The Macroeconomics of Energy Price Shocks and Electricity Market Reforms:The Case of Bangladesh

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The Macroeconomics of Energy Price Shocks and Electricity Market Reforms: The Case of Bangladesh

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A Thesis Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Economics at Durham University

June 2015

Declaration

I hereby confirm that the materials contained in this thesis have not been previously submitted for a degree in this or any other university. I further declare that this thesis is solely based on my own research. All sources are fully acknowledged and referenced.

Sakib B. Amin

Statement of Copyright

Acknowledgements

Undertaking a PhD programme has been my long cherished dream and I am very thankful to the ALMIGHTY ALLAH for giving me the opportunity and strength to begin the programme and help me to complete this PhD thesis.

At the outset, I would like to express my sincere appreciation to my supervisors Dr. Laura Marsiliani and Dr. Thomas Renström for their creative ideas, valuable advice and suggestions in completing this thesis. This work would not have been accomplished without their extensive knowledge in the field of Dynamic Macroeconomics and Energy Economics that provided exceptional guidance and enabled me to overcome every obstacle at every stage till the completion of this PhD thesis. To me, they were a source of knowledge from whom I learned a great deal. They made me realise the importance of developing dynamic models for policy related analysis rather than aimlessly running regressions. I will be grateful to them always for being available anytime to discuss my research questions. I also extend my most sincere thanks to my respected supervisors for their persistent support, kindness and dedication all along. They are not only very seasoned academic supervisor but also very good kind hearted person. They will always be remembered with respect as my "role-models" in my academic and non-academic life for their outstanding directions, motivations, encouragement, patience, help and affection. I am indebted to them forever. Moreover, I am very grateful to Professor Peter Sinclair and Professor Tooraj Jamasb for their valuable advice and suggestions on my thesis.

I would also like to express my gratitude to my loving parents Mr. S.M Aminur Rahman Amin and Mrs. Akhter Jahan Selima Aziz Arzoo for their unconditional and endless love, care, understanding and encouragement all through my life. They provide all kind of financial support I need during my PhD period. Every success in my life has been achieved because of the love and blessings of my parents. I will forever be indebted to them for their love and affection towards me. I thank my only sister Tanjila Amin Bintu for her persistent support on me. I appreciate my wife Sameena Shahzadi Mim's effort to take care of our 3 years and 6 months old son Sabir Amin during my absence and for her tireless support during the last three years. I am also thankful to all my family members. Furthermore, I remember my late paternal and maternal grandparents and all my late relatives. I am still feeling blessed to spend some unforgettable memories with my maternal grandfather Late A.K.M Aziz Uddin and paternal grandmother Late Abeda Rashid. I also believe that the blessings of my late relatives were always with me which helped a lot to overcome all the hurdles at different stages of my life. Thanks also go to Late Dr. Shah Rahman and his family, Dr. Andrew Rahman and Dr. Adrian Rahman, Dr. Salam and his family, Mr. Abdul Latif Barabhuiya and his family and Mr. Mamun for their care during my staying in UK.

The appreciations and conceptual contributions of Professor Guido Cozzi during the first year of my research are highly appreciated. I am also very thankful to Professor Parantap Basu for his useful comments during the 21 months review presentation and kindness all along. I gratefully acknowledge the valuable comments and feedback received at different stages from Professor Angus Chu, Dr. Leslie J Reinhorn, Dr. Ashar Aftab, Professor Abul Barkat, Professor Mustafizur Rahman, Professor Bazlul H. Khondker, Professor Nazma Begum, Professor Mohammed Farashuddin, Professor Ray Land, Professor Pual Levine and Professor Golam Mohammad. I would also like to express my sincere gratitude to Professor Tooraj Jamasb for his kind behaviour and valuable advice every time we met in UK and Turkey. Special gratitude is also due to Dr. Theresa McKinven for her persistent support to get me involved in Ustinov Intercultural Forum (UIF) and Professor A.F.M. Ataur Rahman to encourage me to initiate research in Energy Economics and his kind support all along.

A great number of friends and colleagues here in Durham and Bangladesh that ultimately enriched my life academically and socially must be acknowledged. At first, I would like to thank Mr. Agnirup Sarkar for being such a good colleague and friend all along. I would also like to thank all my PhD colleagues especially Dr. Manzoor Ahmed, Dr. Sheshadri Banerjee, Dr. Eun Young OH, Dr. Peter Robejsek, Dr. Postrick Mushendami, Mr. Sigit Wibow, Mr. Jiunn Wang, Mr. Bledar Hoda, Mr. Yongdae Lee, Mrs. Hala Alqobali for the thoughtful discussions at different stages of my research. I am also very grateful to Dr. Hong Il Yoo, Dr. Manuel Llorca, Dr. Rosen Azad Chowdhury, Dr. Paola Bassino, Dr. Michele Filippo Fontefrancesco, Dr. Emilio G. Berrocal, Dr. Anna Caludia Morgavi, Dr. Dori Beeler, Mr. Yannis Soniglouth, Mrs. Nahid Rezwana, Mrs. Dilshad Jahan, Mr. Muhammad Jahedul Huq, Mr. Lee Jonathan, Miss. Mehrin Chowdhury, Miss. Yuexian Hong, Dr. George Gazis, Miss Aspasia Christodoulou, Stefan Renström, Alexander Renström, all my colleagues in Ustinov Intercultural Forum (UIF) and North South University (NSU), all my students in UK and Bangladesh, especially, Mr. Shahnawaz Ferdous, all the staffs of Ustinov College especially Glenn, Sarah, Rebecca, Lynsey, Brenda, Sheila, Jonathon, Maureen, Brian, all the Staffs of Park and Ride and Arriva Bus Companies, all my neighbours in Keenan House, Century State Apt. and Baily Square, all the staffs of Durham University Business School and Fusion Restaurant, all my musical band members and all my friends in Durham and Bangladesh for being so nice to me all the time. I am very grateful to Nui and Frankie for their support all along. Many thanks should also go to Md. Mizanur Rahman, Md. Anwarul Islam and Mr. Hridoy of Janata Bank Limited for their cooperation during my study.

I am extremely gratitude to North South University for granting me four years study leave to continue my research. I am also grateful for the financial assistance provided by Ustinov College (Durham University) for the year 2012-2015. The generous funding for the PhD researchers from the Durham University Business School is gratefully acknowledged. I am also grateful to Janata Bank Limited for the support and cooperation during my research. The conference funding from Summit Power Limited Company and Orion Group Bangladesh is also highly acknowledged. My thanks are also due to Thermax Group Bangladesh for their encouragement.

Finally, I would like to acknowledge my only son Sabir Amin, who gives me inspirations all the time. All my tiredness and stress simply disappears when I see my son and parent's face.

Dedication

To my Parents: Mr. S.M. Aminur Rahman and Mrs. A.J. Selima Aziz

Abstract

Electricity is a vital instrument for economic growth and human development. The measure of growth in developing countries like Bangladesh is synonymous with the level of electricity use. Energy (oil) price shocks are often identified as a source of macroeconomic fluctuations since they affect economic development as well as business cycle. Accordingly, it has been argued that electricity market reforms are a possible tool to improve economic performance, efficiency, welfare and overall economic development. The Bangladesh economy is vulnerable to energy (oil) price shocks and the government has adopted different electricity reform policies in the past few years. However, there is a real gap in the energy literature with regard to the qualitative and quantitative analysis of the consequences of energy (oil) price shocks and electricity market reforms towards the Bangladesh economy.

This thesis is divided into two main parts. The first part contains two chapters titled, "A Survey of Literature" and "Energy Scenario in Bangladesh" which extensively review the related literature and underline the research gaps that this thesis intends to address. The second part of this thesis includes three novel papers in the literature on energy (oil) prices, electricity market reforms and the macro economy, all applied to the case of Bangladesh: "Energy Price Shocks and Real Business Cycle", "A DSGE Analysis of Oil Price Shocks" and "A DSGE Analysis of the Welfare Effects of Alternative Electricity Pricing Schemes". The following research questions are addressed:

1. How important aggregate energy price shocks are to explain business cycle fluctuations for the Bangladesh economy?

2. How would oil price shocks affect the macro economy of a small, oil importing, developing country like Bangladesh?

3. How would electricity market reforms affect the Bangladesh Economy?

To answer these questions we develop a Real Business Cycle (RBC) model and a Dynamic Stochastic General Equilibrium (DSGE) model for Bangladesh, the latter including a detailed model of the energy (electricity) sector which has not been attempted before in the literature. We conclude that the RBC model does a reasonable job in capturing the qualitative changes of selected endogenous variables considering the energy and productivity shocks. We find that oil price shocks have a negative welfare effect on consumers and GDP. However, industry expands to produce more exportable goods as higher oil price makes the country worse off with regard to Terms of Trade (TOT). Lower wage and capital interest rate allow industry to employ more labour and capital and increase production. Our results also reveal that electricity reform policies (restructuring of prices and subsidy arrangements) increase household welfare and GDP in Bangladesh. Given our results, it is advisable that policymakers carefully assess the overall welfare effect of oil price shocks and electricity market reforms and when appropriate take some measures to redistribute welfare across sectors. The heterogeneity nature of the households would be more appropriate for policy analysis and the analysis of these redistribution policies is left for future research. As some other developing countries face the same issues as Bangladesh, the novel framework and results of this thesis are of relevance not only for Bangladesh but also for developing countries in general.

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Chapter 1
Introduction

1.1 Introduction

Energy is considered as the lifeblood of the economy and an essential input for almost every good and service. Energy plays a decisive role in the development process of a country. It not only enhances the productivity of factors of production, but also promotes higher living standards. The term “energy” mainly covers a wide range of products such as electricity, oil, natural gas, coal, biomass and other renewable sources. However, electricity is known as one of the most widely used forms of energy and therefore the electricity industry is an important sector for any economy. Electricity, being an energy carrier, provides energy input to different development processes that vary depending on consumer group such as industrial, service, residential and government.

According to World Bank (2000) no country has managed to develop beyond a subsistence economy without ensuring at least minimum access to electricity services for a broad selection of its population. Moreover, in a study of over 100 countries, Ferguson et al. (2000) find a strong correlation between electricity usage and the level of economic development and growth. Oil is another vital source of energy in the economy and always been considered as an indicator of economic stability due to the world’s high dependence on oil products.

Energy price is a crucial driver of the world economy and changes in the price of energy can have significant effect on macroeconomic condition and welfare in both developed and developing countries around the world. The transmission mechanisms through which energy prices have an impact on real economic activity include both supply and demand channels. There is the classic supply side effect according to which rising energy prices are indicative of the reduced availability of a basic input to production, leading to a reduction of potential output (Brown and Yücel, 1999). An energy price increase may also have a negative effect on consumption through its positive relation with disposable income. From demand side perspective, when energy prices rise, consumers are unable or unwilling to reduce energy consumption and may reduce expenditures on other goods and services, potentially upsetting the macroeconomic condition (Lescaroux et al., 2008). Naturally, the bigger the energy price increase and the longer higher prices are sustained, the bigger the macroeconomic impact.

The macroeconomic effects of oil price shocks have been extensively examined since the 1970’s. This relationship between oil prices and macroeconomy has been investigated using several approaches. Different methods of analysis have yielded different results, sometimes sharply different, sometimes modestly. However, in general, macroeconomists have viewed changes in the price of oil as an important source of economic fluctuations, as well as a paradigm of a global shock, likely to affect many economies simultaneously (Blanchard and Gali, 2008). It is worth noting that existing literature mostly focuses on oil or aggregate energy in investigating energy price and macroeconomic relationship.

