Doctoral Thesis

The Role of Energy in an Energy Constrained Economy

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Abstract

The thesis consists of three individual papers on energy and economic development focusing on the energy constrained economies.

The first paper examines how energy subsidies influence the relationship between economic growth and electricity consumption. The study constructs a panel data set consisting of 172 countries to see how the level of economic development, energy availability and energy subsidies affect electricity consumption. To address dynamic panel bias, the study uses the panel estimation technique, generalized method of moments. The findings suggest that in energy subsidized economics, electricity consumption augments economic growth in general but is evident in middle income and energy constrained countries. This relationship, however, is reversed for the high-income countries where economic output and price of electricity influence power consumption. These results suggest that energy subsidies as a policy for transfer payments, especially in middle income and energy deficit countries, has no upward pressure on electricity consumption; rather, it acts as an impetus for economic development thereby endorsing the growth hypothesis in energy economics. Conversely, energy subsidies in high-income countries determine how energy-income or inter-fuel substitution affects environmental outcomes.

The second paper investigates how an energy constrained economy responds to energy shocks by taking Bangladesh as an example. To explore the long run relationship, Autoregressive Distributed Lag bounds testing approach is used followed by an error correction model estimation. The results appear both in the short and long run, whereby output growth precipitates energy consumption, supporting the energy conservation hypothesis. The results, however, do not confirm that energy consumption supports output growth or the growth hypothesis. We also find that, in the time of lower energy consumption, the relationship between energy and output is very weak, but in higher energy consumption periods, output growth increases energy uptake. The argument of the paper is that in an energy constrained economy, energy conservation policies, such as increasing fuel price or reducing oil supply, may potentially destabilize the socio-political environment.

The third paper focuses on oil supply shocks to transportation prices of an emerging economy. The motivation for the analysis is stemmed from the fact that in Bangladesh, despite the combined price of all the other goods and services fluctuating across both the directions, the transport price trends positively only. The study hypothesizes that due to oil supply shocks, the transport price shows this particulate behaviour. Using time series models (ARMA, GARCH and EGARCH), the study finds the evidence of negative impact of oil shocks on transportation. This analysis also concludes that transport price volatility has no impact on its average price, and the volatility itself is not explosive but rather bounded. In tackling the increasing transportation price, importing more oil may be one option but from the environmental perspective, fuel switching or energy efficiency gain would be more sustainable policy options.

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Chapter 1

Introduction

The aim of this thesis is to contribute to our understanding on how energy consumption decisions impact the economy and environment. It has become a common practice in the literature of energy economics to classify the role of energy in the economy through the lens of its capacity to augment output or be augmented by the economic affluence. The underlying assumption of this paradigm is that the economy is sufficiently supplied with energy resources where the ability of the economy to utilize energy is the prime concern, not the availability of energy. In an effort to incorporate the concept of constrained energy supply hypothesis, the thesis proposes an alternative approach in depicting the conventional dynamics of energy-output nexus. While it is customary to opt for the policy of reduction in energy supply, especially fossil fuel, if energy uptake increases due to output push, it is likely that the policy did not account for the fact that the output growth not only encourages additional energy usage but also provides the capability for the marginal population to access their unmet energy requirement, especially in the case of energy deficit countries. Based on this theoretical underpinning, in the first chapter, we analyse countries with different levels of development and their interactions with electricity under different policies of energy subsidy. Following that, in the successive two chapters, we analyse the case of Bangladesh as an energy-constrained country, where decision on energy usage is evaluated under the framework that prioritizing energy security is more important than regulating energy usage behaviour. These chapters propose that once energy availability is ensured for an energy constrained economy, the environmental concern for emissions reduction can be addressed either by fuel switching or by increasing energy efficiency.

The analysis of electricity consumption and economic growth of the first paper shows that the role of electricity in the economy has heterogeneous implications based on the level of development and energy subsidy policy. Power consumption may promote economic growth with or without feedback. Similarly, economic growth may promote power consumption with or without feedback. Formulating energy policy based on these four possibilities may not be sufficient once we analyse specific circumstances of a country. In general, it is thought that the removal of energy subsidies will improve the environment by putting downward pressure on electricity usage, which eventually reduces emissions. The logical argument here is that if growth of output leads to growth of energy usage in a unidirectional path, reducing energy will not necessarily hinder economic growth but improve the environment. This energy conservation policy is favourable for many economies when the policy is to promote fuel switch or energy efficiency. The expected policy outcomes in this case may not be achieved if we introduce energy availability and income level of the countries concerned. To examine this, we categorised the countries broadly into these two groups, and after that, we classify them into different subgroups accordingly. We use generalises generalized method of moments estimation technique to analyse how economic growth or electricity consumption influences each other in an economic environment where capital and labour are another two important determinants of output or electricity consumption. Analysing the estimations, we find from the global sample that electricity consumption influences output without feedback. The price of electricity and output do not influence the quantity of electricity consumption in the same sample. Dividing the global sample into different sub-samples, we find that the middle-income countries that are energy deficit but subsidize their energy system tend to respond more due to electricity consumption compared to any other sub-categories. For the high-income countries, however, consumption of electricity is not an influencing factor for economic growth; rather, the price of electricity influences the level of electricity consumption. So, we conclude that the level of income of a country is important in assessing the impact of electricity consumption and policy of energy subsidy, as we see energy-constrained economies with subsidy are very good at utilizing electricity for economic output.

Turning from the global evidences of the instrumental role of energy in the economy, the following two papers deals with an energy-constrained economy to understand how energy interacts with output and the transportation sector. As mentioned above, the conventional nexus of energy-output is distorted if the economy is not sufficiently supplied with energy. To elaborate the idea, in the second paper we examine how primary energy influences output in Bangladesh. We employ the monthly data of the last 20 years, during which the country faces both energy shortage and moderate energy sufficiency, respectively. Using estimation techniques such as Autoregressive Distributed Lag and Granger causality, the study finds that both in the short and long run, output influences energy consumption but not vice versa. The conventional literature terms this as energy conservation hypothesis, which argues that the situation is conducive for energy conservation as shocks to energy will not transmit to output. This unidirectional causality from output to energy implies that the economic growth would not be hampered by reduction in energy supply. Such energy conservation policy is likely to induce energy efficiency and fuel switching. But we know that Bangladesh is an energy deficit country with strong evidence of energy poverty in the population. Following energy conservation, in turn, may deteriorate the ability of the country in ensuring the basic energy requirements for its population. The argument of the paper is that the inability of energy to become a productive capital in Bangladesh is not because people are overusing energy as output grows but because the lack of energy supply keeps the country away from energy-intensive industrialization. To clarify the proposition, the study takes a period of energy crisis under analysis and finds that both energy and output are indifferent to each other. Our conclusion is that being a fundamental commodity in the modern economy, energy requirements should be fulfilled first and then proceed to alternative solutions such as fuel switching or energy efficiency gain for better environmental outcomes.

The third paper looks at the impact of oil shocks on a specific sector instead of evaluating the whole output spectrum in the context of Bangladesh. Using time series models (ARMA, GARCH and EGARCH), the study evaluates transport price in the context of the prices of other goods and services and oil supply. The key finding of the paper is that a higher availability of oil reduces increasing inflationary pressure in transport. This study also shows that while prices of all other goods and services impart a positive pressure on transport price, the supply of oil does just the opposite. We also estimate the variance of the inflation and find that both long and short run volatility of transportation prices are not explosive but rather bounded and mean reverting. By specifying an exponential model, we also show that the volatility has a symmetric impact, implying both positive and negative shocks have similar persistence. Bangladesh, being a small oil importing country, is likely to address the issue of transport inflation by increasing importation of oil. However, from an environmental perspective, a balanced score-card is expected to weigh the benefit of this measure against the other alternatives such as fuel switching or increasing energy efficiency.

Statement of Authorship

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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	
Contribution to the Paper	

Chapter 2

Impact of energy subsidies to the nexus of economic growth and electricity consumption: a cross country analysis

Abstract

This paper demonstrates how energy subsidies influence the relationship between economic growth and electricity consumption. We construct a panel data set with price and yearly electricity consumption in 172 countries over 2010-2017. Countries are divided into two broader categories based on energy availability and the levels of economic development. We conduct a literature survey on studies that encompass all the global regions, and then we combine the outcomes of those studies into different categories to find the general pattern of power consumption in each group. Next, we utilize a dynamic panel technique through a two-step system generalized method of moments (GMM) to estimate the aggregate production function of each of the country categories. Our study, in conformity with the literature, suggests that electricity consumption augments economic growth in general, but specifically for the middle-income and energy deficit countries. The direction of causality is reversed for the high-income countries where we see an increase in income induces greater electricity consumption. These results help to conclude that energy subsidy as a policy for transfer payments, especially for middle-income and energy-deficit countries, has no upward pressure on electricity consumption; rather, it acts as an impetus for economic development, endorsing the growth hypothesis. Conversely, energy subsidies for the high-income countries are needed to determine how energy impacts inter-fuel substitution or environmental outcomes.

2.1 Introduction

It is expected that removal of energy subsidies would protect the environment by decreasing energy consumption, as renewable energy sources would become cheaper as an alternative compared to the fossil fuels dominating global energy mix (Monasterolo and Raberto, 2019; Mundaca, 2017b). The arguments against energy subsidies are that apart from being a fiscal burden, it increases social inequality, damages macroeconomic efficiency, induces aggregate welfare loss and suppresses GDP growth (Monasterolo and Raberto, 2019; Feng et al., 2018; Li, Shi, and Su, 2017; Mundaca, 2017a; Davis, 2014; Plante, 2014; Clements et al., 2014; Coady and Granado, 2012). Some studies even suggest that appropriate fuel pricing, through removal of energy subsidies, could increase government revenue to up to 3.8% of GDP (Coady et al., 2019). Breaking down the prevalence of subsidies across global regions reveals that 96% of total pretax energy subsidies in 2013 are provided to non-advanced economies (Coady et al., 2017). Therefore, removal of subsidies may have far-reaching impacts on global governance and development. As emerging countries are the driving force for the global economy, and at the same time utilize much of the aggregated energy resources, reduction of energy supply may hamper global growth. Removal of subsidies may also induce price hikes on energy, which could infuse public dissatisfaction and sociopolitical turbulence, as we have seen in countries like Haiti, Belgium, Bulgaria, Burkina Faso, France, India and Sierra Leone in 2018. In this context, this study proposes a framework for analyzing the impacts of energy subsidies on economic output and energy consumption based on income level and energy resource availability. We have taken electricity as a principal component of energy for analysis, as a significant portion of the total energy subsidies goes to electricity alone. There is also an indirect impact of energy subsidies as primary energy is utilized in producing electricity as a final good in most cases.

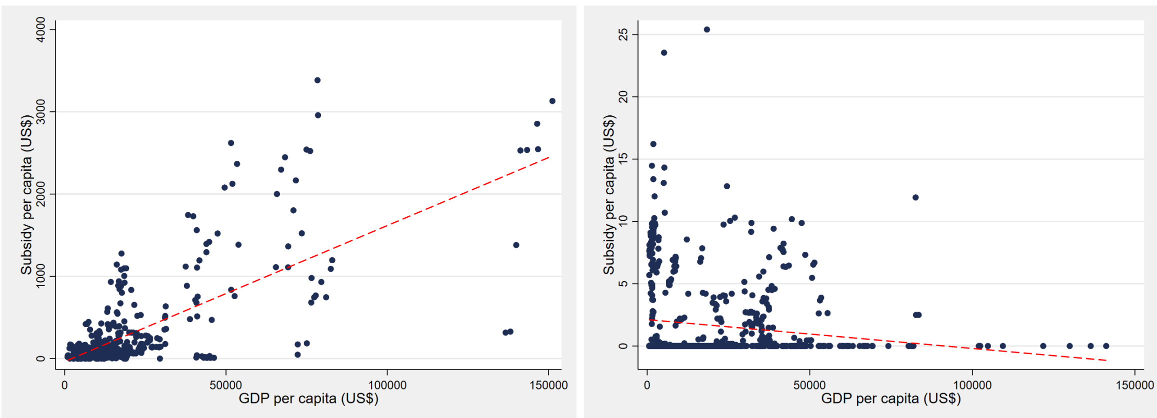
The goal of our study is to understand the dynamics of electricity consumption under different economic development stages. Literature on electricity-growth nexus provides mixed results as the causality may run from either direction depending on the period of study, countries under consideration, econometric method of estimation, economic structure of the countries, and so on. To enrich the existing knowledge on energy subsidies, this study disaggregates the global sample of 172 countries into two broader categories based on energy resources and economic development. The purpose of this categorization is to see how group specific characteristics shape electricity consumption behaviour under different energy subsidy regimes.

This paper contributes to the existing literature in a number of ways. First, this is a pioneering attempt to conduct a comprehensive study on the impact of energy subsidies to the economic growth and electricity consumption. Second, this study includes a literature survey on 100 countries to investigate the nature of this relationship. Third, a unique panel database is constructed where the final price of electricity is included along with other macroeconomic variables. Finally, this analysis introduces two new indicators for energy availability and energy subsidy prevalence in a country. Overall, we see this study stands out in the literature in terms of country coverage, literature survey and identification technique.

The rest of the paper is arranged as follows: section (2.2) details the background of the study, section (2.3) provides a survey on the literature of electricity consumption and economic growth nexus, section (2.4) describes data and methodology, section (2.5) presents the results, followed by discussion and conclusion in sections (2.6) and (2.7).

2.2 Background

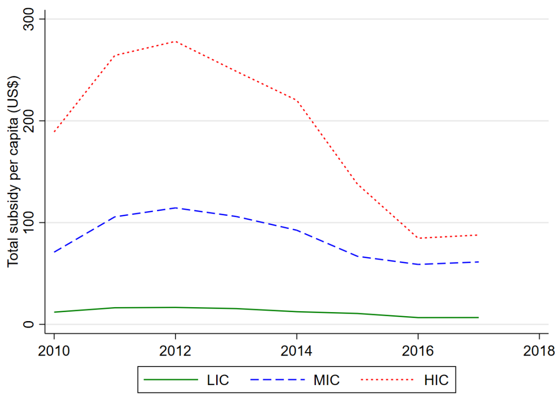
The amount of per capita annual energy subsidies during 2010-2017 ranges from 0 to 3,384 US$ globally. Anecdotal evidences and previous studies show that oil-rich countries with poor bureaucracy are the ones that provide higher levels of energy subsidy. However, analysing individual countries, it appears that oil-importing countries with reasonably proficient bureaucracies also provide energy subsidies, implying energy abundance is not the only motivation. We provide here a background on global energy subsidy prevalence and the economic circumstances during the study period.



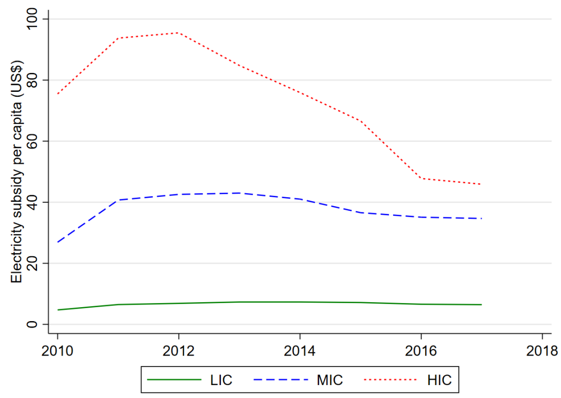
(A) High subsidizing countries (B) Low subsidizing countries

FIGURE 2.1: Subsidy-GDP relationship.

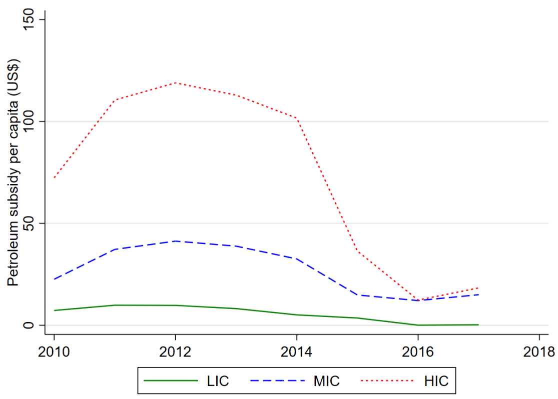
Based on the distinction of high and low levels of energy subsidy[1], Figure (2.1) shows that GDP growth is positively associated with higher subsidies (Figure 2.1a) while the reverse is true for low levels of subsidization (Figure 2.1b). Intuitively, the graphs above do not provide much information on the question of subsidy-GDP relationship for the following reasons: First, the higher income of a country may enable it to provide more subsidies or vice versa; second, subsidy policy may not be a principle macroeconomic determinant to influence economic growth or, in other words, the relationship between subsidy and income may be spurious; and third, in the zero subsidized economies, the amount of subsidy does not vary over time to demonstrate any dynamic relationship. Therefore, including "subsidy" as a continuous variable in this analysis would be misleading. This would be more appropriate if we analyse the two groups separately.



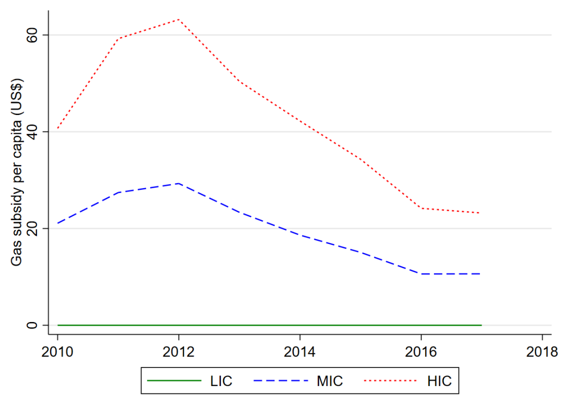
(A) Total energy subsidy



(B) Electricity subsidy



(C) Petroleum subsidy

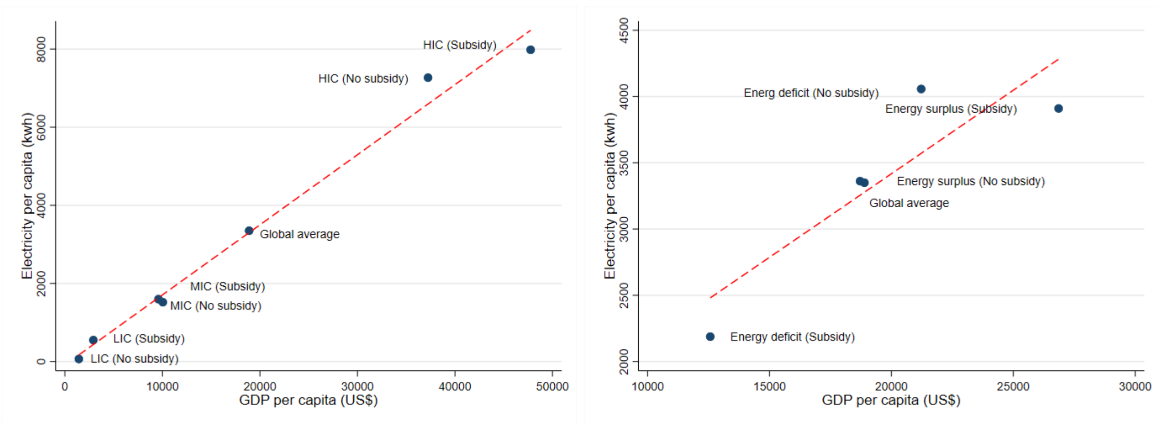


(D) Gas subsidy

FIGURE 2.2: Subsidy trend - 2010-2017
*LIC: Low Income Countries; MIC: Middle Income Countries; HIC: High Income Countries

[1]Low subsidizing countries are the ones that provide either 0 or minimum up to 10 US$ average annual energy subsidy per capita.

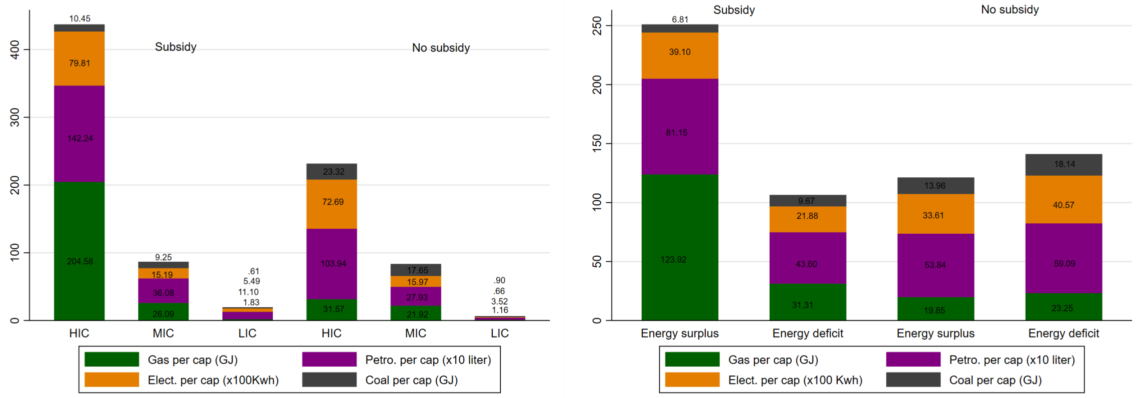
If we analyze the trend of energy subsidies in different income groups, we see a downward slope for all the energy products over time during the study period (Figure 2.2). Starting with the total energy subsidies in Figure (2.2a), we see that high-income countries provide higher amounts of energy subsidies compared to MIC or LIC. Owing to global criticism for overuse, the HIC's total energy subsidies, however, declined by more than 50% from 2010 to 2017. Following a similar trend, electricity, petroleum and natural gas subsidies also declined during that period in this income group. Energy subsidies for the middle-income countries are roughly half of that of HIC, and the downward trend is not as prominent as in the HIC. In fact, the trend is somewhat steady-state except for the natural gas subsidies where we see around a 50% decline in subsidies for this relatively clean fuel. Energy subsidies to the low-income group are insignificant compared to the HIC or MIC and still, we see a declining trend of subsidies in these income groups. Another feature here is that natural gas subsidies are absent in the LIC, indicating low income-countries have lesser access to natural gas (Figure 2.2d). Our data also show per capita subsidies on coal are almost negligible in all the income groups. From an environmental perspective, less polluting products such as electricity or natural gas should be subsidized highly compared to the more polluting coal and petroleum. There is an apprehension that removal of subsidies from less carbon containing energy products may induce the uptake of high polluting cheaper alternative fuel such as coal, indicating rebounding effects (Jewell et al., 2018).



(A) Income levels (B) Energy availability

FIGURE 2.3: Electricity consumption and GDP

From economic theory, the idea that energy subsidies may influence energy consumption through price elasticity is obvious. The less obvious part of the price-quantity transmission mechanism is whether there exists an efficient market for electricity where the consumers and the producers exert sufficient bargaining power. In many of the energy constrained economies, income rather than price determines the consumption of electricity. To test this hypothesis, the study shows how electricity as a principal component of energy products is positively associated with income under various development stages and energy availability of the countries under consideration. To illustrate the relationship, Figure (2.3) shows a strictly positive relationship between energy consumption and GDP, although it is not certain about causality or direction for that matter. Specifically, Figure (2.3a) shows that electricity consumption in the high- and low-income countries is relatively higher if they subsidize energy. But the electricity consumption in the middle-income countries shows the same level of average electricity consumption regardless of their subsidy prevalence. It is important to note here that much of the global growth comes from the middle-income countries (*see* Table 2.6) and we can assume that the demand for electricity here is largely propelled by economic growth and expansion. Next, we see how energy availability influences electricity consumption both in energy surplus and deficit economics. Interestingly, Figure (2.3a) shows that despite providing energy subsidies, the energy deficit countries consume the lowest quantity of electricity in all the sub-categories here. By contrast, the energy surplus countries consume more than double the amount of electricity without even subsidies.

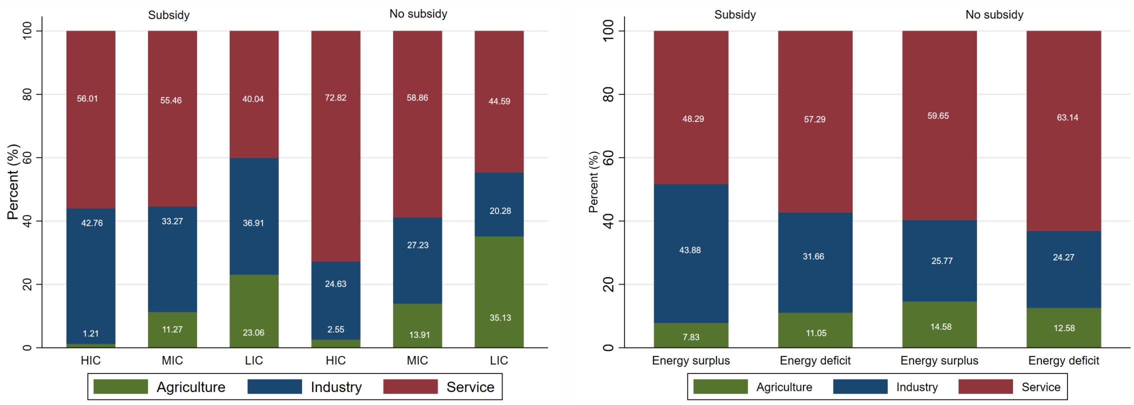


(A) Income level

(B) Energy availability

FIGURE 2.4: Global energy consumption mix

To understand the role of energy subsidy on the electricity-growth nexus we now turn to look into how subsidies impact the pattern of the global energy mix . To depict that, Figure (2.4) illustrates consumption of different energy products (electricity, petroleum, natural gas and coal) by groups of countries based on income and energy availability. In particular, Figure (2.4a) shows that energy consumption in the high-income countries is approximately doubled when they are subsidized. The influence of subsidy on the middle-income countries, however, is not as prevalent compared to the other income groups. It is instructive to note that energy consumption in low-income countries is somewhat insignificant compared to their high-income counterparts. Another important aspect of the energy mix is that electricity and petroleum products are comprised of the major portion of the total energy consumption in all the sub-categories. Usage of natural gas is higher in the high- and middle-income groups indicating that high subsidies for this product augment its uptake (*as seen in* Figure 2.2). Turning to the energy mix under energy availability, we see from Figure (2.4b) that the energy surplus countries consume more than double the amount of energy compared to the energy deficit countries, even if both the groups are subsidized. But energy usage in non-subsidized economies does not depend much on the availability of energy resources. In other words, energy surplus countries without energy subsidies use moderate levels of energy. Analyzing individual components of the mix, we counter-intuitively see that consumption of coal in the non-subsidizing economies is nearly double the amount of their subsidizing counterparts (Table 2.1) . This has a profound environmental implication as coal is the dirtiest of all energy sources, reduction in subsidy on petroleum, gas would make them expensive and consumer may opt for coal instead. Therefore, subsidy in this case is improving environment by channeling investment towards relatively cleaner energy sources.



(A) Income level (B) Energy availability

FIGURE 2.5: Economic structure

The structure of the economy[2] and level of energy demand are other important

[2]From WDI, 2020 database of World Bank

aspects to consider in the electricity-growth nexus. In Figure (2.5a), we see that the relatively large industrial sector comes up with energy subsidy indicating a correlation between subsidy and industrialization. On the other hand, a non-subsidizing economy has a larger service sector, implying lesser energy requirements for the service sector. Regarding agriculture, we see a diminishing influence in the economic structure as income grows. In fact, the percentage share of agriculture is almost zero in the high-income countries when the countries are provided with energy subsidies reinforcing the conviction that energy subsidies proliferate industry at the cost of eliminating agriculture in the high-income countries. The delineation of the economic structure under energy availability, illustrated in Figure (2.5b), endorses the idea that availability of energy helps industry grow even without energy subsidies. To be specific, there is around a 10% augmentation in industrialization for both energy surplus or deficit countries when energy subsidies are in place.

TABLE 2.1: Energy consumption and subsidy growth - 2010-2017

		Subsidy			No Subsidy		
Per capita*	Global	LIC	MIC	HIC	LIC	MIC	HIC
Elect.(Kwh)	3349	549	1519	7981	66	1597	7268
	(-.03)	(-8.20)	(.89)	(-.36)	(.66)	(.78)	(-.16)
Petroleum (liter)	564	111	361	1422	35	279	1039
	(-.51)	(-9)	(.60)	(-.35)	(5.31)	(.63)	(-1.14)
Gas (GJ)	38	1.83	26	205	1.16	22	32
	(-.32)	(-19)	(1.09)	(-.11)	(5.57)	(.34)	(-2.08)
Coal(GJ)	13	.61	9.25	10.45	.90	18	23
	(-.28)	(7)	(.67)	(.93)	(2)	(.16)	(-1.14)
		Energy surplus			Energy deficit		
Total subsidy (US$)	110	9.36	168	328	13	53	131
	(-4.11)	(-15)	(-3.28)	(-10)	(-1.63)	(5.33)	(-4.15)
Elect. subsidy (US$)	45	4	48	103	7.5	34	61
	(-1.08)	(-5.20)	(1.68)	(-11)	(8)	(8)	(2)

*The growth rates (%) are in the parenthesis.

It is not surprising to see that the average growth rate of the global energy consumption is on the negative side largely due to energy efficiency gain and environmental concern. Table (2.1) shows that electricity consumption on average is reduced by 0.03% globally during the study period. This reduction is largely contributed by the high-income countries that subsidized their energy products. Energy subsidies also seem to play a crucial role in electricity consumption in low-income countries as we see the subsidized group consumes more than 8 times of electricity (549 kWh) compared to non-subsidizing LIC group (66 kWh). This comparison may look large, but we need to take into account that the average per capita global electricity consumption is 3,349 Kwh where the HIC consume more than double this amount. Annual electricity consumption in the middle-income group has grown by an average of 0.78% without subsidies and 0.89% with subsidies. The average consumption for this income group is around 1500 kWh per capita annually, which is still half of the global average consumption rate. Subsidy prevalence did not make much difference in electricity consumption in this group, as we have already seen from Figure (2.3). Similar to electricity, petroleum also follows the same trajectory in the HIC with an average annual consumption of 1422 liters with subsidies and 1039 liters without. The large consumption gaps are also prominent in natural gas, where we see that while high-income countries with energy subsidies consume on average 205 GJ[3], the low-income countries consume only 1.83 GJ. Despite these huge differences, the global consumption of petroleum, coal and gas has been reduced by about 0.25% to 0.50% annually during the study period, reinforcing the idea of increase in the global energy efficiency. With the reduction of global energy consumption, energy subsidies also reduced by around 4% annually. The maximum reduction of energy subsidies comes from the energy surplus low-income countries (15%), while the middle-income countries did the minimum. By contrast, energy deficit countries increase subsidies by 5.33% annually during this period. The global subsidies on electricity are also reduced by around 1% annually, with the highest reduction in energy surplus HIC and LIC groups. This reduction is not solely contributed by energy efficiency; the diminishing trend of global energy prices also has a role to play (*see* Table 2.6). For example, the average global electricity price in 2010 was 0.17 US$ per kWh, while in 2017 it came down to 0.15 US$ per kWh.

Overall, we find a large gap in per capita energy consumption between the high and low-income countries. Similarly, the dominant energy products of these income groups are different with different environmental consequences. Providing energy subsidies to a high-income energy surplus country is not the same as providing subsidies to a low-income energy deficit country. Despite these differences, this analysis indicates a strong association between energy and economic growth, which is needed to explore in terms of the direction of causality and their relative impacts on each other in different economic environments.

[3]One Gigajoule (GJ) of natural gas is equivalent to 277 kilowatt hours (kWh) of electricity; 27 litres of fuel oil; 39 litres of propane or 26 litres of gasoline.

