175.041**	I(1)
ln Generation minus DL	0.810	-9.123**	I(1)	32.607	163.008**	I(1)
ln Import	-0.431	-12.186**	I(1)	33.270	182.839**	I(1)
ln Export	-0.054	-11.171**	I(1)	31.359	152.023**	I(1)
ln Distribution loss (DL)	-4.216**		I(0)	310.123**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Europe (45 countries) 1971-2007 (Unbalanced Panel)						
	Im, Pesaran and Shin Test			Fisher-ADF Test		
	Level c	1st diff c	Concl	Level c	1st diff c	Concl
ln CO_2 emissions	-0.370	-16.773**	I(1)	86.960	439.610**	I(1)
ln Generation for country	-3.599**		I(0)	159.485**		I(0)
ln Generation minus DL	-3.346**		I(0)	153.632**		I(0)
ln Import	-2.995**		I(0)	120.986**		I(0)
ln Export	-2.089**		I(0)	120.932**		I(0)
ln Distribution loss (DL)	-2.530**		I(0)	131.471**		I(0)
	Level c, t	1st diff c, t	Concl	Level c, t	1st diff c, t	Concl
ln CO_2 emissions	0.334	-14.673**	I(1)	81.505	359.359**	I(1)
ln Generation for country	-0.670	-13.604**	I(1)	107.840	373.169**	I(1)
ln Generation minus DL	-1.035	-14.381**	I(1)	109.590	388.353**	I(1)
ln Import	-4.118**		I(0)	139.471**		I(0)
ln Export	-3.214**		I(0)	137.334**		I(0)
ln Distribution loss (DL)	-2.667**		I(0)	148.569**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.

(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Australia (2 countries) 1971-2007 (Balanced Panel)							
	Im, Pesaran and Shin Test				Fisher-ADF Test		
	Level c	1st diff c	Concl		Level c	1st diff c	Concl
ln CO_2 emissions	0.192	-6.193**	I(1)		2.806	38.446**	I(1)
ln Generation for country	-2.429**		I(0)		13.605**		I(0)
ln Generation minus DL	-2.364**		I(0)		13.918**		I(0)
ln Import							
ln Export							
ln Distribution loss (DL)	-1.441	-6.697**	I(1)		7.923	42.037**	I(1)
	Level c, t	1st diff c, t	Concl		Level c, t	1st diff c, t	Concl
ln CO_2 emissions	-1.990**		I(0)		10.583**		I(0)
ln Generation for country	-0.560	-5.357**	I(1)		6.243	29.967**	I(1)
ln Generation minus DL	0.074	5.014**	I(1)		2.958	27.782**	I(1)
ln Import			I(0)				I(0)
ln Export			I(0)				I(0)
ln Distribution loss (DL)	-1.542	-6.355**	I(1)		9.738**		I(0)

Notes: (1) The null hypothesis of a unit root is rejected for large values of χ^2 statistic. ** rejects at 5% level.
(2) Concl denotes conclusion number of unit root, while c and c, t indicate that a constant term and a constant term plus a trend components are included in the regression respectively.

Table A-3.3: Correlation Test at Continent Level Results

Asia (20 countries) 1971-2007 (Unbalanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.726***	1.000			
Δln (M): Import	-0.089***	0.140***	1.000		
Δln (X): Export	0.084***	0.161***	0.350***	1.000	
Δln (DL): Distribution loss	0.583***	0.862***	0.126***	0.105***	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.721***	1.000			
Δln (M): Import	-0.089***	0.140***	1.000		
Δln (X): Export	0.084***	0.159***	0.350***	1.000	

Note: *** denotes significant level at 1%.