Subsidies in energy markets are another important policy issue for many developing and emerging countries in the world (Plante, 2014). Energy (electricity, gas and petroleum) subsidies lower the prices paid by energy consumers, lower the cost of energy production or raise the revenues of energy producers (IEA, OECD and World Bank, 2010). Subsidies of energy are provided through several common channels such as price control and direct financial transfers. Energy subsidies may also occur when the government provides under-priced access to scarce resources that are under its own control (Manzoor et al., 2012). In particular, state-owned companies are allowed to produce, transmit and sometimes distribute energy to end-use customers. For example, countries like Bangladesh and Iran, the government sets the price in the market, where there is no competition. However, in developed countries, government mainly abstains from interfering with market processes. They can tax goods or inputs to implement any reform policies. Energy (mainly fuel and electricity) subsidies are very important for many developing countries because of the cost of providing them. According to Mujeri et al. (2013), subsidies on electricity and petroleum products in Bangladesh are 1.62% of GDP in 2012. Moreover, energy subsidies depress growth through a number of channels. Subsidies can discourage investment in the energy sector; can crowd out growth enhancing public spending. Some countries spend more on energy subsidies than on public health and education. Reallocating some of the resources freed by subsidy reform to more productive public spending could help boost growth over the long run (International Monetary Fund, 2013).

Electricity prices in many developing countries are highly distorted as the prices are controlled by government and set below the long run marginal cost. This electricity prices are not based on economic principles but rather on vested interests and political motives. In Nepal, electricity is supplied to consumers at highly subsidised rates creating distortions in demand (Jamasb and Nepal, 2011). In a competitive market, cost reflective price can send correct signals to the market participants. Cost reflective prices can also eliminate the subsidy prevailing in the energy sector which can be used to increase electricity access in rural areas. Higher electricity price can also be socially defended as this reduce government budget deficit and enhance the opportunity the poorer class to get electricity access. Hence, cost reflective tariffs and proper subsidy schemes are crucial for the sustainability of reforms.

Having realised the importance of electricity sector, the policymakers in different countries have focused on electricity sector reform to achieve higher efficiency and to promote better services across the world during the last two decades. The electricity sector reform started in the 1980's which is limited to a few countries (Chile, UK and Norway), but by the 1990's widespread reform activity has been extended in many other countries. However, most of the developing countries face a range of challenges in their electricity sectors. Electricity industries in the developing countries are still mostly or entirely dominated by government and electricity and fuels prices are set by government. Moreover, there is very little competition, low rate of electrification, low per capita electricity consumption, prevalence of high energy subsidies and distorted prices, high technical and non-technical energy losses in the transmission and distribution networks, vertically integrated setup in the market despite the fact of private firms' entrance in electricity generation and the distribution and transmission of electricity remains in the hands of monopolies, usually owned by government in most of the developing countries. Therefore, electricity reform policies are crucial in order to ensure an adequate supply of electricity so that their economies continue to grow and the livelihoods of their people continue to improve.

In almost all reforming countries, electricity reform has been a part of wider policies towards a liberal market economy (Erdogdu, 2010). Many developing countries started putting effort on implementing market-oriented electricity reforms in developing countries since early 1990's. The major reforms that have been taking place in the developing countries are structural changes and privatisation of electricity utilities. Moreover, most of the countries reforming their electricity sector have mainly corporatised their utilities and invited private Independent Power Producers (IPPs) to balance the generation shortfall experienced by the state-owned utilities. The reforms mainly aimed at introducing energy policies, legislation, regulations and institutions that would unfetter the monopoly of state-owned utilities and provide opportunities for private actors to participate in a competitive market. Jamasb et al. (2014) argue that the reforms consisted of both high and low level reform measures. The high level reforms focussed on introducing competition in the wholesale and retail segments of energy supply, the horizontal unbundling of the incumbents to create viable competitors, the creation of an independent regulatory body and often (but not necessarily always) privatisation. The low level reforms included aspects of cost-reflective pricing (such as removal of subsidies and subsidies restructuring, tariff liberalisation and price setting), adoption of new energy technology, new financial schemes and community involvement (Prasad, 2008). These reform programmes are particularly very important and the main thrust of electricity sector reform is price reform in many developing countries who takes initiatives to move from a planned to a market economy. According to Jamasb (2006), in most developing countries, electricity reform requires extensive restructuring of prices and subsidy arrangements.

Furthermore, electricity reform should however be seen in its wider macroeconomic context (Pollitt, 2008). Electricity, as an energy carrier is considered as a key sector in the modern economy and moves to improve the operation of the market more generally since 1980, form the backdrop to electricity reform. In all of the leading countries, electricity reform has been part of wider moves towards privatisation, smaller government participation and the extension of the role of the market. This is especially true in transition economies where electricity sector reform is clearly merely a part of wider reforms. From this wider perspective electricity reform requires careful evaluation, not just in terms of its effect on electricity consumers and producers but also in terms of the promotion of efficient markets and good government more generally (Pollitt, 2008). Jamasb and Nepal (2011) propose a two stage electricity reform programmes. In the short run and medium run, priority should be given towards tariff and subsidy restructuring and creating an effective independent regulatory body. As the economy develops, in the long run, focus can be shifted towards complete vertical separation of utility networks.

Bangladesh has also experienced a process of institutional reforms in energy sector during last two decades. Although the energy sector in Bangladesh covers a wide range of products such as electricity, petroleum products, natural gas, coal, biomass and other renewable sources, policy makers have been most pre-occupied by electricity, the most widely used form in energy (International Institute for Sustainable Development, 2010). The operation of the power sector has been the responsibility of the Bangladesh Power Development Board (BPDB), reporting to the Ministry of Power, Energy and Mineral Resources (MPEMR). Since the mid-1990s, the government of Bangladesh has continued with the vertical unbundling of the sector, through the creation of separate publicly owned entities for generation, transmission and distribution utilities. The unbundling has led to the creation of a number of independently managed entities which are gradually taking over the operational responsibility previously vested with BPDB, thereby changing its status to that of a holding company, with management control being decentralised into the business units. As part of the on-going programmes of power sector reform, a regulatory body, the BERC (Bangladesh Energy Regulatory Commission) has been set up, and a unit called Power Cell has been set up within the MPEMR to drive the reform process forward.

Although Bangladesh government has adopted a comprehensive energy development strategy for exploring supply-side options along with demand management, still the country is unable to ensure necessary energy supplies to meet the energy demand of the country and faces energy crisis. However, Bangladesh has shown significant economic performances in recent past, maintaining an average of 6.01% GDP growth rate since 2010. It is widely believed that the country's growth might even be higher figure if it could mitigate the energy crisis. The government has committed to ensuring access to affordable and reliable electricity for all citizens by 2021 (Planning Commission, 2012). But, only 69% of the population in Bangladesh has access to electricity compared with 74.5% in South Asian region and 83.1% worldwide. The picture looks even gloomier in the rural areas of Bangladesh where only 42.5% of rural population has access to electricity compared to 66.3% in South Asia and 70.2% globally (World Development Indicator, WDI, 2012).

Moreover, the state owned energy utilities suffer from large deficits. The energy sector has also failed to attract adequate private investments due to poor pricing policies along with other bottlenecks such as lack of appropriate organisational structure, efficiency in decision making process, political instability etc. Bangladesh Energy Regulatory Commission (BERC) is the responsible agency to fix the tariff rates of electricity, natural gas, petroleum products, coal and other mineral resources. However, in setting energy prices, BERC mainly gears the governmental decisions which are highly politically motivated rather than economical. BERC occasionally fixes the prices of all energy products such as petroleum products and electricity which is controlled by the government. So, government controls some energy prices in Bangladesh and market has a very limited role in fixing the energy prices. Energy subsidy is also very high in Bangladesh as these results mostly from setting retail prices for fuel and electricity at lower than their true market prices.

There are two types of electricity subsidies in Bangladesh. One type of subsidy lowers production cost through subsidised fuel (e.g., natural gas, coal, diesel, furnace oil, etc.) in electricity generation. Another type offers electricity tariffs for groups of consumers (including residential customers and farmers) that are lower than production costs. It may be noted that, the electricity tariff structures in Bangladesh differ across sectors and levels of consumption. Industrial and service sectors pay higher tariffs while domestic and agriculture sectors pay lower, subsidised tariffs. Thus, the domestic sector is partially cross-subsidised by the industrial and commercial sectors. As a result of the latter, the Bangladesh Power Development Board (BPDB), which generates around 60% of the country's total electricity, has consistently incurred losses by selling electricity at prices lower than the break-even point. Obviously, these losses are the results of distorted electricity prices and adjusted mainly through budgetary transfers by the government every year.

In recent years, macroeconomic pressures have intensified on the Bangladesh economy resulting from a number of adverse internal and external developments (Mujeri et al., 2014). While the global financial and economic crisis in 2008 created certain pressures, one of the major domestic factors creating fiscal pressure on the economy is the below-cost provision of fuel and electricity against the backdrop of a rapid expansion in oil-dependent quick rental power generation firms to increase electricity generation (IMF, 2012). Here it needs to be mentioned that, the Power System Master Plan (PSMP), adopted by Bangladesh government in 2010 allows a number of Quick Rental (QR) power plants as immediate measures to meet the electricity demand in the short run. Thus, the energy crisis in Bangladesh is exaggerated because of fuel constraints, poor performance of the state owned electricity sector, absence of rational tariff policy, lack of appropriate organisational structure, efficiency in decision making process, high dependence on imported fuel used by the privately owned quick rental electricity companies and poor energy structure.

Since electricity tariffs and fuel subsidies have important macroeconomic implications for the developing countries who consider energy as a prerequisite for future development, electricity reform requires extensive restructuring of tariffs and subsidies arrangements (Jamasb, 2006). The tariffs can contain government subsidies to specific users, cross subsidies from industrial and commercial users to residential customers, and cross subsidies among residential customer groups. The extent of price distortions in many developing countries is considerably higher. Restructuring of tariffs can result in substantial price increases for residential customers while commercial and industrial are usually the first group to benefit from cost-reflective pricing reforms (Jamasb, 2002). Cost-reflective tariffs and proper subsidy schemes are crucial for the sustainability of reforms. Economic theory suggests that cost-reflective prices result in net social welfare gain. This implies that the welfare economic gains by those who benefit from lower prices will exceed the welfare losses incurred by those who stand to lose from price increases (Jamasb, 2002). So, pricing reform continues to be one of the most important and challenging tasks facing by the policymakers in the electricity sectors of developing countries. The historic policies of under-pricing and cross-subsidies are being reversed but only very gradually. In many countries, efforts to rebalance tariffs have been encountering considerable public opposition on social equity grounds (Kessides, 2012). Therefore, there is an urgent need to identify electricity pricing schemes that strike a more satisfactory balance between economic efficiency and social equity.

In order to strengthen the country's macroeconomic stability and withstand the adverse developments, among other measures, the government of Bangladesh also undertook steps to reduce subsidy costs through adjustment of fuel and electricity prices. Despite a series of retail energy price adjustments since the adoption of the programmes in 2011, the total subsidy bill still remains high, especially in view of the rapid expansion in demand for fuels and sustained increase in supply costs. This shows the urgent need to introduce further price adjustments and subsidy reforms to ensure economic sustainability. The policy of reducing subsidies in electricity sector thus requires narrowing the gap between the selling prices and supply cost. Recently, government has expressed its intention to adjust fuel price gradually to eliminate the disparities with international prices. Moreover, government needs to exercise greater scrutiny of rental power plant contracts, which burns imported oil to generate electricity and absorb a disproportionate share of subsidy costs (BPDB, 2015). If government could implement such efforts of removing price distortions in energy sector and ensuring gradual phase out of prevailing subsidies, this would build up more space for development spending and enhance economic activities and welfare.