2.3 Literature Review

A broad array of studies on electricity-growth in particular and energy-growth nexus in general are found in the literature where the nature of relationships and possible directions of their causality are postulated under the following four hypotheses: growth, conservation, feedback and neutrality. The growth hypothesis refers to the idea that electricity as a constituent component of the production function increases productivity in a way that induces economic growth under constant or increasing return to scale production technology. The conservation hypothesis, in contrast, assumes that people tend to consume more energy as they get richer. In other words, in these economies, energy is not a constraint for the economy; rather, income augmentation or energy price reduction or both together push energy consumption up. The third hypothesis, feedback, indicates a complementary relationship between economic growth and energy consumption. This is especially true for growing economies with industrialization where energy simultaneously fuels economic production and consumer demand of the emerging affluent population. The fourth hypothesis is neutrality, where we see energy shocks do not have a substantial impact on GDP or vice-versa. These types of economies are not energy dependent in general and are likely to be flexible in fuel switching.

It is obvious that country-specific characteristics and policy of the government are responsible for the above mentioned hypothesis categories to which a country belongs to. Based on the findings of previous literature, we categorize a country's electricity consumption based on energy availability, economic output, prevalence of energy subsidies and their interactions within these categories. Specifically, we find previous studies conducted on the high, low and middle income countries where energy subsidies may have impacted energy consumption. Similarly, we also find literature on energy surplus or deficit countries, where subsidies might have made a difference in the electricity consumption. Going through the literature, we have found 64 such studies where 100 individual countries are studied, of which some countries are analyzed multiple times. As a result, we come up with 188 outcomes from where we explore the particular hypothesis predominant in different country categories along with the study periods, resource availability and estimation methods[4] used.

In the economic growth literature, electricity as an important component for the high-income countries is studied extensively. Individual countries are analysed based

[4]ARDL: Autoregressive Distributed Lag; DOLS:Dynamic OLS; ECM: Error Correction Model FOLS: Fully modified Ordinry Least Square; GC: Granger Causality; GMM: Generalized Method of Moments; IV: Instrumental Variable; TY: Toda-Yamamoto causality; VAR: Vector Autoregressions; VECM: Vector Error Correction Model; UECM: Unrestictred Error Correction Model

on the data from as early as 1960 and onward. We have enumerated 68 such outcomes (from 41 countries), of which only 9 are from the energy subsidized countries and the rest, 59, are from the non-subsidizing economies (Table 2.2). The predominant conclusion in the subsidizing section is the conservation or feedback hypothesis indicating economic growth and electricity consumption complement each other, or at least people increase power consumption with more income (Hamdi, Sbia, and Shahbaz, 2014; Squalli, 2007; Sbia, Shahbaz, and Ozturk, 2017). The evidences of neutrality and growth hypotheses can be seen only in Canada and Germany respectively (Narayan and Prasad, 2008 ; Murry and Nan, 1994). Another important aspect of this group is that almost all the countries are energy surplus, which can give us an indication that availability of energy resources may influence the decision on subsidy despite being in the high-income category. On the other hand, we notice the prevalence of neutrality hypothesis for the non-subsidizing high-income countries where around 37% cases are indicating electricity consumption does not have a direct implication to the economic growth (Faisal et al., 2018; Wolde-Rufael, 2014; Chen, Kuo, and Chen, 2007; Narayan and Prasad, 2008;). But, almost half of the outcomes in this segment demonstrate the important role of energy in the economy as we see 27% outcomes for feedback and 20% for conservation (Wu et al., 2019; Salahuddin and Alam, 2015; Wolde-Rufael, 2014; Polemis and Dagoumas, 2013; Tang, Shahbaz, and Arouri, 2013 E Bildirici and Kayikci, 2012; Gurgul and Lach, 2012; Shahbaz, Tang, and Shabbir, 2011; Ciarreta and Zarraga, 2010a; Narayan and Prasad, 2008; Chen, Kuo, and Chen, 2007; Zachariadis and Pashourtidou, 2007; Yoo, 2006a; Narayan and Smyth, 2005; Yoo, 2005; Murry and Nan, 1994). Finally, it is not surprising to note that energy is not a constraint for economic growth in high-income countries as only 9% of the outcomes endorse the growth hypothesis (E Bildirici and Kayikci, 2012; Narayan and Prasad, 2008; Ho and Siu, 2007; Murry and Nan, 1994). Overall, we see the prevalence of neutrality hypothesis (35%) in the HICs followed by feedback (28%), conservation (22%) and growth (15%). It is important to notice here that most of the non-subsidizing countries in this group are energy deficit, indicating that consumers are capable enough to procure their electricity demand even without energy subsidies.

TABLE 2.2: Literature on high Income Countries

Country	Author(s)	Period	Results (method)	Energy
Subsidizing				
Bahrain	Hamdi, Sbia, and Shahbaz, 2014	1980-2010	Feedback (ARDL, VECM)	Surplus
Canada	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Surplus
	Murry and Nan, 1994	1970-1990	Growth (VAR, GC)	
Kuwait	Squalli, 2007	1980-2003	Conservation (UECM, TY)	Surplus
Qatar	Squalli, 2007	1980-2003	Feedback (UECM, TY)	Surplus

Country	Author(s)	Period	Results (method)	Energy
Saudi Arabia	Squalli, 2007	1980-2003	Conservation (UECM, TY)	Surplus
UAE	Squalli, 2007	1980-2003	Conservation (UECM, TY)	Surplus
	Sbia, Shahbaz, and Ozturk, 2017	1975-2011	Feedback (ARDL, VECM)	
Germany	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Non-ubsidizing				
Australia	Salahuddin and Alam, 2015	1985-2012	Conservation (ARDL, VECM)	Surplus
	Narayan and Prasad, 2008	1960-2002	Growth (Bootstrap)	
	Narayan and Smyth, 2005	1966-1999	Conservation (VECM)	
Denmark	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Surplus
Norway	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Surplus
Austria	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Belgium	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Cyprus	Zachariadis and Pashourtidou, 2007	1960-2004	Feedback (VECM)	Deficit
Czech Rep	Wolde-Rufael, 2014	1975-2010	Conservation (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1971-2009	Feedback (ARDL)	
	Narayan and Prasad, 2008	1960-2002	Growth (Bootstrap)	
Finland	Narayan and Prasad, 2008	1960-2002	Conservation (Bootstrap)	Deficit
France	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Greece	Polemis and Dagoumas, 2013	1970-2011	Feedback (VECM)	Deficit
	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	
Hong Kong	Chen, Kuo, and Chen, 2007	1971-2001	Conservation (ECM, GC)	Deficit
	Ho and Siu, 2007	1966-2002	Growth(VECM)	
	Murry and Nan, 1994	1970-1990	Growth (VAR, GC)	
Hungary	E Bildirici and Kayikci, 2012	1971-2009	Feedback (ARDL)	Deficit
	Narayan and Prasad, 2008	1960-2002	Conservation (Bootstrap)	
Iceland	Faisal et al., 2018	1965-2013	Neutral (ARDL, VECM)	Deficit
	Narayan and Prasad, 2008	1960-2002	Feedback (Bootstrap)	
Ireland	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Italy	Narayan and Prasad, 2008	1960-2002	Growth (Bootstrap)	Deficit
Japan	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Korea	Narayan and Prasad, 2008	1960-2002	Feedback (Bootstrap)	Deficit
	Chen, Kuo, and Chen, 2007	1971-2001	Conservation (ECM, GC)	
	Yoo, 2005	1970-1990	Feedback(ECM, GC)	
	Murry and Nan, 1994	1970-1990	Feedback (VAR, GC)	
Latvia	Wolde-Rufael, 2014	1975-2010	Conservation (Bootstrap)	Deficit
Lithuania	Wolde-Rufael, 2014	1975-2010	Conservation (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1990-2010	Feedback (ARDL)	
Luxembourg	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Macedonia	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
Netherlands	Narayan and Prasad, 2008	1960-2002	Conservation (Bootstrap)	Deficit
New Zealand	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Poland	Wolde-Rufael, 2014	1975-2010	Neutral(Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1970-2009	Feedback (ARDL)	
	Gurgul and Lach, 2012	2000-2009	Feedback (VECM, TY)	
	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	
Portugal	Tang, Shahbaz, and Arouri, 2013	1974-2009	Feedback (ARDL, VECM)	Deficit
	Shahbaz, Tang, and Shabbir, 2011	1971-2009	Conservation (ARDL, VECM)	
	Narayan and Prasad, 2008	1960-2002	Growth (Bootstrap)	
Romania	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1980-2009	Feedback (ARDL)	

Country	Author(s)	Period	Results (method)	Energy
Singapore	Chen, Kuo, and Chen, 2007	1971-2001	Neutral (ECM, GC)	Deficit
	Yoo, 2006a	1971-2002	Feedback (ECM, GC)	
	Murry and Nan, 1994	1970-1990	Growth (VAR, GC)	
Slovak Rep	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1982-2009	Growth (ARDL)	
	Narayan and Prasad, 2008	1960-2002	Growth (Bootstrap)	
Slovenia	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
Spain	Ciarreta and Zarraga, 2010b	1971-2005	Conservation (TY, DL)	Deficit
	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	
Sweden	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
Switzerland	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Deficit
UK	Narayan and Prasad, 2008	1960-2002	Feedback (Bootstrap)	Deficit
USA	Wu et al., 2019	1971-2014	Feedback (Bootstrap ARDL)	Deficit
	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	

The middle-income countries are the ones for which the maximum number of studies are conducted for this purpose. We have collected evidence of 112 such outcomes of which 85 countries subsidize their energy system while the rest, 27, do not (Tabel 2.3). In contrast to the high-income countries where neutrality hypothesis prevails, the middle-income counties are mostly in favour of the growth hypothesis (34%) followed by the conservation (24%), feedback (21%) and neutrality (21%) hypotheses. In the energy subsidized middle-income economies, electricity has a very active role in the economy, as we see that around 80% cases here are in favour of either Growth (28%), conservation (27%) or feedback (24%) hypotheses (Usman, Iortile, and Ike, 2020; Lin and Wang, 2019; Samu, Bekun, and Fahrioglu, 2019; Wu et al., 2019; Zhong et al., 2019; Long, 2018; Wang, Zhao, and Li, 2018; Abeberese, 2017; Solarin, Shahbaz, and Shahzad, 2016; Tursoy, Resatoglu, et al., 2016; Fakih and Marrouch, 2015; Cowan et al., 2014; Wolde-Rufael, 2014; Bildirici, 2013; Tang and Tan, 2013; E Bildirici and Kayikci, 2012; Shahbaz and Lean, 2012; Ahamad and Islam, 2011; Chandran, Sharma, and Madhavan, 2010; Yoo and Kwak, 2010; Abosedra, Dah, and Ghosh, 2009; Ghosh, 2009; Odhiambo, 2009; Tang, 2008; Chen, Kuo, and Chen, 2007; Mozumder and Marathe, 2007; Squalli, 2007; Yuan et al., 2007; Wolde-Rufael, 2006; Yoo, 2006a; Yoo and Kim, 2006; Morimoto and Hope, 2004; Shiu and Lam, 2004; Ghosh, 2002; Murry and Nan, 1994). Only 21% of the outcomes in this segment favour the neutrality hypothesis, indicating the important role of electricity is this economy (Bah and Azam, 2017; Cowan et al., 2014; Wolde-Rufael, 2014;Bildirici, 2013; Narayan and Prasad, 2008; Chen, Kuo, and Chen, 2007; Squalli, 2007; Wolde-Rufael, 2006; Murry and Nan, 1994). Similar to the energy subsidizing economies, the non-subsidized countries of this group are also in favour of growth hypothesis, entailing more than 50% of the outcomes (Etokakpan et al., 2020; Iyke, 2015; Wolde-Rufael, 2014; Bildirici, 2013; Acaravci and Ozturk, 2012;

E Bildirici and Kayikci, 2012; Acaravci, 2010; Akinlo, 2009; Narayan and Singh, 2007; Squalli, 2007; Wolde-Rufael, 2006; Altinay and Karagol, 2005; Murry and Nan, 1994; Ramcharran, 1990). Provided the empirical evidences above, it appears that most of the middle-income countries' economic growth is constrained by reliable electricity supply regardless of the availability of energy subsidy. The rest of the countries in this segment are in favour of the neutrality, conservation and feedback hypotheses (Kyophilavong et al., 2017; Aslan, 2014; Wolde-Rufael, 2014; Bildirici, 2013; Yoo and Kwak, 2010; Narayan and Prasad, 2008; Chen, Kuo, and Chen, 2007; Wolde-Rufael, 2006; Murry and Nan, 1994).

Now let us consider how the outcomes of the middle-income countries vary based on the energy resources availability. To do so, we have gathered evidences from 72 energy deficit, out of the total 112, middle-income countries where we notice 37% of the outcomes endorses the growth hypothesis. Interestingly, energy surplus countries in this segment also endorse growth hypothesis (29%) as a dominant outcome, indicating the instrumentality of electricity so long as the economic growth of these middle-income countries are concerned. We also notice from Table (2.6) that the middle-income countries are the fastest growing economies that require an uninterrupted supply of electricity for sustained economic growth (Abeberese, 2017).

TABLE 2.3: Literature on middle Income Countries

Country	Author(s)	Period	Results (method)	Energy
Subsidizing				
Algeria	Squalli, 2007	1980-2003	Neutral (UECM, TY)	Surplus
	Wolde-Rufael, 2006	1971-2001	Neutral (UECM, TY)	
Angola	Solarin, Shahbaz, and Shahzad, 2016	1971-2012	Feedback (VECM)	Surplus
Cameron	Bildirici, 2013	1970-2010	Growth (ARDL, VECM)	Surplus
	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	
Congo Rep	Bildirici, 2013	1970-2010	Growth (ARDL, VECM)	Surplus
	Wolde-Rufael, 2006	1971-2001	Neutral (UECM, TY)	
Colombia	Yoo and Kwak, 2010	1975-2006	Growth (VECM)	Surplus
	Murry and Nan, 1994	1970-1990	Conservation(VAR, GC)	
Egypt	Wolde-Rufael, 2006	1971-2001	Feedback (UECM, TY)	Surplus
Ecuador	Yoo and Kwak, 2010	1975-2006	Growth (VECM)	Surplus
Indonesia	Chen, Kuo, and Chen, 2007	1971-2001	Growth (ECM, GC)	Surplus
	Squalli, 2007	1980-2003	Growth (UECM, TY)	
	Yoo, 2006a	1971-2002	Conservation (ECM, GC)	
	Yoo and Kim, 2006	1971-2002	Conservation (ECM, GC)	
	Murry and Nan, 1994	1970-1990	Conservation(VAR, GC)	
Iran	Squalli, 2007	1980-2003	Feedback (UECM, TY)	Surplus
Iraq	Squalli, 2007	1980-2003	Neutral (UECM, TY)	Surplus
Libya	Squalli, 2007	1980-2003	Neutral (UECM, TY)	Surplus
Malaysia	Tang and Tan, 2013	1970-2009	Feedback (ARDL, VECM)	Surplus
	Chandran, Sharma, and Madhavan, 2010	1971-2003	Growth (ARDL, VECM)	
	Tang, 2008	1972-2003	Feedback (ARDL, GC)	

Country	Author(s)	Period	Results (method)	Energy
	Chen, Kuo, and Chen, 2007	1971-2001	Conservative (ECM, GC)	
	Yoo, 2006a	1971-2002	Feedback (ECM, GC)	
	Murry and Nan, 1994	1970-1990	Feedback (VAR, GC)	
Maxico	Narayan and Prasad, 2008	1960-2002	Neutral (Bootstrap)	Surplus
	Murry and Nan, 1994	1970-1990	Conservation(VAR, GC)	
Russia	Tursoy, Resatoglu, et al., 2016	1990-2011	Feedback (VAR, TY)	Surplus
	Cowan et al., 2014	1990-2010	Feedback (Panel Causality)	
	Wolde-Rufael, 2014	1975-2010	Conservation (Bootstrap)	
South Africa	Cowan et al., 2014	1990-2010	Conservation (Panel Causality)	Surplus
	Bah and Azam, 2017	1971-2012	Neutral (ARDL, UECM, TY)	
	Odhiambo, 2009	1971-2006	Feedback (ECM, GC)	
	Wolde-Rufael, 2006	1971-2001	Neutral (UECM, TY)	
Venezuela	Yoo and Kwak, 2010	1975-2006	Feedback (VECM)	Surplus
	Squalli, 2007	1980-2003	Growth (UECM, TY)	
Vietnam	Long, 2018	1990-2015	Growth (ARDL, VECM, TY)	Surplus
Albania	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1971-2009	Conservation (ARDL)	
Argentina	Yoo and Kwak, 2010	1975-2006	Growth (VECM)	Deficit
Bangladesh	Ahamad and Islam, 2011	1971-2008	growth (VECM)	Deficit
	Mozumder and Marathe, 2007	1971-1999	Conservation (VECM)	
Belarus	Wolde-Rufael, 2014	1975-2010	Growth (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1971-2009	Feedback (ARDL bound)	
Brazil	Usman, Iortile, and Ike, 2020	1971-2014	Feedback (FOLS/DOLS)	Deficit
	Cowan et al., 2014	1990-2010	Neutral (Panel Causality)	
	Yoo and Kwak, 2010	1975-2006	Growth (VECM)	
China	Wu et al., 2019	1971-2014	Feedback (Bootstrap ARDL)	Deficit
	Zhong et al., 2019	1971-2009	Growth (ARDL, VECM)	
	Lin and Wang, 2019	2000-2016	Feedback (Panel VAR, GMM)	
	Wang, Zhao, and Li, 2018	1992-2016	Conservation (Boostrap)	
	Cowan et al., 2014	1990-2010	Neutral (Panel Causality)	
	Yuan et al., 2007	1978-2000	Growth (ECM, GC)	
	Chen, Kuo, and Chen, 2007	1971-2001	Neutral (ECM, GC)	
	Shiu and Lam, 2004	1971-2000	Growth(ECM, GC)	
Chile	Yoo and Kwak, 2010	1975-2006	Growth (VECM)	Deficit
El Salvador	Murry and Nan, 1994	1970-1990	Conservation(VAR, GC)	Deficit
Ghana	Bildirici, 2013	1970-2010	Feedback (ARDL, VECM)	Deficit
	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	
Guatemala	Bildirici, 2013	1970-2010	Feedback (ARDL, VECM)	Deficit
India	Wu et al., 2019	1971-2014	Growth (Bootstrap ARDL)	Deficit
	Abeberese, 2017	2001-2008	Growth (IV estimation)	
	Cowan et al., 2014	1990-2010	Neutral (Panel Causality)	
	Ghosh, 2009	1970-2006	Conservation (ARDL, VECM)	
	Chen, Kuo, and Chen, 2007	1971-2001	Neutral (ECM, GC)	
	Ghosh, 2002	1950-1996	Conservation(GC)	
	Murry and Nan, 1994	1970-1990	Neutral (VAR, GC)	
Labanon	Fakih and Marrouch, 2015	1980-2011	Conservation(VECM)	Deficit
	Abosedra, Dah, and Ghosh, 2009	1995-2005	Growth (VAR, GC)	
Morocco	Wolde-Rufael, 2006	1971-2001	Feedback (UECM, TY)	Deficit
	Bildirici, 2013	1970-2010	Neutral (ARDL, VECM)	
Pakistan	Shahbaz and Lean, 2012	1972-2009	Feedback (VECM)	Deficit
	Murry and Nan, 1994	1970-1990	Growth (VAR, GC)	

Country	Author(s)	Period	Results (method)	Energy
Senegal	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	Deficit
	Bildirici, 2013	1970-2010	Conservation (ARDL, VECM)	
Sri Lanka	Morimoto and Hope, 2004	1960-1998	Growth (GC)	Deficit
Thailand	Yoo, 2006a	1971-2002	Conservation (ECM, GC)	Deficit
	Chen, Kuo, and Chen, 2007	1971-2001	Neutral (ECM, GC)	
Tunisia	Wolde-Rufael, 2006	1971-2001	Growth (UECM, TY)	Deficit
Ukraine	Wolde-Rufael, 2014	1975-2010	Feedback (Bootstrap)	Deficit
Zambia	Bildirici, 2013	1970-2010	Conservation (ARDL, VECM)	Deficit
	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	
	Murry and Nan, 1994	1970-1990	Neutral (VAR, GC)	
Zimbabwe	Samu, Bekun, and Fahrioglu, 2019	1971-2014	Growth (DOLS, TY)	Deficit
	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	
Non-subsidizing				
Nigeria	Iyke, 2015	1971-2011	Growth (VECM)	Surplus
	Akinlo, 2009	1980-2006	Growth (ECM, GC)	
	Squalli, 2007	1980-2003	Growth (UECM, TY)	
	Wolde-Rufael, 2006	1971-2001	Conservation (UECM, TY)	
Peru	Yoo and Kwak, 2010	1975-2006	Neutral (VECM)	Surplus
Benin	Wolde-Rufael, 2006	1971-2001	Growth (UECM, TY)	Deficit
Bulgaria	Wolde-Rufael, 2014	1975-2010	Growth (Bootstrap)	Deficit
	E Bildirici and Kayikci, 2012	1971-2009	Growth (ARDL bound)	
Fiji	Narayan and Singh, 2007	1971-2002	Growth(ARDL, UECM)	Deficit
Gabon	Bildirici, 2013	1970-2010	Feedback (ARDL, VECM)	Deficit
	Wolde-Rufael, 2006	1971-2001	Feedback (UECM, TY)	
Jamaica	Ramcharran, 1990	1970-1986	Growth (Demand model)	Deficit
Kenya	Bildirici, 2013	1970-2010	Growth (ARDL, VECM)	Deficit
	Wolde-Rufael, 2006	1971-2001	Neutral (UECM, TY)	
	Murry and Nan, 1994	1970-1990	Conservation(VAR, GC)	
Lao PDR	Kyophilavong et al., 2017	1984-2012	Conservation (ARDL, VECM)	Deficit
Moldova	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
Philippines	Chen, Kuo, and Chen, 2007	1971-2001	Conservation (ECM, GC)	Deficit
	Murry and Nan, 1994	1970-1990	Neutral (VAR, GC)	
Serbia	Wolde-Rufael, 2014	1975-2010	Neutral (Bootstrap)	Deficit
Turkey	Etokakpan et al., 2020	1970-2014	Growth (ARDL, VECM)	
	Aslan, 2014	1968-2008	Feedback (ARDL)	
	Acaravci and Ozturk, 2012	1968-2006	Growth (ARDL, VECM)	
	Acaravci, 2010	1968-2005	Growth (VECM)	
	Narayan and Prasad, 2008	1960-2002	Neural (Bootstrap)	
	Altinay and Karagol, 2005	1950-2000	Growth (TY, DL)	
	Murry and Nan, 1994	1970-1990	Growth (VAR, GC)	Deficit

The low-income countries are the final group of economies, in which we analyze 8 studies on 8 different countries (Table 2.4). Almost all the studies support either growth or feedback hypothesis, indicating the vital role of electricity for these countries. Being economically constrained, only 2 out of the 8 countries subsidize their energy system. Among the non-subsidized countries, all of them endorse either feedback or growth hypothesis (Sekantsi and Okot, 2016; Solarin, 2014 Bildirici, 2013; Ouédraogo, 2010; Wolde-Rufael, 2006; Jumbe, 2004). On the other hand, for subsidizing countries, we find evidence of growth and neutrality hypothesis (Bildirici, 2013; Wolde-Rufael, 2006). One of the most important findings from the literature is that the low-income countries do not endorse conservation hypothesis, implying expansion of electrification will propagate economic growth. Therefore, restricting electricity expansion for this group is likely to jeopardize their economic growth and basic electricity requirements for the population.

TABLE 2.4: Literature on low Income Countries

Country	Author(s)	Period	Results (method)	Energy
Subsidizing				
Mozambique	Bildirici, 2013	1970-2010	Growth (ARDL, VECM)	Surplus
Sudan	Wolde-Rufael, 2006	1971-2001	Neutral (UECM, TY)	Deficit
Non-subsidizing				
Congo DR	Wolde-Rufael, 2006	1971-2001	Growth (UECM, TY)	Surplus
Burkina Faso	Ouédraogo, 2010	1968-2003	Feedback (ARDL, VECM)	Deficit
Ethiopia	Bildirici, 2013	1970-2010	Growth (ARDL, VECM)	Deficit
Malawi	Jumbe, 2004	1970-1999	Feedback(ECM, GC)	Deficit
Togo	Solarin, 2014	1971-2009	Growth (ARDL, VECM)	Deficit
Uganda	Sekantsi and Okot, 2016	1981-2013	Feedback (ARDL, GC)	Deficit

Apart from income, we also see whether resource availability makes any difference in electricity consumption. To do so, we divide the global outcomes into two separate groups based on countries that are energy surplus or deficit. Surprisingly, we did not find much difference in outcomes as all the four hypotheses are evenly distributed in each resource category. Specifically, in the energy surplus countries, they are distributed as 28% growth, 26% conservation, 25% feedback and 21% neutral; and, in the energy deficit countries, 28% neutral, 27% growth, 22% feedback and 21% conservation. Similarly, if we analyze the outcomes of the global sample based on energy subsidies, again we see an even distribution of the four hypotheses between the categories, reinforcing the idea that the income level is more crucial for different outcomes than energy availability. We further examine if the dominance of a particular hypothesis depends on the interaction between the availability of energy resources and prevalence of energy subsidies, as we have seen resource-rich countries tend to subsidize their energy system highly, which is evident from oil-rich Middle Eastern countries. In the energy surplus countries that subsidize their economy, the feedback (30%) is the dominant outcome, but in the non-subsidized economy, the growth (45%) is dominant. On the other hand, the case of energy deficit countries is different where we see dominance of growth (30%) in subsidized economy, but neutral (31%) in the non-subsidize ones. The summary of the review is presented in Table (2.5).

In addition to the analysis on individual countries, the literature has a number of

TABLE 2.5: Summary of the litterateur review

Groups	Growth (%)	Conservation (%)	Feedback (%)	Neutral (%)
Global	28	22	24	26
HIC	15	22	28	35
MIC	34	24	21	21
LIC	50	0	38	13
Subsidized	27	27	24	22
Non Subsidized	28	17	24	30
Energy surplus	28	26	25	21
Energy deficit	27	21	22	28

*No. of outcomes: 188

cross-country or cross-state studies conducted on panel data framework. The predominant conclusion of these group specific studies is feedback hypothesis as we see from the analysis of global panel consisting 210 countries (Sarwar, Chen, and Waheed, 2017), 160 countries (Karanfil and Li, 2015), 93 countries (Narayan, Narayan, and Popp, 2010) and 88 countries(Apergis and Payne, 2011a). The feedback hypothesis is also predominant in the sub-global studies, as we find that in the analysis on 21 emerging economies (Bayar, Özel, et al., 2014), 18 Latin American countries (Al-Mulali, Fereidouni, and Lee, 2014), 16 emerging economies (Apergis and Payne, 2011b) and 6 countries each from the Middle East (Narayan and Smyth, 2009) $ Gulf Cooperation Council (GCC) (Osman, Gachino, and Hoque, 2016). In some of the panel analysis, we find the prevalence of growth hypothesis also in the studies of 45 developing countries (Das, Chowdhury, and Khan, 2012), 12 European Union members (Ciarreta and Zarraga, 2010a) and 5 ASEAN countries (Lean and Smyth, 2010). The conservation and neutrality are the less common types of hypotheses found in any panel study. Kirikkaleli et al., 2018 conducted a study on 35 OECD countries where they conclude conservation hypothesis while a study on 15 European transition countries conducted by Acaravci and Ozturk, 2010, reveals neutrality hypothesis. Another very interesting research on 48 states of the USA concluded that growth hypothesis is appropriate for the industrial sector while conservation is for residential and commercial sectors (Saunoris and Sheridan, 2013). In a similar note, a panel study across 210 prefecture cities of China categorically shows that industrial consumption of electricity promotes economic growth and human capital (Chen and Fang, 2018). The panel findings here are similar to the reflection of the whole paradigm of electricity-growth nexus where we observe the instrumental role of electricity in growing industrial economies versus the discretionary consumption opportunities of electricity in economically affluent countries.

To sum up, we have seen the crucial role of electricity globally and especially in the emerging economies. The literature survey indicates electricity consumption promotes economic growth either alone (28%) or in conjunction with electricity consumption (24%). The survey, however, does not indicate that growth of income disproportionately propagates electricity consumption, which maybe the case for high-income (22%) or energy surplus (26%) countries. The rest of the subcategories in the literature survey follow similarly to the trend of the global outcomes where electricity consumption promotes economic output.

2.4 Methodology

2.4.1 Data and variable description

The panel data set for this study is constructed from multiple sources based on data availability. In addition to Table (2.1), the key variables and the average growth rate are shown in Table (2.6). Annual data for 172 countries are constructed here for each variable for the period of 2010-2017. The real GDP data is collected from Penn World Table 9, which is adjusted by year 2011 (US$) constant price (Zeileis, 2019). Data on electricity consumption (kWh) and final price of electricity (US$/kWh) to the consumer are collected from International Monetary Fund (IMF) subsidy template (IMF, 2019). Capital and labour as input in the production function are collected from World Development Indicators (WDI), where gross capital formation is a proxy for capital and total labour force is defined by the workers who are more than 15 years of age (WDI, 2020). Apart

TABLE 2.6: Summary statistics.

		Subsidy			No subsidy		
Per capita*	Global	LIC	MIC	HIC	LIC	MIC	HIC
GDP(US$)	18,893	2,925	10,044	47,760	1,431	9,594	37,240
	(3.19)	(-2.96)	(4.12)	(2.62)	(6.00)	(5.04)	(2.02)
Capital (US$)	3,322	208	1,084	7,510	135	1,207	7,926
	(1.27)	(3.04)	(-6.40)	(3.33)	(5.32)	(6.68)	(3.10)
Labor (million)	19.30	6.64	39.90	6.93	8.34	7.28	12.10
	(1.03)	(1.87)	(.88)	(1.58)	(.21)	(1.67)	(.59)
Elect. price (US$/ Kwh)	.17	.12	.13	.14	.21	.17	.21
	(-1.52)	(-1.41)	(-2.67)	(-.78)	(-1.66)	(-1.13)	(-.66)
Obs. (N)	1376	48	448	120	144	272	334

*The growth rates (%) are in the parenthesis.

from the above mentioned continuous variables, we also made use of three categorical variables, namely: income, subsidy and energy resource. According to the World Bank income classification, the level of development of the countries is categorized in three groups, where the high-income group's GDP (2019) is equal to US$12,536/- or above, low income group's GDP is below US$1035/- and middle-income group's GDP is in between. As a result, we have come up with 58 high-income countries, 90 middle-income countries and 24 low-income countries. Next, we classify the countries according to resource availability, which is performed by comparing the total annual production of energy and consumption thereof in the study period. The cumulative energy data is collected from US Energy Information Administration (EIA) where we have isolated 48 energy surplus countries that had positive energy balances in at least 4 out of 8 years during the study period (EIA, 2020). Finally, we have constructed an indicator for subsidy from IMF subsidy template, where we find 46 countries provide 0 US$ subsidy to their energy system and additionally, another 49 countries provide a bare minimum subsidy up to 10 US$ per capita per year. Combining these two groups together, we find 95 lower subsidy providing countries while the remaining 77 countries are categorized as higher subsidy providing countries with an average subsidy of 243 US$ per capita per year. To understand the dynamic evaluation of the variables, we find that while the global GDP growth is 3.16%, the growth rates of capital and labour are around one-third of the GDP. The highest growth rate during this period is achieved by the middle-income countries ranging from 4% to 5% annually. The price of electricity, on the other hand, is decreased by 1.5% annually during the study period with the highest reduction being in the energy subsidized economies compared to the non-subsidized ones. This price reduction is particularly evident in the MICs with subsidies compared to their non-subsidizing counterparts.