Asia: Middle East (13 countries) 1971-2007 (Balanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.919***	1.000			
Δln (M): Import	0.207***	0.243***	1.000		
Δln (X): Export	0.194***	0.197***	0.079*	1.000	
Δln (DL): Distribution loss	0.753***	0.826***	0.214***	0.155***	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.918***	1.000			
Δln (M): Import	0.207***	0.247***	1.000		
Δln (X): Export	0.194***	0.198***	0.079*	1.000	

Note: *** and * illustrate significance at 1% and 10% levels respectively.

Africa (27 countries) 1971-2007 (Unbalanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.660***	1.000			
Δln (M): Import	0.294***	0.096***	1.000		
Δln (X): Export	0.353***	0.358***	0.154***	1.000	
Δln (DL): Distribution loss	0.488***	0.541***	0.179***	0.247**	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.638***	1.000			
Δln (M): Import	0.294***	0.094***	1.000		
Δln (X): Export	0.353***	0.317***	0.154***	1.000	

Note: *** and ** illustrate significance at 1% and 5% levels respectively.

North America (3 countries) 1971-2007 (Balanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.961***	1.000			
Δln (M): Import	0.606***	0.619***	1.000		
Δln (X): Export	0.655***	0.772***	0.425***	1.000	
Δln (DL): Distribution loss	0.842***	0.907***	0.552***	0.751*	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.957***	1.000			
Δln (M): Import	0.606***	0.618***	1.000		
Δln (X): Export	0.655***	0.777***	0.425***	1.000	

Note: *** and * illustrate significance at 1% and 10% levels respectively.

Latin America (21 countries) 1971-2007 (Balanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.746***	1.000			
Δln (M): Import	0.269***	0.305***	1.000		
Δln (X): Export	0.194***	0.363***	0.213***	1.000	
Δln (DL): Distribution loss	0.499***	0.622***	0.180***	0.238***	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.749***	1.000			
Δln (M): Import	0.269***	0.304***	1.000		
Δln (X): Export	0.194***	0.369***	0.213***	1.000	

Note: *** denotes significant level at 1%.

Europe (45 countries) 1971-2007 (Unbalanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.466***	1.000			
Δln (M): Import	0.204***	0.285***	1.000		
Δln (X): Export	0.142***	0.337***	0.413***	1.000	
Δln (DL): Distribution loss	0.435***	0.795***	0.349***	0.335***	1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.479***	1.000			
Δln (M): Import	0.204***	0.312***	1.000		
Δln (X): Export	0.142***	0.348***	0.413***	1.000	

Note: *** denotes significant level at 1%

Australia (2 countries) 1971-2007 (Balanced Panel)					
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GD)	*Δln* (M)	*Δln* (X)	*Δln* (DL)
Δln (CO_2): CO_2 emissions	1.000				
Δln (GD): Generation minus DL	0.966***	1.000			
Δln (M): Import			1.000		
Δln (X): Export				1.000	
Δln (DL): Distribution loss	0.868***	0.891***			1.000
Model 2: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$					
	Δln (CO_2)	*Δln* (GC)	*Δln* (M)	*Δln* (X)	
Δln (CO_2): CO_2 emissions	1.000				
Δln (GC): Generation for country	0.966***	1.000			
Δln (M): Import			1.000		
Δln (X): Export				1.000	

Note: *** denotes significant level at 1%.