Thus, reforms in the electricity market and the interaction between energy (especially, oil) price shocks and macroeconomy in the developing countries are still an area which requires extensive research to develop appropriate models for policy experiments. The complex dynamics between energy and economy have increasingly attracted modelling studies over the past decade. Theoretical models developed through mathematical programing that incorporate effects of energy (oil) price and subsidy changes have played an important role in the energy literature (Jebaraj and Iniyan, 2004). Mathematical programing is the study and use of optimisation and dynamic models available to assist private and public sector in decision making process. The method of mathematical programing not only can generate operational level planning for individual operators, they can also help policy makers to capture a big picture of any industry, like the electricity industry. These models can be defined as the computation of market equilibrium prices, flows and quantities which is often accomplished by solving an appropriate optimisation problem or sequence of optimisation problems. Since the oil embargo of the 1970's, researchers have used extensive mathematical modelling to analyse various energy issues and develop a national energy policy. Among these efforts, Dynamic Stochastic General Equilibrium (DSGE) models have played an important role. Modern macroeconomics is based on DSGE models which are built on microeconomic foundations (Wickens, 2008). DSGE models are dynamic, focusing how the economic variables evolve over time. These models are also stochastic because they consider the fact that the economy is affected by random shocks such as technological change, fluctuations in the price of oil, etc. Moreover, DSGE models are of particular importance to policy makers in that they give insights concerning the trading prices and quantities while generating more comprehensive and higher level information relevant to the entire market. DSGE model also facilitates the forecast of the changes in the level of welfare that would be caused by a change in market condition such as an improvement in the technology or a new government subsidy or tariff policy.

Researchers have spent considerable efforts in attempting to explain the relationship between energy (both at aggregate and disaggregate level) and overall economy. Despite of the extensive literature on Dynamic Stochastic General Equilibrium (DSGE) models, to the best of our knowledge there is no model that focuses on a detailed disaggregation of the energy sector incorporating government price controlling mechanism and consequently implicit subsidies. Some features of energy market situations in developing countries such as prevalence of fuel subsidies, electricity price distortions, transmission and distribution losses etc. are also overlooked in the literature. Amidst of the methodological differences in investigating the energy macroeconomic relationship, most of the existing models do not distinguish between demand for different types of consumption goods.

Furthermore, the RBC models are a combination of the stochastic neoclassical growth model and some kind of real shocks to study business cycle fluctuations (quantitative analysis) in an environment with flexible prices. Many macroeconomic researchers pay attention to the RBC model because it constitutes a useful benchmark framework as a vehicle for developing DSGE model to address the source fluctuations and the behaviour of different macroeconomic variables for policy analysis. The main principle of RBC approach is that a benchmark model of a frictionless and perfectly competitive market economy, populated by utility-maximising rational agents who operate subject to budget constraints and technological restrictions, could replicate a number of stylised business cycle facts when hit by random productivity shocks or any other form of exogenous shocks. This RBC model has made a lasting methodological contribution. Most of the DSGE models adopt the general structure of a RBC model, i.e. they feature an impulse response structure built around optimising agents in a general equilibrium setting. Both theoretical and computational issues are explored when setting up a DSGE model and applying it for macroeconomic analysis. The seminal paper by Kydland and Prescott (1982) started the RBC theory in particular and DSGE modelling in general.

The macroeconomic effects of electricity price reform policies, for example, the introduction of uniform electricity price for all consumers or the reductions in fuel subsidies, are complex and require an explicit dynamic stochastic general equilibrium modelling approach. Despite the focus on the fact that electricity price reform policies have some impacts on macroeconomy, the macroeconomic implications of electricity price reform policies and energy (oil) price shocks for the Bangladesh economy are not yet known precisely. Three decades have elapsed since the introduction of first reforms in Bangladesh and there is now a need for a detailed evaluation on the economic impact of the reforms because understanding how the economy evolves in response to energy (oil) price shocks and electricity price reform policies is important to policy makers and economists to achieve efficiency in energy market.

This thesis aims to contribute to the energy literature by focusing on the qualitative and quantitative analysis of the macroeconomic consequences of energy (oil) price shocks and electricity market reforms (mainly electricity tariff reforms) for the Bangladesh economy. This thesis is divided into two main parts. First part reviews the existing theoretical and empirical literature in the areas of energy (oil) price shocks, electricity market reforms and their effect on economy across the world, emphasis on the energy augmented dynamic models focusing on the relation between macroeconomy and energy (oil) price shocks and energy market reforms and give a brief overview of Bangladesh energy scenario. In the second part, we construct an energy augmented Real Business Cycle (RBC) model and Dynamic Stochastic General Equilibrium (DSGE) model for Bangladesh to analyse the effects of energy (oil) price shocks and electricity market reform on different macroeconomic variables. The model developed in this thesis assumes a mixed economy where electricity comes both from private and public sectors and government controls electricity and fuel prices. Our model further assumes the prevalence of implicit subsidy (due to government controlling prices) and the existence of a fixed rate of system loss. The framework of the models allows us to examine electricity price reforms adjustments on economy as a movement from mixed economy towards free market economy. This study is a first step towards a quantitative analysis of electricity price reform policies for Bangladesh. It is expected that the analysis of this thesis will not only benefit the policy makers in Bangladesh but also guide the policy makers of other countries with similar economic conditions and characteristics.

Highlighting this research gap, the following research questions are addressed in this thesis:

1. How important aggregate energy price shocks are to explain business cycle fluctuations for the Bangladesh economy?

2. How would oil price shocks affect the macro economy of a small, oil importing, developing country like Bangladesh?

3. How would electricity market reforms (Restructuring of electricity price and subsidy) affect the Bangladesh economy at macro level?

1.2 Contribution of this thesis

The major contribution of this thesis is twofold. At first, we develop a Dynamic Stochastic General Equilibrium (DSGE) model with a detailed disaggregation of the electricity sector for a mixed economy where government still controls electricity prices when electricity and fuels enter both production and consumption functions and the economy burns oil to generate electricity (Methodological Contribution). Then, we propose some alternative electricity pricing schemes for Bangladesh (as part of electricity price reforms and liberalisation towards free market economy) and analyse the consequences of the electricity price reforms on household welfare, electricity market condition and macroeconomy in Bangladesh (Policy Contribution).

The followings may be the other key contributions of this thesis to the existing energy literature.

- This study is a first step towards dynamic modelling analysis of energy (electricity) sector in Bangladesh.
- This thesis simulates and calibrates an energy augmented RBC model for Bangladesh economy to investigate the interactions between aggregate energy price and overall economy. This model represents a small first step to examine the stylised evidence on energy and macroeconomic variables in Bangladesh and to develop a DSGE model for energy (oil) price shocks and electricity policy related analysis (**Chapter 4**).
- Another novelty comes from the development of a detailed disaggregation of the electricity sector including both public and private sectors. We construct a Dynamic Stochastic General Equilibrium (DSGE) model to analyse the effects of oil price

shocks in a small open developing economy. The main difference of this model is the presence of three different electricity generating firms and the inclusion of multi fuel options in the production process across the electricity generating firms in addition to two production sectors which has not been experimented in energy literature till now. This feature is particularly important for developing countries perspective as electricity supply in these countries comes from both private and public electricity generating companies and most of the developing countries are now opt for fuel mix options in generating electricity to reduce dependency on mono-fuel option (**Chapter 5**).

- Our model offer richness focusing on the feature that all the economic agents in the economy rely on energy (both at aggregate and disaggregate level) either for household energy consumption or for firm's production.
- Calibrating the DSGE model for Bangladesh economy this thesis contributes to the existing energy literature by asking the question of how the oil price shocks would affect the macro economy of a small, oil importing developing country, like Bangladesh (**Chapter 5**).
- This thesis explores a set of analytical and numerical results that show how the macroeconomy in Bangladesh behaves if government can implement some electricity reform policies (**Chapter 6**).

1.3 Organisation of the Thesis

The thesis is divided into two main parts. The first part reviews the related literature and highlighting the research gap that this thesis intends to address. The second part of this thesis includes three novel papers in the literature on energy (oil) prices, electricity market reforms and the macroeconomy and presents RBC and DSGE models to examine the impact of energy (oil) price shocks and electricity market reforms on Bangladesh economy. **Figure 1.1** and **Table 1.1** at the end of this chapter display the structure of this thesis, and the main features, results and contribution of each chapter.

Chapter 2 surveys existing theoretical and empirical literature in the areas of energy (oil) price movements, electricity market reforms and their effect on economy across the world. This chapter also highlights the energy augmented dynamic models focusing on energy price shocks and energy market reforms. Some relevant DSGE models similar to this thesis are also extensively discussed in this chapter. From our analysis it is revealed that the DSGE literatures are biased in examining the macroeconomic effects of energy (oil) price shocks rather than the electricity market reforms. Finally, **Chapter 2** focuses on the fact that the energy literature on the macroeconomic performance of electricity market reforms across the developing countries needs to be modelled in a DSGE framework considering the large gap in the energy literature.

The **3rd chapter** focuses on overall energy scenarios in Bangladesh with an emphasis on different types of energy used in Bangladesh with their availability and environmental impacts. The same chapter also provides a detailed overview of electricity sector in Bangladesh with historical energy and electricity reform policies and reviews some experiences in energy sector reforms in Bangladesh.

Chapter 4 presents an energy augmented Real Business Cycle (RBC) model for Bangladesh economy in the spirit of a Dynamic Stochastic General Equilibrium (DSGE) analysis considering two policy shocks namely: productivity and aggregate energy price shocks. Calibrating the RBC model we would like to examine how the fluctuations of key economic variables such as investment, consumption and output are explained by the exogenous shocks. The model's ability to describe the dynamic structure of the Bangladesh economy is analysed by means of Impulse Response Functions. Overall, the RBC model developed in this chapter does a reasonable job to capture the qualitative changes of selected endogenous variables like consumption, output, investment etc. when economy faced the exogenous shocks. Our results show that aggregate energy price shock has a negative impact on macroeconomic variables in Bangladesh economy. Moreover, our results reveal that an aggregate energy price shock does not explain the business cycle fluctuations in Bangladesh. Therefore, output fluctuations in Bangladesh are mainly driven by productivity shock. For further research, we would like to extend the model by explicitly modelling the electricity market (including the public and private electricity firms with multi-fuel generating capacity) so that electricity policy reforms and their impact on the overall economy can be accurately analysed.

Considering a detailed disaggregation of electricity sector for a mixed economy where government still controls electricity prices, the **Chapter 5** asks the question of how the oil price shocks would affect macro economy of a small, oil importing developing country. We construct an energy augmented DSGE model which is then calibrated and simulated for Bangladesh economy. The model offer richness focusing on the feature that all the economic agents in the economy rely on energy (both at aggregate and disaggregate level) either for household energy consumption or for firm's production. Electricity and fuel enters in the model as electricity consumption good for households and as a productive input for electricity generating firms in the form of oil and natural gas. The main difference of this model is in the respect to the presence of three different electricity generating sectors with multi-fuel generating capacity in addition to two production sectors which has not been experimented in energy literature till now. This develops an entirely new macroeconomic framework to address the impact of oil price shocks on economy. We run the program Dynare version 4.4.3, which is a pre-processor and a collection of Matlab routines to solve the model and to approximate the dynamics of our model economy. We analyse the impacts of oil price shocks on model economy through Impulse Response Functions (IRF). Our results reveal that oil price shocks have a negative welfare effect on consumers. However, higher oil price makes the country worse off with respect to Terms of Trade (TOT). So, industry expands to produce more exportable goods. Given our results, it is advisable that policymakers carefully assess the overall welfare effect of oil price shocks and when appropriate take some measures to redistribute welfare from industrial sector to the household sector. This is left for future research.