2.4.2 Empirical specification

In demonstrating the relationship between economic growth and electricity consumption, we see a recent development of a multivariate approach instead of classical bivariate specification. The argument is that multivariate specification is more likely to address the issue of omitted variable bias as it incorporates other key macroeconomic variables that are intricately related to the electricity-growth nexus. The literature review above clearly indicates that these two principal variables may have causal relations on each other based on the four above-mentioned hypotheses. To investigate the relationship, we have introduced here two baseline models namely; electricity consumption based economic growth model and income & price lead electricity demand model. In line with the objectives of the study and the short panel size (T=8) of the data, we introduce two-step efficient GMM estimation technique to minimize the data loss in our analysis (Roodman, 2009). Owning to the advantage of the dynamic panel modeling, the persistence of the autoregressive lag dependent variable is utilized here to make a distinction between short and long run estimations of the coefficients.

i) Electricity lead economic growth

In the growth literature, the role of energy in economic growth is controversial. Classical growth theories such as Harod-Domar or Solow-Swan models do not endorse energy as an individual input in the production function. Energy economists, on the other hand, argue that unlike other consumer goods, energy has a unique capacity to transform itself into "productive energy", entailing to be a factor of production in addition to capital and labour in the classical production function (Pokrovski, 2003). This is because, a significant portion of energy is used in producing other intermediate or final goods, which in turn augments the production. However, compared to capital and labor, the monetary share of energy in the economy is insignificant (Ghali and El-Sakka, 2004; Lee and Chang, 2008). In this controversy, to emphasize the crucial role of energy in the economy, Moroney, 1992, argues that the small cost share in GNP does not mean that energy has a secondary role in the production process. Therefore, energy (or electricity) as a third component in the production function is proposed in many studies as shown in equation (2.1) for a modified aggregate production function. (Etokakpan et al., 2020; Long, 2018; Bah and Azam, 2017; Kyophilavong et al., 2017; Das, Chowdhury, and Khan, 2012; Shahbaz and Lean, 2012; Apergis and Payne, 2011a).

$$Y = f(K, L, E) \tag{2.1}$$

Following the Cobb-Douglas production technology in a multivariate framework to explore the relation between electricity consumption and economic growth, we propose equation (2.2) for the panel data framework.

$$Y_{it} = cK_{it}^{\alpha} L_{it}^{\beta} E_{it}^{\gamma} e^{\mu_{it}} \tag{2.2}$$

The trans-log version of the above equation can easily be expressed by the following equation:

$$lnY_{it} = lnc + \alpha lnK_{it} + \beta lnL_{it} + \gamma lnE_{it} + \mu_{it} \tag{2.3}$$

Equation (2.3) is convenient for estimating elasticity where $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\gamma}$ represent the elasticity of capital (K), labour (L) and electricity consumption (E), Y is income, μ_{it} is i.i.d error, i is country, t is year and c is constant term.

ii) Income and price lead electricity demand

The theory of basic economics indicates that demand for any consumer good principally depends on income and price. Following the concept of Tang and Tan, 2013, and Sterner, 2007, among others, we propose a model that provides us with price and income elasticity of the demand for electricity in an aggregate economy. Demand of electricity, in addition to these two variables, also depends on other macroeconomic variables such as capital formation and labor hours put in the economy. Similar to the economic growth model, we propose electricity demand model by the following equation:

$$E_{it} = cP_{it}^{\alpha}Y_{it}^{\beta}K_{it}^{\gamma}L_{it}^{\lambda}e^{\mu_{it}} \tag{2.4}$$

The trans-log version of the above equation can easily be expressed by the following equation:

$$lnE_{it} = lnc + \alpha lnP_{it} + \beta lnY_{it} + \gamma lnK_{it} + \lambda lnL_{it} + \mu_{it} \tag{2.5}$$

In equation (2.5), $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$ and $\hat{\lambda}$ represent estimations of price (P), income (Y), capital (K) and labour (L) elasticity for electricity consumption (E) in an economy respectively.

We did not consider the supply side of energy in the analysis as it depends on a host of factors including mining extraction, international trade and geopolitical environment, which are beyond the scope of the paper.

2.4.3 Dynamic panel specification

One of the fundamental shortcomings of the model specifications in equations (2.3) and (2.5) above is that they demonstrate the contemporaneous relationships only, ignoring the persisting nature of the variables under consideration (Sterner, 2007). Take the demand for electricity as an example, where we see it takes a long time to adjust the level of demand in the economy as infrastructure development spending spreads over more than a single year. In other words, electricity consumption in a particular year is not just a function of that particular year's price and income, but rather a cumulative effect of historic prices and incomes. Therefore, it is customary to use so-called lagged dependent variable as regressor as follows:

$$lnY_{it} = lnc + \theta lnY_{it-1} + \alpha lnK_{it} + \beta lnL_{it} + \gamma lnE_{it} + \mu_{it} \tag{2.6}$$

$$lnE_{it} = lnc + \theta lnE_{it-1} + \alpha lnP_{it} + \beta lnY_{it} + \gamma lnK_{it} + \lambda lnL_{it} + \mu_{it} \tag{2.7}$$

Another advantage of the dynamic specification above is that the auto-regressive coefficient (θ) is used for measuring the cumulative long-run effects of the coefficients by summing up the contemporaneous impact along with all other delayed effects back to the infinite future by the following equation:

$$\hat{A} = \frac{\hat{\alpha}}{1 - \hat{\theta}} \tag{2.8}$$

Where, $\hat{A}$ and $\hat{\alpha}$ are long and short run elasticity of capital (K), respectively, $\hat{\theta}$ is autoregressive coefficient. For a stable system, the absolute value of $\hat{\theta}$ is needed to be less than unity. Within this range, the higher value of $\hat{\theta}$ indicates longer persistence of the elasticity concerned.

2.4.4 Estimation strategies

Estimating the above mentioned dynamic models (generalized in equation 2.9) by ordinary least square (OLS) method has a number of problems even if country-specific heterogeneity is controlled for by first difference or time-demeaning (within-groups) transformation. Bias generated by the endogenous variables (Y_{it-1}) in the level equation eventually persists in the transformed equations (Nickell, 1981; Bond, 2002). This so-called dynamic panel, or Nickell bias, arises due to the fact that by construction ΔY_{it-1} and $\Delta \mu_{it}$ are correlated or $E(\Delta Y_{it-1} .\Delta \mu_{it}) \neq 0$. So, this violates the assumption necessary for consistent OLS estimation of equation (2.10).

$$Y_{it} = \alpha_0 + \sum_{j=1}^{m} \alpha_j Y_{it-j} + \sum_{j=0}^{m} \beta_j X_{it-j} + a_i + \epsilon_{it} \tag{2.9}$$

First difference transformation of equation (2.9) is,

$$\Delta Y_{it} = \sum_{j=1}^{m} \gamma_j \Delta Y_{it-j} + \sum_{j=0}^{m} \delta_j \Delta X_{it-j} + \Delta \mu_{it} \tag{2.10}$$

This violation is a contribution to the fact that Y_{it-1} and μ_{it-1} are contemporaneously correlated in any dynamic specifications as both of them are part of the dynamic differenced terms $\Delta Y_{it-1} = (Y_{it-1} - Y_{it-2})$ and $\Delta \mu_{it} = (\mu_{it} - \mu_{it-1})$, respectively. Similarly, in the case of within-groups transformation, the lagged endogenous transformed variable is correlated with the transformed error terms making OLS bias again. This bias becomes significant, in particular, when T is small, as with large T the dynamic panel bias dwindles due to the fact that a single year's shock on the fixed effect would not persist for long periods (Roodman, 2009). This type of long panel can be estimated efficiently by the conventional fixed-effects estimator as the endogeneity problem that arises by the dynamic term will not interfere with the estimation.

To solve this endogeneity issue in our short panel data, we use instrumental variables, which eventually are generated from within the data generating process. In this case, we use the level lag term of the endogenous variable (Y_{it-2}) or further distant lags as instruments for the troublesome term ΔY_{it-1} in the differenced equation (Arellano and Bond, 1991). These instruments are relevant as Y_{it-2} is a part of ΔY_{it-1} and due to auto-regressive path, the distant lags are likely to be correlated with the endogenous term under consideration. The exclusion restriction of the instruments comes from the fact that the current or past values of a variable are not correlated with the future error terms. This sequential exogeneity assumption allows us to test the validity of the instruments in over-identifying restriction setting. In another version of this approach, we also estimate the level equation (2.9) by instrumenting the endogenous variable Y_{it-1} with ΔY_{it-1} or further distant lagged differences as these first difference instruments are uncorrelated with the fixed effect (α_i) of the level equation. As a system of two equations is estimated simultaneously, this estimation is called system estimation technique (Blundell and Bond, 1998; Arellano and Bover, 1995).

After specifying the model with either formats (difference or system), generalized methods of moments (GMM) estimator is commonly used. Theoretically, the moment conditions arise from the concept of exclusion restriction where we assume that the error terms of the structural equations are uncorrelated with the instruments.

$$E[\Delta\mu_{it}.Y_{it-j}] = 0 \tag{2.11}$$

where, $\forall_j, j = 2, ...t-1; t = 3, ...T$ for difference equation and $E[\mu_{it}.\Delta Y_{it-1}] = 0$ for the system variation. Practically, to find out the moment condition in population, we solve $E[Z'\hat{E}] = 0$ or the equation (2.12) below where $\hat{\beta}$ is the unique $k \times 1$ vector, Y is a column vector of dependent variables, X is the regressor matrix, Z is the instruments matrix and $\hat{E}$ is a column vector of empirical residuals .

$$E[Z'(Y - X\hat{\beta})] = 0 \tag{2.12}$$

2.4.5 Specification tests

The validity of the instruments crucially depends on the assumption that the instruments are not correlated with the structural errors. In the case of just identified model where the number of instruments are equal to the number of endogenous variables, detecting validity is not possible because the estimation of $\hat{\beta}$ here will be done by equating $Z'\hat{E} = 0$ exactly, despite the fact that $E[Z'(Y - X\hat{\beta})] \neq 0$. However, for over-identified model, joint validity of the moment conditions can easily be conducted by Sargan test for over-identifying restrictions. The null hypothesis of the test is to construct a random distribution of the values of the practical moments, i.e., $(1/N)Z'\hat{E}$ around 0. The hypothesis can be tested by the following statistic:

$$s = ((1/N)Z'\hat{E})'Var(Z'\epsilon)^{-1}(1/N)Z'\hat{E}) \tag{2.13}$$

Under the null hypothesis, s has a χ^2 distribution with $M - k$ degrees of freedom, where M is the number of instruments and k is the number of regressors in the model, $Var(Z'\epsilon)$ is variance of moments and N is the sample size. Hansen, 1982 estimated the equation (2.13) efficiently by introducing J test statistic as follow:

$$J = (1/N)(Z'\hat{E})'(Z'Z)^{-1}Z'\hat{E} \tag{2.14}$$

The second specification test for the dynamic panel model above is residual serial correlation test, which indicates that the presence of second order serial correlation ($AR(2)$) in the difference equation which can make the GMM estimator inconsistent. This is due to the fact that the absence of second order correlation allows the second lag of the level variable Y_{it-2} to be a valid instrument for ΔY_{it-1}. Therefore, it is imperative to hold that $E(\mu_{it}.\mu_{it-2}) = 0$; but it is not a problem if $E(\mu_{it}.\mu_{it-1})$ is not equal to zero in the transformed equation. For a rightly specified model, we do not reject the null hypothesis for both the specification tests.

2.5 Empirical results

Provided the short period (8 years) and sufficiently large panel of this study, we have employed dynamic panel specification for an unbiased estimation by eliminating the persistence of year-specific shocks on the estimates (Bond, 2002). On the other hand, due to large $AR(1)$ coefficients of the time series component of the panel data, we have used system GMM approach which enables a large set of instruments from both the level and differences equations (Roodman, 2009). To select appropriate instruments, we ensure sufficient strength by testing over-identifying restrictions, and to ensure relevance we rule out second order serial correlation of the variables. Apart from endogenous instruments, we also use exogenous instruments to improve the results. To correct another specification issue, we use orthogonal deviation technique instead of first difference in the system of equations to overcome the problem that arises from missing observations as we know this method is based on the principle that the difference value is generated not on the basis of the two sequential values but rather on the average of all the available foreword values in the data set, minimizing the dominance of individual quantities or gaps in the observations.

TABLE 2.7: Summary of the findings

Samples	Elasticity (SR/LR)		
	Demand ($\Delta Y/\Delta E$)	*Income* ($\Delta E/\Delta Y$)	*Price* ($\Delta E/\Delta EP$)
Endorsing Growth Hypothesis			
Global	$.05^{***}/.21^{**}$		
Subsidized	$.08^{***}/.26^{***}$		
Surplus	$.07^{***}/.27^{***}$		
Deficit	$.04^{***}/.19^{**}$		
MIC	$.06^{***}/.22^{***}$		
MIC-subsidized	$.10^{***}/.29^{**}$		
Deficit-subsidized	$.07^{***}/.24^{***}$		
Endorsing Conservation Hypothesis			
HIC		$.10^{*}/.44^{**}$	$-.05^{**}/-.21^{***}$
HIC-non sub.		$.03/.19$	$-.10^{***}/-.57^{***}$
HIC-deficit		$.10^{*}/.77^{*}$	$-.05^{**}/-.43^{***}$
Surplus		$.16^{*}/1.01^{***}$	$-.07^{*}$/-.43

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

In reporting the results, we follow a strict set of criteria across all the groups for better comparison. For testing the validity of the instruments, we use Sargan/Hansen joint validation test; for testing the appropriateness of the lags as instruments in the model, we use Arellano and Bond test for second order autocorrelation; for eliminating any possible cross-individual correlation, we use time dummies in each specification; for restricting instrument proliferation in the model, we limit the instruments in such a way that the number of groups is higher than the number of instruments in each model; and finally, we report robust standard errors only to control for heteroskedasticity. Regarding Hansen test, we confirm the validity of the instruments only when the p-value is not below 0.05 or not exactly on 1.0 for that matter. We assume that within this range, if we fail to reject the null hypothesis of strong instruments, we take the instruments as valid for that model. Lastly, for rejecting the null hypothesis of 2nd order auto-correlations, we do not accept p-value below 0.05 also. Based on the specifications and criteria set above, we have summarized the findings of 11 well-specified samples in Table (2.7). In general, we see the dominance of growth hypothesis in different groups and sub-groups with somewhat similar levels of demand, income and price elasticity of electricity, while the conservation hypothesis dominates in HIC and energy surplus categories.

TABLE 2.8: Results: Growth model

Y_{it}	Global	Subsidy	Surplus	Deficit	MIC	Subsidy-MIC	Subsidy-Deficit
Short run							
ΔY_{it-1}	.76***	.68***	.73***	.77***	.74***	.66***	.69***
$\Delta E_i t$	.05***	.08***	.07*	.04***	.06**	.10***	.07***
ΔK_{it}	.13***	.17***	.13***	.12***	.13***	.15***	.16***
ΔL_{it}	.01	.02***	-.00	.01	.02***	.02***	.02***
Δ year*	yes	yes	yes	yes	yes	yes	yes
Long run							
E_{it}	.21***	.26***	.27**	.19***	.22***	.29***	.24**
K_{it}	.53***	.53***	.50***	.53***	.49***	.44***	.53***
L_{it}	.02	.05***	-.01	.02	.06***	.05***	.06***
Specification tests							
Hansen:p	.21	.65	.35	.07	.25	.84	.86
AR(2):p	.25	.72	.83	.27	.27	.37	.48
Instruments	20	20	20	20	20	20	20
Groups	146	62	37	109	75	49	47
N	1003	416	253	750	510	329	317

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

The detailed results for all the 24 groups/sub-groups are included in the Appendix (2A.2). Examining all the estimates, we find that 7 of these samples are following energy lead economic growth hypothesis with appropriate specifications (Table 2.8). As we see the predominance of growth hypothesis in the summary of the findings, the global sample is no exception with both short and long run elasticity of 0.05% and 0.21%, respectively. The results show conformity with the literature reviews, where we find that the highest among the four hypotheses (45%) of the outcomes from 45 studies on 97 different countries endorses the growth hypothesis. Dividing the global sample based on energy subsidy, we see our results on subsidized economies consisting of 77 countries, also endorse growth hypothesis with short and long run elasticity of 0.08% and 0.26%, respectively. The results are also aligned with the literature review where we see that both the growth and conservation hypotheses are equally dominant, indicating subsidized economies are very much sensitive to energy shocks.

Interestingly, both the energy surplus and deficit countries endorse growth hypothesis indicating the importance of electricity in these two opposite economic situations. Turning to how the income levels impacts the economic outcomes, we find only the middle-income countries endorse growth hypothesis, especially those that subsidize their economy, which have the highest impact of electricity consumption on GDP growth. The literature also confirms that growth is the dominant hypothesis for middle-income countries (see Table 2.5). The final category in this segment is the energy deficit group that subsidizes the energy system. We have already noticed that energy deficit countries are in favour of energy lead growth hypothesis. Within this category, the countries that subsidize their energy system also endorse growth hypothesis.

TABLE 2.9: Results: Conservation model

E_{it}	HIC	HIC-Deficit	HIC-No Sub.	Surplus
Short run				
ΔE_{it-1}	$.77^{***}$	$.87^{***}$	$.83^{***}$	$.84^{***}$
ΔY_{it}	$.10^{*}$	$.10^{*}$	.03	$.16^{*}$
ΔEP_{it}	$-.05^{**}$	$-.05^{**}$	$-.10^{***}$	$-.07^{*}$
ΔK_{it}	$.08^{**}$	.02	$.08^{**}$	.03
ΔL_{it}	.00	-.00	-.01	.01
Δ year*	yes	yes	yes	yes
Long run				
Y_{it}	$.44^{**}$	$.77^{*}$	.19	1.01^{***}
EP_{it}	$-.21^{*}$	$-.43^{***}$	$-.57^{***}$	-.43
K_{it}	$.35^{***}$	.14	$.47^{***}$	.21
L_{it}	.00	-.02	-.03	-.04
Specification tests				
Hansen:p	.27	.06	.08	.09
AR(2):p	.87	.87	.97	.15
Instruments	22	22	22	22
Groups	49	36	40	37
N	341	252	280	251

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Next, we see how GDP and price of electricity influence electricity consumption in different country categories. Unlike the growth hypothesis, conservation hypothesis is not generally true across different groups. We find 4 such categories, of which 3 are HICs and the 4th one is energy surplus category (Table 2.9). In general, the HIC category shows that a 1% increase in GDP would induce 0.10% and 0.44% increases in energy consumption in the short and long run respectively. Apart from income, electricity price also influences energy demand in the HIC group, where we see a 1% decrease in energy price leads to 0.05% and 0.21% increases in electricity demand in the short and long run respectively. Although the literature survey indicates the predominance of the neutrality hypothesis (35%) in the HIC category, our results indicate conservation hypothesis for this income group. It is not surprising that the growth hypothesis is the lowest outcome (15%) in the literature amongst the high-income countries. We may infer here that high-income countries' economic growth is not pegged with electricity consumption. Two other HIC sub-category groups, namely HIC-Deficit and HIC-no subsidy, also display similar results as HICs. Incidentally, the energy surplus group is the only one that shows a feedback relation as this group also endorses the growth hypothesis in addition to conservation.

2.6 Discussion and policy implications

The findings have a number of implications regarding energy policy. First, the popular proposition that removal of energy subsidies would increase electricity price which in turn reduces electricity demand, seems to be true only for high-income countries. All the other groups in this study did not show substantial sensitivity towards price or income for electricity demand. This is due to the fact that unlike other consumer goods, electricity cannot be stored for a long time or traded across the border often. Being an essential commodity in modern time, ensuring sufficient electricity for the low- and middle-income countries should be prioritized even with energy subsidies. However, removal of subsidies from HICs may be a better policy option for gaining energy efficiency and better environmental outcomes.

Second, it is evident from the results that the economic growth of the middle income countries is coupled with the availability of electricity, which can be ensured by subsidizing the energy system. In other words, removal of subsidies from this segment would counteract economic growth negatively as numerous studies show unreliable electricity becomes a constraint in industrial development for the growing economies (Abeberese, 2017). The policy objective to keep economic output and electricity growth positive, these countries should switch their fuel mix away from a high to low-carbon electricity generation path even with subsidizing the energy system.

Third, the per capita electricity consumption in low-income countries is such an insignificant amount compared to the high-income counties that it did not make any difference in the aggregate economy as both the growth and conservation models did not provide significant estimations. To make electricity a driving force in the economy, public investment in the energy sector is essential as low-income countries lack efficient market and institutional capacity.

Finally, we see when the energy deficit countries are subsidized, the economy shows substantial improvement with electricity consumption both in the short and long run.

This makes energy subsidy important for energy deficit countries compared to the energy surplus ones.

The paper leads towards a number of areas for further study. First, the demand for electricity may be analyzed in different categories such as service, industry and agriculture to see which sector drives the demand for electricity most based on income or energy availability. Second, a study can be conducted on the role of energy subsidy on energy poverty in general and electricity in particular. Third, different income groups can be studied separately to examine the role of electricity in formation of fixed capital or human capital in the economy. In addition, the role of electricity price could be examined especially in the high income countries to measure the optimum price that would induce alternative fuel options or gain in energy efficiency.

2.7 Conclusion

The goal of the study is to investigate the impact of energy subsidies on the relationship between electricity consumption and economic growth of 172 countries between 2010-2017. In doing so, we have constructed a unique panel data set on the basis of energy availability and prevalence of energy subsidies over the study period. The analysis is conducted on global sample and then on 23 other sub-samples generated by interacting income level, subsidy and energy availability. The estimations are performed by dynamic panel method with two-step system GMM technique on each panel under strict specification criteria. The results suggest the prevalence of growth hypothesis in global sample and in most of the other sub-samples under consideration. Both the empirical evidence from the study and the literature survey conducted here show that electricity consumption and GDP are firmly coupled, especially in the middle and high-income countries. While the GDP of the middle-income group is influenced by electricity, GDP and electricity price influence electricity consumption in the high-income group without feedback. Therefore, energy subsidies in the middle-income countries have the potential to increase economic output, while removal of subsidies from the high-income groups may produce energy efficiency and better environmental outcomes.

Appendix 2A

2A.1 Country lists

High income countries (58), GDP per capita > US$12536:
Antigua and Barbuda, Aruba , Australia, Austria, Bahamas, Bahrain, Barbados, Belgium, Brunei, Darussalam, Canada, Chile, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, China, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Rep, Kuwait, Latvia, Lithuania, Luxembourg, Macao SAR China, Malta, Mauritius, Netherlands, New Zealand, Norway, Oman, Panama, Poland, Portugal, Qatar, Romania, Saudi Arabia, Seychelles, Singapore, Slovak Republic, Slovenia, Spain, St Kitts and Nevis, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, Uruguay
Middle income countries (90), GDP per capita US$12536-US$1035:
Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Cabo Verde, Cambodia, Cameroon, China, Colombia, Comoros, Congo Rep, Costa Rica, Cote d'Ivoire, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt Arab Rep, El Salvador, Equatorial Guinea, Eswatini, Fiji, Gabon, Georgia, Ghana, Grenada, Guatemala, Honduras, India, Indonesia, Iran Islamic Rep, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Lao PDR, Lebanon, Lesotho, Malaysia, Maldives, Mauritania, Mexico, Moldova, Mongolia, Montenegro, Morocco, Myanmar, Namibia, Nepal, Nicaragua, Nigeria, North Macedonia, Pakistan, Paraguay, Peru, Philippines, Russian Federation, Sao Tome and Principe, Senegal, Serbia, South Africa, Sri Lanka, St Lucia, St Vincent and the Grenadines, Suriname, Tanzania, Thailand, Tunisia, Turkey, Turkmenistan, Ukraine, Uzbekistan, Venezuela RB, Vietnam, Zambia, Zimbabwe
Low income countries (24), GDP per capita < US$1035:
Burkina Faso, Burundi, Central African Republic, Chad, Congo Dem Rep, Ethiopia, Gambia The, Guinea, Guinea-Bissau, Haiti, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, Sudan, Syrian Arab Republic, Tajikistan, Togo, Uganda, Yemen Rep

2A.2 Comprehensive results

TABLE 2.10: Combined results-(i)

Sample	Global		Subsidy				Energy availability			
Dept.			Yes		No		Surplus		Deficit	
variables	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}
Short run										
ΔY_{it}	-	-.02	-	-.03	-	-.01	-	.16^c	-	-.04
$\Delta E_i t$	.05^a	-	.08^a	-	.03^b	-	.07^c	-	.04^a	-
ΔY_{it-1}	.76^a	-	.68^a	-	.80^a	-	.73^a	-	.77^a	-
ΔE_{it-1}	-	1.02^a	-	1.03^a	-	.98^a	-	.84^a	-	1.03^a
ΔEP_{it}	-	-.00	-	.00	-	-.04	-	$-.07^c$	-	.01
ΔK_{it}	.13^a	-.01	.17^a	.00	.12^a	.02	.13^a	.03	.12^a	-.00
ΔL_{it}	.01	.00^b	.02^a	.00	-.01	-.00	-.00	.01	.01	.00
Δ year*	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Long run										
Y_{it}	-	1.01^c	-	1.03^a	-	-.34	-	1.01^a	-	1.26^a
E_{it}	.21^a	-	.26^a	-	.15^a	-	.27^b	-	.19^a	-
EP_{it}	-	.18	-	-.01	-	-2.83	-	-.43	-	-.15
K_{it}	.53^a	.36	.53^a	.12	.59^a	1.39	.50^a	.21	.53^a	.02
L_{it}	.02	-.19	.05^a	-.12	-.03	-.01	-.01	.04	.02	-.13
Specification tests										
Hansen:p	.21	.00	.65	.03	.00	.00	.35	.09	.07	.00
AR(2):p	.25	.02	.72	.26	.18	.06	.83	.15	.27	.08
Instruments	20	22	20	22	20	22	20	22	20	22
Groups	146	145	62	62	84	83	37	37	109	108
N	1003	994	416	414	587	580	235	251	750	743

N.B. P-value for the levels of significant are $^a p < 0.01$; $^b p < 0.05$; $^c p < 0.1$

TABLE 2.11: Combined results-(ii)

Sample	Income level						Income-Subsidy			
Dept.	LI		MI		HI		LI-Sub.		LI-No sub.	
variables	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}
Short run										
ΔY_{it}	-	-.05	-	-.09	-	$.10^c$	-	0	-	-.15
ΔE_{it}	.01	-	$.06^a$	-	-.00	-	0	-	-.00	-
ΔY_{it-1}	$.87^a$	-	$.74^a$	-	$.81^a$	-	0	-	$.86^a$	-
ΔE_{it-1}	-	$.95^a$	-	1.06^a	-	$.77^a$	-	0	-	$.47^a$
ΔEP_{it}	-	-.07	-	.01	-	$-.05^b$	-	0	-	$-.32^b$
ΔK_{it}	$.09^a$	.07	$.13^a$	.02	10	$.08^b$	0	0	$.07^b$	$.33^b$
ΔL_{it}	-.03	-.02	$.02^a$	.01	.00	-.00	0	0	-.01	-.03
Δ year*	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Long run										
Y_{it}	-	-.93	-	1.50^a	-	$.44^b$	-	0	-	-.28
E_{it}	.04	-	$.22^a$	-	-.02	-	0	-	-.00	-
EP_{it}	-	-1.41	-	-.12	-	$-.21^c$	-	0	-	$-.60^a$
K_{it}	$.64^a$	1.5	$.49^a$	-.25	$.53^a$	$.35^a$	0	0	$.52^a$	$.62^a$
L_{it}	-.20	-.33	$.06^a$	$-.14^b$	-.02	.00	0	0	-.06	-.05
Specification tests										
Hansen:p	.11	.06	.25	.01	.00	.27	1	1	.51	.55
AR(2):p	.28	.32	.27	.08	.29	.87	.28	.83	.26	.77
Instruments	20	22	20	22	20	22	20	22	20	22
Groups	21	21	75	75	50	49	4	4	17	17
N	143	143	510	510	350	341	24	24	119	119

N.B. P-value for the levels of significant are $^a p < 0.01$; $^b p < 0.05$; $^c p < 0.1$

TABLE 2.12: Combined results-(iii)

Sample	Income-Subsidy								Income-Energy	
Dept.	MI-Sub.		MI-No sub.		HI-Sub.		HI-No sub.		LI-Surp.	
variables	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}
Short run										
ΔY_{it}	-	-.02	-	-.07	-	0	-	.03 '	-	0
ΔE_{it}	.10^{a}	-	.02^{b}	-	.33^{a}	-	-.05	-	0	-
ΔY_{it-1}	.66^{a}	-	.83^{a}	-	0	-	.63^{a}	-	0	-
ΔE_{it-1}	-	1.01^{a}	-	1.04^{a}	-	0	-	.83^{a}	-	0
ΔEP_{it}	-	-.00	-	.03	-	$-.43^{a}$	-	$-.10^{a}$	-	0
ΔK_{it}	.15^{a}	.00	.10^{a}	.05	.32^{a}	0	.24^{a}	.08^{b}	.26^{a}	0
ΔL_{it}	.02^{a}	.00	.01	.01	.00	.17^{a}	-.00	-.01	0	0
Δ year*	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Long run										
Y_{it}	-	2.29	-	1.77^{b}	-	0	-	.19	-	0
E_{it}	.29^{a}	-	.14^{a}	-	.33^{a}	-	-.12	-	0	-
EP_{it}	-	.34	-	-.74	-	$-.43^{a}$	-	$-.57^{a}$	-	0
K_{it}	.44^{a}	-.19	.61^{a}	-.99	.32^{a}	0	.64^{a}	.47^{a}	.26^{a}	0
L_{it}	.05^{a}	-.68	.04	-.23	.00	.17^{a}	-.01	-.03	0	0
Specification tests										
Hansen:p	.84	.01	.01	.13	1	1	.02	.08	1	1
AR(2):p	.37	.14	.45	.28	.04	.17	.58	.97	.20	.62
Instruments	20	22	20	22	20	22	20	22	20	22
Groups	49	49	26	26	9	9	41	40	5	5
N	329	329	181	181	63	61	287	280	35	35

N.B. P-value for the levels of significant are $^{a}p < 0.01$; $^{b}p < 0.05$; $^{c}p < 0.1$

TABLE 2.13: Combined results-(iv)

Sample	Income-Energy									
Dept.	LI-Def.		MI-Surp.		MI-Def.		HI-Surp.		HI-Def.	
variables	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}
Short run										
ΔY_{it}	-	-.14	-	.18	-	-.07	-	.08	-	$.10^c$
ΔE_{it}	.01	-	$.03^b$	-	$.06^b$	-	.17	-	-.01	-
ΔY_{it-1}	$.94^a$	-	$.82^a$	-	$.75^a$	-	.42	-	$.93^a$	-
ΔE_{it-1}	-	$.87^a$	-	$.89^a$	-	1.05^a	-	$.88^a$	-	$.87^a$
ΔEP_{it}	-	-.21	-	-.07	-	$.02^c$	-	-.03	-	$-.05^b$
ΔK_{it}	$.04^b$	.08	$.09^c$	-.05	$.13^a$	.02	.25	.01	.03	.02
ΔL_{it}	$-.02^c$	-.04	.01	-.01	$.01^b$	.00	-.07	.02	-.00	-.00
Δ year*	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Long run										
Y_{it}	-	-1.06^b	-	1.60^b	-	1.48	-	.67	-	$.77^c$
E_{it}	.15	-	$.18^a$	-	$.25^a$	-	$.29^a$	-	-.16	-
EP_{it}	-	-1.64^a	-	-.65	-	-.35	-	-.26	-	$-.43^a$
K_{it}	.77	$.68^c$	$.53^a$	-.41	$.50^a$	-.38	$.42^a$	.04	.46	.14
L_{it}	-.33	-.34	$.05^a$	-.09	$.05^a$	-.10	$-.12^a$	$.17^c$	-.02	-.02
Specification tests										
Hansen:p	.32	.09	.22	.61	.01	.00	.90	.90	.01	.06
AR(2):p	.27	.79	.64	.35	.32	.14	.50	.25	.44	.87
Instruments	20	22	20	22	20	22	20	22	20	22
Groups	16	16	19	19	56	56	13	13	37	36
N	108	108	127	127	383	383	91	89	259	252

N.B. P-value for the levels of significant are $^a p < 0.01$; $^b p < 0.05$; $^c p < 0.1$

TABLE 2.14: Combined results-(v)

Sample	Subsidy-Energy							
Dept.	Sub.-Surp.		Sub.-Def.		No sub.-Surp.		No sub.-Def.	
variables	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}	Y_{it}	E_{it}
Short run								
ΔY_{it}	-	-.04	-	-.06	-	.04	-	-.01
ΔE_{it}	.04	-	.07^{a}	-	.03	-	.03^{a}	-
ΔY_{it-1}	.81^{a}	-	.69^{a}	-	.73^{a}	-	.80^{a}	-
ΔE_{it-1}	-	1.07^{a}	-	1.04^{a}	-	.77^{a}	-	1.01^{a}
ΔEP_{it}	-	-.03	-	.01	-	-.17	-	-.01
ΔK_{it}	.10	-.02	.16^{a}	.01	.19^{a}	.22	.12^{a}	-.01
ΔL_{it}	-.00	-.01	.02^{a}	.01^{c}	-.01	-.03	-.01	.00
Δ year*	yes	yes	yes	yes	yes	yes	yes	yes
Long run								
Y_{it}	-	.58	-	1.30^{a}	-	.16	-	.96
E_{it}	.22^{b}	-	.24^{a}	-	.09	-	.12^{a}	-
EP_{it}	-	.48	-	-.29	-	$-.74^{c}$	-	.60
K_{it}	.50^{a}	.36	.53^{a}	-.23	.69^{a}	.97^{b}	.59^{a}	.40
L_{it}	-.00	.07	.06^{a}	-.18	-.03	-.13	-.02	-.03
Specification tests								
Hansen:p	.92	.59	.86	.03	.27	.20	.01	.00
AR(2):p	.48	.25	.48	.26	.60	.49	.18	.11
Instruments	20	22	20	30	20	22	20	22
Groups	15	15	47	47	22	22	62	61
N	99	97	317	317	154	154	433	426

N.B. P-value for the levels of significant are $^{a}p < 0.01$; $^{b}p < 0.05$; $^{c}p < 0.1$

Statement of Authorship

Statement of Authorship

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i. the candidate's stated contribution to the publication is accurate (as detailed above);

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Signature		Date	

Chapter 3

Primary energy and output nexus in an energy constrained economy: Empirical evidence from Bangladesh

Abstract

This study investigates the short- and long-run relationship between primary energy consumption and output using monthly macroeconomic data for Bangladesh from July 2003 to December 2020. We use ARDL bounds test of cointegration to understand the long-run relationship. We then use Granger causality in a multivariate framework to detect the existence of causal link and the direction of causality. The ARDL estimates indicate that primary energy consumption and output has a long-run relationship where output causes primary energy consumption, supporting the energy conservation hypothesis. Conversely, our analysis does not support that primary energy consumption causes output growth or the growth hypothesis. We argue here that energy has a dual role in the economy: a) satisfying consumption; and b) augmenting production. An economy with constrained energy supply tends to increase energy consumption, which may not contribute to output growth but fulfill the basic energy requirements as the country progresses towards a higher output accumulation trajectory. To demonstrate this hypothesis, we estimate the model separately for low and high energy consumption periods in Bangladesh, and find that energy and output do not impact each other during the low energy consumption period. However, during high levels of energy consumption, output growth clearly pushes up energy use. Nevertheless, pursuing energy conservation policy to restrict energy usage through supply restriction or price control for such an economy could be detrimental to the sociopolitical environment.