Table A-3.4: Standard Linear Panel Model Estimators Results

Asia (19 countries) 1971-2007 (Unbalanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\,t-1}$): lag1_CO_2 emissions	-0.002 (0.025)	-0.006 (0.025)	-0.013 (0.025)	-0.017 (0.025)	-0.002 (0.025)	-0.006 (0.025)
Δln(GC): Generation for country		0.903*** (0.031)		0.899*** (0.031)		0.903*** (0.031)
Δln(GD): Generation minus DL	1.079*** (0.060)		1.074*** (0.061)		1.079*** (0.060)	
Δln(M): Import	-0.158*** (0.021)	-0.160*** (0.021)	-0.153*** (0.021)	-0.155*** (0.021)	-0.158*** (0.021)	-0.160*** (0.021)
Δln(X): Export	0.025 (0.024)	0.034 (0.024)	0.027 (0.024)	0.036 (0.024)	0.025 (0.024)	0.034 (0.024)
Δln(DL): Distribution loss	-0.188*** (0.056)		-0.186*** (0.056)		-0.188*** (0.056)	
α_0	-0.002 (0.016)	-0.001 (0.017)	-0.002 (0.016)	-0.001 (0.017)	-0.002 (0.016)	-0.001 (0.017)
σ_μ			0.063	0.063	0	0
σ_ε			0.432	0.440	0.432	0.440
ρ			0.021	0.021	0	0
F-Statistics	185.40***	218.42***	180.59***	212.78***		
χ^2					927.00***	873.67***
Observations	696	696	696	696	696	696

Notes: (1) Standard errors in ( )
(2) *** illustrates significance at 1% level.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Asia: Middle East (13 countries) 1971-2007 (Balanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\ t-1}$): lag1_CO_2 emissions	0.018 (0.018)	0.016 (0.018)	0.013 (0.018)	0.011 (0.019)	0.018 (0.018)	0.016 (0.018)
Δln(GC): Generation for country	0.611*** (0.021)		0.609*** (0.021)		0.611*** (0.021)	
Δln(GD): Generation minus DL		0.595*** (0.012)		0.593*** (0.012)		0.595*** (0.012)
Δln(M): Import	-0.008 (0.008)	-0.009 (0.009)	-0.007 (0.009)	-0.008 (0.009)	-0.008 (0.008)	-0.009 (0.009)
Δln(X): Export	0.006 (0.009)	0.006 (0.009)	0.006 (0.009)	0.006 (0.009)	0.006 (0.009)	0.006 (0.009)
Δln(DL): Distribution loss	-0.008 (0.015)		-0.007 (0.015)		-0.008 (0.015)	
α_0	-0.001 (0.008)	-0.001 (0.008)	-0.001 (0.008)	-0.001 (0.008)	-0.001 (0.008)	-0.001 (0.008)
σ_μ			0.023	0.024	0	0
σ_ε			1.177	0.178	0.177	0.178
ρ			0.017	0.018	0	0
F-Statistics	513.78***	636.07***	503.01***	623.49***		
χ^2					2,568.92***	2,544.28***
Observations	479	479	479	479	479	479

Notes: (1) Standard errors in ( )
(2) *** illustrates significance at 1% level.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Africa (27 countries) 1971-2007 (Unbalanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\ t-1}$): lag1_CO_2 emissions	0.012 (0.023)	0.013 (0.024)	-0.005 (0.024)	-0.006 (0.024)	0.012 (0.023)	0.013 (0.024)
Δln(GC): Generation for country		0.312*** (0.014)		0.307*** (0.014)		0.312*** (0.014)
Δln(GD): Generation minus DL	0.300*** (0.016)		0.297*** (0.016)		0.300*** (0.016)	
Δln(M): Import	0.054*** (0.006)	0.058*** (0.006)	0.053*** (0.007)	0.057*** (0.006)	0.054*** (0.006)	0.058*** (0.006)
Δln(X): Export	0.029*** (0.008)	0.042*** (0.008)	0.030*** (0.008)	0.042*** (0.008)	0.029*** (0.008)	0.042*** (0.008)
Δln(DL): Distribution loss	0.076*** (0.015)		0.075*** (0.015)		0.076*** (0.015)	
α_0	-0.001*** (0.007)	0.001 (0.007)	-0.001 (0.007)	0.001 (0.007)	-0.001*** (0.007)	0.001 (0.007)
σ_μ			0.034	0.035	0	0
σ_ε			0.209	0.213	0.209	0.213
ρ			0.025	0.026	0	0
F-Statistics	192.35***	214.79***	192.35***	214.79***		
χ^2					961.75***	859.17***
Observations	905	905	905	905	905	905