The electricity pricing structures in the developing countries generally follow a differential pricing system among various groups of consumers and highly distorted. For example, the largest electricity price faced by the commercial electricity consumers is at least two times higher than electricity price paid by the household consumers in Bangladesh. Additionally, subsidies on electricity sector have been an important issue for many developing countries because of huge cost of providing them. In order to bring the fiscal burden under control by removing subsidy and price distortion in electricity market, the Chapter 6 proposes some alternative electricity pricing schemes (For example, Equal electricity price scheme for all consumers, Flexible electricity price scheme etc. as a step towards electricity tariff liberalisation) and analyses the consequences of the electricity price reforms on household welfare, electricity market conditions and macroeconomy in Bangladesh. Thus, we consider the same energy augmented DSGE model developed in the previous chapter. The model is calibrated for Bangladesh economy to compute steady state values for different variables in the model and household's welfare in the presence of existing electricity pricing schemes in Bangladesh. Then we compute the changes of the steady state values and household's welfare from the proposed alternative electricity pricing schemes to draw policy implications. Our results show some common outcomes in all the policy experiments, for example, higher GDP, reallocation of fuel within electricity industry, higher household welfare etc. Given our results, it is worthwhile that government could offer monetary and non-monetary incentives to the electricity generators for the use of renewable inputs in the production process or for the introduction of renewable technology. As other developing countries face the same issues as Bangladesh, this analysis is of relevance not only for Bangladesh but also for developing countries in general. Finally, **Chapter 7** concludes the entire thesis with a summary of results, a discussion on the limitations of this thesis and further directions for research.

Figure 1.1: Structure of this Thesis

Chapter 1: Introduction

Part I: Conceptual Framework and Literature Review

Chapter 2: A Survey of Literature

Chapter 3: Energy Scenario in Bangladesh

Part II: Dynamic Stochastic General Equilibrium Model with Energy

Chapter 4: Energy Price Shocks and Real Business Cycle: The Case of Bangladesh

Chapter 5: A DSGE Analysis of Oil Price Shocks: The Case of Bangladesh

Chapter 6: A DSGE Analysis of the Welfare Effects of Alternative Electricity Pricing Schemes: The Case of Bangladesh

Chapter 7: Conclusion

Table 1.1: Basic Framework, Contribution & Results of the Chapters Presented in the Thesis

Chapter 4: Energy Price Shocks and the Real Business Cycle: The Case of Bangladesh
Basic Framework An energy augmented RBC model is developed to explain the quantitative business cycle properties of macroeconomic variables in Bangladesh economy and to examine how the fluctuations of key economic variables are explained by the exogenous shocks, once the model is extended to allow for energy price shocks. **Key Contribution** To date, no researcher has calibrated energy augmented RBC model for Bangladesh economy to investigate the interactions between energy and overall economy. **Main Results** Overall, the RBC model developed in this chapter does a reasonable job to capture the qualitative changes of selected endogenous variables like consumption, output, investment etc. when economy faced the exogenous shocks. Our results show that energy price shocks have a negative impact on macroeconomic variables in Bangladesh economy. Moreover, we find that output fluctuations in Bangladesh are mainly driven by productivity shock.
Chapter 5: A DSGE Analysis of Oil Price Shocks: The Case of Bangladesh
Basic Framework We construct a Dynamic Stochastic General Equilibrium (DSGE) model to analyse the effects of oil price shocks in a small open developing economy. The model includes domestic energy generating firms and different types of consumption. The model is then calibrated for Bangladesh economy. **Key Contribution** The main contribution of this chapter is to develop a DSGE model with a detailed disaggregation of the electricity sector which focuses on a mixed economy where government still controls some electricity prices when energy enters both production and consumption functions This chapter considers disaggregation in energy sector including both public and private sectors. The model also allows the flexibility of multi-fuel option in the electricity generating sectors. All these features are very important for developing country's perspective. **Main Results** Our results reveal that oil price shocks have a negative effect on household welfare and economic output in Bangladesh economy.
Chapter 6: A DSGE Analysis of the Welfare Effects of Alternative Electricity Pricing Schemes: The Case of Bangladesh
Basic Framework This chapter considers the same energy augmented DSGE model developed in previous chapter to study electricity pricing experiment for policy purposes in Bangladesh as a small developing country where government controls electricity prices and energy subsidy is high. **Key Contribution** This chapter proposes some alternative electricity pricing schemes (Restructuring of electricity prices and energy subsidy) and analyses the consequences of the electricity price reforms on household welfare, electricity market condition and macroeconomy in Bangladesh. **Main Results** Our results reveal that reforms in electricity market (restructuring tariff and subsidy) increase household welfare and GDP in Bangladesh. Moreover, our results reveal a reallocation of fuel within electricity industry in all the policy experiments.

PART I: CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Chapter 2

A Survey of Literature

2.1 Introduction

Energy is considered as an important driver of economic development. The term "energy" generally comprises a variety of products such as electricity, oil, natural gas, coal, biomass and other renewable sources. The strength of the link between energy and macroeconomy is affected by different factors. The long run level of economic activity is determined principally by labour productivity, which is determined part by the net supply of energy (Kaufmann and Kuhl, 2015). In the short run, economic theory argues that an increase in energy prices leads to an increase in the domestic price level and a decrease in output due to higher cost. There is growing recognisation that energy supply can transform people's lives and does serve as an engine for economic and social opportunity (World Bank, 2013). Therefore, subsidies in energy market are widespread and a common phenomenon across the world, especially in the developing countries to ensure the adequate supply of energy to the energy consumers and producers. However, the effectiveness of these subsidies schemes seems to be questionable as they can place a heavy burden on government finances and hamper the economic development. These subsidies are most common for electricity but are still important for oil products, coal and natural gas. Subsidies might be justified if overall social welfare is increased. However, Moltke et al. (2004) provides evidence that, in many instances, the net effect of subsidies is negative. So in addition to consider the standard reform sequence and steps, in most developing countries, electricity reform requires extensive restructuring of prices and subsidy arrangements (Jamasb, 2006).

After the first oil crisis in 1973, the energy resources and their prices have gained much more research attention and energy (oil) price movements have been considered by many economists and econometricians as a major source of business cycle fluctuation. Since then efforts have been made to analyse the mechanisms whereby energy (oil) price shocks affect the macroeconomy and to measure the impact of these shocks on macroeconomic condition (Jones and Leiby, 1996 and Brown and Yücel, 2002). However, the existing literature is more concentrated on aggregate energy and oil price shocks rather than energy (electricity) price/subsidy reform. This chapter reviews the theoretical and empirical literature on macroeconomic effects of energy (oil) price shocks and energy (electricity) market reform and highlights their special features, findings and evolution through time as well as their limitations. A wide range of macroeconomic models used in energy studies show that such models are suitable for studies on energy (oil) price shocks and macroeconomy interactions. As a consequence of these efforts, the understanding of the interplay between energy (oil) prices and macroeconomy has improved. Of the vast literature, on the macroeconomic effects of energy (oil) price shocks, one particular stream (consists of studies that examine the role of energy (oil) price shocks in a DSGE framework) is more germane to this thesis. DSGE models have become dynamic, stochastic and systematically being used for energy policy analysis. Therefore, we also stress reviewing a number of earlier energy augmented DSGE models and explore the possibility of developing DSGE model with energy for a developing country like Bangladesh to test whether aggregate energy price shocks can mimic the business cycle properties of developing countries and examine the channel through which oil price shocks can affect the macroeconomy of a small oil importing developing country. This would also create the platform for analysing the macroeconomic effects of electricity market reforms.

2.2 Empirical Literature on Energy and Macroeconomy: Some Stylised Facts

Although economic theories do not have a conclusive relationship between energy, energy price and economic development, their relationship is now well documented in the empirical literature. This has been a significant issue of concern among economists and policymakers. Since the seminal work of Kraft and Kraft (1978), many studies have examined the relationship between energy, energy price and economic development across the world. Although the energy sector covers a variety of products, existing energy literature focusing causality has mostly focused on aggregate energy or electricity, the most widely used form in energy.

Ferguson (2000) analysed the correlations between electricity use and economic development in over 100 countries and found strong correlation between these concerned variables throughout the globe. Since the strong associations between these two variables do not imply a causal relationship, recent empirical literature till to date observes over a hundred studies on causality between GDP and energy (both at aggregate and disaggregate level) consumption using various methodologies across the countries. For example, Karanfil and Li (2015), Dagher and Yacoubian (2012), Payne (2010), Ouedrago (2010), Tsani (2010), Odhiambo (2009), Halicioglu (2009), Belloumi (2009), Zamani (2007), Al-Irani (2006), Wolde-Rufael (2006), Narayan and Smith (2005), Yoo (2005), Oh and Lee (2004), Shiu and Lam (2004), Moritomo and Hope (2004), Jumbe (2004), Sari and Soytas

(2003), and Ghosh (2002) have focused on the causal relationship between energy consumption (like electricity consumption) and economic growth for several developing countries using various methodologies across the countries. Determination of the explicit direction of causality is not simply an issue of empirical concern, but one that has significant policy implications.

The overall findings vary significantly with some studies concluding that causality runs from economic growth to energy consumption, other conclude the complete opposite, while a number of studies find bidirectional causality. One of the first relevant studies was the one from Kraft and Kraft (1978) that examined energy consumption and GNP of the USA within the period 1947-1974. They found out that the causality runs from GNP to energy consumption. This pioneering study intensified the interest in the research of the relationship between economic growth and energy consumption. Akarca and Long (1980) changed the time period used in Kraft and Kraft and found no statistically significant causal relationship. Erol and Yu (1987) found a significant causal relationship between energy consumption and income in the case of Japan for the period 1950-1982, supporting the view that Granger causality runs from energy consumption to income. Inconsistent results for the causality direction might be due to the methodological differences and the choice of different time periods.

Broadly speaking, existing empirical literature finds support for four possible hypotheses between energy consumption and economic growth; they are growth, conservation, neutrality and feedback hypotheses. The growth hypothesis suggests that causality runs from energy consumption to economic growth and an economy is energy dependent where energy consumption leads to growth. Conversely, a shortage of energy may negatively affect economic performance, leading to a fall in income and employment (Jumbe, 2004). It is argued that energy is a vital and necessary input along with other factors of production (such as labour and capital). Consequently, energy is a necessary requirement for economic and social development so that energy is potentially a "limiting factor to economic growth" (Ghali and El-Sakka, 2004). On the other hand, the conservation hypothesis suggests that causality runs from economic growth to energy consumption and an economy is not energy dependent where energy conservation policies may be implemented with no adverse effect on growth and employment (Masih and Masih, 1997). However, it is possible that a growing economy constrained by politics, weak infrastructure, or mismanagement of resources could generate inefficiencies and the reduction in the demand for goods and services, including energy consumption (Squalli, 2007). The feedback hypothesis suggests that energy consumption and real GDP are interrelated and complementing each other. Finally, the neutrality hypothesis suggests that there is no causality in either direction and changes in energy consumption are not associated with changes in GDP, so that energy conservation policies may be pursued without adversely affecting the economy (Jumbe, 2004). They have argued that since the cost of energy is a very small proportion of GDP, it is unlikely to have a significant impact; hence there is a "neutral impact of energy on growth".

Most of the studies evaluated the relationship between energy (electricity) consumption and economic development within a bivariate model framework. However, a common problem of bivariate model is the possibility of omitted variable bias (Lutkepohl, 1982). The problem with including just energy and GDP is that energy may not be enough to act as a spur for aggregate output. The potential gains from economic development may depend on the degree to which capital, energy and labour act as complements. Although multivariate analysis is commonly used in recent literature, most studies suffer a lack of theoretical underpinnings. Ghali and El-Sakka (2004), Soytas and Sari (2007) and Yuan et al. (2008) have utilised the capital-energy-labour-GDP approach originated with Stern (1993). Ghali and El-Sakka (2004) assume a neoclassical one sector aggregate production function with three inputs where energy consumption is included as an additional input because of its technological progress effect on economic development for Canada and find bilateral causality between energy use and output. Employing a four variable model (value added, capital, labour and energy), Soytas and Sari (2007) found unidirectional causality from electricity consumption to output in the Turkish manufacturing industry. Karanfil (2009) suggests that there are other potentially interesting variables, like financial variables, that could impact the demand for energy.