3.1 Introduction

Since the global oil shocks in 1973, many studies have demonstrated the link between oil and output, especially for energy importing countries. The causal link between these variables has been studied extensively to understand how economies respond towards energy shocks, or how those shocks impact output of an economy. For an ideal economy, it is expected that more energy would increase output due to the productive potential of energy in the economy. Empirical literature, however, does not support the idea that energy is always productive. In fact, a literature survey on 101 studies shows that only in around 25% of the countries does support energy induced economic growth hypothesis (Payne, 2010). These inconclusive findings lead this study to further investigate the topic in the context of Bangladesh to explore the dynamics of this relationship.

Bangladesh is an energy constrained economy that relies mostly on imported fuel and domestically procured natural gas as the primary source of energy. In addition to these two commercial energy sources, non-commercial fuel such as fire wood and crop residues account for a significant portion of the primary energy. The energy system of Bangladesh has had a bad reputation for being poorly managed (Mozumder and Marathe, 2007). Energy poverty is widespread, especially, in the rural population of Bangladesh, where we see more than half of the people live below the energy poverty line (Barnes, Khandker, and Samad, 2011). In fact, the energy poverty is more prevalent than income poverty amongst the rural population of Bangladesh where the per capita energy consumption is one of the lowest in the world. Surprisingly, despite all the constraints in the energy sector, Bangladesh has achieved spectacular economic growth ranging from 6 to 8% annually over the last three decades. This apparent gap between economic growth and energy consumption can be explained by the fact that the current economic growth is fostered by the less energy intensive ready made garment sector (RMG) and foreign remittances, especially since the 1990s (Moazzem, 2019). Despite improvement in the energy intensity of output, Bangladesh is still lagging behind in adequate investment in the energy sector, which is reflected by the lower level of per capital energy consumption. This scenario is likely to change as we see an upsurge of energy demand from household sector with the increasing economic affluence.

It is not surprising that energy turns out to be a crucial economic determinant for countries that are not sufficiently endowed with its availability (Stern, 2015). Similarly, an economy with a sufficient energy supply has different expectations from energy than the constrained ones. This is because primary energy, such as oil, can be consumed as a commodity or can be utilized to augment production of other commodities (Pokrovski, 2003). A study conducted on 30,000 firms in India reveals that constrained power supply may impact industrialization and productivity growth adversely (Abeberese, 2017). Thus, if an economy is not sufficiently supplied with energy, energy intensive production is not likely to flourish. Therefore, we put forward the hypothesis that in an energy constrained economy, energy as a consumption good is more prevalent than energy as a productive resource. In other words, higher energy consumption may not increase output but as income grows, people tend to demand more energy for their unmet consumption requirements. This output-lead energy consumption is termed as energy conservation hypothesis, while the reverse of this relationship is termed as growth hypothesis. If the relationship simultaneously causes each other, we term that as the feedback hypothesis and finally, if there is no causal link found, it is the neutrality hypothesis.

One of the drawbacks in analysing the above mentioned causality-based hypothesis is that the time span of cause and effect of these two variables are much shorter than a year (Akarca and Long, 1980). Another distinctive. In this respect our monthly frequency time series is expected to improve estimation. Another caveat of the previous studies in general, and especially for Bangladesh, is that the issue of energy availability is generally not taken into account. This is important because output and energy are coupled tightly only when the economy is not energy constrained (Stern, 2019). An economy with greater availability of energy has the potential to generate more output compared to an energy constrained economy. Therefore, it is not surprising that Bangladesh being an energy constrained economy with limited infrastructure, may not utilize its insufficient energy resources towards greater energy-lead output accumulation.

Keeping the above mentioned gaps in perspective, the study raises a number of questions, such as: 1) What is the role of primary energy in Bangladesh? 2) Is energy dominant here as a consumption good or productive capital? 3) Should Bangladesh follow energy conservation or energy lead economic growth policies for energy security? To address these questions, we need to keep in mind the fact that Bangladesh had faced severe power shortages before the year 2010. After initiating a series of policy modifications from 2010 onward, the power and energy systems of Bangladesh have gained sufficient momentum in mitigating this crisis (Moazzem, 2019). This known structural break in 2010 is likely to provide us with insight on how energy crisis and output dynamically impact each other before and after the crisis period.

The key variables of this study comprise of monthly index of industrial output as a proxy of output; and monthly imports of petroleum products as a proxy of primary energy use in Bangladesh. Although natural gas (domestic resource) is another significant source of primary energy in Bangladesh, due to lack of reliable monthly data, we use only the total petroleum products instead. We provide details of the variables in the data section. Utilising time series techniques such as Autoregressive Distributed Lag (ARDL) and Vector Error Correction Model (VECM) in a multivariate framework, we find that in general, output influences energy consumption positively indicating the energy conservation hypothesis. However, during the periods of acute power shortage in Bangladesh, energy consumption and output did not impact each other. These findings lead us to rethink the policy of energy conservation for an energy constrained economy like Bangladesh, where to attain energy sufficiency, an increase in energy consumption is warranted, despite the fact that higher consumption may not influence output directly. Similarly, if we see that energy is neutral in an energy constrained economy, as we have seen during the energy crisis period of Bangladesh, a strong energy policy is needed to make energy available in the economy despite the analysis indicating energy has little influence on the economic growth.

This study contributes to the literature in several of ways. First, we show empirically that the conventional energy hypotheses are not always appropriate for an energy constrained economy. Second, we introduce a known structural break in our analysis to observe how energy policy impacts the energy-economic growth nexus. Third, we show why energy conservation policies may be counterproductive for an energy constrained economy like Bangladesh. Finally, although a number of studies are conducted on energy-growth nexus based on yearly data from Bangladesh, this is the first attempt to use monthly data for this purpose. We also control for two important macroeconomic variables of Bangladesh, namely ready made garment and foreign remittances. Comparing the existing literature, the distinctive feature of the paper is that we consider pre and post policy intervention in the energy sector to evaluate the impact of energy availability on the output of Bangladesh.

The rest of the paper is arranged as follows: section (3.2) provides a brief account of the primary energy system of Bangladesh, section (3.3) explores literature on energy-growth nexus, section (3.4) describes the model and data, section (3.5) provides estimation strategies, section (3.6) presents the results, followed by discussion and conclusion in sections (3.7) and (3.8) respectively.

3.2 Primary Energy in Bangladesh

Bangladesh is in her transition phase to become an industrial and service-oriented economy from a primary agrarian one. This transition leads to delving into a number of issues regarding the energy security of Bangladesh. The concerns stem from the fact that the primary energy mix of Bangladesh is heavily dependent upon rapidly depleting indigenous natural gas sources and on imported petroleum products sourced from competitive world markets. On the other hand, the scenario of alternative sources with only 0.01% of total energy generation is way behind to compete in the conventional fossil fuel driven energy system (Moazzem, 2019). All these factors impose restrictions upon the energy system as long as the reliability, affordability and accessibility of primary energy are concerned.

Natural gas has been a reliable source of primary energy for the last four decades. According to sector-wise consumption of natural gas in the financial year 2009-10, a significant portion of it goes to national and captive power generation (50%), then to commerce and industry (20%), domestic consumption (13%), fertilizer (11%), and finally to transport sector (5%) (Rahman, Tamin, and Rahman, 2012). The household and transport system in the city areas, along with power generation and commercial establishments within the vicinity of the cities, are provided with a direct gas pipeline. The reliance on cumulative power generation from gas is also significant, which is around 60% of the total 11,000 MW electricity generated in 2018 (Moazzem, 2019). Similarly, the transport sector is also increasingly relying upon natural gas as we see 33% of the total energy consumption of 157.04 Petajoules[1] (PJ) in 2017 is fueled by natural gas alone (Chowdhury et al., 2021). This consumption scenario would have been ideal from an environmental and economic perspective had there been a reliable supply of natural gas for the long term. Alarmingly, the final geological assessment in 2018 concluded that Bangladesh has only 11.92 Trillion Cubic Feet (TCF) of natural gas reserve left, which is good enough to run another 10-12 years provided the business as usual scenario remains (Das et al., 2020). This poses a big threat to the energy security of the country for a number of reasons. First, the power generation of the country has already made a large investment in infrastructure, keeping natural gas as input in mind. Second, the distribution network of gas through pipelines has already incurred a huge fixed investment and now, if the supply of gas is stopped abruptly, all these infrastructures will be wasted. Third, with the increase of GDP, there will likely be a large demand for cooking energy in Bangladesh, where currently around 90% of the population uses traditional biomass such as wood, husks, leaves, cow dung, jute and

[1]One Petajoules = 10^{15} Joules or 278 Gigawatt hours

other agricultural waste for cooking (Uddin, 2020). In addition, the situation would be compounded when the fertilizer, transport or industrial sector of Bangladesh would demand more natural gas or alternative fuel to carry out their usual activities.

The second dominant source of primary energy in Bangladesh is imported petroleum oil, which, in collaboration with a number of companies, is managed by state-owned Bangladesh Petroleum Corporation (BPC). In financial year 2019-20, a total of 5.5 million metric tons petroleum oil is being imported in Bangladesh of which 65% went to transport sector, 18% agriculture, 8% industry and 7% power generation (BPC, 2021). Now, if a major shift in the fuel mix occurs due to depletion of natural gas, petroleum is the only immediate viable source to secure primary energy in Bangladesh. Pursuing such an alternative pathway requires a significant increase in oil import, which has both environmental and financial consequences as long as reliability is concerned. As global communities are largely agreed upon reducing carbon emissions, procuring large amounts of oil would be more costly because of the additional carbon pricing. On the other hand, converting the economy from gas dominated energy system to petroleum has to face at least two other financial challenges. First, the current storage capacity of oil (1.3 million MT) is barely able to store a three-month supply for the existing demand (BPC, 2021). To become an oil dominated economy, the storage facility has to increase in many folds. Second, unlike gas, the transport and distribution of oil cannot be done economically through pipelines. Therefore, a large investment in pipelines and vehicles are also required.

Understanding the risks associated with fossil fuel-based primary energy, Bangladesh has embarked upon accessing non-fossil energy such as nuclear and renewable sources. As such, the first nuclear power plant project in Bangladesh is expected to contribute 20% of the total power generation (2400 MW) by 2024. The estimated cost of the project is US$ 12.65 billion which will be financed by a credit line from the Government of Russia (Moazzem, 2019). At the same time, Bangladesh government is also undertaking initiative to explore the options for renewable energy. In this regard, Sustainable and Renewable Energy Development Authority (SREDA) was established in 2014 to oversee and promote solar, wind, hydro and biogas projects as an alternative energy source for Bangladesh. Although there is a plan to produce 10% of the total energy from these renewable sources, it will be difficult to achieve that goal provided the current sparse contribution of alternative energy (SREDA, 2021).

In an effort to ensure energy security, Bangladesh has signed an energy deal with Qatar for importing 2.8 million tons of liquefied natural gas (LNG) per year for the next 15 years. Keeping the import in mind, two Floating Storage and Re-gasification Units (FSRU) with a cumulative capacity of 1 billion CFT have been established (Moazzem, 2019). This arrangement has two implications for the primary energy system of Bangladesh. One is that the shocks from abrupt discontinuation of the existing gas wells could largely be alleviated by this imported LNG. Second, the existing gas distribution network (i.e., pipelines, depots) can be re-used by these new enterprises to make this venture viable.

After addressing reliability and accessibility of primary energy, the question of affordability of energy to general population is the next concern for Bangladesh. This implies that distribution of energy resources through a combination of central planning and market mechanism has to work in harmony for maximising welfare in an equitable manner. As we have seen, the distribution networks of the key energy resources are mostly concentrated in and around the major city areas; there are scope for price manipulation especially in rural areas. Owing to the unmet demand of primary energy in the semi-urban and rural areas, a number of unregulated companies are entering into the market and exploiting consumers in supplying cooking energy in the form of Liquefied Petroleum Gas (LPG) (GOB, 2020). Without stringent regulation and proper public investment, addressing the price manipulation and associate accidental risk of expired LPG cylinders would be difficult. Market development in the energy sector is complicated here as we see the tariff system of Bangladesh is highly regulated and the energy products are either subsidized or priced below opportunity cost in the case of domestic extraction (Timilsina and Pargal, 2020). Various studies suggest that without a proper design of subsidy structure, there is a possibility of inequitable benefits channeling towards the richer population of a country (Coady and Granado, 2012).

Putting all these initiatives together, we see a consistent upward trend of energy uptake in terms of per capita energy consumption, which has been more than doubled in the last four decades (Figure 3.1). But in comparison to the global average of 2,000 kg of oil equivalent per capita[2], Bangladesh is only consuming 10% of that average level (WDI, 2021). Even neighbouring India, Nepal, Pakistan and Sri Lanka consume around three times Bangladesh's consumption of energy. Despite this lower level of energy consumption, the economic growth of Bangladesh outperforms the neighbouring counterparts. This can be explained by the fact that the energy intensity of the GDP of Bangladesh is one of the lowest in the world. According to World Bank estimation, in 2014 the country utilized only 65 kg of oil equivalent to generate US$ 1,000 while India used 125 kg, Nepal 154 kg and Pakistan 110 kg (WDI, 2021). At the same time, Bangladesh has achieved considerable success in reducing energy intensity of GDP as

[2]Primary energy use before transformation in the end user level (WDI, 2020)

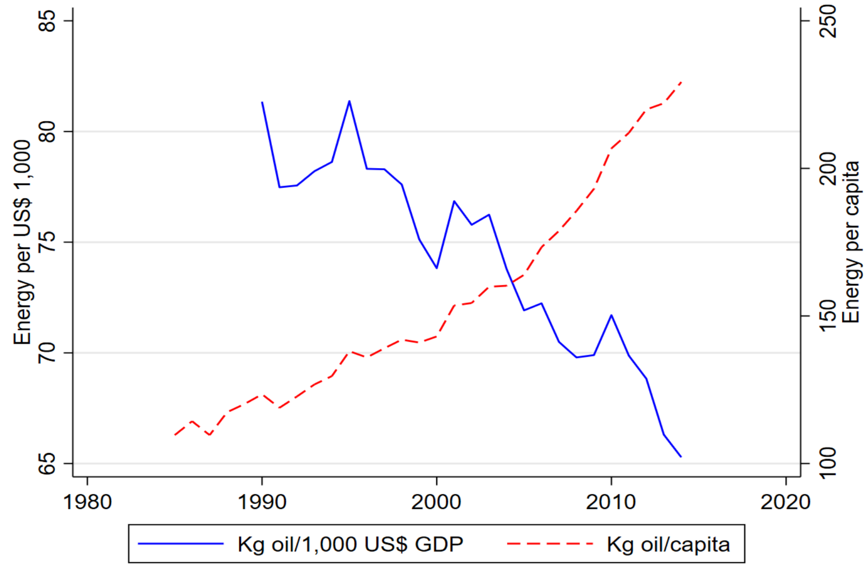


FIGURE 3.1: Energy consumption: Bangladesh

we see around 20% improvement in energy intensity during the last four decades (Figure 3.1). A number of policies such as Energy Efficiency and Conservation Master Plan up to 2030, Energy Efficiency and Conservation Rules 2016 and Energy Audit Regulation 2018 are initiated to ensure country-wise efficient use of energy (GOB, 2020). These actions are likely to address both energy security and environmental mitigation for the future energy utilization road map.

3.3 Literature

The literature on the economic attributes of energy is divided into two categories: one deals with the physical contribution of energy to production, and the other one assesses the monetary value addition of energy to the economy. The former is also termed as biophysical theory, which assumes that energy can substitute other production inputs such as capital and labor and act as an independent input in the production possibility frontier. A further subdivision of individual energy inputs (e.g. coal, gas, oil) can also be done to disentangle individual contributions of the energy products in the production process. In such a framework, the nexus between energy and output can be affected by capital-energy substitution, change in energy and output mix and technological change, which in turn influence total factor productivity. The second type of analysis tries to establish causality between energy with other economic variables, especially with output. By observing the direction of causality, the relationship can be reduced into energy lead economic growth hypothesis; economic growth lead energy conservation hypothesis; and lastly, feedback and neutrality hypotheses when both or none impact each other respectively. One thing to notice here is that unlike in the first category, the role of energy in the production function is not much of a concern in the causality analysis of the second category.

Emphasizing the importance of energy in production function, Stern, 2015 argues that because of its unique role in production process, there is a limit of substitution with other inputs. Some analysts also term it as "productive energy" to rationalize the inclusion of energy as the third element in addition to capital and labour in the production function (Pokrovski, 2003). A further justification for this inclusion is that when conventional inputs become less productive, a transformation of the radical input-output system is needed to accelerate the production process where energy becomes instrumental (Stern, 2019). This is the reason we see that growth during the post-industrial revolution is largely driven by the discovery of fissile fuel (Wrigley, 2018). The constraint on manual energy-driven economic growth is mostly removed by this new source of automated energy. Although energy has been a crucial part of the modern economic growth, we see a global reduction in the value addition of energy in the GDP, especially at the beginning of the twenty-first century. This is similar to the fact that land, being an essential input in the 20th century's production system, lost its importance as the contribution to GDP is reduced over time (Schultz, 1951). The role of energy in production, however, is different as energy is still not readily available at zero cost and the value of it is not only judged by the percentage share to GDP but also by the unique contribution to the production process (Moroney, 1992).

Based on these theoretical underpinnings, applied economists tend to explore the causality relationship through widely used regression or correlation methods. The first influential analysis of this kind was conducted by Kraft and Kraft, 1978 where they show that after World war II, GNP growth of the USA Granger caused energy consumption growth but energy per say did not cause economic growth during that period. This implies that variation in energy supply, such as energy conservation, would not adversely affect economic outputs. This counter-intuitive conclusion of this study evoked a number of criticisms on the methodology used, sample selection and estimation strategy. Regarding the methodology of the study, it is apparent that the authors did not take into account the fact that any two totally unrelated variables may show correlation simply because of their shared path of direction. Akarca and Long, 1980, criticised the results by indicating that the inclusion of the data of 1973-74 created a bias in the conclusion as those are the years of global oil crisis. By including an extra two more years in that data, Akarca and Long, 1980, showed that the causal order of Kraft and Kraft, 1978 is actually a spurious one. Still there is controversy on the causal relation of output and energy in the academia. To address the anomaly, we need to take into account that there is a time delay between cause and effect of the two variables (Granger and Newbold, 2014). In other words, making energy available for a country is pretty straight forward, provided that the global market has the supply, compared to increasing economic growth through utilizing energy in the economy. Regarding estimation, due to lack of available procedure in the early 1980s, that study could not test for unit root in the variables and eventually could not test cointegration proposed by Engle and Granger, 1987. The subsequent study using this method is conducted by Cheng, 1995, on the USA and finds that GDP and energy are neutral to each other. Similar results are also obtained from Mexico and Venezuela in a separate study based on this method (Cheng, 1997). The result for Brazil from the same study, however, indicates that energy promoted economic growth during 1963-1993. This method is also used for analysing the nexus for Iran, Pakistan and Turkey and found that economic growth induces energy consumption without any reverse causality (Zamani, 2007; Aqeel and Butt, 2001; Lise and Van Montfort, 2007). In case of India, Haiti, Jamaica and Trinidad & Tobago, on the other hand, the relationship shows a feedback loop between energy and economic growth (Paul and Bhattacharya, 2004; Francis, Moseley, and Iyare, 2007).

With the evolution of advanced econometric strategies, the recent causality literature on energy-growth nexus introduces techniques such as Johanse-Juselius cointegration, Auto Regressive Distributed Lags (ARDL), panel cointegration and error-correction model. The idea of Johanse-Juselius method is that if we combine two non-stationary variables (in level) together in such a way that the error term of that combination becomes stationary, then we conclude that the two series are integrated or they have long-run relationship. We find an extensive use of this methodology in the literature of causality started in the late 1990s. Using this method, Masih and Masih, 1996, analysed energy consumption and economic growth of six Asian countries where they found energy leads economic growth in India, feedback in Pakistan and energy conservation for Indonesia. The same study also concluded that energy and economic growth do not have any relationship in Malaysia, Singapore and Philippines. However, in most of the studies, we find a pivotal role of energy in the economy where we see either energy promotes economic growth and/or economic growth promotes energy uptake. Thus, the feedback relationship can be found in a large number of countries such as Korea, Taiwan, USA, Greence, Argentina, Turkey, Canada, Germany, Italy, Japan, UK, Spain, China (Masih and Masih, 1997; Glasure, 2002; Hondroyiannis, Lolos, and Papapetrou, 2002; Soytas and Sari, 2003; Ghali and El-Sakka, 2004; Oh and Lee, 2004; Soytas and Sari, 2006; Yoo, 2006b; Climent and Pardo, 2007; Yuan et al., 2008). Studying the same countries with this method in different time periods can produce different conclusions. As we see in the case of the USA, using data for the period of 1948-94, Stern, 2000, showed that energy causes economic growth while using a slightly different time frame (1950-90), Soytas and Sari, 2003, concluded that energy is neutral in the USA economy. Interestingly, using annual data for 1970-1992, Zarnikau, 1996, showed that energy and gross national product of the USA has a feedback relationship. Another notable feature of the analysis is that the stage of development seems to play little role in fashioning the outcome of the relationship, as we see both developed Japan and developing India increase more energy consumption as income grows but not vice versa (Cheng, 1998; Cheng, 1999).

While the majority of the studies are conducted on Johansen-Juselius method, a relatively new approach, namely Auto Regressive Distributed Lags (ARDL) method proposed by Pesaran, Shin, and Smith, 2001 is becoming very popular in energy economics. The method gains in popularity because it is more flexible in terms of the order of integration of the variables and provides better estimation in small samples (Jordan and Philips, 2018). An earlier study with ARDL bounds test was conducted by Wolde-Rufael, 2005 on 19 African countries with mixed results. Akinlo, 2008 also conducted a study on 11 African countries but used commercial energy instead of energy as a whole where the results are still mixed as the preceding study. Another study using the same method on Tanzania for the period of 1971-2006 reveals that both energy and electricity promote economic growth (Odhiambo, 2009). Growth hypothesis is also supported by Nigeria where it is shown that petroleum or electricity consumption and economic growth has a long run relationship (Dantama, Abdullahi, and Inuwa, 2012). Study on four Southern European countries, however, does not show the instrumental role of energy in the economy as we see no cointegration for Albania, Bulgaria and Romanian while Hungry is the only country to display feedback relationship (Ozturk and Acaravci, 2010). Two separate studies conducted on Iran and Pakistan indicate that economic growth pushes up energy uptake but energy does not feedback the economy (Ahmad and Du, 2017; Khan, Teng, and Khan, 2019). More recently, investigating the relationship in Malaysia and Vietnam indicates that both energy and economic growth feedback each other in the long run (Hussain et al., 2019; NGUYEN and NGOC, 2020).

Apart from studying an individual country, a number of studies are conducted on panel data using panel cointegration and error correction model. Lee, 2005 conducted a study on a panel of 18 developing countries for the period of 1975-2001 and found that energy promotes economic growth without feedback. The growth hypothesis is also realised from the studies on the panel of Group 7 (G7) countries, Central American countries and Asian countries (Narayan and Smyth, 2008; Apergis and Payne, 2009; Lee and Chang, 2008). The outcomes of the studies conducted on oil-exporting countries are, however, in favour of energy conservation as we find the results from Gulf and oil exporting countries' panel (Al-Iriani, 2006; Mehrara, 2007). Mahadevan and Asafu-Adjaye, 2007 constructed 4 panels out of 20 countries to investigate whether energy availability and stage of economic development played any role in energy consumption. They concluded that all developed countries are in favour of feedback hypothesis regardless of being energy importers or exporters. The energy-importing developing countries are the only ones that displayed growth hypothesis among the 4 panels in the study. The central role of energy in the economy is also reinforced from the study of Lee, Chang, and Chen, 2008 on OECD panel where they concluded that both energy and income impact each other dynamically.

Now we turn to explore the applied works conducted on energy or other energy aggregates in the context of Bangladesh economy. Surveying the literature, we find that most of the studies are conducted on annual macroeconomic time series, starting from 1971 (year of independence of the country) onward, where the predominant conclusions are in favour of energy conservation hypothesis. The earlier study of this category is conducted by Mozumder and Marathe, 2007, where they show that per capita GPD Granger causes per capita electricity consumption in Bangladesh. Utilizing bi-variate model for the period of 1971-1999, the study also shows that electricity consumption and GDP are cointegrated and the resulting short-run relationship is unidirectional. Interestingly, using the same two variables for an extended period of 1971-2008, Ahamad and Islam, 2011 came up with a different conclusion on the relationship between electricity and GDP of Bangladesh. According to this study, in the short run, electricity consumption promotes economic growth while in the long run, both variables cause each other. This is not surprising in applied economics as we see that by just adding additional nine years' data, the second analysis reverses the conclusion of the first study. Another type of study takes overall consumption of energy (kg of oil equivalent) in the economy instead of electricity alone as an indicator of energy consumption. Paul and Uddin, 2011 analysed energy consumption of Bangladesh with a bi-variate VAR model for the period of 1971-2010 and came up with the conclusion that GDP growth of the country causes energy consumption (unidirectional), indicating energy conservation policy for the country. Using the same time period (1971-2010) but a different methodology, Islam, Shahbaz, and Butt, 2013 also came up with conservation hypothesis for Bangladesh. In addition, using a sophisticated econometric technique such as the bootstrap method, Alam, Ahmed, and Begum, 2017 concluded that GDP growth of Bangladesh causes non-renewable energy consumption, which requires energy conservation policy for switching to renewable sources. Even using industrial production instead of GDP, Rahman and Kashem, 2017 indicated that industrialization causes energy uptake but not the vice versa. Overall, these analysis reveal that the output of Bangladesh's economy does not respond much due to the variation in energy supply indicating energy conservation hypothesis.

3.4 Model and Data

3.4.1 Theoretical specifications

As we have seen from the literature, energy is taken as an independent input in the production function for many instances. The idea is that energy is a productive resource like capital which can be accumulated over time (Pokrovski, 2003). The underlying assumption here is that the economy is well equipped with utilizing energy, most of which is used as input in the production process; and there is an easy substitution between capital and energy. In such an economy, the neoclassical production function can be expressed as follows:

$$Y = f(X_1, E^p) \tag{3.1}$$

Where Y is output; E^p is energy use in an energy lead production intensive economy; X_1 is the vector of all other inputs determining outputs. Following the same theoretical framework, energy can also be expressed as a function of outputs as follows:

$$E^p = f(X_2, Y, P) \tag{3.2}$$

Where X_2 is vector of economic activities determining energy use; P is the market price of energy. Equations (3.1) and (3.2) are the representations of an ideal economy with developed market and functionality. In practice, however, we do not have such an ideal situation especially for countries with limited energy supply. For example, if any country has a limited opportunity to convert energy into economic output, the representations above would be inappropriate for the following two reasons: One is that if energy does not influence output, it cannot be an independent production input in the equation (3.1), and the other one is that energy as dependent variable in equation (3.2) may wrongly signal inefficiency in energy utilization despite the economy is not well equipped with energy utilization. This is likely to occur when much of the energy is utilized as consumer good instead of productive input. Because of these inconsistencies, many mainstream growth economists did not put energy in the production function in the first place (Stern, 2010).