Notes: (1) Standard errors in ( )
(2) *** illustrates significance at 1% level.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

North America (3 countries) 1971-2007 (Balanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
$\Delta ln(CO_{2,t-1})$: lag1_CO_2 emissions	-	-	-	-	-	-
Δln(GC): Generation for country		1.019*** (0.041)		1.019*** (0.041)		1.019*** (0.041)
Δln(GD): Generation minus DL	1.070*** (0.055)		1.072*** (0.056)		1.070** (0.055)	
Δln(M): Import	-0.0003 (0.010)	0.001 (0.011)	0.0002 (0.010)	0.002 (0.011)	-0.0002 (0.010)	0.001 (0.011)
Δln(X): Export	-0.52*** (0.010)	-0.057*** (0.010)	-0.052*** (0.010)	-0.060*** (0.010)	-0.052*** (0.010)	-0.057*** (0.010)
Δln(DL): Distribution loss	-0.107* (0.056)		-0.108* (0.060)		-0.107* (0.057)	
α_0	0.008 (0.007)	0.008 (0.008)	0.008 (0.007)	0.008 (0.008)	0.009 (0.007)	0.008 (0.008
σ_μ			0.009	0.009	0	0
σ_ε			0.074	0.079	0.074	0.079
ρ			0.016	0.012	0	0
F-Statistics	436.27***	514.52***	427.27***	502.45***		
χ^2					1745.08***	1543.56***
Observations	110	110	110	110	110	110

Notes: (1) Standard errors in ( )
(2) ***, ** and * illustrate significance at 1%, 5% and 10% levels respectively.
(3) Intraclass correlation $\rho = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Latin America (21 countries) 1971-2007 (Balanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\ t-1}$): lag1_CO_2 emissions	-0.014 (0.024)	-0.010 (0.024)	-0.020 (0.024)	-0.017 (0.024)	-0.014 (0.024)	-0.010 (0.024)
Δln(GC): Generation for country		0.479*** (0.016)		0.477*** (0.017)		0.479*** (0.016)
Δln(GD): Generation minus DL	0.453*** (0.020)		0.451*** (0.020)		0.453*** (0.020)	
Δln(M): Import	0.012** (0.005)	0.013** (0.005)	0.013** (0.006)	0.013** (0.006)	0.012** (0.005)	0.013** (0.005)
Δln(X): Export	-0.021*** (0.006)	-0.022*** (0.006)	-0.020*** (0.006)	-0.021*** (0.006)	-0.021*** (0.006)	-0.022*** (0.006)
Δln(DL): Distribution loss	0.019** (0.009)		0.019** (0.009)		0.019** (0.009)	
α_0	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)
σ_μ			0.021	0.021	0	0
σ_ε			0.179	0.179	0.179	0.179
ρ			0.014	0.014	0	0
F-Statistics	202.31***	256.36***	196.83***	249.24***		
χ^2					1,011.53***	1,025.45***
Observations	775	775	775	775	775	775

Notes: (1) Standard errors in ( )
(2) *** and ** illustrate significance at 1% and 5% levels respectively.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Europe (45 countries) 1971-2007 (Unbalanced Panel)						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\ t-1}$): lag1_CO_2 emissions	-0.029 (0.024)	-0.028 (0.024)	-0.051** (0.025)	-0.051** (0.025)	-0.029 (0.024)	-0.028 (0.024)
Δln(GC): Generation for country		0.499*** (0.028)		0.492*** (0.028)		0.499*** (0.028)
Δln(GD): Generation minus DL	0.346*** (0.041)		0.334*** (0.041)		0.346*** (0.041)	
Δln(M): Import	0.030*** (0.011)	0.031*** (0.011)	0.031*** (0.011)	0.031*** (0.011)	0.030*** (0.011)	0.031*** (0.011)
Δln(X): Export	-0.021** (0.009)	-0.021** (0.009)	-0.022** (0.009)	-0.021** (0.009)	-0.021** (0.009)	-0.021** (0.009)
Δln(DL): Distribution loss	0.152*** (0.040)		0.158*** (0.040)		0.152*** (0.040)	
α_0	0.003 (0.009)	0.003 (0.009)	0.003 (0.009)	0.003 (0.009)	0.003 (0.009)	0.003 (0.009)
σ_μ			0.057	0.056	0	0
σ_ε			0.345	0.344	0.345	0.344
ρ			0.026	0.026	0	0
F-Statistics	81.33***	102.84***	81.33***	97.79***		
χ^2					406.64***	411.36***
Observations	1,328	1,328	1,328	1,328	1,328	1,328