Stern et al. (2014) carry out a meta-analysis of the very large literature on testing for Granger causality between energy use and economic output to determine if there is a genuine effect in this literature or whether the large number of apparently significant results is due to publication or misspecification bias. Their model extends the standard meta-regression model for detecting genuine effects in the presence of publication biases using the statistical power trace by controlling for the tendency to over fit vector auto regression models in small samples. Granger causality tests in these over fitted models have inflated type I errors. They cannot find a genuine causal effect in the literature as a whole.

2.3 Energy and the Macroeconomic Models

Energy and environmental problems are often complex and detailed modelling are necessary to analyse the interactions of the energy sector and the overall economy for policy references. Therefore, the complex dynamics between energy and economy have increasingly attracted modelling studies over the past decade. Analysing the interaction of the macroeconomy and the energy sector is also essential for gaining understandings into the mid to long term development of each of them (Bauer et al., 2010). The field of macroeconomics and the corresponding models is organised into many different views on how the markets and their participants operate. These macroeconomic models may be logical, mathematical, and/or computational and widely used in academia and research, and are also widely used by international organisations, national governments and policymakers. For example, studies linking energy (oil) prices to the macroeconomy through the channels of labour market dispersion (Loungani, 1986; Finn, 2000; Davis and Haltiwanger, 2001), investment uncertainty (Bernanke, 1983), consumption smoothing in durable goods (Hamilton, 2003) and the consequences for inflation (Mork, 1989; Bruno and Sachs, 1985) suggest that indirect transmission mechanisms may be the crucial means by which energy (oil) price shocks have macroeconomic consequences.

2.3.1 Earlier Macroeconomic Models, Energy and Ecological Models

Economic theory has long struggled in attempting to explain the energy-macroeconomic relationship (Finn, 2000). Researchers investigated the theoretical relationship between the use of energy and macroeconomy through different possible channels. For example, Tsani (2010) mentions that energy is an intermediate input of production. Bartleet and Gounder (2010) argue that there are some mechanisms by which economic growth could remain in spite of a limited source of energy resources. Proponents of this view focus on the possibility of technological change and substitution of other physical inputs for energy to use existing energy resources efficiently, and to generate renewable energy resources that are not subject to binding supply constraints (Solow, 1974, 1997; Stiglitz, 1974). The advocates of this theory support the 'neutrality hypothesis' and 'conservation hypothesis'. These hypotheses imply that energy would not have any negative effect on economy. Thus, the government can simultaneously adopt the energy conservation and macroeconomic policies (Bartleet and Gounder, 2010).

In contrast, the ecological economic theory states that energy consumption is a limiting factor to economic growth. Ecological economists judge that technological progress and other physical inputs could not possibly substitute the vital role of energy in production process (Stern, 1993, 2000, 2004, 2010). They even consider energy as the prime source of value because other factors of production such as labour and capital cannot perform without energy (Belloumi, 2009). The advocates of this theory highlights the so-called 'growth hypothesis'. They advise that any shock to energy supply will ultimately have an inverse effect on economic growth. Consequently, they stand against the energy conservation policies.

After the oil crisis in 1973, many researchers have extended the mainstream macroeconomic models including energy (oil) on it as a step toward reconciling macroeconomic models and ecological economic models and to examine whether energy could be a vital factor in explaining economic fluctuations and if so, what factors affect the strength of the relationship between energy and economy (Among others, Smulders (2005), Bovenberg and Goulder (1998)). Another reason behind the formulation of theoretical energy macroeconomic model is to understand the effect of energy (oil) price shocks on economy.

Contributions which utilise models without rigorous micro-foundations include, among others, Bhandari (1981), Bhandari and Turnovsky (1984), Bruno and Sachs (1985), Lee and Chang (2005), Wohltmann and Winkler (2008) and Stern (2010).

2.3.2 Energy Augmented CGE Models

The development of energy and environment statistics made it possible to develop Computable General Equilibrium (CGE) models with a rigorous description of energy supply and demand, and the inter linkages between economic activity, energy production, energy use, and emissions to air. These integrated CGE models have been used for forecasting purposes and numerous analyses of energy and environmental policies during the last two decades. Especially, the models have been developed to be suitable for analysing different economic policy options to deal with the global climate issue as design of optimal carbon tax or carbon quota schemes. Over time energy and emission modules have been integrated in the economic core model, allowing for consistent analyses of economic, energy and environmental issues based on one and same modelling framework. Alves and Pereira (2006) and Bhattacharyya (1996) survey the literature on computable general equilibrium models as applied to energy studies, and reports their special features to identify and analyse the main areas of investigation in general equilibrium models applied to the environment and energy. The models presented in their survey are applied to various countries: Norway (Bruvoll and Ibenholt, 1997), Germany (Böhringer and Rutherford, 1997), U.S.A. (Bovenberg and Goulder, 1997), India (Fisher-Vanden et al., 1997), Pakistan (Naqvi, 1998), Italy (Pench, 2001) and Turkey (Sahin, 2002). They also analyse GEM-E3, which models an open economy representing 14 countries of the European Union. Additionally, there are also few CGE exercises in modelling energy price reforms and evaluating the impacts of energy policies on specific issues like climate change (Böhringer et al., 2006), income inequality (Yang, 2000), social security finance (Felder and Nieuwkoop, 2000), non-energy markets (Gohin and Chantret, 2010), labour market (Welsch, 1996), output and welfare (Manzoor, Shahmoradi and Haqiqi, 2012) and capital formation (Struckmeyer, 1986).

However, a standard static CGE model examines one period sectoral reallocation of resources, while, in contrast, a dynamic stochastic CGE model allows us to analyse the path of a transitional dynamics toward a new steady state after an initial shock. Moreover, in contrast to a static CGE model, a dynamic counterpart is characterised by the inclusion of a driving force to move the economy from period to period. This driving force may be the growth in the underlying labour force and/or a change in the level of technology in one or more sectors of the economy. Unlikely the CGE models, DSGE models are typically limited with respect to the number of variables under consideration due to computational issues. Additionally, In contrast to computable general equilibrium models, agent maximisation takes place within a stochastic environment. Technological progress is assumed to follow an AR (1) process; the level of technology in each period depends on the previous period level plus a random component.

2.3.3 Energy Augmented DSGE Models

Economists of 1980s and 1990s began to construct micro founded macroeconomic models based on rational choice which have come to be called Dynamic Stochastic General Equilibrium (DSGE) models. In modern macroeconomics, the economy is described as a

DSGE system that reflects the collective decisions of rational individuals over a range of variables that relate to both the present and the future. These individual decisions are then coordinated through markets to produce the macro economy.

Dynamic stochastic general equilibrium (DSGE) modelling began with work in Real Business Cycle (RBC) analysis (Kydland and Prescott, 1982; Long and Plosser, 1983). The models assume fully-specified optimising behaviour by forward-looking agents, possess well-defined stochastic structure of exogenous forces, and impose explicit general equilibrium structure. In providing the microeconomic underpinnings which were largely absent in macroeconomic models, DSGE models provide a theoretically consistent framework for testing macroeconomic theories and for quantitative policy assessment (Kydland and Prescott, 1982).

The earliest DSGE models were formulated in an attempt to provide an internally-consistent framework to investigate RBC theory. RBC models are underpinned by neoclassical general equilibrium economic theory (Kydland and Prescott, 1991). In these models, rational, infinite-lived, identical households maximise inter-temporal utility over consumption and leisure, use of capital and labour in production of an aggregate good is governed by constant returns to scale technology, and markets clear each period. Net investment in each period determines the change in capital stock. Apart from the extensive empirical literature examining energy-economic activity, there is another kind of literature, which has analysed the energy shocks on economic variables using RBC models. The case for incorporating energy shocks into the RBC models has been made credibly by McCallum (1989). Moreover, the RBC model is considered as a simple neo-classical growth model which is the building block of almost all modern DSGE models with energy (Kim and Loungani (1992)).

It is also worth noticing that, the impact of rising energy (oil) prices has never received substantial attention from growth economists, possibly because this has been perceived as a short run issue. The main concentration of the mainstream economic growth literature has been on the optimal depletion and the price path of exhaustible resources, following the original study of Hotelling (1931) as mentioned in Berk and Yetkiner (2014). Main contributors of this stream are Solow (1956, 1974, 1978, 1997, 1993), Dasgupta and Heal (1979), Stiglitz (1974a, 1974b), Pyndick (1978, 1981). More recently, the "new" growth economics, i.e. the endogenous economic growth literature, has focused on transition/substitution between energy sources (Tahvonen and Salo (2001), Chakravorty et al. (1997)), directed technical change in an economy with energy sources (Smulders and De Nooji, 2003) and induced energy-saving technologies and environmental issues (Smulders (1999, 2005) and Goulder and Schneider, 1999). Therefore, the issue of effects of energy prices on economic growth seems to be an unexplored area in the theoretical economic growth literature.

2.4 Macroeconomic Effects of Energy (Oil) Price Shocks

A large body of research suggests that energy (oil) price fluctuations have considerable consequences on economic activity. The link between energy (oil) prices and GDP can be understood via the classic supply side effect according to which rising energy (oil) prices are indicative of the reduced availability of a basic input to production, leading to a reduction of potential output (Barro, 1984; Brown and Yücel, 1999; Abel and Bernanke, 2001). Consequently, there is an increase in production cost, and the growth of output and productivity are slowed. This link between energy (oil) prices and GDP has been widely studied in the literature (Brown and Yücel, 2002; Hamilton, 2005). Generally, the studies tend to find that energy (oil) price increases have a negative impact on output, while this impact seems to have weakened over time, especially since the late 1990s. One interpretation is that, since the late 1990s, the global economy has experienced two major oil shocks. While being of a sign and magnitude comparable to those of the 1970s, GDP growth and inflation have remained quite stable in the majority of industrialised countries. According to Blanchard and Gali (2007), a plausible explanation is that the effects of an oil price increase are similar across periods, but have coincided in time with large shocks of a very different nature: large increases in other commodity prices in the 1970s, and high growth of productivity and world demand for oil in the 2000s.

An energy (oil) price increase may also have a negative impact on consumption, investment and employment. Consumption is affected through its positive relation with disposable income, and investment by increasing firms' costs. Considering households, an energy (oil) price increase generates a rise in domestic fuel prices leading to a decrease of their purchasing power and slowing their consumption expenditures. This effect can however be tempered if consumers expect the rise in energy (oil) prices to be transitory. In this case, they will attempt to smooth their consumption by saving less or borrowing more, pushing upward real interest rates. Turning to employment, if the energy (oil) price increase is long lasting, it may lead to a change in the production structure and have a deeper impact on unemployment (Lescaroux and Miggon, 2008)

The analysis of the macroeconomic effects of energy (oil) prices has evolved along two distinct dimensions. On the one hand, the oil price shocks of the 1970s and 1980s generated extensive empirical studies, aimed at investigating the relationship between energy (oil) price change and macroeconomic variables such as GDP, inflation etc. Depending on estimation technique (GARCH Model/VAR model etc.), the identification of energy (oil) price 'shocks', or the sample period, very different conclusions can be drawn. Some researchers focus on short term interactions (causality analysis) between energy (oil) prices and economic activity in developed countries (Hamilton (1983), Burbidge and Harrison (1984)) while others focus on the long run (cointegrating) interactions between energy (oil) price and macroeconomic variables (Hooker, 1986). The remaining researchers made an attempt to investigate both short run and long run relationship between energy price and the various macroeconomic variables (Lescaroux, 2008). On the other hand, theoretical studies have investigated different channels through which energy (oil) prices might affect macroeconomic outcomes. While these studies provide important insights regarding the transmission of energy (oil) price changes, the practical relevance of the different theoretical channels is not always clear, given the lack of empirical evidence.