This so-called energy insufficiency may arise from the fact that a country may be resource-poor with least developed energy system, along with a less energy-intensive production sector. In our study, we term this as an energy constrained economy, such as Bangladesh. In such a situation, energy, far from being a productive input, becomes more of a consumption commodity. Still, despite not being a crucial input in the production function, the variation in economic growth is likely to influence the variation of energy consumption. This is because increasing income would allow a higher level of energy consumption by the affluent population to meet their consumption need. Thus, we propose a modified version of the above models for an energy constrained economy as follows:

$$Y = f(X_1, E^c) \tag{3.3}$$

Where Y is output; E^c is energy consumption in an energy constrained economy; X_1 is the vector of all other inputs determining outputs. Our argument of the paper here is that equation (3.3) may provide with a misleading conclusion regarding the instrumentality of energy in an economy. As energy consumption (E^c) may not directly influence output but meet the consumption requirements of the population. Therefore, before estimating the equation we need to consider whether the economy is utilizing energy as productive capital or consumption good.

Finally, we specify the energy consumption model for an energy constrained economy where output is likely to influence energy not because of its productive capacity but because of meeting the basic consumption needs.

$$E^c = f(X_2, Y, \bar{P}) \tag{3.4}$$

We have put $\bar{P}$ here to denote fixed price instead of P as in an energy constrained economy. The market mechanism is not likely to be functional as we see most of such energy markets are controlled by state-owned regulators (Cheon, Lackner, and Urpelainen, 2015).

3.4.2 Empirical specifications

Based on the theoretical expression of equation (3.3), we specify the economic growth of an energy constrained economy by Cobb-Douglas technology as follows:

$$Y = A(X_1)^{\alpha}(E^c)^{\beta}e^{\mu} \tag{3.5}$$

Where A is factor productivity; e^{μ} is error term; $\hat{\alpha}$ and $\hat{\beta}$ are elasticities and also parameters of the model. The inclusion of E^c in equation (3.5) is needed to explain by the fact that energy does not play a very significant role in the output augmentation in this instance. In estimating $\hat{\beta}$, we need to be careful that the output share of energy may not be significant if energy is not productive. Keeping that in perspective, this study is particularly focusing on a class of countries that are not highly developed in terms of energy utilization, and their outputs are not highly energy-intensive, and their economic growth may also be influenced by other macroeconomic variables as we have included in equation (3.5).

As we analyse the economy of Bangladesh, we find that the recent economic growth is led by less energy-intensive sectors (Moazzem, 2019). Historically being an agrarian economy, the country's growth for the last two decades is mostly dominated by ready made garments (RMG) exports (denoted here as industrial export, IE) and incoming foreign remittances (FR). To capture the growth dynamics of the economy, we introduce the concept of endogenous growth theory where output growth accrues over through dynamic accumulation of productivity of the factors of production. So, we model productivity for the economy of Bangladesh as follows:

$$A(t) = \psi.IE(t)^{\gamma_1}.FR(t)^{\gamma_2}.ER(t)^{\gamma_3} \tag{3.6}$$

We have included exchange rate (ER) as an additional variables here as we see both industrial exports (IE) and foreign remittances (FR) are highly influenced by exchange rate. After combing equations (3.5) and (3.5), we obtain our base-line model as below:

$$Y(t) = \psi.IE(t)^{\gamma_1}.FR(t)^{\gamma_2}.ER(t)^{\gamma_3}.X(t)^{\alpha}.E(t)^{\beta}.e^{\mu_t} \tag{3.7}$$

Here, $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}_i$ are elasticities, $\hat{\psi}$ is time-invariant constant and e^{μ_t} is white noise. At this stage, for convenience of estimation, we assume that X_t remains constant over the estimation period, and as a result, this constant term will be absorbed with the time invariant constant term $\hat{\psi}$. Before estimating the modified version of equation (3.7), we use log-linear specification as suggested by Shahbaz, Zeshan, and Afza, 2012, among many others as follows:

$$lnY_t = \psi + \gamma_1 lnIE_t + \gamma_2 lnFR_t + \gamma_3 lnER_t + \beta lnE_t + \mu_t \tag{3.8}$$

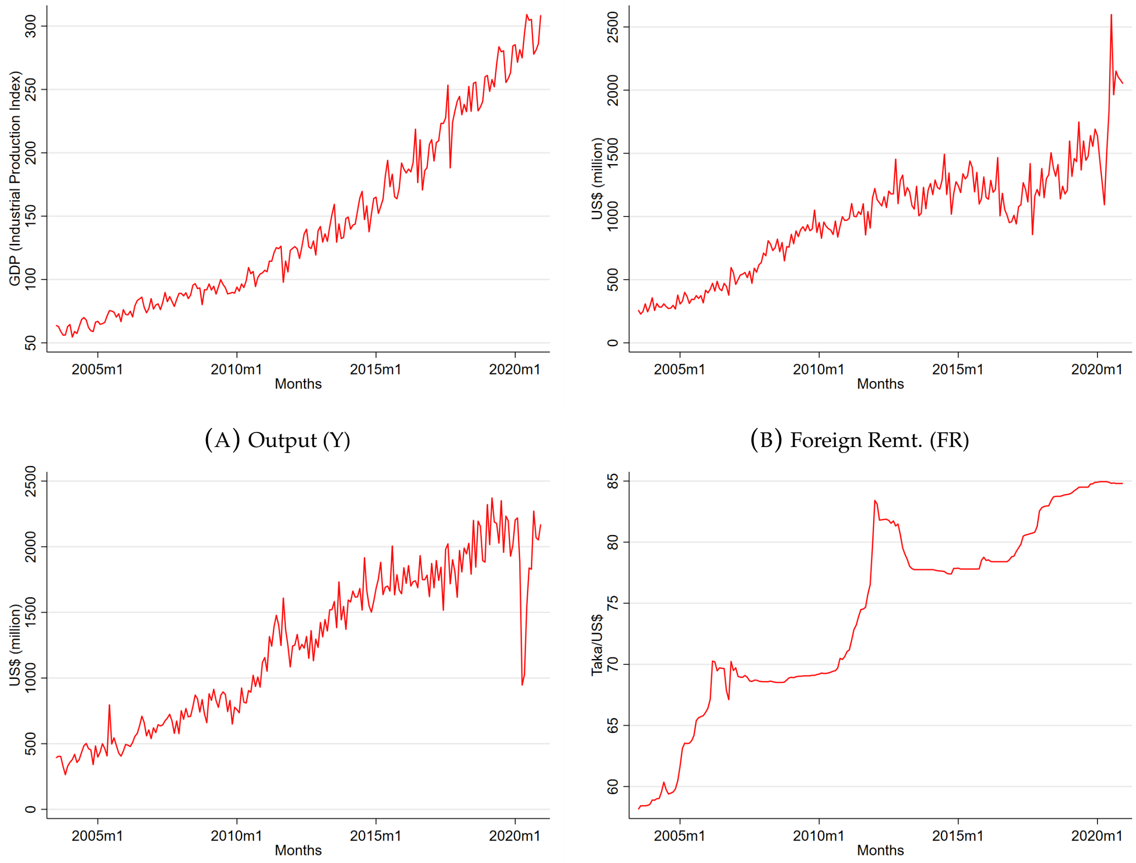
Now, let us turn to the energy consumption function expressed in equation (3.4) where we argue that most of the energy in a constrained economy is utilized for consumption rather than being an input in the production function. Modeling such an economy implies that growth of economic affluence enables more energy consumption, which turns out to be a function of income (Y), industrial export (IE), remittances (FR) and exchange rate (ER) for Bangladesh. We also see in addition to all the variables, a fixed price $\bar{P}$ is incorporated as an explanatory variable. Like most of the energy constrained countries, the energy supply of Bangladesh is controlled by state-owned companies where the price is not reflected as market price and thus, we discard price from the equation. Finally, following the same modification as with the growth function in equation (3.7), we specify the energy function with natural log as follows:

$$lnE_t = \Phi + \delta_1 lnIE_t + \delta_2 lnFR_t + \delta_3 lnER_t + \theta lnY_t + \epsilon_t \tag{3.9}$$

Here, $\hat{\theta}$, $\hat{\delta}_i$ are elasticities, $\hat{\phi}$ is time-invariant constant and ϵ_t is white noise.

3.4.3 Data and variables

Most of the literary works on energy-growth nexus we surveyed are conducted on annual data. In this study, however, keeping the objective of investigating the nature of the relationship between energy and economic growth in perspective, we utilize high-frequency data for more precision in estimation. The output (Y) data in this study is collected from the International Financial Statistics (IFS) database of International Monetary Fund (IMF, 2021). As monthly frequency data on the output of Bangladesh is not available, we take industrial production index (IPI) as a proxy for this instance. In many of the applied works, it is customary to use this index for Bangladesh (*see* Alam, 2015; Islam and Kabir, 2004). Based on this, we have constructed a data set on output for the period of July 2006 to December 2020, of which the last 1.5 years' data are extrapolated based on the trend and frequency of the previous 16 years. The next important variable of our analysis is primary energy consumption (E), for which we use monthly petroleum consumption data as a proxy. As the data on the amount of petroleum products consumed within the country is not publicly available, we estimated the data from the monthly import payments on petroleum, collected from different publications of Monthly Economic Trends of the central bank of Bangladesh

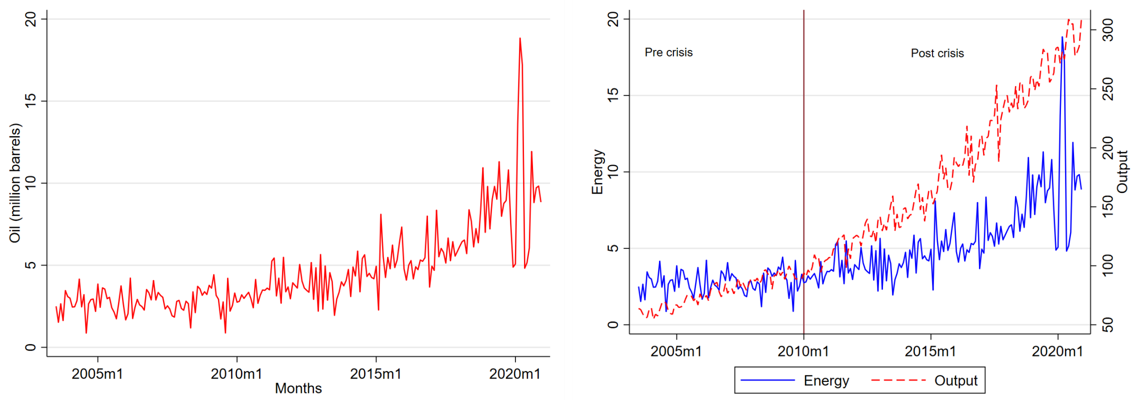


(A) Output (Y) (B) Foreign Remt. (FR)

(C) Industrial Export (IE) (D) Ex. Rate (ER)

FIGURE 3.2: Variables in level

(BB, 2021). As the data are compiled in domestic currency, we have converted that into US dollars and then convert that to billion barrels by using the world petroleum price index collected from Index Mundi (Index, 2021). The data on Foreign remittances (FR), ready made garments export (IE) and exchange rate (ER) are also collected from Monthly Economic Trends of the central Bank of Bangladesh (BB, 2021). Displayed in Figure (3.2) are the output and the key determinants of the output of Bangladesh. The output (Y) series clearly illustrates an upward growth trend during the entire period of analysis. Another important aspect of the output series is the cyclic component which follows a consistent pattern, especially after 2010, indicating the resilience of the economy in converging to the long run trend. Although we observe sufficient variation in the cycle, we do not visualise any seasonal pattern in the data, which may rule out the existence of seasonal unit root. Not surprisingly, another two most important determinants of the output of Bangladesh, namely foreign remittances (FR) and ready made garment export (IE) also follow similar trajectories in terms of trend and cycle of the output series. The final variable or control here is the exchange rate (ER), which does not have a regular cyclic pattern but follows a similar trend like the rest of the three variables.



(A) Energy (lnE) (B) Output(lnY) and Energy(lnE)

FIGURE 3.3: Pre and post-2010 energy crisis

Next, we describe our second variable of interest, the primary energy consumption (E) series displayed in Figure (3.3). Overall, we see an upward trend in the energy series especially after January 2010. A close examination of Figure (3.3a) reveals that up to Jan/2010, the average energy consumption level did not change much, implying a constant mean during this time. But a clear upward trend of the average energy consumption is evident after Jan/2010. This is not surprising as we find that a major shift in energy policy occurred during the transition period to mitigate the pre-2010 energy crisis of Bangladesh that started in 2009 onward (Moazzem, 2019).

TABLE 3.1: Energy-Output pre & post 2010 energy crisis

	Full sample		**Pre 2010**		**Post 2010**		**Diff.(Per-Post)**	
	lnE_t	lnY_t	lnE_t	lnY_t	lnE_t	lnY_t	lnE_t	lnY_t
Mean	1.38^a	4.85^a	$.98^a$	4.34^a	1.62^a	5.15^a	$-.65^a$	$-.81^a$
Std. Error	(.04)	(.04)	(.04)	(.02)	(.04)	(.03)	(.06)	(.04)
Corr. (lnE_t, lnY_t)	.80	-	.04	-	.77	-	-	-
N	210	210	78	78	132	132	-	-

*P-value for the levels of significant are $^c p < 0.1$; $^b p < 0.05$; $^a p < 0.01$

Interestingly, despite the differences in the level of energy consumption, the output growth remains consistent in the entire period as we can see from Figure (3.3b). This change in policy and the subsequent change in the level of energy uptake provides us with an opportunity to study the energy-growth nexus during the lower and higher levels of energy consumption. Table (3.1) describes the comparison of these two variables before and after the energy crisis of Bangladesh where we see the differences are significant at even 1%. The table also indicates that the average consumption of energy has increased by around 65% in the post-crisis period compared to the pre-crisis era. The average output level and the growth trend of output, however, remained the same during both the periods concerned as evident from Figure (3.3b).

3.5 Estimation strategy

Based on the dynamic variations and associated trends of the variables, we estimate our models specified in equations (3.8) and (3.9) in three stages. First, we look for a long-run relationship in the variables from cointegration estimations; second, we estimate the short and long run coefficients of the model by autoregressive distributed lags (ARDL) method; and finally, we find out the direction of causality by Granger causality under vector error correction method (VECM).

3.5.1 Unit root testing

Test of stationarity of the variables turns out to be the most important step in our estimation process as the subsequent estimation directions are based on the order of integration $I(d)$ of the variables concerned. For that, we first employ augmented Dickey-Fuller (ADF) test where the null hypothesis is that the time series is $I(1)$ against the alternative $I(0)$ (Dickey and Fuller, 1981). The test assumes that the errors of the series approximately follow an autoregressive moving average (ARMA) structure. ADF test also requires optimal lags selection for obtaining results with minimum power loss and stable size (Ng and Perron, 1995). Including less than optimal lags in the test would likely introduce auto-correlation in the error term, which eventually gives bias results. On the other hand, more than optimal lags would cause power loss of the test. In this study, we will be using ACI information criteria for selecting optimal lags. Despite its wide-spread use, ADF test is often criticized for being non-robust. Therefore, to reconfirm the order of integration of the series, we use Phillips-Perron (PP) test (Phillips and Perron, 1988). The main difference of the PP compared to the ADF test lies in the treatment of the serial correlation and heteroskedasticity of the error terms. While the ADF test assumes the error terms of the series are independent and identically distributed (iid) with constant variance, the PP test is less restrictive regarding the distribution of the errors. Therefore, PP test results are more robust than ADF results in the case of heteroskedasticity. Additionally, unlike the ADF test, lag selection is not an important issue for the PP test.

3.5.2 ARDL bounds testing for cointegration

After ensuring the order of integration of the time series, we use autoregressive distributed lags method and bounds testing procedure (ARDL bounds) developed by Pesaran, Shin, and Smith, 2001. This is a comprehensive approach of model specification where we can test for cointegration, error correction and recover short and long-run coefficients. The decision of bounds testing, however, depends on the stationarity of the independent variable of the model. Thus, our strategy engages two possible directions. First, we will proceed for bounds testing if the following three conditions are fulfilled: a) The dependent variable is $I(1)$; b) The independent variables are either $I(0)$ or $I(1)$ but not explosive or in a higher order of integration than $I(1)$; c) There is no autocorrelation in the error term. Second, if we find the independent variable is not $I(1)$, we then only estimate the short-run ARDL(p,q) model where error correction will not be necessary. The ARDL bounds testing procedure is implemented after specifying a dynamic unrestricted error correction model (UECM) by integrating the short-run dynamics with the long-run equilibrium without losing any long run information. Thus, the UECM is specified as follows:

$$\Delta lnY_t = a_1 + \gamma_1 lnY_{t-1} + \gamma_2 lnIE_{t-1} + \gamma_3 lnFR_{t-1} + \gamma_4 lnER_{t-1} + \gamma_5 lnE_{t-1} + \sum_{i=1}^{k} \alpha_1 \Delta lnY_{t-i} + \sum_{i=0}^{l} \alpha_2 \Delta lnIE_{t-i} + \sum_{i=0}^{m} \alpha_3 \Delta lnFR_{t-i} + \sum_{i=0}^{n} \alpha_4 \Delta lnER_{t-i} + \sum_{i=0}^{p} \alpha_5 \Delta lnE_{t-i} + u_t \tag{3.10}$$

$$\Delta lnE_t = a_2 + \delta_1 lnE_{t-1} + \delta_2 lnIE_{t-1} + \delta_3 lnFR_{t-1} + \delta_4 lnER_{t-1} + \delta_5 lnY_{t-1} + \sum_{i=1}^{k} \beta_1 \Delta lnE_{t-i} + \sum_{i=0}^{l} \beta_2 \Delta lnIE_{t-i} + \sum_{i=0}^{m} \beta_3 \Delta lnFR_{t-i} + \sum_{i=0}^{n} \beta_4 \Delta lnER_{t-i} + \sum_{i=0}^{p} \beta_5 \Delta lnY_{t-i} + v_t \tag{3.11}$$

Here, Δ is difference operator, γ_i and δ_i are the long run, α_i and β_i are the long run coefficients, a_1 and a_2 are time invariant constants, u_t and v_t are white noise. The optimal lag selection of the differenced terms is obtained from Akaike information criteria (AIC). To find out the existence of cointegration, a joint F-test for the coefficients of the long run variables is conducted. As the estimated F-test has a non-standard distribution, Pesaran, Shin, and Smith, 2001 suggest a boundary of the critical values for decision making. The critical values above the upper boundary are assumed to be $I(1)$ and thus cointegrated and critical values below the lower boundary are $I(0)$ with no cointegration. But if the critical values lie in between the upper and lower bound, no conclusion can be drawn from the test. In our study, for example, the null hypothesis of no long run relationship between the variables for equation (3.10) is $H_0 : \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$ against the alternative of cointegration $H_1 : \gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq 0$. Now, rejecting the null hypothesis implies that inclusion of the long run variables in the UECM equations is important, which suggests a long run relationship or cointegration. If we fail to reject the null hypothesis, it indicates that the true UECM model is a short run one, suggesting no cointegration. The reliability of the bounds test depends on the fact that there is no serial correlation in the error terms of the UECM models. In our study, we implement the Durbin–Watson test to ensure that the test statistic is within the vicinity of 2, indicating no serial correlation.

3.5.3 Short- and long-run estimation

The outcomes of the ARDL bounds test will determine whether we estimate both the long run error correction model or only the short run one. If we find cointegration, we specify the error correction model for the long run relationship in two steps. At first, we run the long run model in equation (3.12) and collect the error terms. In the next step, we use the lag of the error terms in the error correction model in equation (3.13).

$$lnY_t = a_1 + \gamma_1 lnY_{t-1} + \gamma_2 lnIE_{t-1} + \gamma_3 lnFR_{t-1} + \gamma_4 lnER_{t-1} + \gamma_5 lnE_{t-1} + a_2 ECT_{t-1} + \epsilon_t \tag{3.12}$$

$$\Delta Y_t = a_0 + \lambda ECT_{t-1} + \sum_{i=1}^{p} \alpha_{1i} \Delta Y_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta X_{t-1} + ... + e_t \tag{3.13}$$

Here, the coefficient of the error correction term (ECT), λ implies convergence speed from short run to long run. The notation X, in equation (3.13) indicates all the explanatory variables of the model. In the case of no cointegration, the model specification is simply a short run estimation as follows:

$$\Delta Y_t = a_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta Y_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta X_{t-1} + ... + e_t \tag{3.14}$$

A number of diagnostic tests needs to be performed before accepting the estimates of the ARDL model. To check the higher order serial correlation in the disturbance, we implement Breusch–Godfrey test. This is a suitable test for this class of model as it does not require the regressors to be strictly exogenous. The null hypothesis of the test is that the residuals are not serially correlated. The second diagnostic test is the

Engle's Lagrange Multiplier (LM) test for autoregressive conditional heteroskedasticity (ARCH) where the null hypothesis is that the model does not have ARCH effect. We expect not to reject the null hypothesis as heteroskedasticity leads to large errors in the estimation. The third standard test of this series is the Ramsey test for model specification which has a null hypothesis that the model has no omitted variables. Finally, we test structural stability of the parameters of the dynamic models by cumulative sum (CUSUM) and cumulative sum square (CUSUMSQ) analysis. To test the stability of the intercept, CUSUM test is important, and to test the stability of the regression errors, CUSUM Sq. test is necessary.

3.5.4 Granger causality

Although we may grasp some ideas on the causality of the variables from the ARDL model, for a systemic analysis, we implement Granger causality through vector error correction model (VECM). If the bounds test reveals that the variables are cointegrated, we specify VECM and proceed for causality, or else we specify VAR model with differenced stationary process followed by causality testing. The idea of Granger causality is based on the fact that if the history of one time series improves the prediction of another time series, the former is said to be causing the latter (Granger, 1969). The underlying assumption here is that cause happens before its effect and the cause has a set of exclusive information for the future trajectory of the effect. For example, in the case of cointegration, we specify the long run VECM model as follows:

$$\begin{pmatrix} \Delta lnY_t \\ \Delta lnE_t \\ \Delta lnIE_t \\ \Delta lnFR_t \\ \Delta lnER_t \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix} + \sum_{i=1}^{p}(1-L) \begin{pmatrix} A_{11i} & A_{12i} & A_{13i} & A_{14i} & A_{15i} \\ A_{21i} & A_{22i} & A_{23i} & A_{24i} & A_{25i} \\ A_{31i} & A_{32i} & A_{33i} & A_{34i} & A_{35i} \\ A_{41i} & A_{42i} & A_{43i} & A_{44i} & A_{45i} \\ A_{51i} & A_{52i} & A_{53i} & A_{54i} & A_{55i} \end{pmatrix} \begin{pmatrix} lnY_{t-i} \\ lnE_{t-i} \\ lnIE_{t-i} \\ lnFR_{t-i} \\ lnER_{t-i} \end{pmatrix} + \begin{pmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \\ \zeta_4 \\ \zeta_5 \end{pmatrix} \hat{e}_{t-1} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{pmatrix} \tag{3.15}$$

Where Δ is difference operator, L is lag operator, $\hat{e}_{t-1}$ is lagged errors estimated from the long run specification, $a's$ are time invariant constants, $A's$ are short run coefficients, $\zeta's$ are long run coefficients, $\varepsilon's$ are white noises.The optimal lags for the specification are started from $i = 1$ up to p, which are selected by Akaike information criteria (AIC). The advantage of this residual-based test is that we can find the direction of causality for both short and long run models. For short run causality, we conduct a joint significant test $(F - test)$ or or χ^2 test of the lagged differenced variables and for long run causality, we observe the significance $(t - test)$ level of the $\hat{e}_{t-1}$ coefficients. For instance, in equation (3.15), $A_{12i} \neq 0, \forall_i$ indicates that energy consumption Granger causes output in sort run and $\zeta_1 \neq 0$ indicates the same relationship holds in the long run. When we find both short and long run relationships hold at the same time, we call it a strong causality with cointegration.

3.5.5 Impulse response function (IRF)

Although Granger causality shows the direction of causality, it does not indicate how persistent the relationship is. To find that out, we plot impulse response function (IRF) after specifying the model with VAR. In this study, we present orthogonalized IRF after ordering the variables according to the contemporaneous effects. We will be using Granger causality to confirm the Cholesky ordering of the variables. After confirming the ordering, we display graphically how shocks (one standard deviation) on one variable impacts the future trajectory of another variable. Thus, with the VAR model, we can observe the temporary shocks with stationary variables. In addition, we can also plot IRF after specifying the model with VECM if we find the variables are to be cointegrated. In this case, we would see the permanent impact of the shocks in the non-stationary variables.

3.5.6 Robustness analysis

The key model we use in this study is the ARDL technique by which we have tested cointegration and estimated short and long run coefficients. To verify the robustness of the results, we specify Johansen and Juselius, 1990 cointegration technique as follows:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \epsilon_t \tag{3.16}$$

Where X is a $(K \times 1)$ vector variables with $I(1)$ series, Π is long term and Γ_i is short term $(K \times K)$ parameter matrices and ϵ_t is $(K \times 1)$ vector of serially uncorrelated normally distributed errors. The key idea of this method is to find out the rank (r) of the Π matrix, which contains long run information along with error correction term or speed of adjustment from short to long run. We know the rank of a matrix is determined by the number of linearly independent rows or columns. Two rows (or columns) are said to be linearly independent if it is not possible to express one of the rows as a multiple of another one. From equation (3.16), we can think of three distinct scenarios. First, if the π matrix has a full rank, then it is invertible and all the variables of the system are stationary $I(0)$ at the level. In such a case, we cannot proceed with cointegration. Second, if the rank of the π matrix is 0, then the linear combination of the $I(1)$ variables of the system is not stationary, which implies no cointegration. Third, when the rank of the π matrix is between 0 and full rank $(0 > r < K)$, we assume there is a possibility for cointegration. Based on this possibility, Johansen and Juselius, 1990 propose two test statistics, namely tress and maximum eigenvalue statistics as follow:

$$\lambda_{trace} = -T \sum_{i=r+1}^{K} ln(1 - \hat{\lambda}_i) \tag{3.17}$$

Where T is the number of observations, $\hat{\lambda}_i$ are the estimated eigenvalues. This statistic has a non-standard distribution under null hypothesis as it places restrictions on the coefficients of the long run parameters (X_{t-1}), which are assumed to have $K - r$ random-walk processes. We test the null hypothesis here by the rank of the Π matrix, which is equal to r against the alternative that the rank is strictly larger than that. Another way to test cointegration relation in the model is by maximum eigenvalue statistic as follow:

$$\lambda_{max} = -Tln(1 - \hat{\lambda_{r+1}}) \tag{3.18}$$

Here, we assume a given rank (r) of the Π matrix under null hypothesis against the alternative that there are $r + 1$ cointegrating equations. In most of the empirical literature, we find trace statistic as a primary decision tool compared to maximum eigenvalue statistic.

After confirming the cointegration relationship, the subsequent estimation technique is similar to that of ARDL(p,q) estimation. The only difference in VECM estimation is that unlike ARDL it is conducted on VAR framework. In the case of all stationary variables we run a k dimensional VAR model as follows:

$$X_t = \alpha_0 + \Gamma_1 X_{t-1} + \Gamma_2 X_{t-2} + ... + \Gamma_p X_{t-k} + \epsilon_t \tag{3.19}$$

Where α_0 is time-invariant constant of $k \times 1$ vector, Γ_i are the coefficient matrix of $k \times k$ dimensions, X is a vector of stationary variables, and ϵ_t is $k \times 1$ vector of white noise disturbance term.

If we find cointegration among the variables, we specify the error correction model by modifying the equation (3.16) as below:

$$\Delta X_t = \alpha(\beta' X_{t-1}) + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \epsilon_t \tag{3.20}$$

Where β is a matrix of co-integrating equation $p \times r$ and α refers to the speed of adjustment matrix of $p \times r$ dimension, where r is the number of co-integrating vectors or rank of the Π matrix in equation (3.16).

3.6 Results

Table (3.2) provides the descriptive statistics and correlation coefficient matrix for the variables in natural log form. We find here that the mean and median of the variables are approximately the same in magnitude. Regarding standard deviation, we see that except for exchange rate (lnER), the rest of the variables have almost similar magnitudes (0.50). This wide variation in the data, especially for the key variables of interest, is likely to be conducive for the statistical analysis. Turning to the correlation matrix, we find the pair-wise correlation to be positive and higher for all the variables in the study.

TABLE 3.2: Descriptive statistics and correlation matrix

Variables	lnY_t	lnE_t	$lnIE_t$	$lnFR_t$	$lnER_t$
Mean	4.85	1.38	6.98	6.76	4.30
Median	4.83	1.32	7.13	7.00	4.35
Std. Dev.	.49	.50	.56	.54	.11
Maximum	5.73	2.94	7.77	7.86	4.44
Minimum	4.00	-.14	5.58	5.43	4.06
Correlation matrix					
lnY_t	1.00	-	-	-	-
lnE_t	.80	1.00	-	-	-
$lnIE_t$	.93	.71	1.00	-	-
$lnFR_t$	.87	.64	.92	1.00	-
$lnER_t$	.93	.72	.93	.92	1.00
N	210	210	210	210	210

3.6.1 Unit root testing

The results of the unit root test are displayed in Table (3.3). We have included 4 lags for the ADF test as suggested by AIC. The test reveals that all the variables in level are not stationary, but after the 1st difference, they become stationary with a 1% significant level. To reconfirm the results, we have used Phillips-Perron (PP) test and find that all but the energy series are non-stationary at level. Like the ADF test, the PP test also indicates that after the 1st difference, all of the variables are stationary at 1% significant level. The decision regarding the energy consumption series is based on the fact that as both the tests are not indicating stationary at level, we consider, conservatively, that the series is not stationary at level.

TABLE 3.3: Unit roots test results

Variables	ADF test		PP test		Decision
	Level	*1^{st} diff.*	*Level*	*1^{st} diff.*	
lnY_t	-.07	-12.69^a	-.04	-28.12^a	$I(1)$
lnE_t	-1.2	-10.88^a	-5.98^a	-40.01^a	$I(1)$
$lnIE_t$	-2.00	-10.43^a	-1.58	-25.23^a	$I(1)$
$lnFR_t$	-1.48	-9.31^a	-1.73	-28.98^a	$I(1)$
$lnER_t$	-1.98	-6.48^a	-1.97	-10.73^a	$I(1)$

*P-value for the levels of significant are $^c p < 0.1$; $^b p < 0.05$; $^a p < 0.01$

3.6.2 ARDL bounds test

The results of the unit root test confirm that all the variables in the model are $I(1)$ and, therefore, we now proceed for the ARDL bounds test to find out cointegration relationship. The results displayed in Table (3.4) indicate that energy (lnE), output (lnY), industrial export (lnIE) and foreign remittances (lnFR) are cointegrated with the rest of the other variables, with at least a 5% significant level. Exchange rate (lnER) is the only variable that is cointegrated at a 10% significant level. We come up with the

TABLE 3.4: ARDL Bounds test

Models	lags	F-stat	Adj-R^2	D.W. test
$lnE_t = f(lnY_t, lnER_t, lnIE_t, lnFR_t)$	$(2,3,1,0,1)$	14.15^a	.54	1.97
$lnY_t = f(lnE_t, lnER_t, lnIE_t, lnFR_t)$	$(4,2,0,0,1)$	4.18^b	.99	2.15
$lnER_t = f(lnE_t, lnY_t, lnIE_t, lnFR_t)$	$(4,0,0,2,3)$	3.98^c	.99	1.97
$lnIE_t = f(lnE_t, lnY_t, lnER_t, lnFR_t)$	$(2,0,4,0,0)$	6.59^a	.96	2.04
$lnFR_t = f(lnE_t, lnY_t, lnER_t, lnIE_t)$	$(3,0,1,1,2)$	4.48^b	.97	2.08
Significance	*Lower bounds I(0)*		*Upper bounds I(1)*	
1% level	3.74		5.06	
5% level	2.86		4.01	
10% level	2.45		3.52	

*P-value for the levels of significant are $^c p < 0.1$; $^b p < 0.05$; $^a p < 0.01$

conclusions from the fact that the bounds estimated from the data generating process of the model are between 2.86 to 4.01 at a 5% significant level and all of our estimated F statistics are above the lower bound $I(0)$, indicating the long run relationship of the variables. To confirm the validity of the model, we ensure that the error terms do not contain any auto-correlation as we find the results of Durbin-Watson test to be within the vicinity of 2.0 for each model. One of the advantages of the ARDL model is that we can include the required number of individual lags until the disturbance term becomes white noise process. Based on the Akaike Information Criteria (AIC), we have included the lags as we see in Table (3.4). Finally, to observe the goodness of the fit, we have included $Adj - R^2$ and find the models to be well-fit.