Notes: (1) Standard errors in ( )
(2) *** and ** illustrate significance at 1% and 5% levels respectively.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

Australia (2 countries) **1971-2007 (Balanced Panel)**						
Model 1: $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GD_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + \beta_5\Delta\ln(DL_{it}) + u_{it}$ **Model 2:** $\Delta\ln(CO_{2,it}) = \alpha_0 + \beta_1\Delta\ln(CO_{2,i,t-1}) + \beta_2\Delta\ln(GC_{it}) + \beta_3\Delta\ln(M_{it}) + \beta_4\Delta\ln(X_{it}) + u_{it}$						
	POLS		**FIXED (WITHIN)**		**RANDOM**	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Δln($CO_{2,\ t-1}$): lag1_CO_2 emissions	-	-	-	-	-	-
Δln(GC): Generation for country		1.608*** (0.052)		1.608*** (0.052)		1.606*** (0.051)
Δln(GD): Generation minus DL	1.517*** (0.110)		1.518*** (0.110)		1.517*** (0.110)	
Δln(M): Import	-	-	-	-	-	-
Δln(X): Export	-	-	-	-	-	-
Δln(DL): Distribution loss	0.063 (0.138)		0.066 (0.139)		0.063 (0.137)	
α_0	-0.022 (0.017)	-0.021 (0.017)	-0.022 (0.017)	-0.21 (0.017)	-0.022 (0.017)	-0.021 (0.017)
σ_μ			0.011	0.012	0	0
σ_ε			0.144	0.144	0.144	0.144
ρ			0.005	0.007	0	0
F-Statistics	494.28***	962.74***	481.44***	962.74***		
χ^2					988.56***	987.63***
Observations	73	73	73	73	73	73

Notes: (1) Standard errors in ( )
(2) *** illustrates significance at 1% level.
(3) Intraclass correlation $\rho = \dfrac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2}$

SUPPLEMENT TO CHAPTER 4

Table A-4.1: Correlation Test Results of Household Electricity Price for Canada from Model C1(a) and Model C1(b)

	Δ*ln*(PH)	**Δ*ln*(FF)**	**Δ*ln*(NU)**	**Δ*ln*(HY)**	**Δ*ln*(SO)**	**Δ*ln*(TW)**	**Δ*ln*(WI)**	**Δ*ln*(OG)**	**Δ*ln*(M)**	**Δ*ln*(X)**	**Δ*ln*(ES)**
Δ*ln* Household Price	1.000										
Δ*ln* Fossil Fuel	0.006	1.000									
Δ*ln* Nuclear	0.161	0.076	1.000								
Δ*ln* Hydro	-0.134	0.448**	0.190	1.000							
Δ*ln* Solar	-0.229	0.024	-0.154	-0.176	1.000						
Δ*ln* Tide Wave and Ocean	-0.137	-0.031	0.237	-0.044	-0.121	1.000					
Δ*ln* Wind	0.115	0.048	0.100	-0.132	0.498**	-0.121	1.000				
Δ*ln* Other Generation	0.172	0.045	-0.046	-0.068	0.065	-0.014	0.008	1.000			
Δ*ln* Import	-0.082	-0.277	-0.154	-0.119	-0.143	0.033	-0.014	-0.090	1.000		
Δ*ln* Export	-0.043	0.086	0.146	0.150	0.139	0.009	0.114	0.072	-0.627**	1.000	
Δ*ln* Excess Supply	-0.029	0.608**	-0.081	0.335	-0.226	0.002	-0.090	0.034	-0.347	0.142	1.000

Note: ** denotes significant level at 5%.