2.4.1 Empirical Contributions on Macroeconomic Effects of Energy (Oil) Price Shocks

The two oil price shocks in 1970s and the subsequent global recession sparked a wave of empirical studies. There have been extensive empirical studies on the interactions between energy (especially oil) prices and macroeconomic indicators following the pioneering study of Hamilton (1983). Although there has been debate over the nature of the relationship, such as non-linearities (Hamilton (1996, 2003, 2009) and Kilian et al. (2011)) and asymmetries, i.e. differences in response to positive and negative shocks ((Mork (1989) and Balke et al. (2002)), there seems to be a consensus on the fact that energy (oil) price changes would at least have a particular, if not pivotal, effect on macroeconomic variables (Brown and Yücel (2002), Sill (2007), Kilian (2008, 2009)).

Many researchers have concluded that there is a negative correlation between increases in oil prices and the subsequent economic downturns in the United States (Hamilton 1983; Burbidge and Harrison 1984; Gisser and Goodwin 1986; Mork 1989; Hamilton 1996; Bernanke et al., 1997; Hamilton and Herrera 2004; and Hamilton 2003). Also, other studies for other countries found that strong correlation or cointegration relationship between world oil prices and macroeconomic variables exist in the long run (Boukez et al., 2008; Hamilton 2003; Jones et al., 2004; Rodrigues and Sanchez 2005). This relationship seems weaker, however, when data from 1985 onwards is included. Nevertheless, the role of the break-date, 1985-1986, has been considered by only very few researchers, where most of them argued that the instability observed in the relationship may well be due to a misspecification of the functional form employed. The linear specification might as well misrepresent the relationship between GDP growth and oil prices. Blanchard and Gali (2007) propose explanations for the observed change in the effects of the oil price shocks. First, they argue that labour markets are more flexible now than in the past, and hence some of the negative effects of the oil price shocks can be observed by the labour market. Second, more credible and stronger anti-inflationary stance of monetary policies may have kept inflation relatively stable.

Early studies documented and explained the inverse relationship between an increase in the oil price and aggregate economic activity. A major illustration of the extent and relevance of this relationship was put forward by Hamilton (1983), who argued in one important paper that nine out of ten North-American recessions since the Second World

War had been preceded by increases in oil prices, i.e. he finds evidence of Granger causality between oil prices and real GNP. Gisser and Goodwin (1986) employ a reduced-form approach to assess the quantitative significance of crude oil prices on US economy using US data for the period of 1961 and 1982. They have revealed that crude oil prices have had a significant impact on a broad range of macroeconomic indicators and this relationship appears to have been remarkably stable during the sample periods. Mork (1989) highlights the fact that the Hamilton's (1983) study pertained to a period in which all the large oil price movements were upward, and thus it left unanswered the question that whether the correlation persists in periods of price decline. Therefore, he extends his analysis adding the real price of oil to the six-variable equation and extending the sample size till 1988. However, Mork (1989) confirms Hamilton's (1983) observation of a negative correlation between output growth and oil price increases.

Hooker (1996) reveals that the fact that oil prices Granger cause a variety of U.S. macroeconomic indicator variables in data up to 1973 but not in data from then to the present is shown to be robust. He refutes the linear relation between oil prices and output (Hamilton 1983) and the asymmetric relation based on oil price increases (Mork 1989). Later on Hamilton (1996) agrees completely with Hooker refuting linearity and asymmetry in the oil price macroeconomy relationship. Additionally, aanalysis of the late 1980s indicates that the oil price-macroeconomy relationship has changed in a way not well represented by a simple price increase/price decrease asymmetry (Hooker, 1996). Earlier studies for oil price change and economic growth relationship were carried out mostly for developed countries using VAR model. However, over the following years studies for developing countries have also been carried out.

Abeysinghe (2001) carried out a study for 12 different countries (Hong Kong, South Korea, Singapore, Taiwan, China, Japan, Indonesia, Malaysia, Philippines, Thailand, USA and rest of OECD as a group) using a structural VARX model. Results from this study showed that for oil importing developing countries like Philippines and Thailand, direct impact of oil price increase by 50% would cause GDP growth to decline by 5.5% and 5.7% respectively in the long run. Direct impact on growth of developed countries like USA and rest of OECD was comparatively small. USA GDP growth declined by 0.7% and OECD growth was reduced by 0.2% in the long run. So, he conclude that the transmission effect of oil prices on growth may not be that important for a large economy like the US but it could play a critical role in small open economies.

Bacon (2005) concluded a study for 131 countries. The study finds that impacts of higher crude oil prices were more severe for oil importing poorer countries as compared to developed countries. The findings showed that with $10 per barrel increase in the price of crude oil, for some poor countries with GDP per capita below 300 US$, economic growth could decrease up to 4%. If oil price increase was $20 per barrel, the shock was doubled. In contrast, countries with higher foreign reserves and GDP per capita over 900 US$, economic growth shock could be 0.4% on average.

Kumar (2009) assesses the oil prices-macroeconomy relationship by means of multivariate VAR using both linear and non-linear specifications. Scaled oil prices model outperforms other models used in the study. It studies the impacts of oil price shocks on the growth of industrial production for Indian economy over the period 1975Q1-2004Q3. It is found that oil prices Granger cause macroeconomic activities. Evidence of asymmetric impact of oil price shocks on industrial growth is found. Oil price shocks negatively affect the growth of industrial production and he find that a 100% increase in oil prices lowers the growth of industrial production by 1%. Moreover, the variance decomposition analysis while putting the study in perspective finds that the oil price shocks combined with the monetary shocks are the largest source of variation in industrial production growth other than the variable itself.

Blanchard et al. (2007) with evidence from USA, France, Germany, UK, Italy and Japan economies concludes that effects of oil price shocks have changed over time. Impacts of crude oil price change have become smaller on prices, wages, employment and output over time. Kilian (2008) empirically analysed the effects of oil supply shocks on US real GDP growth and Consumer Price Index (CPI). Study concluded that oil supply shocks negatively affected real GDP growth after five quarters. Lescaroux and Mignon (2008) investigate the links between oil prices and various macroeconomic and financial variables for a large set of countries, including both oil-importing and exporting countries. Both short run and long run interactions are analysed through the implementation of causality tests, evaluation of cross-correlations between the cyclical components of the series in order to identify lead/lag relationships and cointegration analysis. Their results highlight the existence of various relationships between oil prices and macroeconomic variables and, especially, an important link between oil and share prices on the short run. Turning to the long run, numerous long-term relationships are detected, the causality generally running from oil prices to the other variables. An important conclusion is relating to the key role played by the oil market on stock markets.

Du et al. (2010) conducted a study to investigate crude oil price shocks on macroeconomic growth of China. Through a VAR analysis they concluded that oil price increase had positive significant impacts on macroeconomic activity of China. Their results showed that a 100% increase in crude oil price showed a positive growth of Chinese economy by 9% and CPI by 2.08% for linear model specification. The non-linear model specification results were asymmetric and yield different results for different transformation. Results showed that a 100% decrease in world oil prices cumulatively decreased the growth rate of China's GDP by 17% for Mork (1989) transformation, 10% for Hamilton (1996) transformation and 1% for transformation as suggested by Lee et al. (1995).

Narayan et al. (2014) test whether oil price predicts economic growth for 28 developed and 17 developing countries. They use predictability tests that account for the key features of the data, namely, persistency, endogeneity, and heteroskedasticity. Their analysis considers a large number of countries, shows evidence of more out-of-sample predictability with nominal than real oil prices, finds in-sample predictability to be independent of the use of nominal and real prices, and reveals greater evidence of predictability for developed countries. Ftiti et al. (2014) assesses the impact of oil prices on economic growth of the four major OPEC countries (United Arab Emirates, Kuwait, Saudi Arabia and Venezuela) over the period spanning from 2000 to 2010. They aim at complementing the results from existing analyses (mainly focused on oil-importing countries) by using the evolutionary co-spectral analysis as defined by Priestley and Tong (1973). They find that co-movements between oil and economic growth have different patterns depending of the studied horizons. This interdependence is a medium lived phenomenon, revealed on a three years and one quarter horizon, being weak in the short-run (ten months). They show that oil price shocks in periods of world turmoil or during fluctuations of the global business cycle (downturn or growth, as for instance the 2008 financial crisis) have a significant impact on the relationship between oil and economic growth in oil-exporting countries.

Cuando et al. (2015) analyses the macroeconomic impact of structural oil shocks in four of the top oil-consuming Asian economies, using a VAR model. They identify three different structural oil shocks via sign restrictions: an oil supply shock, an oil demand shock driven by global economic activity and an oil-specific demand shock. The main results suggest that economic activity and prices respond very differently to oil price shocks depending on their types. In particular, an oil supply shock has a limited impact, while a demand shock driven by global economic activity has a significant positive effect in all four Asian countries examined. Their finding also includes that policy tools such as interest rates and exchange rates help mitigating the effects of supply shocks in Japan and Korea; however, they can be more actively used in response to demands shocks.

From the existing literature it is difficult to draw conclusive results about the impacts of energy (oil) prices on economic growth. It varies country to country. The majority of researchers for developed countries agree upon the negative relationship between energy (oil) price and economic growth. Empirical findings for developing countries vary depending on the model specification and choice of variables.

2.4.2 Theoretical Contributions on Macroeconomic Effects of Energy (Oil) Price Shocks

The search for the routes by which energy (oil) price shocks work their way through the economy has had led to the development of theoretical analyses relying on aggregate models of the economy and connected with data by simulations.

Now we will briefly explain the detailed model structure of some selected DSGE papers which are mostly relevant to our proposed model (as some similarities can be found in the specification of production and utility function).

Kim and Loungani (1992) Model

In their seminal paper Kim and Loungani (1992) included energy as a productive input and modelled the relative price of energy as an exogenous random process in a standard RBC model. They examine the extent to which the introduction of energy price shocks reduces the reliance of the RBC model on unobserved technology shocks. And the main goal of their paper is to see how important technology shocks are to the basic RBC model, once the model is extended to allow for the possibility of other real shocks, like energy price shocks.

The Model

The production technology of firms is described by a nested Constant Elasticity of Substitution (CES) function with Constant Returns to Scale (CRS):

$$y=\tau h^{\theta}[(1-\alpha)k_t^{-v}+e_t^{-v}]^{-\frac{1-\theta}{v}}$$

In addition to the usual inputs, labour (h) and capital (k), production is assumed to require the use of energy (e). The parameter v is equal to (1-s)/s, where s is the elasticity of substitution between capital and energy. Labour's distributive share is given by the parameter θ. This functional form allows them, potentially, to relax the assumption of unitary elasticity of substitution between capital and energy that would be imposed by a Cobb-Douglas (CD) function.

The law of motion of the stochastic technology shock, τ, is assumed to be:

$$\tau_t = \alpha_0 + \alpha_1\tau_{t-1} + \epsilon_t$$

Where, ϵ's are i.i.d. with standard deviation σ. The relative price of all energy used in the economy, P, is given exogenously and follows the process

$$P_t = \gamma_0 + \gamma_1 P_{t-1} + \phi_t + \eta\phi_{t-1}$$

with an error variance of ε_P. In order to determine a suitable process for the relative price of energy, the authors tried to fit several ARMA processes to the actual data on P for the period 1949 to 1987 and the above model best fitted the data.

Capital accumulates according to the law of motion:

$$k_t = (1-\delta)k_{t-1} + i_t ,$$

Where 0<δ<1 is the depreciation rate and i_t is the period t investment. The economy's resource constraint for period t is given by

c + i + pe ≤ y, where c is consumption.