3.6.3 Economic output lead energy conservation model

As the results of the ARDL bounds test indicate cointegration for all the variables, now we estimate long and short run parameters along with error correction terms for speed of adjustment from short to long run trends. In this section, we particularly investigate two of our key variables of interest, namely output (lnY) and energy consumption (lnE) in a multivariate framework. The first model we consider here is based on the hypothesis that output and other covariates of the model have a long run impact on the level of energy consumption. This one-way influence is termed as energy conservation hypothesis in energy economics. The reason for this terminology is based on the idea that reduction of energy or energy conservation is feasible without off-setting economic growth if the model provides significant estimates. The underlying assumption of the hypothesis is that the economy is endowed with sufficient energy which does not put a restriction on the output but rather, the output determines how much energy to utilise in the production process. The energy conservation hypothesis is very popular from an environmental point of view as the reduction in energy usage turns out to be a reduction in carbon emissions in a fossil fuel-dominated energy system. This conclusion, however, is challenged by many empirical literatures as an energy constrained economy does not respond similarly to an energy sufficient economy. In persuasion to understand the distinction, we estimate the parameters of the model for low and high energy consumption periods of Bangladesh along with the combined sample (Table 3.5). The estimated parameters of the model provide a number of interesting insights on energy conservation hypothesis. The estimation of the full sample shows that energy elasticity of output ($\frac{\Delta E_t}{\Delta Y_t}$), is 1.12 in the long run and 0.71 in the short run. This high response of energy due to output fluctuation indicates that the energy consumption of Bangladesh is largely output-driven. The coefficient of the error correction term, $\hat{\lambda}$ = -0.80, indicates a very quick adjustment[3] (around 1 month) from short to long run trend. Incidentally, studies conducted by Mozumder and Marathe, 2007,

[3] 100% adjustment occurs in $(\frac{1}{0.80}) = 1.25$ months.

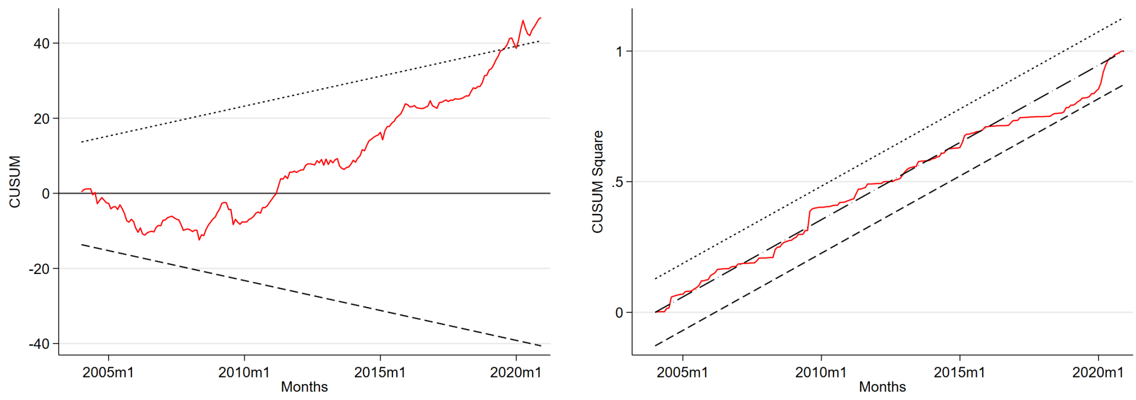
TABLE 3.5: Energy Conservation Model

Dependent variable: lnE_t			
Variables (Lags)	**Full sample** (2 3 1 0 1)	**Before 2010m1** (2 0 0 0 0)	**After 2009m12** (3 3 1 0 1)
Long run results			
lnY_t	1.12***	-	.94***
$lnIE_t$	-.02	-	.02
$lnFR_t$	-.16	-	.21
$lnER_t$	-.47	-	-.33
$Ajd-R^2$	.54	-	.55
*Short run results**			
ECM_{t-1}	$-.80^{***}$	-	-1.06^{***}
ΔlnE_{t-1}	.01	-.04	.01
ΔlnY_t	.71**	-.28	.55
$\Delta lnIE_t$	-.02	-.27	.02
$\Delta lnFR_t$	$-.70^{***}$	.18	$-.47^{**}$
$\Delta lnER_t$	7.03	.87	6.27*
constant	-.63	- .96	-3.51
$Ajd-R^2$	.70	-.02	-3.63
N	207	76	132
Diagonostic tests			
$\chi^2 Serial(p-value)$	4.99(.29)	1.78(.78)	7.97(.09)
$\chi^2 ARCH(p-value)$	.92(.34)	.55(.46)	15.4(.00)
$\chi^2 Remsay(p-value)$	1.78(.15)	2.43(.07)	2.51(.06)
$CUSUM/CUSUMsq.$	Stable(5%)	Stable(5%)	Stable(5%)

*P-value for the levels of significant are *p<0.1; **p<0.05; ***p<0.01

*Short-run lag coefficients are not included.

Paul and Uddin, 2011 and Ahamad and Islam, 2011 also provide similar results with analysis conducted in different time-frame and econometric methodologies. Now, let us examine how the relationship evolves dynamically in low and high levels of energy consumption periods. As we see from the data section (Table 3.1), Bangladesh faced an energy crisis before 2010 that eventually mitigated that within the next subsequent years. Using the model for low energy availability period, we find that output has no short or long run impacts on the level of energy consumption. In energy economics, such an economy is termed as an energy neutral economy. The estimations for a relatively higher level of energy consumption period, however, show the instrumental role of output in determining the level of energy consumption. These results are eventually supporting our theoretical postulation that in an energy constrained environment, the normal energy-output relationship is disrupted. We assume here that the supply of energy in the economy is such an insufficient quantity that output or other macroeconomic variables did not respond to the variation of energy. The diagnostic tests are included with the lower part of the table where we find all the samples pass the auto-correlation, Remsay model specification tests with a 5% significant level. For conditional heteroskedasticity test, the sample with higher energy consumption period is the only one that could not pass. For the dynamic stability of the model, we use CUSUM and CUSUM Sq. test and find that all the samples are dynamically stable within a 95% confidence interval (Figure 3.4).



(A) CUSUM (B) CUSUM Squared

FIGURE 3.4: Dynamic stability tests (Combined sample)

3.6.4 Energy lead economic output model

So far we have seen how output impacts energy consumption in the short and long run. In this section, we will be dealing with how energy influences output in different economic environments. This specification takes output as an independent variable and observes how energy, along with other control variables, impact output in different energy availability scenarios. We specify an error correction model here as the bounds test shows cointegration. The estimations of the full sample indicate output elasticity of energy ($\frac{\Delta Y_t}{\Delta E_t}$), 0.61 in the long run (Table 3.6). The short run elasticity of energy (0.02) in this model is not significant at a 5% level but is at a 10% level. Convergence to the long run trend of output from short run is very slow here as the error correction coefficient is -0.15. This indicates that it will take almost 7 months to reach from short run fluctuation to long run trends of output. The evidence of slow adjustment compared to the conservation model above can be observed from the error correction plots included in Appendix (3A.1). Evaluating the diagnostics tests, we see that the full sample could not pass the test of serial correlation and model specification test. This sample also fails in dynamic stability as the results of CUSUM/CUSUM Sq. tests. Now, let us evaluate

TABLE 3.6: Energy lead growth model

Dependent variable: lnY_t			
Variables (Lags)	**Full sample** (4 2 0 0 1)	**Before 2010m1** (4 0 3 4 0)	**After 2009m12** (4 2 0 0 1)
Long run results			
lnE_t	.61***	-.00	.67***
$lnIE_t$	.26	.25	.29
$lnFR_t$	.06	.11	.07
$lnER_t$	.77	.60	.30
$Ajd - R^2$	.49	.59	.55
*Short run results**			
ECM_{t-1}	$-.15$***	-1.86***	$-.16$***
ΔlnY_{t-1}	.63	.18	.66
ΔlnE_t	.02*	-.00	.04**
$\Delta lnIE_t$	.04	.16***	.02
$\Delta lnFR_t$	.27***	.12***	.33***
$\Delta lnER_t$	.11	1.55***	.08
constant	-.21	-.52	-.15
$Ajd - R^2$	.99	.91	.97
N	206	77	132
Diagnostic tests			
χ^2Serial(p-value)	19.32(.00)	13.31(.01)	12.20(.02)
χ^2ARCH(p-value)	.00(.97)	.03(.87)	.02(.88)
χ^2Remsay(p-value)	10.37(.00)	.19(.91)	7.53(.00)
$CUSUM/CUSUMsq.$	Unstable(5%)	Stable(5%)	Unstable(5%)

*P-value for the levels of significant are *p<0.1; **p<0.05; ***p<0.01

*Short-run lag coefficients are not included.

the model for low and high energy consumption periods. The model in low energy period (before 2010) is proved to be stable and passed all the diagnostic tests except serial correlation. Interestingly, the estimations of this period indicate no impact of energy on output both in the short and long run. On the other hand, the sample with higher energy consumption periods (after 2010) displays similar estimates as in the full sample. Overall, from the estimates and the diagnostic tests, we find relatively weak evidence of energy-led growth in Bangladesh. To explain the apparent discrepancies of the estimations of the model, we call for the theoretical specification of the study where we show that in an energy constrained economy, energy, rather than being a productive resource, becomes a mere consumer good. This proposition is supported by the sample where energy consumption was very low due to energy crisis. An analyst looking at the estimates based on the energy crisis period data, from both the energy conservation and growth models, may wrongfully conclude that this economy is energy neutral both in the long and short run.

3.6.5 VECM Granger causality

Although the estimations of the previous section already give us an indication of the direction of causality, we systematically estimate Granger causality to confirm the results. As all our variables are $I(1)$, we specify the model with VECM, and from the estimates of difference and error correction coefficients, we conclude on short and Long run causality, respectively (Table 3.7). Long run estimates of the full sample shown in Table (3.8) indicate that both energy and output impact each other in the short and long run. However, as we see in the preceding section the energy lead growth model is not dynamically stable and fails in diagnostic test, we can reliably confirm that the history of output influences the contemporaneous uptake of energy. In other words, the economy of Bangladesh endorses energy conservation hypothesis both in short and long run. The Granger causality results for the sample with a lower level of energy consumption period indicate no causality or neutrality hypothesis as we see the same from the ARDL estimations. Finally, the causality results for a higher energy consumption period is similar to that of the full sample results.

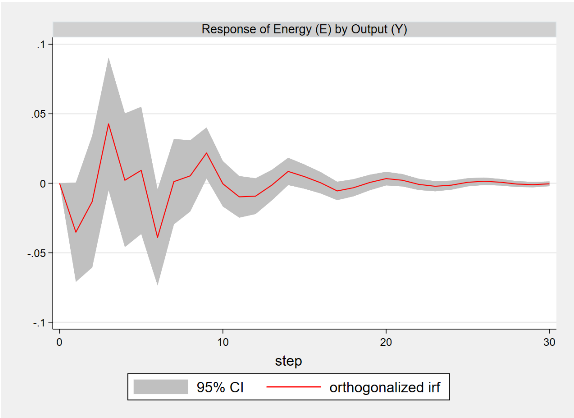
TABLE 3.7: VECM Granger causality

	Full sample			Low energy			High energy		
	ΔE_{t-i}	ΔY_{t-i}	ECT_{t-1}	ΔE_{t-i}	ΔY_{t-i}	ECT_{t-1}	ΔE_{t-i}	ΔY_{t-i}	ECT_{t-1}
ΔE_t	-	24.62^a	$-.71^a$	-	.43	.01	-	10.7^a	$-.80^a$
ΔY_t	11.69^a	-	$-.11^a$	3.51	-	-1.44^a	10.13^a	-	$-.13^a$

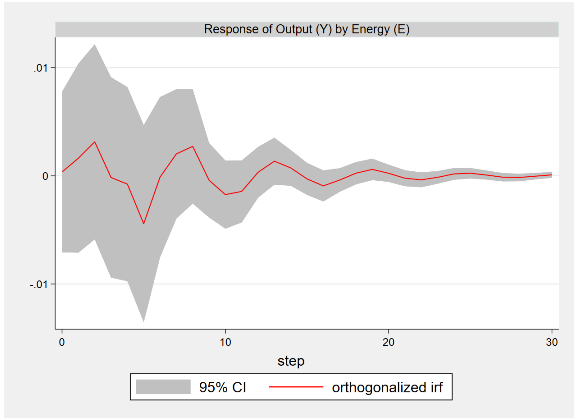
*F-test statistics P-value for the levels of significant are $^c p < 0.1$; $^b p < 0.05$; $^a p < 0.01$

3.6.6 Temporary and permanent IRF

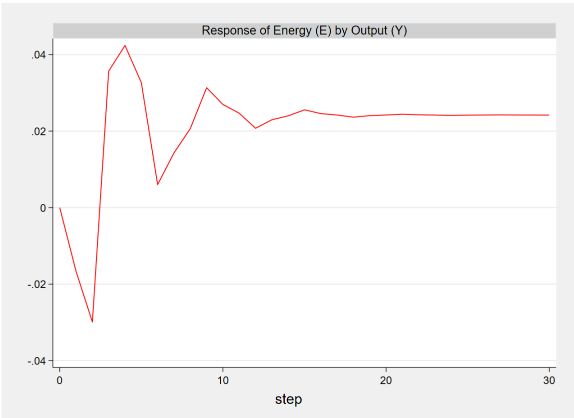
Although Granger causality indicates the direction of causality, it could not capture the relative strength and dynamic persistence of the relationship. To observe the out-of-sample behaviour of the variables, we present both temporary and permanent IRF by specifying the model with VAR and VECM respectively. To disentangle orthogonalized impulse responses, we order the variables from the least to the most endogenous sequence in the VAR model. From Granger causality, we find out that the energy (lnE) is the most contemporaneously exogenous while output (lnY) is the most contemporaneously endogenous variable. Analysing the temporary IRF presented in Figure (3.5a), we observe a profound impact due to one standard deviation shock to output on the



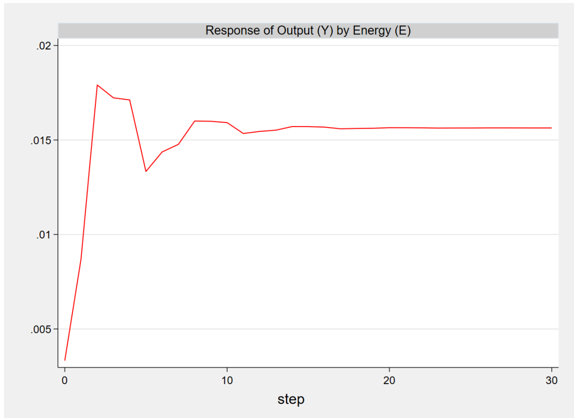
(A) Response of Energy (E), VAR



(B) Response of Output (Y), VAR



(C) Response of Energy (E), VECM



(D) Response of Output (Y), VECM

FIGURE 3.5: Temporary (VAR) and permanent (VECM) IRFs

level of energy consumption, which lasts around 24 months. Initially, the impact of output on energy is negative for 2 to 3 months before it picks upward and follows a sin-wave like trajectory until it dies down. On the other hand, the temporary impact of energy on output is insignificant and the trajectory is unreliable, provided the large confidence interval shown in Figure (3.5b). Next, we estimate permanent IRF by specifying the model with VECM as all our variables $I(1)$. Figures (3.5c) and (3.5d) display IRF's of energy and output for the full sample. Similar to the VAR model, we see a wide fluctuation of energy due to the variation of output before it plateaued permanently at a positive level. Finally, the impulse of energy on output is still less significant but showed a positive tenet all the way before settling down to a positive permanent level.

3.6.7 Johansen cointegration test and VECM estimates

In this section, we test the robustness of the results estimated by the ARDL method by Johansen test of cointegration and VECM estimation techniques. The cointegration results and VECM estimations are included in the Appendices (3A.2 & 3A.3). For comparison, we present the summary of the results from each method in Table (3.8). In general, we see similar results in terms of sign and magnitude of the estimates in both methods. However, during the low energy consumption period (before 2010), the results of the model are different. This is because VECM specification requires all the variables to be $I(1)$ while the sample of pre-2010 shows that Energy (lnE) is $I(0)$ at level. Therefore, we could not specify the VECM for that period. On the other hand, we specify the ARDL model for the same period as this specification requires only the dependent variable to be $I(1)$ and the regressors can be either $I(0)$ or $I(1)$ but not an explosive term. Although the ARDL method shows a cointegration of output with

TABLE 3.8: Comparing ARDL and VECM estimates

	Full sample		**Pre 2010**		**Post 2010**	
Dep.var. lnE_t	ARDL	VECM	ARDL	VECM	ARDL	VECM
Cointegration	Yes	Yes	No	No	Yes	Yes
ECT_{t-1}	$-.80^{***}$	$-.71^{***}$	-	-	-1.06^{***}	$-.80^{***}$
lnY_t	1.12^{***}	1.40^{***}	-	-	$.94^{***}$	$.97^{***}$
$lnIE_t$	-.02	-.38	-	-	.02	$-.14$
$lnFR_t$	-.16	-.03	-	-	.21	$.65^{***}$
$lnER_t$	-.47	-.17	-	-	-.33	-.75
Dep.var. lnY_t						
Cointegration	Yes	Yes	Yes	No	Yes	Yes
ECT_{t-1}	$-.15^{***}$	$-.12^{***}$	-1.86^{***}	-	$-.16^{***}$	$-.13^{***}$
lnE_t	$.61^{***}$	$.75^{***}$	-.00	-	$.67^{***}$	1.03^{***}
$lnIE_t$	.26	$.29^{***}$	$.25^{***}$	-	.29	.14
$lnFR_t$	.06	.02	$.11^{***}$	-	.07	$-.67^{***}$
$lnER_t$	.77	.13	$.30^{***}$	-	.30	.75

*P-value for the levels of significant are $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

energy, the coefficient of energy is 0, indicating no impact of energy on output during this period. So, we conclude neutrality hypothesis from ARDL for the low energy consumption period.

3.7 Discussion

The study starts with a hypothesis that in an energy constrained economy, energy demand is derived mostly by consumption need rather than by production purpose. We examine this hypothesis in two stages. First, we test how economic output influences energy consumption for an energy constrained economy. In support to our hypothesis we find that long run output elasticity of energy demand ($\frac{\Delta E}{\Delta Y}$) is more than unity, implying output change leads to a substantial change in energy demand. In conventional energy economics, this situation entails for an energy conservation policy to seize the excessive demand for energy principally for better environmental outcomes. However, if we follow the proposed constrained energy hypothesis, we need to ensure energy sufficiency before taking energy conservation policy as this is likely to hinder the much-needed consumption demand amongst the population. In addition, in an energy constrained economy, it is less likely to flourish energy-intensive production system. Introducing energy conservation policy in such an economy will further jeopardise energy use. The mistreating of energy conservation policy can also be examined by the fact that if energy supply to an economy is such a scanty amount that it does not display any long run relationship with output, it may wrongly signal that energy is irrelevant for the economy. This is what exactly happened in the energy crisis periods of Bangladesh, where we find energy did not cointegrate with the output trend in the long run. Again, following our constrained energy hypothesis, we would first ensure energy sufficiency to the economy before drawing conclusions based on the causality analysis. Additionally, energy conservation policy in an energy constrained economy may backfire by giving rise to socio-political unrest as it happened in Haiti, Belgium, Bulgaria, Burkina Faso, France, India and Sierra Leone in 2018 (Timilsina and Pargal, 2020).

Second, to further elaborate the constrained energy hypothesis, we specify an energy lead growth model for an energy constrained economy. Ideally, this model implies that a higher level of energy input is likely to be converted into higher economic output or vice versa. We scrutinize this energy to output conversion process under the capability of an economy in energy utilization. This is because an industrial economy is well equipped with augmenting output by energy input compared to a non-industrial one. This proposition turns out to be true as we see the growth of energy consumption did not promote desired level of output growth in Bangladesh. Here, we find long run energy elasticity of output ($\frac{\Delta Y}{\Delta E}$) is less than unity indicating lesser productivity of energy in the economy. Although output is converging towards the long run trajectory of energy, the speed of adjustment is only 15% in one month, which would require around 7 months for full adjustment. This slow adjustment is also an indication of less efficient energy utilization infrastructure. Conclusion based on the productivity of energy in the economy is likely to be flawed as an energy constrained economy primarily uses energy for consumption which may not increase output directly. We can further clarify the idea that in energy crisis period of Bangladesh, energy elasticity of output was 0, indicating the inability of energy to become a productive resource. Energy policy for such an economy should be prioritizing energy availability at first, despite output being independent to energy growth.

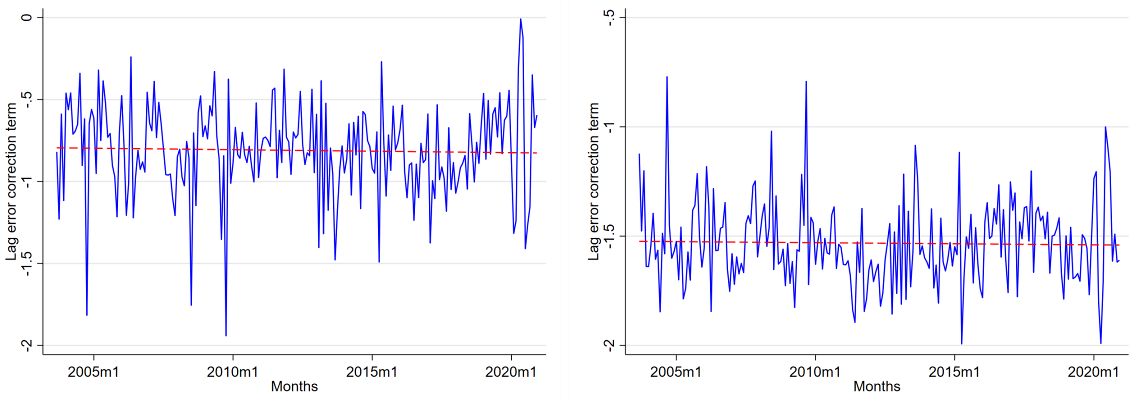
Although this study encapsulates different aspects of energy-growth nexus for any energy constrained economy in general, we discuss some policy aspects for Bangladesh in particular. The issue of energy security became essential in Bangladesh during the energy crisis of 2010. Our analysis also shows that the macroeconomic significance of energy has only become prominent after the energy crisis. This is due to the fact that a series of investment policies are implemented to ensure energy availability during the post-crisis period. The impact is evident from the estimates of post-crisis Bangladesh where we find output and energy follow each other in a long run growth trend. In particular, we see that short run energy consumption converges with the long run output trend in the immediate next period, indicating a strong presence of cointegration. The obvious criticism of this output lead energy consumption policy is that economy may misuse the available energy in an unproductive way owing to the affluence ensued from output growth. To counter this criticism, we find from the energy lead growth model that energy started promoting economic output in the post-crisis period, which was literally absent before the crisis. This gives us an indication that making energy available for Bangladesh initiates the feedback loop from energy to economic output. Provided a relatively improved energy consumption level after the energy crisis, Bangladesh can now initiate fuel-switching policy to step out from the higher carbon economy to a renewable one.

3.8 Conclusion

The paper investigates the dynamic relationship between primary energy and output for the period of July 2003 to December 2020 in Bangladesh. Using a unique data set with monthly frequency, we utilize time series techniques Autoregressive Distributed Lag and Vector Error Correction Model to examine the long run trends, short run movements, marginal impacts, direction of causalities and persistence of shocks in a multivariate framework. To address omitted variable bias, we have included covariates that are relevant for the economic environment of Bangladesh during the period of analysis. Our results, in conformity with most of the previous studies conducted on Bangladesh, suggest that output unidirectionally causes energy consumption without feedback, implying energy conservation hypothesis. Counter-intuitively, Bangladesh, being mostly an energy constrained economy, is expected to impart energy lead growth feedback through output accumulation. To examine this puzzle, we divide our full sample according to high and low energy consumption periods and find that during an energy crisis, energy and output do not display any statistical relation, or the economy becomes energy neutral. We explain this phenomenon by a theoretical proposition that the usefulness of energy as a productive input is diminished when the economy is not sufficiently supplied with energy. In such a case, energy becomes a consumption good with limited output potential. This is a situation when energy conservation policies such as reduction in energy supply or increase in energy price are conventionally recommended. As an energy crisis has the potential for destabilising the sociopolitical environment, energy availability should be prioritized before pursuing energy conservation policies.

Appendix 3A

3A.1 Error correction plots



(A) Conservation model (Adj. -.80)

(B) Growth model (Adj. -.15)

FIGURE 3.6: Error correction terms comparison

3A.2 Johansen cointegration test

Maximum rank	Parms	Eigenvalue	Trace statistic	5% critical value
0	80	.	90.62	68.52
1	89	.22	39.74*	47.21
2	96	.11	15.40	29.68
3	101	.04	6.92	15.41

Variables: lnE_t, $lnER_t$, $lnIE_t$, $lnFR_t$ lnY_t,

TABLE 3.9: Cointegration rank test (full sample)

3A.3 VECM estimation

TABLE 3.10: VECM estimates

Variables	lnE_t	lnY_t	$lnIE_t$	$lnFR_t$	$lnER_t$
ECT_{t-1}	$-.71^a$	$-.12^a$	-.01	.00	.00
Long run					
lnE_t	-	$.75^a$	2.60^a	32.92^a	-5.88^a
lnY_t	1.40^a	-	3.49	44.10^a	7.88^a
$lnIE_t$	-.38	$.29^a$	-	-12.64^a	2.26^b
$lnFR_t$	-.03	.02	.08	-	-.18
$lnER_t$	-.17	.13	.44	-5.60	-
Short run					
ΔlnE_{t-1}	$-.22^c$	$-.08^a$	-.06	$-.01^b$	$-.01^b$
ΔlnE_{t-2}	-.02	-.03	$-.08^c$	$-.01^a$	$-.01^a$
ΔlnE_{t-3}	-.10	-.01	-.01	.00	.00
ΔlnY_{t-1}	-1.27^a	$-.28^a$	$.34^b$	.01	.01
ΔlnY_{t-2}	-1.61^a	$-.16^b$	$.54^a$	-.01	-.01
ΔlnY_{t-3}	-.48	$-.30^a$	.16	-.01	-.01
$\Delta lnIE_{t-1}$	.27	-.03	$-.56^a$	$-.01^b$	$-.01^b$
$\Delta lnIE_{t-2}$	$.40^b$	$-.13^a$	$-.23^a$	.00	.00
$\Delta lnIE_{t-3}$	.14	$-.09^a$	$-.15^b$	.00	.00
$\Delta lnFR_{t-1}$	.18	$-.19^a$	-.09	.00	.00
$\Delta lnFR_{t-2}$	.16	.05	$.22^b$	.00	.00
$\Delta lnFR_{t-3}$	.22	$.14^a$	$.29^a$	.00	.00
$\Delta lnER_{t-1}$	$.19^b$	1.22^b	.01	$.32^a$	$.32^a$
$\Delta lnER_{t-2}$	2.05	-.45	-.03	$-.13^c$	$-.13^c$
$\Delta lnER_{t-3}$	2.93	-.67	-1.18	.06	.06

N.B. P-value for the levels of significant are $^a p < 0.01$; $^b p < 0.05$; $^c p < 0.1$

Statement of Authorship

Statement of Authorship

Title of Paper	Oil supply shocks on the price levels of transportation: evidence from Bangladesh		
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Publication Details	This paper is written in manuscript style for submission to a journal.		

Principal Author

Name of Principal Author (Candidate)	K M Alamgir Kabir		
Contribution to the Paper	The paper is written by a sole author (the candidate).		
Overall percentage (%)	100%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	15 Dec. 2021

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Contribution to the Paper			
Signature		Date	

Chapter 4

Oil supply shocks on the price levels of transportation: evidence from Bangladesh

Abstract

This study examines the relationship between oil imports and the domestic transport price index (TPI) using monthly data (July 2003 - Dec 2020) from Bangladesh for the first time. Utilizing Auto-Regressive Moving Average (ARMA) and Generalized Auto-Regressive Conditional Heteroskedasticity (GARCH) models, we find that higher availability of oil reduces the increasing inflationary pressure in transportation. In a multivariate modeling, we observe that while prices of all other goods and services (XCPI) impart a positive pressure on TPI, the supply of oil does the opposite. We also estimate the variance of the inflation, and find that both long and short run volatility of transportation prices are not explosive but rather bounded. Finally, by specifying an exponential GARCH (EGARCH) model, we show that the volatility has a symmetric impact, implying both positive and negative shocks have similar persistence. Bangladesh, being a small oil-importing country, is likely to address the issue of transport inflation through increasing imports of oil. However, from an environmental perspective, a balanced score-card is expected to weigh the benefits from this measure against the other alternatives such as fuel switching or increasing energy efficiency.

4.1 Introduction

Studies show that oil supply shocks immediately pass through to the transportation sector (Zhang, Broadstock, and Cao, 2014). This is pertinent to Bangladesh, as we see more than 65% of the total road, rail, naval and air transportation is fueled by imported petroleum products (Chowdhury et al., 2021). Reduction in oil availability in the economy may create inflation in the transport sector, which eventually may constrain economic activities. From the environmental point of view, however, oil shocks provide us with an opportunity to step out from the carbon lock-in to a renewable green economy. To justify intervention in this sector by the government or development partners, it is expected that the measures address issues such as affordable transportation, lesser uncertainty and clean environment at the same time. Apart from the theoretical disposition, such intervention also requires quantifiable impact measurements of the economic variables concerned.

This study identifies variables relevant in determining the price levels of transportation. The Transport price index (TPI[1]) is likely to be influenced by the consumer price index of all other goods and services (XCPI[2]). Similarly, transport price may also influence the price of other goods and services within the economy. Oil, on the other hand, being the principal fuel for the transport system, is likely to influence transport price directly or via the price of other goods and services. Emphasising the pivotal role of oil, Kilian and Park, 2009 show that global crude oil shocks account for around a quarter of the total long-run variation in the US real stock returns. By contrast, Stern, 2015 argues that energy in an economy becomes instrumental for output only when there is scarcity of the energy resources. An energy constrained economy generally faces supply shocks, which eventually turn into price shocks in the market. In an effort to address this puzzle, we answer the following questions in the context of Bangladesh's economy: a) How much of the oil supply shocks pass through to TPI? b) Does TPI and XCPI show similar trajectories in their dynamic evolution? c) Does XCPI influence TPI or vice versa?