Table A-4.2: Correlation Test Results of Industry Electricity Price for Canada from Model C2(a) and Model C2(b)

	***Δln*(PI)**	***Δln*(FF)**	***Δln*(NU)**	***Δln*(HY)**	***Δln*(SO)**	***Δln*(TW)**	***Δln*(WI)**	***Δln*(OG)**	***Δln*(M)**	***Δln*(X)**	***Δln*(ES)**	***Δln*(DP)**
Δln Industry Price	1.000											
Δln Fossil Fuel	0.154	1.000										
Δln Nuclear	0.082	0.076	1.000									
Δln Hydro	0.079	0.448**	0.190	1.000								
Δln Solar	-0.424**	0.024	-0.154	-0.176	1.000							
Δln Tide Wave and Ocean	-0.165	-0.031	0.237	-0.044	-0.121	1.000						
Δln Wind	-0.024	0.048	0.100	-0.132	0.499**	-0.121	1.000					
Δln Other Generation	0.370**	0.045	-0.046	-0.068	0.065	-0.014	0.008	1.000				
Δln Import	0.037	-0.277	-0.154	-0.119	-0.143	0.033	-0.014	-0.090	1.000			
Δln Export	-0.069	0.086	0.146	0.150	0.139	0.009	0.114	0.072	-0.627**	1.000		
Δln Excess Supply	0.114	0.608**	-0.081	0.335	-0.226	0.002	-0.090	0.034	-0.347	0.142	1.000	
Δln Difference of Prices	-0.427**	-0.078	0.105	-0.115	0.225	0.010	0.101	-0.302	-0.191	0.094	-0.115	1.000

Note: ** denotes significant level at 5%.

Table A-4.3: Correlation Test Results of Household Electricity Price for the U.S. from Model U1(a) and Model U1(b)

	***Δln*(PH)**	***Δln*(FF)**	***Δln*(NU)**	***Δln*(HY)**	***Δln*(SO)**	***Δln*(WI)**	***Δln*(OG)**	***Δln*(M)**	***Δln*(X)**	***Δln*(ES)**
Δln Household Price	1.000									
Δln Fossil Fuel	0.407**	1.000								
Δln Nuclear	0.056	0.233	1.000							
Δln Hydro	0.036	0.082	0.135	1.000						
Δln Solar	-0.078	-0.381**	0.202	0.043	1.000					
Δln Wind	-0.127	-0.286	-0.165	-0.158	0.733**	1.000				
Δln Other Generation	-0.123	0.433**	0.089	-0.126	-0.144	-0.038	1.000			
Δln Import	0.069	-0.085	0.116	0.349	0.209	0.118	-0.093	1.000		
Δln Export	-0.026	-0.143	0.123	-0.389**	0.176	-0.043	-0.132	-0.557**	1.000	
Δln Excess Supply	0.053	-0.103	0.095	-0.114	-0.098	0.035	-0.340	0.289	-0.138	1.000

Note: ** denotes significant level at 5%.