Households in the economy are infinitely-lived and have preferences defined over consumption and leisure. Each household's endowment of time is normalised to 1 so that leisure is equal to 1-h. So, the utility function considered in Kim and Loungani's (1992) paper is as follows:

U(c, h) = log c + A log (1-h)

Model Calibration

Following Kydland and Prescott's (1991) approach, they calibrate the model based on microeconomic evidence and also on long-run considerations, i.e., it is required that values for the parameters are chosen such that the model steady state values are close to average values for the U.S. economy over the data period being studied. For this purpose, they compute the steady state for the model. To hold the steady state conditions, they present results for two cases, v=0.001 and v=0.7. The remaining parameters are chosen in conformity with earlier studies. The parameter θ, labour's share in production, is set equal to 0.64, the depreciation rate, δ, assumed to be 10% a year and the annual discount factor, β, is set equal to 0.96. The parameter A in the utility function is set equal to 2.

Model Results

They present results for three model economies to check the robustness of their findings. The first model is simply the energy augmented basic RBC model. For this model, the standard deviation of the error term in the technology shocks, σ, was picked to match the standard deviation of Solow residuals, measured using actual data on output, capital, hours and energy for the 1949-87 period. The second model allows for both technology and energy price shocks where, σ_P is picked to match the actual volatility of energy prices over the 1949-87 periods. In the third model, σ was set equal to zero which implies the model abstracts completely from stochastic shocks to technology.

The authors found that the inclusion of energy price shocks leads to only a modest reduction in the RBC model's reliance on unobserved technology shocks. The addition of energy price shocks raises the percentage of output volatility explained by the basic RBC model by about 13% (from 80 to 90%) in the CD case (s =1) and by 4% in the CES case (s =0.6). So, the basic RBC model does a good job replicating the broad features of the data. For example, investment is far more volatile than consumption, and the correlation between output and capital predicted by the model is close to that observed in the data.

A model with only energy price shocks accounts for 16% of output volatility in the CES case and 35% in the Cobb-Douglas case. While these are not trivial amounts, this model does not mimic other features of the data, such as the fact that consumption is much smoother than output, with the same success as the basic RBC model.

So, their model simulation showed that energy price shocks can only generate a small fraction of the output fluctuations observed in the U.S. data. A strong conclusion from their research is that output volatility is mainly driven by shocks to Total Factor Productivity (TFP), and going one step further-all previous recessions would have occurred even without energy price shocks.

Dhawan and Jeske (2007) Model

Dhawan and Jeske (2007) highlighted that the literature on DSGE models with energy price shocks mainly uses energy on the production side only. In those models, energy shocks are responsible for only a negligible share of output fluctuations. In order to study the robustness of the earlier findings, Dhawan and Jeske (2007) extended Kim and Loungani's (1992) model by explicitly modelling private consumption of energy at the household level in addition to energy use at the firm level to account for total energy use in the economy. Additionally, they distinguish between investment in consumer durables and investment in capital goods. Introducing durable goods and household energy consumption actually decreases the relevance of energy price shocks for output volatility, despite higher total energy use. This surprising outcome happens because households now have two margins of adjustment for their investment decision-durable consumption goods and fixed capital-in response to exogenous shocks. This ability to rebalance their portfolio is missing in a typical DSGE model, with or without energy use, when responding to a shock (TFP or energy).

The Model

The representative household gets utility from consuming three types of consumption goods: consumption of nondurables and services excluding energy (N), the flow of services from the stock of durables goods (D) and energy use (E). The household uses the following aggregator function to combine these three types of consumption into C^A:

$$C_t^A = N_t^{\gamma}[\theta(D_{t-1}^{\rho})^{\rho} + (1-\varphi)E_t^{\rho}]^{\frac{1-\gamma}{\rho}}$$

Where $\theta \in (0, 1)$ and $\rho \leq 1$. With this aggregation the elasticity of substitution between energy and durable goods is $\frac{1}{1-\rho}$. They picked $\rho<0$, which implies that the durable goods and energy are complements. The elasticity of substitution between non-durable consumption and the composite of durables and energy goods is 1 in their model. This is similar to the aggregator function used by Fernandez-Villaverde and Krueger (2001) who use a Cobb-Douglas aggregator between non-durable and durable consumption. However, they have extended it to include the third type of consumption good, which is energy. This feature is motivated by Ogaki and Reinhart (1998) who found that in the U.S. data the elasticity of substitution between durables and nondurable goods was close to 1. It is worth noticing that the stock of durables from last period enters today's utility function. That way the timing of durable goods investment is analogous to fixed investment where yesterday's capital stock K_{t-1} enters today's production function.

They write the t period utility function as following:

$$U(C_t^A, h_t) = \varphi \log C_t^A + (1-\varphi)\log(1-h_t)$$

Where $\varphi \in (0, 1)$ and h denotes hours worked. This log-utility specification is the same as in Kim and Loungani (1992).

The timing convention is as follows: Households set the durable goods stock D_{t-1} in period t-1 and this stock will produce the flow of durable goods services in period t. In other words, the durable goods stock D_{t-1} is a state variable at time t: Durable goods depreciate at rate δ_d per period. Moreover, there are convex adjustment costs for adjusting the stock of durable goods. Thus, the durable goods investment $I_{d,t}$ necessary to alter the durable goods stock from D_{t-1} to D_t is:

$$I_{d,t} = D_t - (1-\delta_d)D_{t-1} + \frac{\omega_{1,d}}{1+\omega_{2,d}}(\frac{D_t - D_{t-1}}{D_{t-1}})^{1+\omega_{2,d}}$$

Where $\omega_{1,d} \geq 0,\ \omega_{2,d} > 0$. Notice that in steady state adjustment costs will be zero.

Following Kim and Loungani (1992), firms produce output by combining three inputs, labour h, capital K and energy e according to the following production function:

$$F = Z_t[\eta k_{t-1}^{\psi} + (1-\eta)e_t^{\psi}]^{\frac{\alpha}{\psi}} h_t^{1-\alpha}$$

Where the term Z_t is a TFP shock that follows a stochastic process and $\psi \leq 1$.

Similar to the durable goods, there is an adjustment cost for altering the capital stock from K_{t-1} to K_t, which implies that capital investment $I_{K,t}$ is:

$$I_{K,t} = K_t - (1-\delta_K)K_{t-1} + \frac{\omega_{1,K}}{1+\omega_{2,K}}(\frac{K_t - K_{t-1}}{K_{t-1}})^{1+\omega_{2,K}}$$

Where $\omega_{1,K} \geq 0,\ \omega_{2,K} > 0$.

Just as Cooley and Prescott (1995), they assume that log-TFP follows AR (1) process:

$$Z_t = \rho_Z Z_{t-1} + \varepsilon_{Z,t}$$

The authors then consider the following shock process for energy price as in Kim and Loungani (1992):

$$P_t = \rho_P P_{t-1} + \varepsilon_{P,t} + \rho_\epsilon \varepsilon_{p,t-1}$$

Model Calibration

The model economy is calibrated to match total energy use and durable goods consumption as observed in the US data. They follow the same techniques as explained in Kim and Loungani's (1992) model.

Main Results

The main conclusion from their work is that energy price shocks are not a major factor for business cycle fluctuations even when incorporating three distinct categories of consumption: durables, nondurables and energy. Simulation results indicate that, despite higher total energy use, the economy has an even smaller proportion of output fluctuations attributable to energy price shocks. Productivity shocks continue to be the primary force behind business cycle fluctuations. The driving force behind their results is that the household now has the flexibility to rebalance its investment portfolio. Specifically, the energy price hike is absorbed by reducing durable goods investment more than investment in capital goods, thereby cushioning the hit to future production at the expense of current consumption. Therefore, the household in their model can cushion the drop in output by adjusting on the durable goods margin instead of just fixed capital. This rebalancing ability keeps productivity shocks as the driving force behind output fluctuations.

They further show that an energy price increase has a larger negative effect on durables than on fixed capital. Even though both capital stocks decrease in response to higher energy prices, the fixed capital drops by less than the stock of durables after households rebalance their portfolio. Furthermore, the drop in fixed capital is less than that in a Kim and Loungani type economy, which explains why energy accounts for less output fluctuation in our model. Consequently, productivity shocks alone account for the majority of output fluctuations.

Tan (2012) Model

Tan (2012) introduces an RBC model with energy that expands upon those of Finn (2000) and Dhawan and Jeske (2007) to investigate the roles of energy in the economy. The aim of Tan's (2012) paper is to contribute to the theoretical side of the energy research by developing a multiple sector model with endogenous energy production. The goal is to explore the set up as a further step forward in the theoretical efforts to model energy in the macroeconomy. The model has multiple sectors, and introduces energy as endogenously produced. It also models durables explicitly in the household's utility function, and all agents in the economy rely on energy either for household's durables consumption or for production of various goods. All these elements enable the analysis of how the effects of changes in energy prices are transmitted in the economy, in particular the impact on overall output and on durables consumption and production. Overall the model is quite successful in replicating the aggregate behaviours of the economy in the events of adverse energy price shocks from the supply side. It is able to model large impacts on overall output, emphasising the important role that energy plays.

Model Description

In the setup of this model, household consumes a CES aggregation of durables (d_t) and non-durables (n_t), and also derives utility from leisure. They also decide how much time to devote to labour (h_t) and what is the utilisation rate (u_t) of its stock of durables. Similar to Dhawan and Jeske (2007), it implicitly models the consumption of durables and nondurables in the household's utility function with the following form of utility function:

$$\varphi \log[\alpha(u_t d_t)^\rho + (1-\varphi) n_t^\rho]^{\frac{1}{\rho}} + (1-\varphi)\log(1-h_t)$$

Household's use of durables needs energy, the amount of which $(e_{h,t})$ is variable in each period and directly dependent on the utilisation rate and the stock of durables that the household has at the start of the period. As can be seen, energy consumption does not enter the utility function directly, but rather it is needed to enable the household to derive utility from the stock of durables that it has. Therefore, the cost of energy used in the household enters into each period's budget constraint.

The amount of energy used in each period by the household can be thought to be a function of the stock of durables times its utilisation rate $e_{h,t} = f(u_t d_t)$. In all analyses carried out in their paper the amount of energy needed to sustain a utilisation rate u_t of a stock of durables d_t is assumed to be linearly dependent on their product $u_t d_t$ that is $e_{h,t} = a(u_t d_t)$, where a is a constant to be calibrated. This should be a fairly reasonable approximation to the relationship between durables and their energy consumption, and suffices to demonstrate the dynamics of the model.

In each period the household also makes new investments in capital $(i_{K,t})$ and durables $(i_{d,t})$, both of which are subject to adjustment costs. For income, it earns interest and wage from the labour and capital it provides to the producers. The budget constraint for the household in each period is thus:

$$P_{e,t} a(u_t d_t) + P_{n,t} n_t + i_{k,t} + i_{d,t} = r_t k_t + w_t h_t$$

Investment in capital and durables are subject to the following adjustment costs:

$$i_{d,t} = d_{t+1} - (1-\delta_d) d_t + \frac{\omega_{1,d}}{1+\omega_{2,d}} \left(\frac{d_{t+1} - d_t}{d_t}\right)^{1+\omega_{2,d}}$$

$$i_{K,t} = k_{t+1} - (1 - \delta_k)k_t + \frac{\omega_{1,k}}{1 + \omega_{2,k}}(\frac{k_{t+1} - K_t}{K_t})^{1+\omega_{2,k}}$$

With the incorporation of variable utilisation rate of durables it is fairly intuitive to also employ variable rate of depreciation of durables in this model. Naturally, the depreciation rate should vary positively with utilisation rate. In the paper, Tan (2012) mainly use a power-function form for the depreciation rate

$$\delta_{d,t} = a_1 \frac{u_1^{a_2}}{a_2}$$

Where a_1 and a_2 was calibrated in the model.