We propose a modeling framework in this study consisting of exogenous oil supply and endogenous prices of transportation and other goods & services. Before estimating the full model, the sequential ordering of the endogenous variables is performed by ARDL bounds testing and VECM Granger causality. Based on that specification, the time series technique Auto-Regressive Moving Average (ARMA) is used to evaluate conditional mean of TPI and Generalized Auto-Regressive Conditional Heteroskedasticity (GARCH) model for volatility modeling. We also specify an exponential GARCH (EGARCH) model to see if positive and negative volatility impacts asymmetrically on the variation of the transport prices. Our analysis finds that XCPI influences TPI positively without feedback, whereas oil shocks impact negatively on TPI. We also conclude that the short and long-run volatility of TPI are not explosive but rather bounded

[1]TPI exerts 4.17% weight to the CPI computation.
[2]XCPI is the weighted measure of Consumer Price Index (CPI) except TPI.

and mean reverting.

We add to the literature in a number of ways. First, this is the first attempt to model transport inflation in the context of Bangladesh. Although several studies are conducted on consumer price index (CPI), food & non-food inflation and the impact of those on other macroeconomic variables, we do not find any analysis on TPI in the literature. Second, we introduce a unique monthly data set for the analysis compared to most of the other studies that are based on yearly observations. This is important as the causes and effects of these variables are much shorter than a year's interval (Granger and Newbold, 2014). Anecdotal evidence from newspaper reporting indicates that the transport sector does not delay a year to raise their tariff in response to fuel shocks (Report, 2011). Third, we provide an estimate for the extent of fossil fuel dependency of the transport sector in Bangladesh, which has implications for both the environment and energy security.

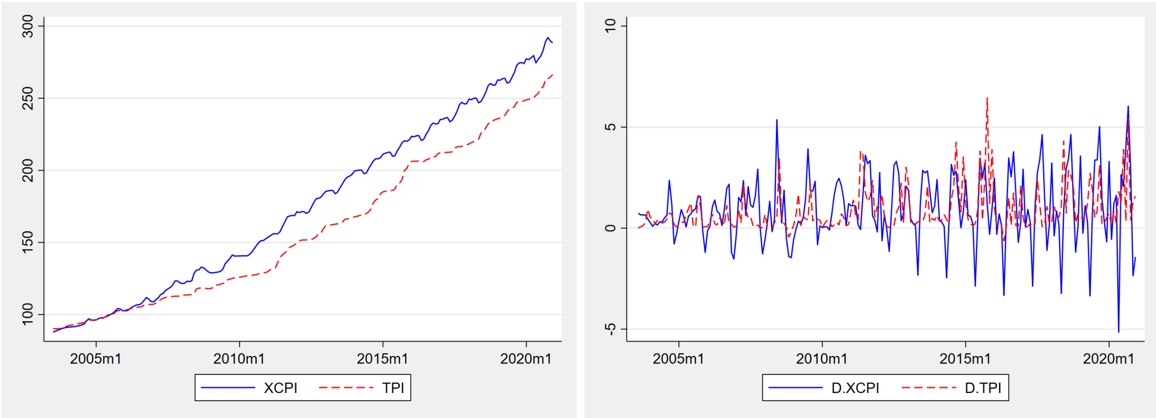
The rest of the paper comprises seven sections. Section (4.2) presents a brief description of motivation for the study and the relevant literature on the subject. The modeling approach and data are described in section (4.3). The specification testing of the model is included in section (4.4). Section (4.5) provides the estimation strategies while section (4.6) presents the results. Finally, sections (4.7) and (4.8) include discussion and conclusion, respectively.

4.2 Motivation and literature

4.2.1 Motivation

Different sub-classes of inflation exert heterogeneous impacts on different income categories as well as on different spatial distributions. An analysis of Bangladesh shows that poor and lower middle-income households face higher inflationary pressure both in rural and urban regions (Hussain and Zaman, 2008). On the other hand, much of the inflationary pressure of Bangladesh in the recent decades (especially after 2010) is coming from non-food sources such as transport, rent and other services. While food inflation is dominant mostly in urban areas, non-food inflation impacts equally in all the spatial regions (Hussain and Zaman, 2008). We are motivated to model TPI in this study, as it is an integral part of the non-food inflation basket, which has become an essential component of our modern life.

TPI also turns out to be an interesting topic for analysis as despite evolving similarly with XCPI (with similar mean and variance in both level and first difference), TPI behaves distinctly in a certain way throughout the study period (Figure 4.1). Examination of Figure (4.1b) reveals that while the first difference series of TPI is almost always positive, the D.XCPI displays both positive and negative fluctuations at regular intervals. In other words, people had to pay incrementally in subsequent months for transportation despite the prices of other goods and services sometimes being less than their previous month's prices. This puzzle suggests the likelihood of the presence of other determining factors in the economy for which TPI behaves in this particular way.



(A) Level (μ_{tpi} : 159, μ_{xcpi} : 175) (B) Differenced (μ_{tpi} : .84, μ_{xcpi} : .95)

FIGURE 4.1: Evolution of CPI and TPI

Finally, we are motivated by the fact that per capita carbon emissions in Bangladesh have risen by 200% from the year 2000 to 2019, while the neighbouring India and Pakistan have augmented emissions by only 105% and 55% respectively (GCP, 2021). Therefore, the transport sector of Bangladesh, being highly dependent on fossil fuel, is expected to take initiatives for decarbonisation. In accordance with the commitment on affordable clean energy (Goal 7) and climate action (Goal 13) of the Sustainable Development Goals (SDGs), Bangladesh is expected to implement the action plan by 2030.

4.2.2 Literature

Despite households facing various shocks, oil shocks draw a disproportionate amount of attention from policy-makers to the media. One reason for that, as Stern, 2015 argues, is the limited scope for substitution of energy. The indispensable requirement of energy in the modern economy cannot be evaluated only by its percentage share of GNP (Moroney, 1992). Secondly, oil is becoming very price sensitive as we see a steady decline in the short run price elasticity of oil demand since the 1980s (Baumeister and

Peersman, 2013). As a result, any unforeseen shock to oil availability has the potential to destabilize the socio-political environment of a country. The recent mass-scale public demonstrations against fuel price hikes in Belgium, Bulgaria, Burkina Faso, India, Iran and Sierra Leon, and other regions around the globe, signify the critical role of oil in the economy. The third reason is that oil shocks have become a leading indicator for other macroeconomic variables which impart economy-wide ripple effects. On a number of occasions, the US economy faces widespread economic turmoil because of these shocks (Kilian, 2008).

Oil shocks can stem from exogenous supply disruption, from demand shocks due to economic expansion, or from precautionary demand for cushioning volatility (Kilian, 2009). The responses to shocks differ widely based on whether the countries are importing or exporting oil. The study by Cashin et al., 2014, conducted on 38 countries and regions, shows that the supply driven oil shocks typically induce a long-term slump to the economic activities of oil-importing countries, while the impact is positive for their oil-exporting counterparts. Similarly, supply and demand shocks have different extents of impact on the economy. Analysing historical oil supply and price data, Baumeister and Hamilton, 2019 conclude that supply shocks impart a long lasting global economic activity reduction, while shocks due to oil demand have only transitory economic implications. Studying the impact of oil shocks to inflation, Kilian, 2008 shows that oil supply shocks have only mild inflationary pressure compared to demand driven oil shocks on the US economy. This is an indication that the energy intensity of GDP is decreasing around the globe in recent years (Stern, 2017). Although the general price level does not vary much due to oil supply disruption, the energy-intensive sectors such as transportation experience direct pass-through effects due to negative oil supply shocks (Zhang, Broadstock, and Cao, 2014). Micro-economic analysis on commuters also reinforces this idea that fuel shocks influence transportation significantly regardless of the length of travel (Graham and Glaister, 2004).

The modeling approach of oil shocks and economic activities has evolved significantly during the last four decades. Starting with the seminal work of Hamilton, 1983, where he notices that oil supply disruptions are followed by oil price upsurges during 1948-1972 periods. Based on the insight and subsequent improvement in the time series estimation techniques, Hamilton, 2003 developed a quantitative model with reasonable predictive power. Since then, oil shocks have been modeled based on the assumption that the source of shocks is not important in analysing the impact. Challenging the idea of homogeneity of all oil shocks, Kilian, 2009 proposes a structural vector autoregressive (SVAR) model to disentangle oil supply and demand shocks based on the fact that price changed due to supply disruption or demand surged due to good economic outlook, are not the same. Later, a modified version of the model is proposed by Kilian and Murphy, 2012, where instead of imposing exclusion restrictions, they impose sign restrictions for identifying the structural parameters where they come up with similar conclusions as before. In an effort to formulate a less restrictive method, Baumeister and Hamilton, 2019 construct a Bayesian inference based model of SVAR and conclude that the price elasticity of oil supply shocks estimated by Kilian and Murphy, 2012 is under estimated while oil demand shocks are over estimated.

Apart from estimating the structural parameters, another class of model based on volatility has also become popular especially in estimating market returns and risk premium. Using univariate and multivariate ARCH and GARCH models, Hammoudeh, Dibooglu, and Aleisa, 2004 model the volatility of the US stock market and find that there is a significant bi-directional relationship between stock returns and oil shocks. Based on the similar volatility modeling in VAR framework, Agren, 2006 analyses five developed countries (Japan, Norway, Sweden, the UK and the US) and concludes that there is strong evidence of volatility spillover in almost all the countries. Similar volatility transmission is observed in Gulf Cooperation Council (GCC) and European countries in multiple studies (Malik and Hammoudeh, 2007; Malik and Ewing, 2009; Arouri, Lahiani, and Nguyen, 2011; Arouri, Jouini, and Nguyen, 2012; Jouini and Harrathi, 2014). The extent of impact of volatility ensued from oil shocks on all the economic sectors are, however, not the same, as Elyasiani, Mansur, and Odusami, 2011 indicate that oil user industries are the ones most vulnerable to this uncertainty. Similarly, the expectation of investors based on the prevailing financial environment may also influence the outcome; as Mollick and Assefa, 2013 show before the financial crisis of 2008-09, oil prices used to impact negatively to the stock returns while the situation has reversed in the post-crisis era.

Literature on price volatility modeling in Bangladesh is very limited, while any study on transport price volatility is absent altogether. Using annual data, Paksha Paul, 2013 modelled CPI over the period of 1976-2009 in a bivariate exponential GARCH framework to conclude that inflation volatility unidirectionally impacts economic growth positively while mean inflation and economic growth influence each other negatively. Hossain, 2015, by contrast, concludes from the historical (1950-2012) evidence that both inflation volatility and inflation persistence impact economic growth adversely. In an effort to define the driving factors of inflation in Bangladesh, Mujeri, Shahiduzzaman, and Islam, 2009 show that the real sector can explain inflation better than the monetary aggregates. They concluded this by specifying inflation as a function of output gap and other covariates in a dynamic framework. Similarly, the weak transmission of monetary policy in Bangladesh is echoed by Nasir, 2011, who concludes that institutional rigidity is driving inflation rather than money supply. We may deduce from the analysis that the constant increase of TPI (Figure 4.1b) is also largely a non-monetary phenomenon. This higher TPI has an economy-wide implication for the consumers as well as for the exporters, as we see higher domestic logistic cost cut down upon the global competitive advantage of the key exports (Ready made garments) of Bangladesh (Rahaman and Hasan, 2015). Another contributing factor for the persisting upsurge of TPI is likely to be the fact that the transportation sector of Bangladesh is very inefficient in utilizing energy compared to other neighbouring countries (Chowdhury et al., 2021). In such an economy, oil supply shocks are likely to be instrumental in determining TPI.

4.3 Modeling approach and data

4.3.1 Theoretical specification

The literature in the previous section has provided us with some ideas on how oil supply can influence TPI directly or via prices of other goods and services. Based on this understanding, we have constructed a path diagram to illustrate the interaction between oil supply and inflation (Figure 4.2). We have constructed the model for a small

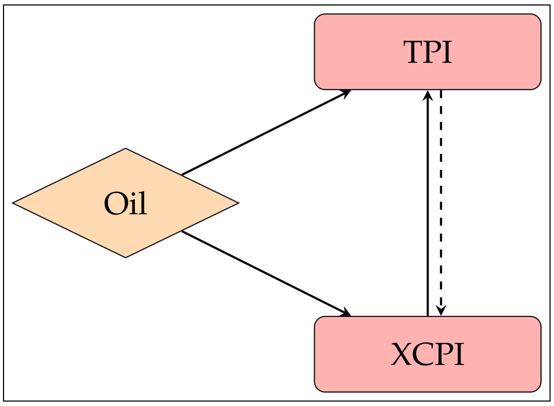


FIGURE 4.2: Oil-Inflation path diagram

open economy that does not produce oil endogenously but tries to meet the demand from importing. In such a case, it is likely that we would see cost-push inflation more often than demand-pull inflation in the event of oil shocks. This is due to the fact that in an energy constrained economy, an energy-intensive production process does not flourish extensively, which has been seen from a firm-level study in India (Abeberese, 2017). In addition, the conclusion of Baumeister and Hamilton, 2019 further reinforces the idea that demand shocks for oil supply are transitory in nature compared to supply shocks. Therefore, we did not consider the reverse causality from inflation to oil demand.Instead, we follow the hypothesis of Darby, 1982, where he postulates that imported oil influences aggregate production function, which determines output and eventually inflation. As demand for energy is sufficiently inelastic and there is a limit of substitution for energy, most of the time negative oil shocks in the US economy are followed by a higher price level. Studying all such shocks after 1970s, Kilian, 2009 concluded that volatility in oil supply also induces precautionary demand shocks as market expectation shifts in securing more oil to cushion uncertainty. Further empirical studies also reinforce the idea that markets overreact in the short run due to oil supply shocks (Huang, Li, and Wu, 2021). Thus, we propose the following dynamic function to illustrate the determinants of TPI:

$$TPI_t = f(TPI_{t-i}, XCPI_t, Oil_t, \sigma_t^2) \tag{4.1}$$

Here, apart from including TPI lags, XCPI and oil supply, we also introduce variance (σ_t^2) dynamics as a function of TPI to examine the extent of precautionary demand shocks due to volatility in the transport prices. In addition to modeling conditional mean, we also model conditional variance to assess how the volatility evolves dynamically over time, which may provide us with information on the stability of the market in the short and long run.

$$\sigma_t^2 = f(\sigma_{t-i}^2|C, \sigma_{t-i}^2|UC) \tag{4.2}$$

Here, C and UC are denoted for conditional and unconditional variances; i's are lags, $\forall_i = 1, 2..$

The modeling approach above is based on a number of assumptions regarding the nature and dynamics of the variables. First, we assume that XCPI in this model is contemporaneously exogenous or predetermined. The logic behind this is that TPI at time *t* is not determined by XCPI on the same temporal domain, rather the history of XCPI may have shaped the current TPI. Second, the quantity of oil supply is strictly exogenous here as oil procurement is an administrative decision and the availability oil in the global market is dependent on geopolitical factors. Third, the model specification denotes TPI as a dependent variable as opposed to XCPI, assuming that prices of all other goods and services influence TPI but not vice versa. This is *a priori* that we examine in the specification testing section. The reasoning behind this specification is based on the fact that as energy and labour are the two principal components responsible for determining TPI, any variation of these factors is likely to impact the model. In this instance, we try to capture the variation of energy directly from oil supply and the variation of labour supply via prices of all other goods and services. Finally, TPI also may have some influence over XCPI as both the prices are endogenous in the economy. Hence, we have denoted the causality from TPI to XCPI with a dashed line in the path diagram (Figure 4.2).

4.3.2 Data and variables

The key variables used in this study are transport price index (TPI), consumer price index for all goods and services except for transportation price (XCPI) and total quantity of petroleum products (Oil) imported on monthly basis (million barrels) from the period of July 2003 to December 2020. Compiled by Bangladesh Bureau of Statistics (BSS), CPI is an aggregate index of weighted prices (shown in the parenthesis) consisting of food (58.84%), clothing & footwear (6.85%), gross rent, fuel & lighting (16.87%), furniture, furnishing & others (2.67%), medical care & health expenses (2.84%), transport & communications (4.17%), recreation, entertainment, education & cultural services (4.13%), misc. goods & services (3.63%). The monthly index consists of an aggregation of the prices of 318 rural and 422 urban goods and services of Bangladesh (BBS, 2016). From this aggregate, we take the TPI series denoted as transport & communication indicating domestic price level of public commuting and freight movement. Similarly, we also construct XCPI series from this aggregation excluding TPI. There are two bases (100 points) used during the period of our sample compilation, of which one is on 1995-96 and another one is on 2005-06. For consistency, we have converted the whole sample into a single series, keeping the later base (2005-06) points as reference. The monthly series on quantity of oil import is estimated from monthly import payment for petroleum products compiled by Bangladesh Bank (BB, 2021). Using the global petroleum price index from Index Mundi (Index, 2021), we have converted the payment into million barrels, which is an approximation to the total oil available for Bangladesh for that month.

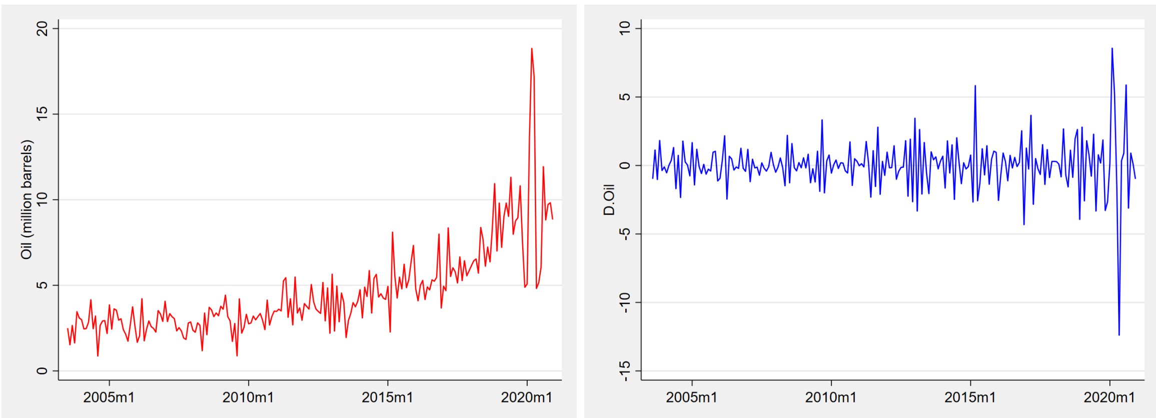
The descriptive statistics are presented for both level and first difference to compare the distribution of the variables (Table 4.1). We see here that the differenced variables are more inclined towards normal distribution than their level counterparts. Investigating the correlation metrics, we find that all the three variables are highly correlated in level while the correlations are much lower or even of opposite sign in the first differences. As all the variables here are trending upward in level, the high correlation is expected to be contributed by the trend components compared to the de-trended series. The correlation matrix of the first difference variables, on the other hand, provides a more realistic association pattern among the variables. Another important aspect of the series is that all the variables have a strong autocorrelation even up to 12 months.

TABLE 4.1: Descriptive statistics

	Level			1st diff.		
	TPI	**XCPI**	**Oil**	**D.TPI**	**D.XCPI**	**D.Oil**
Mean	159.42	176.03	4.54	.84	.96	.03
Standard deviation	52.40	61	2.60	1.07	1.65	1.87
Skewness	.41	.20	2.11	2.23	-.08	-.72
Kurtosis	1.83	1.74	9.69	8.70	4.06	13.69
Correlation matrix						
TPI/D.TPI	1	-	-	1	-	-
XCPI/D.XCPI	.99	1	-	.30	1	-
Oil/D.Oil	.78	.77	1	-.13	.15	1
Autocorrelation (Q-statistic)						
Lag(1)	206.89	207.24	114.38	12.40	21.04	19.23
	(.00)	(.00)	(.00)	(.00)	(.00)	(.00)
Lag(6)	1165.7	1170	522.55	39.25	66.58	62.47
	(.00)	(.00)	(.00)	(.00)	(.00)	(.00)
Lag(12)	2164.7	2181.5	955.16	55.24	242.01	66.46
	(.00)	(.00)	(.00)	(.00)	(.00)	(.00)
N	210	210	210	209	209	209

*P-value in the parenthesis

To test that, we report here Ljung-Box Q-statistic, where the null hypothesis is that there is no autocorrelation. After examining the p-value of the statistic, we see here that all the series, both in level and first difference, fail to reject the null hypothesis at any significant levels. This strong presence of autocorrelation primarily indicates the existence of unit root in the series.

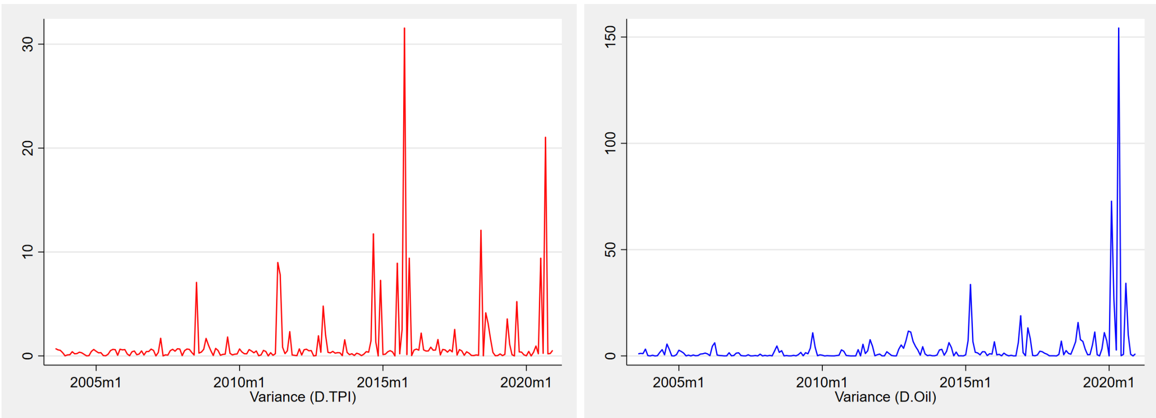


(A) Level (B) 1st differenced

FIGURE 4.3: Oil import per month

The prevalence of autocorrelation is also displayed in the plots, especially in the differenced ones. For instance, the differenced graphs of TPI and XCPI follow a particular cycle over the entire period, indicating the influence of the previous month's value on the successive months (Figure 4.1). Similarly, the series of oil imports display both an upward trend and cycle at level, but after first difference, the trend is no longer visible. The cycle, however, continues roughly around a constant mean at zero (Figure 4.3).

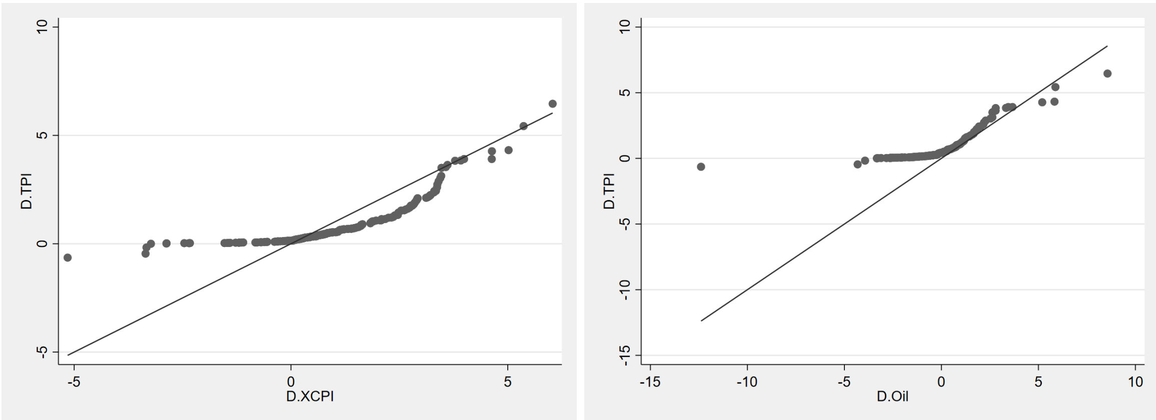
Next, we consider whether any seasonality is exhibited by the monthly series of the variables. Overall, visual inspection of the plots of the variables does not show any repetitive pattern. To reconfirm that, we also test for seasonality in the data and found that no particular month is statistically different than the mean outcome of the variables, indicating absence of seasonality in the data (Appendix 4A.1). One of the probable reasons for no seasonality in the variables is that the price level upsurge in Bangladesh is normally contributed by two festival months (Eid al-Adha and Eid al-Fitr), which are 2.5 months apart, that revolve in subsequent months of the year. Therefore, the high demand for travel and transportation and, consequently, their prices during these two months of a year, do not posit as a seasonal pattern.



(A) D.TPI (B) D.Oil

FIGURE 4.4: Volatility clustering

Apart from modeling the mean relationship, we also investigate the variance trajectory from the variance plots of the variables. If we observe the variance of the differenced series of TPI and Oil, we see the presence of volatility clustering, which implies that the overall volatility of the variables follows an autoregressive process similar to that of their dynamic mean counterparts (Figure 4.4). The idea of volatility clustering is first observed by Mandelbrot, 1967 where he postulates that in a clustered series, small variations are followed by small ones and the large ones are by large. From this particular pattern of the volatility dynamics, important information can be extracted for both mean and variance forecasting of the respective series. This is one of the reasons for which in most of the stock returns analysis, we find the inclusion of volatility in the modeling to improve forecasting.



(A) D.TPI and D.XCPI

(B) D.TPI and D.Oil

FIGURE 4.5: quantile-quantile plots

Finally, we illustrate quantile-quantile plots to check the normality and commonality of distribution of variables as we estimate the models by maximum likelihood method where we assume a normal distribution of the errors. Plotting against D.TPI, two other variables (D.XCPI and D.Oil) tend to distribute similar to that of normality, which is assessed by the 45 degrees lines approximation in the two plots (Figure 4.5).

4.4 Model specification testing

In the theoretical model specification, we took TPI as the dependent and XCPI as the independent variable, along with other covariates. To test the validity of this specification, we determine whether TPI or XCPI follow each other in the short and long run. To perform that, at first we determine the order of integration of the series, and based on that, we apply the Auto regressive distributed lag (ARDL) bounds testing approach to see if there is any long run cointegration relation. After that, we specify the resulting cointegrating equation into the error correction model (ECM) to estimate the speed of adjustment of the cointegrating variables along with other short and long run coefficients. Finally, we perform a Granger causality test with the estimates to determine the direction of causality.

4.4.1 Unit root test

Although the plots of all the variables in level show non-stationary, we conduct Augmented Dickey-fuller (ADF) and Phillips–Perron (PP) tests to confirm the presence of unit roots. For optimum lag selection, we use Akaike information criterion (AIC) and found that TPI requires 3 lags while XCPI and Oil series need 4 lags each in the testing specification. The null hypotheses for both the tests are that the variables are unit root processes. We report the t-statistic and find all the variables are non-stationary at level and are covariance stationary in first difference. The PP test, on the other hand, is in conformity with the ADF test for TPI and XCPI series, but the Oil series appeared to be stationary at the level as well (Table 4.2). After inspecting the upward trend of the Oil series in Figure (4.3), we follow the ADF test result and consider the series to be a unit root process at level.

TABLE 4.2: Unit roots test (t-value)

Variables	ADF test		PP test		Decision
	Level	1st diff.	Level	1st diff.	
TPI_t	2.17	-5.4^{***}	3.29	-11.46^{***}	$I(1)$
$XCPI_t$	2.29	-7.83^{***}	1.44	-9.86^{***}	$I(1)$
Oil_t	-1.00	-10.91^{***}	-4.84^{***}	-27.52^{***}	$I(1)$

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

4.4.2 Auto regressive distributed lag (ARDL) bounds testing for cointegration

As we see, all the variables here are covariance stationary or I(1), there exists a possibility of long run relationship especially between the two endogenous variables namely TPI and XCPI. To test that, we specify ARDL bounds testing approach developed by Pesaran, Shin, and Smith, 2001. We have selected the ARDL approach due to the fact that our data set is relatively small with only 210 observations. Philips, 2018 shows by Monte Carlo experiments that compared to Johansen or Engle-Grnager cointegration procedures, the ARDL technique performs better, especially in a small sample. The bounds testing specification is as follows:

$$\Delta TPI_t = a_0 + \alpha_1 TPI_{t-1} + \alpha_2 XCPI_{t-1} + \sum_{i=1}^{k} \beta_{1i} \Delta TPI_{t-i} + \sum_{i=0}^{l} \beta_{2i} \Delta XCPI_{t-i} + u_t \quad (4.3)$$

$$\Delta XCPI_t = b_0 + \gamma_1 TPI_{t-1} + \gamma_2 XCPI_{t-1} + \sum_{i=0}^{k} \delta_{1i} \Delta TPI_{t-i} + \sum_{i=1}^{l} \delta_{2i} \Delta XCPI_{t-i} + v_t \quad (4.4)$$

The specifications of equation (4.3) and (4.4) are termed as dynamic unrestricted error correction model (UECM), where both long run variables in level with first lag and short run variables in difference form with multiple lags are included. To make the errors independent and identically distributed (i.i.d), appropriate number of lags are included with the help of information criteria. To test the cointegration relation, the long run parameters of the level variables are set to be 0. For example, to test whether TPI is cointegrated with XCPI in equation (4.3), the null hypothesis is $H_0 : \alpha_1 = \alpha_2 = 0$ against the alternative of cointegration $H_1 : \alpha_1 \neq \alpha_2 \neq 0$. The rejection of the null hypothesis in this setting indicates that the level variables are important for the specification, which eventually implies cointegration of the dependent variable with the independent ones. As the the asymptotic distributions of the F-statistic for I(0) or I(1) variables are non-standard, Pesaran, Shin, and Smith, 2001 proposed two sets of asymptotic critical values. The first set assumes that all the variables are I(0), implying a short run relation only while the 2nd set of critical values assumes I(1), implying cointegration or long run relation. The test results are included in Table (4.3), where

TABLE 4.3: ARDL Bounds test

Models	**lags**	**F-stat**	**Adj-R^2**	**D.W. test**
$TPI_t = f(XCPI_t)$	$(3,1)$	5.01*	.17	2.03
$XCPI_t = f(TPI_t)$	$(3,2)$	.65	.19	2.04
Significance	*Lower bounds* $I(0)$		*Upper bounds* $I(1)$	
1% level		6.84		7.84
5% level		4.94		5.73
10% level		4.04		4.78

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

the lags length are selected by AIC and the residuals are checked for serial correlation by Durbin–Watson statistic (values within 2) which shows the model fits well with the data. The F-stat for equation (4.3) is 5.01, which is above the upper bound of 10% level (4.78) indicating at 10% significant level, TPI is cointegrated with XCPI. The F-stat, however, could not surpass the upper bound of 5% significant level (5.73) but remains in between the lower bound and upper bound of 5%. On the other hand, the F-stat of the equation (4.4) is 0.65, which is far below the lower bound of 10% significant level (4.04), implying no cointegration of XCPI with TPI. Therefore, we conclude that TPI alone is maintaining the long run relationship with XCPI in its dynamic evolution.

As we know now that TPI is cointegrated with XCPI, we investigate how TPI maintains the relationships with XCPI both in the short and long run by specifying an Error Correction Model (ECM).