Table A-4.4: Correlation Test Results of Household Electricity Price for the U.S. from Model U1(c) and Model U1(d)

	Δln(PH)	Δln(FF)	Δln(NU)	Δln(HY)	Δln(SO)	Δln(WI)	Δln(OG)	Δln(MC)	Δln(MM)	Δln(XC)	Δln(XM)	Δln(ES)
Δln Household Price	1.000											
Δln Fossil Fuel	0.436**	1.000										
Δln Nuclear	0.067	0.229	1.000									
Δln Hydro	0.084	0.082	0.137	1.000								
Δln Solar	-0.080	-0.382**	0.205	0.050	1.000							
Δln Wind	-0.134	-0.287	-0.163	-0.150	0.732**	1.000						
Δln Other Generation	-0.123	0.434**	0.089	-0.124	-0.148	-0.042	1.000					
Δln Import from Canada	0.192	-0.095	0.093	0.310	0.225	0.143	-0.113	1.000				
Δln Import from Mexico	0.069	0.275	0.398**	0.029	0.321	0.323	0.388**	0.101	1.000			
Δln Export to Canada	-0.032	-0.166	0.047	-0.397* *	0.173	-0.040	-0.152	-0.652**	-0.192	1.000		
Δln Export to Mexico	-0.280	-0.081	-0.528**	-0.113	0.083	0.258	-0.030	0.040	-0.237	-0.079	1.000	
Δln Excess Supply	0.082	-0.103	0.098	-0.127	-0.101	0.032	-0.342	0.289	0.022	-0.196	0.098	1.000

Note: ** denotes significant level at 5%.

Table A-4.5: Correlation Test Results of Industry Electricity Price for the U.S. from Model U2(a) and Model U2(b)

	Δ*ln*(PI)	**Δ*ln*(FF)**	**Δ*ln*(NU)**	**Δ*ln*(HY)**	**Δ*ln*(SO)**	**Δ*ln*(WI)**	**Δ*ln*(OG)**	**Δ*ln*(M)**	**Δ*ln*(X)**	**Δ*ln*(ES)**	**Δ*ln*(DP)**
Δ*ln* Industry Price	1.000										
Δ*ln* Fossil Fuel	0.497**	1.000									
Δ*ln* Nuclear	-0.009	0.233	1.000								
Δ*ln* Hydro	0.083	0.082	0.136	1.000							
Δ*ln* Solar	-0.331	-0.381**	0.202	0.043	1.000						
Δ*ln* Wind	-0.424**	-0.286	-0.165	-0.158	0.733**	1.000					
Δ*ln* Other Generation	0.032	0.433**	0.089	-0.126	-0.144	-0.038	1.000				
Δ*ln* Import	-0.016	-0.085	0.116	0.349	0.209	0.119	-0.093	1.000			
Δ*ln* Export	0.082	-0.143	0.123	-0.389**	0.176	-0.043	-0.132	-0.557**	1.000		
Δ*ln* Excess Supply	-0.045	-0.103	0.095	-0.114	-0.098	0.035	-0.340	0.289	-0.138	1.000	
Δ*ln* Difference of Prices	-0.688**	-0.264	0.085	-0.054	0.278	0.323	-0.202	0.135	-0.145	0.138	1.000

Note: ** denotes significant level at 5%.

Table A-4.6: Correlation Test Results of Industry Electricity Price for the U.S. from Model U2(c) and Model U2(d)

	***Δln*(PI)**	***Δln*(FF)**	***Δln*(NU)**	***Δln*(HY)**	***Δln*(SO)**	***Δln*(WI)**	***Δln*(OG)**	***Δln*(MC)**	***Δln*(MM)**	***Δln*(XC)**	***Δln*(XM)**	***Δln*(ES)**	***Δln*(DP)**
Δln Industry Price	1.000												
Δln Fossil Fuel	0.568**	1.000											
Δln Nuclear	-0.023	0.229	1.000										
Δln Hydro	0.083	0.082	0.137	1.000									
Δln Solar	-0.349	-0.382**	0.205	0.050	1.000								
Δln Wind	-0.443**	-0.287	-0.163	-0.150	0.732**	1.000							
Δln Other	0.064	0.434**	0.089	-0.124	-0.148	-0.042	1.000						
Δln Import from	-0.011	-0.095	0.093	0.310	0.225	0.143	-0.113	1.000					
Δln Import from	-0.094	0.275	0.398**	0.029	0.321	0.323	0.388* *	0.101	1.000				
Δln Export to Canada	0.049	-0.166	0.047	-0.397**	0.173	-0.040	-0.152	-0.652**	-0.1916	1.000			
Δln Export to Mexico	-0.100	-0.081	-0.528**	-0.113	0.083	0.258	-0.030	0.040	-0.2370	-0.079	1.000		
Δln Excess Supply	-0.017	-0.103	0.098	-0.127	-0.101	0.032	-0.342	0.289	0.0223	-0.196	0.098	1.000	
Δln Difference of Prices	-0.484**	-0.052	0.240	0.039	0.248	0.295	-0.198	0.207	0.3728	-0.145	-0.229	0.257	1.000

Note: ** denotes significant level at 5%.

Table A-4.7: Durbin-Watson d-statistic of Model without a Lagged Dependent Variable

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
Durbin-Watson d-statistic	1.086	1.006	1.247	1.239	1.444	1.432
Number of dependent variables	11	10	9	8	11	10
Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
Durbin-Watson d-statistic	1.461	1.370	1.171	1.162	1.400	1.394
Number of dependent variables	12	11	10	9	12	11

Table A-4.8: Durbin's Alternative Test for Autocorrelation of Model without a Lagged Dependent Variable

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
chi2	6.757	8.923	6.412	5.595	3.329	2.637
Prob > chi2	0.009	0.003	0.011	0.018	0.068	0.104
Number of dependent variables	11	10	9	8	11	10

Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
chi2	2.241	3.224	7.399	6.135	3.113	2.462
Prob > chi2	0.134	0.073	0.007	0.013	0.078	0.117
Number of dependent variables	12	11	10	9	12	11

Table A-4.9: Breusch-Godfrey LM Test for Autocorrelation without a Lagged Dependent Variable

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
chi2	8.133	9.564	7.317	6.339	4.749	3.705
Prob > chi2	0.004	0.002	0.007	0.012	0.029	0.054
Number of dependent variables	11	10	9	8	11	10
Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
chi2	3.432	4.498	8.448	7.079	4.723	3.669
Prob > chi2	0.064	0.034	0.003	0.008	0.030	0.055
Number of dependent variables	12	11	10	9	12	11

Table A-10: Durbin's Alternative Test for Autocorrelation of Model with a Lagged Dependent Variable

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
chi2	0.026	0.452	0.335	0.003	0.970	0.023
Prob > chi2	0.872	0.501	0.563	0.955	0.325	0.880
Number of dependent variables	14	13	11	10	13	12
Number of lagged dependent variables	3	3	2	2	2	2
Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
chi2	0	0.188	0.027	0.031	0.215	0.117
Prob > chi2	0.998	0.665	0.869	0.861	0.643	0.732
Number of dependent variables	15	14	11	10	13	12
Number of lagged dependent variables	3	3	1	1	1	1

Table A-4.11: Breusch-Godfrey LM Test for Autocorrelation with a Lagged Dependent Variable

Model 1: Household Electricity Price (PH)						
	CANADA		U.S.			
	Model C1(a)	Model C1(b)	Model U1(a)	Model U1(b)	Model U1(c)	Model U1(d)
chi2	0.055	0.876	0.574	0.005	1.815	0.042
Prob > chi2	0.814	0.349	0.449	0.942	0.178	0.837
Number of dependent variables	14	13	11	10	13	12
Number of lagged dependent variables	3	3	2	2	2	2
Model 2: Industry Electricity Price (PI)						
	CANADA		U.S.			
	Model C2(a)	Model C2(b)	Model U2(a)	Model U2(b)	Model U2(c)	Model U2(d)
chi2	0	0.399	0.046	0.049	0.411	0.211
Prob > chi2	0.998	0.528	0.830	0.825	0.522	0.646
Number of dependent variables	15	14	11	10	13	12
Number of lagged dependent variables	3	3	1	1	1	1

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