4.4.3 Vector Error Correction Model (VECM) identification

After confirming cointegration, we specify a bi-variate VECM with TPI and XCPI as follows:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + v + \epsilon_t \tag{4.5}$$

In this specification, Y_t is 2×1 vector of variables $[TPI_t \;\; XCPI_t]$, α and β are both $2 \times r$ matrix, where r is the number of linearly independent cointegrating vectors, which we have found from previous section that only one cointegrating relationship exists. Here, α is known as loading matrix defining the adjustment speed while β is long run cointegrating matrix, Γ_i is short run 2×2 matrix of coefficients, v is a vector of constants and ϵ_t is i.i.d disturbance. Inclusion of number of lags is performed by AIC and in this instance, we specify 3 lags; although estimation is conducted by 2 lags as one of the lags is lost due to difference operator (Δ). The estimates of equation (4.5) are as follows:

$$\hat{\alpha} = (-0.022^{***}, 0.000); \;\; \hat{\beta} = (1, -1.01^{***}); \;\; \hat{v} = (0.004, 0.58^{**}),$$

$$\hat{\Gamma_1} = \begin{pmatrix} 0.14^{**} & 0.07 \\ 0.29^{***} & 0.32^{**} \end{pmatrix}; \; \hat{\Gamma_2} = \begin{pmatrix} 0.18^{***} & -.10^{**} \\ 0.08 & -0.24^{***} \end{pmatrix};$$

Using the notations of equation (4.5), the outputs above indicate a well specified model. The coefficients of the adjustment ($\hat{\alpha}$) and long run cointegration ($\hat{\beta}$) in this bi-variate setting are in correct signs. We see here that the adjustment parameter of TPI is negative significant with relatively slow adjustment toward long run path with a rate of 2.2% per month. On the other hand, the adjustment coefficient of XCPI here is positive, as expected, but not significant. This implies that, on average if TPI moves too high above the equilibrium path, it returns toward the XCPI to adjust but XCPI does not adjust toward the TPI at the same time. This is consistent with the ARDL bounds testing results, where we see TPI is cointegrated with XCPI but not the other way round. Finally, from the short run coefficient matrices ($\hat{\Gamma_i}$), we implement Granger causality test to see how the history of one variable explains another contemporaneous variable. The short run causality results are given in Table (4.4), where we see from the χ^2 statistics and associated p-value in parenthesis that TPI Granger causes XCPI with 1% significant level, while XCPI does not Granger cause TPI with even at 5% significant level.

TABLE 4.4: Granger Causality test, χ^2 statistics

	$\sum \Delta TPI_{t-i}$	$\sum \Delta XCPI_{t-i}$
ΔTPI_t	-	5.6 (0.06)
ΔXPI_t	8.46 (0.01)	-

*p-value in the parenthesis

Overall, from reviewing the results of the ARDL bounds test, estimates of VECM and Granger causality tests, we find evidences that TPI has very little or no influence on XCPI both in the long and short run. Therefore, we take TPI as a dependent variable as opposed to XCPI in our model specification in equation (4.1).

4.5 Model estimation strategies

The estimation strategies are based on the model specification of equations (4.1) and (4.2) in the previous section. A close examination of the models along with the path diagram (Figure 4.2) reveals that the relationship of the variables is dynamic recursive given the time series data. We rule out the existence of a possible simultaneous relationship between TPI and XCPI from our model specification as we find in the specification testing section that XCPI is contemporaneously independent of TPI in both short and long run. The idea of recursive estimation is as follows:

$$Y_t = E(Y_t|\mathcal{I}_{t-i}) + \varepsilon_t \tag{4.6}$$

Here, $\mathcal{I}_{t-i}$; $\forall_i = 1, 2..$ is history of information set from the recursive path and ε_t is innovation or white noise. The content of the information set will determine the type of models we are estimating. We can also include exogenous variables or controls in this framework to improve estimation. The models are estimated by maximum likelihood assuming normal distribution of the error terms. After estimation, we test for autocorrelation (Ljung–Box Q-statistic) and autoregressive conditional heteroskedasticity (ARCH-LM) tests for up to 12 lags to make sure that the errors are i.i.d.

4.5.1 Auto regressive moving average (ARMA)

ARMA is a univariate process where the contemporaneous outcome is explained by the history of recurrent outcomes and innovations. Since its inception by Box and Jenkins, 1970, the method is widely used in time series modeling and forecasting in economics and finance. The general specification is as follows:

$$Y_t = a_0 + \sum_p \phi_p Y_{t-p} + \sum_q \psi_q \varepsilon_{t-q} + \varepsilon_t \tag{4.7}$$

Where Y_t is current outcome, ε_t is error terms with normal distribution and constant variance σ^2, ϕ_p and ψ_q are coefficients for autoregressive (AR) and moving average (MA) components of the model. ARMA model assumes both mean and variance to be constant over time for which the variables are to be stationary. While making a series stationary ensures a constant mean, the variance may not be constant over time, for which we need to model the volatility to examine how it impacts the model.

4.5.2 Generalised auto regressive conditional heteroskedasticity (GARCH)

In an effort to model the volatility over time, we incorporate the ARMA model with GARCH framework. Proposed by Engle, 1982 and Bollerslev, 1986, GARCH model is used extensively in financial data that display time-varying volatility. This model particularly becomes popular in stock market forecasting as in most of the cases, market volatility shows persistence over time compared to the mean prices. The model is a combination of the following two equations as below:

Mean equation,

$$Y_t = a_0 + \sum_p \phi_p Y_{t-p} + \sum_q \psi_q \varepsilon_{t-q} + \theta X_t + \xi \sigma_t^2 + \varepsilon_t \tag{4.8}$$

This is an example of ARMA-GARCH(p,q)-M model where, in addition to the ARMA specification, we have included ${\sigma_t}^2$ as time-varying volatility and X_t as exogenous variables where ξ and θ are coefficients of them respectively. The inclusion of variance in this model is termed as GARCH in the mean (GARCH-M) where the coefficient of that expects to capture the marginal impact of volatility of Y_t at the mean of Y_t. The second equation is for variance, which is nested with the mean equation in the final outcomes.

Variance equation,

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-p}^2 + \beta \sigma_{t-q}^2 \tag{4.9}$$

The equation explains the contemporaneous volatility by the history of recurrent conditional and unconditional variances, where α, β are termed as short and long-run volatility coefficients respectively. The idea here is that we can estimate the current volatility by the past errors and variances of the series.

4.5.3 Exponential GARCH (EGARCH)

Although the GARCH model is used extensively in literature, the estimates are restrictive as in some occasions the oscillatory behaviour of the variance is excluded by imposing assumptions. To minimize the drawbacks, Nelson, 1991 proposed a less restrictive exponential estimation technique as follows:

$$ln(\sigma_t^2) = \omega + \alpha|\frac{\varepsilon_{t-p}}{\sigma_{t-q}}| + \gamma\frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \beta ln(\sigma_{t-q}^2) \tag{4.10}$$

In this specification α and β are still short and long-run volatility parameters, respectively, but in addition, it estimates whether shocks have symmetric or asymmetric impacts for volatility, which is measured from the coefficient gamma (γ). A positive significant γ implies that positive shocks impart higher volatility compared to negative shocks, and vice versa. In some literature, this is termed as news shocks. If the dynamics of volatility are indifferent from positive or negative shocks, the estimate of γ is likely to be insignificant.

4.6 Results

Based on the estimation strategies illustrated in the previous section, we estimate a bivariate model (Model-1) consisting of TPI and XCPI to observe how prices of other goods and services explain transport price. We then specify a multivariate model (Model-2) by adding oil supply to examine how oil shocks impact TPI. In an effort to identify the most parsimonious model, we start with OLS first and subsequently progress to ARMA, GARCH and EGRACH to find out the best model to fit with the data. Finally, we perform in and out of sample forecasting with the competing models and compare their performances in respect to the real data both in short and long run before selecting the appropriate model.

4.6.1 OLS

As we see from the theoretical specification that both XCPI and Oil are exogenous to TPI, we may estimate the mean equations with OLS after confirming stationarity of the variables concerned. Assessing the results of both the models (Model 1 & 2) presented in Table (4.5) and (4.6), we see the existence of strong autocorrelation in the error terms in both cases. This leads to an unreliable estimation despite the results showing significant estimates even at 1% level. To remedy this drawback, we introduce ARMA specification next.

4.6.2 ARMA

In selecting appropriate lag lengths in the ARMA model, we utilize AIC criteria and find that we can use up to 4 lags in our model. However, to minimize data loss, we use maxim 2 lags in this analysis. After testing all the possible combinations of AR and MA lags, we come up with ARMA(1,1) model which has the lowest IC value with parsimonious specification (Appendix 4A.2). Examining the results from Table (4.5), we see a positive significant impact of inflation shocks on transportation. In particular, it shows that a 1 point increase in the price level of all other goods and services leads to an increase of 0.15 inflation points in TPI. The AR coefficient here is below 1, which indicates a stable autoregressive process where any shocks to the transportation price are likely to taper off within a few periods. The diagnostics tests show a well behaved model with no auto correlation or conditional heteroskedasticity even up to 12 months lags. Despite being a suitable specification for the mean equation, we may improve upon these estimations by incorporating variance in the model. The idea here is that by incorporating the prediction errors of the mean equation in the model, it is likely to make an improvement in the estimation and consequently in forecasting. The rationale for modeling volatility here stems from the fact that the variances are clustered (Figure 4.4) and the square of the prediction errors from ARMA estimations also display volatility clustering (Appendix 4A.3). It is expected that the volatility carries important information for better model fit.

4.6.3 GARCH and EGARCH

Understanding the importance of volatility from the prediction errors of ARMA and volatility clustering of the variables from Figure (4.4), we specify a GARCH(p,q)-M model as illustrated in equation (4.8). The values of p and q of the model are selected by AIC (Appendix 4A.2). After confirming that GARCH(1,1) is the suitable fit for the

TABLE 4.5: Inflation shocks (Model-1)

D.TPI	OLS	ARMA(1,1)	GARCH(1,1)-M	EGARCH(1,1)-M
D.XCPI	.19***	.15***	.16***	.08***
ar(1)		.77***	.63***	.74***
ma(1)		−.59***	-.24	−.46***
ξ			-.11	-.86
α			.65***	.50***
β			.22**	.65***
γ				-.02
Q-statistics(1)	4.93	.89	2.64	4.55
	(**.03**)	(.35)	(.10)	(**.03**)
Q-statistics(6)	25.59	8.67	8.14	11.46
	(**.00**)	(.19)	(.23)	(.08)
Q-statistics(12)	31.67	14.32	12.72	17.68
	(**.00**)	(.28)	(.39)	(.13)
ARCH-LM(1)	.09	.68	.97	2.83
	(.77)	(.41)	(.32)	(.09)
ARCH-LM(6)	11.43	9.24	8.88	11.68
	(.08)	(.16)	(.18)	(.07)
ARCH-LM(12)	15.46	12.83	13.15	15.94
	(.22)	(.38)	(.36)	(.19)
N	209	209	209	209

*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

data, we estimate Model-1 and find that both conditional and unconditional variances come up with significant coefficients with values less than unity (Table 4.5). The other improvement of the estimations is that the MA coefficient is no more significant, but was significant at 1% level in the ARMA(1,1) model. The rest of the estimations and diagnostics are, however, similar in both the specifications. In an effort to further improve the estimations, we specify Model-1 with EGARCH(1,1)-M and find a moderate diagnostic outcomes with somewhat similar estimations to GARCH(1,1)-M. The important take-away from the EGARCH specification is that there is no asymmetric impact of volatility indicated by γ being non-significant. Overall, we see here that both ARMA and GARCH specifications provide reliable estimations so long as the diagnostic tests are concerned.

As we determine now that ARMA and GARCH are better model fits for the data, we estimate Model-2 with them to observe the oil shocks on TPI. The estimates are found in Table (4.6), where we see both the specifications show similar estimates with good model fit. The estimation of the coefficients of Oil (-0.10 or -0.06) clearly indicates a negative significant relationship with TPI in the mean equation. This is one of the key findings of this study, where we try to show that after controlling the prices of all other goods and services (XCPI), the availability of oil is one of the determining factors for the transportation price in Bangladesh. Turning to the variance equation, we see that both short and long run volatility are statistically significant with values less than unity indicating a stable volatility process. The higher value of the short run variance coefficient (0.53) compared to the long run one (0.33) indicates that short run volatility has higher persistence compared to the long run volatility.

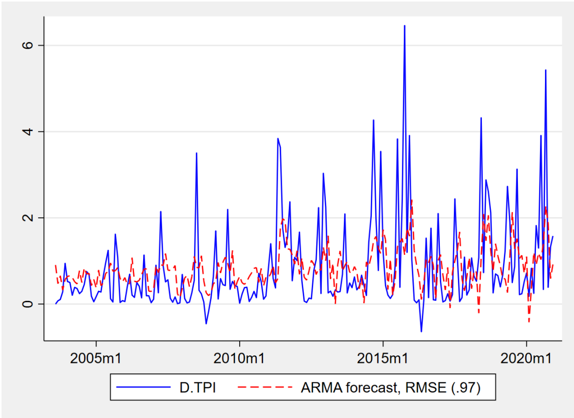
TABLE 4.6: Oil shocks (Model-2)

D.TPI	**OLS**	**ARMA(1,1)**	**GARCH(1,1)-M**
D.Oil	$-.10^{***}$	$-.10^{***}$	$-.06^{***}$
D.XCPI	$.21^{***}$	$.17^{***}$	$.17^{***}$
ar(1)		$.76^{***}$	$.60^{***}$
ma(1)		$-.56^{***}$	-.22
ξ			-.12
α			$.53^{***}$
β			$.33^{**}$
Q-statistics(1)	7.69	.27	2.18
	(**.01**)	(.60)	(.14)
Q-statistics(6)	25.32	5.18	7.22
	(**.00**)	(.52)	(.30)
Q-statistics(12)	30.04	9.38	11.01
	(**.00**)	(.67)	(.53)
ARCH-LM(1)	.04	.23	.57
	(.84)	(.63)	(.45)
ARCH-LM(6)	11.81	10.76	11.84
	(.07)	(.10)	(.07)
ARCH-LM(12)	16.23	14.75	16.62
	(.18)	(.26)	(.16)
N	209	209	209

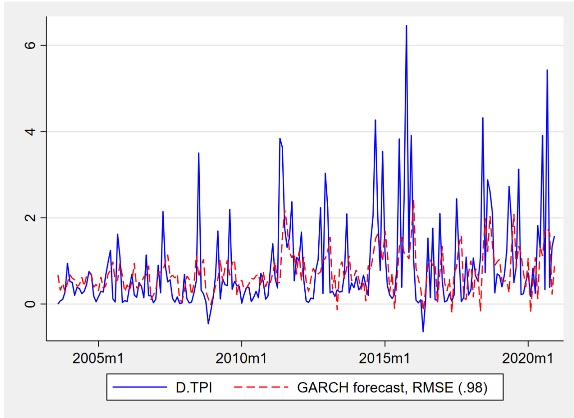
*P-value for the levels of significant are $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

4.6.4 Forecasting

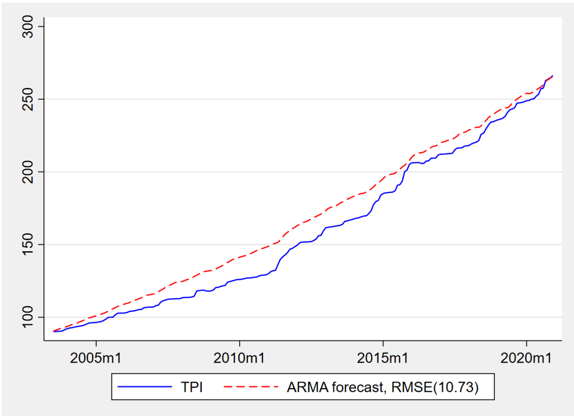
Although both ARMA and GARCH models perform well in predicting oil and inflation shocks on TPI, we want to compare their forecasting performance in the short and long run. To examine that, we use in-sample static forecasting technique first, and after that, we compare the performance of the models with out-of-sample prediction by dynamic and static forecasting methods. In static forecasting, we take all the previous actual data points for estimation and predict the next one period based on those estimations.



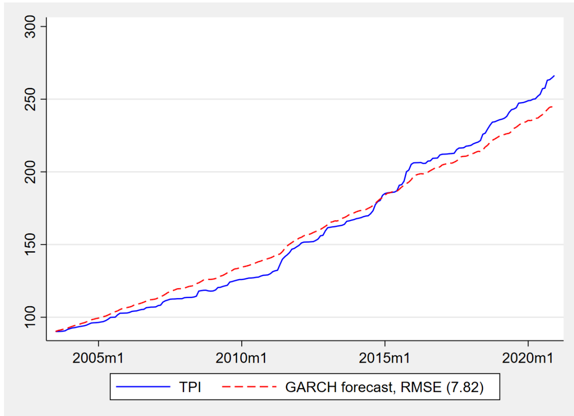
(A) In-sample Static (ARMA-SR)



(B) In-sample Static (GARCH-SR)



(C) In-Sample Static (ARMA-LR)

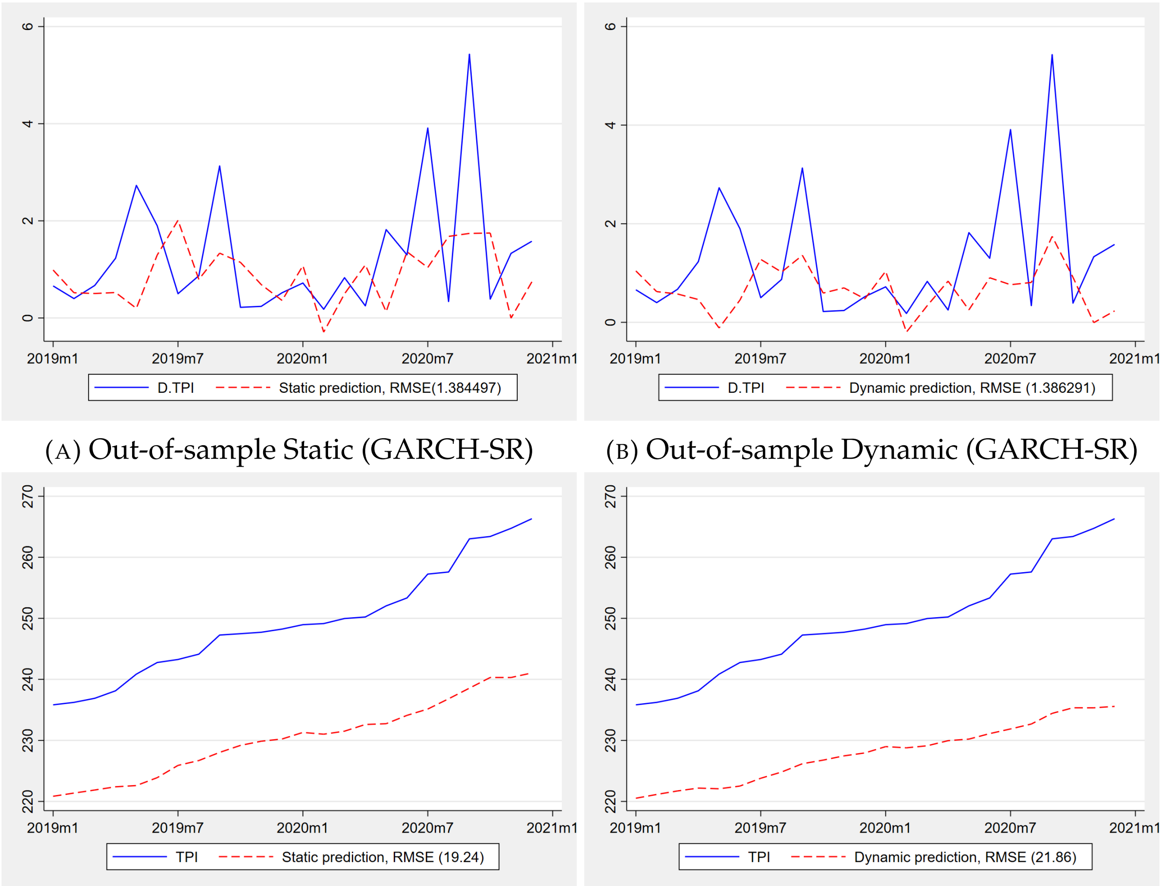


(D) In-sample Static (GARCH-LR)

FIGURE 4.6: In-sample forecasting (SR/LR)

On the other hand, in dynamic forecasting, we include all the foretasted data points in addition to the actual data. Therefore, the errors of the previous forecasting periods will be accumulated in dynamic forecasting but not in the static one. One limitation with static forecasting is that we can predict only the next one period while in dynamic, there is no limitation for forecasting horizon. Analysing the in-sample static forecasting by ARMA and GARCH models in Figure (4.6), we see that both the models perform similarly in mimicking the actual data in the short run with almost similar root mean squared errors (RMSE). However, for long run prediction, GARCH model outperforms substantially in forecasting compared to ARMA model with around 30% less RMSE in prediction. This is an indication that without incorporating variance in our model, we may lose important information for accurate prediction.

Now that we know GARCH specification is appropriate for forecasting, we use this in Model-2 for predicting out-of-sample data points for both dynamic and static settings. To perform that, at the first stage, we estimate our model with actual data ranging from July 2003 to December 2018, and thereafter, we forecast the next 24 months



(A) Out-of-sample Static (GARCH-SR)

(B) Out-of-sample Dynamic (GARCH-SR)

(C) Out-of-sample Static (GARCH-LR)

(D) Out-of-sample Dynamic (GARCH-LR)

FIGURE 4.7: Out-of-sample forecasting (SR/LR)

with GARCH specification and compare the outcomes with our actual data up to December 2020. The short- and long run out-of-sample forecasting are illustrated in Figure (4.7) , where we see both static and dynamic forecasting perform similarly with almost the same RMSE's. On the other hand, the long run out-of-sample forecasting with this specification displays a slightly improved performance by statistic prediction with a RMSE of 19.24 compared to 21.86 in the dynamic one. To sum up, after analysing the RMSE's of the competing specifications, we see the static GARCH specification outperforms ARMA and dynamic GARCH models in forecasting.

4.7 Discussion

The study indicates a number of policy implications for the transportation sector in terms of the transmission of inflation shocks and the impact of oil availability in the economy of Bangladesh. We find that the short run adjustment of TPI towards XCPI is 2.2% per month, which is very slow as it would take almost 4 years (45 months) to adjust from any short run disequilibrium to the long run equilibrium trajectory of inflation. The policy objective in such a situation is to increase the speed of adjustment by minimising the length of price disequilibrium periods of TPI before it reaches along the common path of the general price level in the economy. This can be accomplished through either price or cost support to the transportation sector. Cost support can be given to the transport suppliers by reducing the input cost while price support to the consumer by transport price subsidy. To implement these strategies, we need to quantify the marginal impact of general price level on the transportation price. Our estimations suggest that a 1% point[3] increase of XCPI leads to around a 0.17% point increase in TPI in the short run.

The next policy objective here is to decrease the pressure on TPI. We find that increased oil supply decreases TPI, which might be a conducive policy option for counteracting TPI. The transmission of the downward pressure on TPI is expected to come from the fact that greater oil supplies decrease the energy cost off the transport providers which in turn leads to cheaper transport services. In particular, increased oil supplies act as cost support to the transport sector. Both ARMA and GARCH estimations show similar negative marginal impacts of oil on TPI in the short run with coefficients ranging from -0.10 to -0.06, implying an additional one million barrels of oil in the economy on average decrease the increment of TPI by 0.10 to 0.06 inflation points (CPI basis: 100 at 2005-2006). In Bangladesh, the average oil import is 4.5 million barrels per month with an average increment of only 0.03 million barrels per month. One million barrels of additional oil import is equivalent to a 22% increase in oil import every month. From the environmental point of view, this policy option may have negative repercussions as 65% of the total transportation is dependent on fossil fuel alone. In such a case, fuel switching or renewable energy sources would be more appropriate courses of action.

Apart from the impact of exogenous variation of XCPI and oil supply, TPI can also be influenced by its own lagged variable as we see the AR(1) coefficient of D.TPI is 0.60 in GARCH specification. The implication of this is that the current value of TPI can be predicted by observing the previous period's outcome with significant accuracy. In other words, the mean TPI value is not explosive but rather bounded and mean reverting after shocks. This is a conducive business environment for investors as the predictable price ensures a predictable return to investment in the transport sector.

[3]As both TPI and XCPI share the same 100 basis points, the marginal effects can be approximated as percentage points.

Similar to the variation of mean, the variances of TPI are also bounded and predictable, which follows an autoregressive path. The coefficient (0.53) of the unconditional volatility is below 1, which indicates that a relatively calm period is followed by another calm period, and a more volatile period is followed by more volatility in the short run. In other words, the likelihood of starting an unpredictable volatility clustering in the TPI series in the short run is relatively low as the variances themselves are clustered within specific domains consisting of a number of time periods. On the other hand, the impact of long run volatility (0.33) in the model is lower compared to the short run as the market reacts less to volatility in the long run than short run. Still, an analyst can have significant insights on contemporaneous long run volatility from the previous clustering. The magnitude of the coefficient below 1 also assures that the general volatility is not explosive but rather mean reverting and bounded, indicating a stable market.

Finally, an important aspect here is that the unconditional volatility does not impact the mean outcome of TPI. We have seen in many developed countries that higher volatility in the oil supply leads to precautionary purchase to smooth future consumption. The situation of Bangladesh is different as being a less developed economy, consumers generally can not afford precautionary purchases due to lack of resources which becomes evident from this estimation.

4.8 Conclusion

This is the first study to examine the relationship between oil supply shocks and transport inflation for the period of July 2003 to December 2020 in Bangladesh. We propose a multivariate framework by including the consumer price index of all goods and services except transport (XCPI), volume of oil import and transport price index (TPI) in a dynamic recursive time series modeling. After addressing the endogeneity issue between XCPI and TPI by ARDL bounds testing and VECM Granger causality, we estimate the recursive model with ARMA and GARCH. The outcomes of the specification testing and subsequent estimations lead us to conclude that TPI gravitates toward XCPI both in the long and short run while XCPI has little or no impact on TPI as such. The estimations of the contemporaneous variables fitted with GARCH model indicate that an additional 1% point increment in XCPI leads to a 0.17% increase in TPI in the short run. This relationship is, however, reversed for oil supply where 1 million barrels of additional oil induce a decrease of TPI by 0.06 inflation points in the short run. We also find that inclusion of variance in the modeling through GARCH compared to

ARMA model produces better in and out-of-sample forecasting especially in the long run.

The findings suggest to a possible policy intervention to reduce the upward pressure of TPI by either importing additional oil or shift the transport sector toward renewable sources by improving energy efficiency. Consumer price support or input subsidies to the transport suppliers can also be intervention tools to promote business. In addition, our volatility modeling on transport price indicates a stable market conducive to public and private investment in the transport sector.

Appendix 4A

4A.1 Seasonality testing

TABLE 4.7: Seasonality testing

Variables	F-Stat. (Month Dummies)	P-value	Decision
TPI	0.02	1.00	No seasonality
XCPI	0.02	1.00	No seasonality
Oil	0.62	0.81	No seasonality

4A.2 Model selection

TABLE 4.8: ARMA model selection

Model: D.TPI=f(D.XCPI)

ARMA(p,q)	IC (AIC)	ARMA(p,q)	IC (AIC)
0,1	607	0,2	601
1,0	605	2,0	601
1,1	599*	1,2	600
2,1	599	2,2	601

*ARMA(1,1) model is elected for lowest IC with parsimonious specification.

TABLE 4.9: GARCH-M model selection

Model: D.TPI=f(D.XCPI)

GARCH(p,q)-M	IC (AIC)	GARCH(p,q)-M	IC (AIC)
1,0	584	2,0	588
1,1	578*	2,1	585
1,2	579	2,2	590

*GARCH(1,1)-M with ARMA(1,1) model is elected for lowest IC.

4A.3 Volatility clustering: ARMA residuals

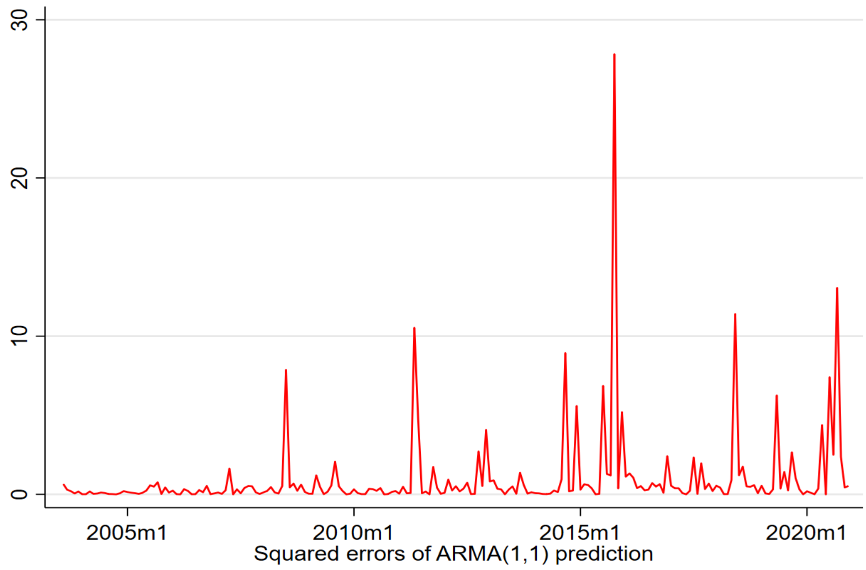


FIGURE 4.8: ARMA (1,1) residuals (Model 1)

Chapter 5

Conclusion

The three papers in the thesis are put together on the premise that energy consumption decisions, based on economic outcomes alone would be incomplete without taking the country's specific circumstances into consideration. Throughout our analysis, the principal argument is that energy can become productive capital when its supply and affordability are ensured. To ensure affordability, energy subsidies are shown to be instrumental for energy deficient and low to middle-income countries. Conversely, we find that subsidies may be counterproductive for high income and energy rich countries, as relatively cheap energy may lead to over-consumption and inefficiency. The impact differs not only based on the income level but also on the country's ability to utilize energy in a productive manner. Accordingly, we investigate an energy deficient country focusing on the relationship between primary energy and output. Using monthly time series data over 20 years, the second study examines the economy of Bangladesh to observe how these two variables interact in the short and long run. Estimating by Autoregressive Distributed Lag and Granger causality techniques, we find that economic output induces energy consumption without feedback. A further analysis leads us to the conclusion that as an energy-constrained small open economy, Bangladesh could not flourish on energy intensive industries. Much of the energy here is utilized as consumption for the energy poor population. In such an economy, energy conservation would further exacerbate welfare through energy inequalities. The conclusion from our third paper also reinforces the idea that energy is important for transport sector. Constructing a model for a small open economy, we show that while the prices of all other goods and services pushes up transport prices, additional oil supply decreases that pressure. Using volatility modeling, we conclude that transport price volatility of Bangladesh is not explosive, but rather bounded and mean reverting. Overall, we find that energy plays a critical role in energy constrained economies, where securing energy through fuel switching would be conducive for welfare of the population and environment, as opposed to the policies of restricting energy supply.

The thesis contributes to the literature in a number of ways. First, we question the usual exposition of the energy-growth nexus in a way that energy is not just an instrument for economic growth, rather, it has a multifaceted role in the economy. Second, we propose the concept of a constrained energy hypothesis, which indicates that an energy constrained economy is likely to be less efficient in energy induced productivity. Third, we underline energy security as a priority for an energy constrained economy, rather than energy conservation. Fourth, we construct unique data sets and theoretical models for the three studies in the thesis. Finally, we discuss specific policy options to ensure affordable energy and a clean environment.

Based on the novel understanding of the utility of energy, we can further explore the thesis for energy sufficient economies to observe how people adapt to energy conservation policies, targeting certain environmental outcomes.

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