On the production side, three sectors have been considered in Tan's (2012) model: a durable sector, a non-durable sector and an energy sector. The energy sector is needed to provide energy to the other two sectors including the own sector and also energy to the household in their use of durables. Each sector's energy use is tied directly to its use of capital. In their model calibration, this relationship is captured by a simple linear function; that is, each sector's energy consumption is given by $e_{f,t} = bk_t$, where b is a parameter and constant for all three sectors.

All three sectors are assumed to have Cobb-Douglas production functions, but with different capital share parameters. The durables and non-durables sectors share the same productivity factor/process, while the energy sector has its own. This serves the purpose of simulating a productivity shock to the energy sector alone to bring about adverse energy price shocks. All the firms are profit maximiser and wage and interest rate are assumed to be equalised across all three sectors.

The three sectors' production functions are given as:

$$y_{d,t} = \exp(A_t) k_{d,t}^{y_d} h_{d,t}^{1-y_d}$$

$$y_{n,t} = \exp(A_t) k_{n,t}^{y_n} h_{n,t}^{1-y_n}$$

$$y_{e,t} = \exp(A_t) k_{e,t}^{y_e} h_{e,t}^{1-y_e}$$

Tan (2012) assume that all energy produced in each period is consumed; while durables and non-durables produced are used for consumption of non-durables and investments in capital and durables. The capital and labour market, as usual, also clear in every period. Also in the model prices are introduced for non-durables and energy and these prices are thus relative price only. No money is involved in the model. The market clearing conditions are:

$$y_{e,t} = a(u_t d_t) + b k_t$$

$$y_{d,t} + P_{n,t} Y_{n,t} = P_{n,t} n_t + i_{k,t} + i_{d,t}$$

$$h_t = h_{e,t} + h_{d,t} + h_{n,t}$$

$$k_t = k_{e,t} + k_{d,t} + k_{n,t}$$

Additional price relations need to be imposed, so that a composite price of consumption (or output) can be calculated. This allows for the quantity of real output to be extracted from the model.

$$p_t [\alpha (u_t d_{t)}{}^{\rho} + (1-\alpha) n_t^{\rho}]^{\frac{1}{\rho}} = p_{e,t} a(u_t d_t) + p_{n,t} n_t$$

$$p_t y_t = y_{d,t} + p_{n,t} y_{n,t} + p_{e,t} y_{e,t}$$

To make the model complete and consistent, an additional relation is introduced in the model. A kind of aggregate production needs to be imposed in the model, since there are three separate sectors. For this, it is assumed that the three production functions can be aggregated into one single production function:

$$y = \exp(A'_t) k_t^{\gamma} h_t^{1-\gamma}$$

where y, k, h are total output, total capital and total labour respectively and γ is the aggregate share of capital.

The basic model is driven by two shocks: the conventional productivity shock that is common to both the durables and non-durables sectors, and a productivity shock that affects the energy sector alone. Both the shocks are assumed to follow an AR (1) Process.

$A_t = \rho_A A_{t-1} + \varepsilon_{A,t}$

$A_{e,t} = \rho_e A_{e,t-1} + \varepsilon_{e,t}$

Model Calibration

To facilitate comparison the various macro data series are obtained from the US economy provided by NIPA, the same ones obtained in Dhawan and Jeske (2007). The computed aggregate moments are also pretty close to those in Dhawan and Jeske (2007), hence their values are used here for the calibration of the model.

Certain standard parameters are calibrated following standard literature. The discount factor β is set at 0.99; the share of consumption in the household's utility function φ is set at 0.34. The share of durables α in consumption is set at 0.2. Empirical research puts the elasticity of substitution between durables and nondurables close to 1. In the paper, the household's utility function follows a general CES form, meaning that it cannot be used to model an elasticity of substitution of exactly 1. Here it is set at 0.9 for the main analyses, and the CES parameter of the household's utility function ρ is therefore 1−1/ 0.9, which is negative and indicates that durables and non-durables are somewhat complementary. Other parameters are calibrated to produce theoretical moments of model aggregates that reproduce as best possible the empirical moments found in aggregate US data.

Main Results

Tan's (2012) model performs well with respect to that in Dhawan and Jeske (2007) and Finn (2000) and with respect to empirical investigations on the impact of oil prices on the macroeconomy. Overall the model is quite successful in replicating the aggregate behaviours of the economy in the events of adverse energy price shocks from the supply side. Tan (2012) observe the not insignificant effects of a supply-side shock to energy prices on the overall economy, confirming the important role of energy on both the household's side and the side of producers. They also gain insights on the interplay among the different production sectors when such shocks hit, and the feedback into the production of energy carried by the changing energy demands, since energy price is no longer exogenously imposed upon the agents in the economy but is endogenously determined.

De Miguel, Manzano and Martin-Moreno (2003, 2005)

De Miguel et al. (2003, 2005) develop a standard DSGE model to analyse the effects of oil price shocks on the business cycle and welfare of a small open economy that needs to import oil to produce goods such as in the case of the Spanish economy. Calibrating the same model for EU-15 countries, they also check the robustness of their model.

The Model

Following Kim and Loungani (1992), they assume the economy produces an internationally tradable good (y), combining labour (n), capital (k) and oil (e) using the production function as follows:

$$y=n^{\theta}[(1-\alpha)k_t^{-v}+e_t^{-v}]^{-\frac{1-\theta}{v}}$$

The parameter v is equal to (1-s)/s, where s is the elasticity of substitution between capital and energy. Labour's distributive share is given by the parameter θ.

The aggregate resources constraint is given by the following equation in their model where c is private consumption, i is investment and xn are net exports:

$$c_t + i_t + xn_t = y_t$$

Capital (k) accumulates according to the law of motion:

$$i_t = k_{t+1} - (1-\delta)k_t + \Phi(k_t, k_{t+1})$$

Where δ is the depreciation rate and Φ is the capital adjustment cost function which they assume to be quadratic:

$$\Phi(k_t, k_{t+1}) = \frac{\phi}{2}\frac{k_t - k_{t+1}}{k_t}^2$$

The firm which operates under perfect competition maximises profits as following:

$$Max\ F(n_t, k_t, e_t) - w_t n_t - r_t k_t - p_t e_t$$

Where w is the wage rate, r is the interest rate and p is the relative oil price.

The relative oil price follows a stationary stochastic process:

$$\ln p_t = p + \ln p_{t-1} + \epsilon_t, \quad \epsilon_t \sim N(0, \sigma_P)$$

The representative household is infinitely lived and has preference over consumption (c) and labour (n) is defined in the following utility function:

$$U(c_t, n_t) = \frac{1}{1-\sigma}[(c_t - \psi n_t^{\nu})^{1-\sigma} - 1]$$

Where σ>0 is the parameter of relative risk aversion, ν is one plus the inverse of the inter-temporal elasticity of substitution of labour supply and ψ is a positive parameter.

They also propose a measure of the Welfare Cost (WC) of energy price fluctuations as follows:

$$WC = x.\frac{c_{ss}}{y_{ss}}$$

Where WC is the percentage increase in the GDP needed to make households indifferent between an economy with or without energy price fluctuations and x is the percentage consumption increase needed to equalise both utilities.

Model Calibration

The models are calibrated to reproduce average values of the Spanish economy during the period 1970:1-1998:4 and the European Union in annual data from 1960-2003.

Model results

They reveal that the case of the US economy does not seem to be applicable to the rest of the oil importing countries whose economies depend heavily on energy especially, oil. They show that the ability of the RBC model to reproduce the cyclical path of the Spanish economy, especially in those periods when oil price shocks were most dramatic. They further mention that oil shocks can account for a significant percentage of GDP fluctuations in many of the European countries, but the explanatory power is quite smaller for others which can be explained by differences in the strength of monetary policies. A possible source for a weak link between energy prices and economic activity might be the fact of a declining importance of energy for industrial production and in addition industrial production becomes less important for the overall added value in US economy. They also show that the increase in the relative price of oil had a negative and significant effect on welfare both in Spanish economy and European Union.

Manzano and Rey (2012)

Manzano and Rey (2012) extends De Miguel et al. (2003, 2005) model to quantify the welfare cost of energy price fluctuations. The aim of their paper is to provide a macroeconomic measure of the welfare cost of energy insecurity since energy security has become once again a priority of energy policy. The high volatility and uncertainty on the energy markets has increased the interest in this dimension of the energy policy. The literature has put much effort into trying to define and measure energy security. Nevertheless, little is known about its economic consequences. They relate energy security to energy price volatility and, therefore, quantify the welfare cost caused by the fluctuations in the energy price. They focus on the price dimension of energy security. They assume that analysing the fluctuations in the price of energy is a good way to quantify energy security.

The Model

They take mainly the De Miguel et al. (2003, 2005) model and one of the differences observed between the two models is in the utility function. Unlike the previous model, they assume that the representative household has now preferences over non-energy and energy consumption and leisure that are defined in the following utility function:

$$U(A_t, n_t) = \frac{(A_t^{1-\mu}(1 - n_t)^{\mu})^{\sigma}}{\sigma}$$

With $A_t(c_t, eh_t) = [(1 - \gamma)c_t^{\alpha} + \gamma eh_t^{\alpha}]^{\frac{1}{\alpha}}$

A is the aggregate good that combines non-energy (c) and energy consumption (eh). The elasticity of substitution between non-energy and energy is 1/ (1-α).

Since the main focus of this model is on the welfare issue, they do not consider the capital adjustment cost like the previous model.

Thus, in this model, energy is considered as consumption good for households and production input for firms. Thus, energy price fluctuations affect households' utility in two ways. First, energy enters utility function as a consumption good, and therefore, energy price fluctuations have a direct impact on energy consumption and, consequently, on households' welfare. Second, firms use energy for production and, thus, the fluctuations in the energy price lead to increase the volatility of output, leisure and non-energy consumption, which affect ultimately households' welfare.

Model Calibration

Their model is calibrated for the Spanish economy following De Miguel and Manzano (2011). The parameters are chosen to reproduce the main long run characteristics of the Spanish economy.

Model Results

Their results also show that energy price fluctuations mainly affect utility through household energy consumption. They increase the volatility in energy consumption which causes a decline in households' welfare. On the other hand, energy price fluctuations have not a significant impact on the volatility of output, non-energy consumption and leisure. Consequently, in an economy in which energy is only used for production, the welfare loss caused by price fluctuations is much lower.

Rotemberg and Woodford (1996) study output impulse response functions and show that under imperfect competition the effect of an energy price shock is stronger than under perfect competition. **Finn (2000)** shows that one can increase the economy's response to an energy price shock even under perfect competition when one models energy use as a function of capacity utilisation. However, both papers are silent on the business cycle properties of the model in response to energy price shocks. Specifically, they do not report the share of output fluctuations explained by energy price shocks and the other business cycle facts such as volatility of key economic variables such as investment, consumption and output. **Table 2.1** at the end of this chapter provides a synopsis of the energy augmented DSGE models.

Another strand of the literature studies the interaction between energy (oil) price shocks and monetary policy. Among others, Hamilton (1983), Hamilton and Herrera (2004), Bernanke et al. (1997) and Barsky and Kilian (2002) examine this relationship numerically. Theoretical contributions are for example, Leduc and Sill (2004), Medina and Soto (2005), and Blanchard and Gali (2007). They seek to answer the question whether the recessionary consequences of oil price shocks are caused by the oil price hike or by the monetary response to the rise in oil prices. However, since this thesis does not concentrate on the monetary policy, we do not discuss them.

Finally, primary commodity price stabilisation is another very important economic aspect as shocks to world commodity prices can have a profound impact on the economies of both exporting and importing countries (Cashin et al., 1999). To tackle the consequences of commodity price fluctuations, many countries across the world have resorted to stabilisation schemes. IMF (2012) categorise commodity products as energy, metals, food and agricultural raw materials.

Most of the advocates of price stabilisation argue that reducing price variability is good itself (Newbery and Stiglitz, 1979). Newbery and Stiglitz (1982) further argue that there are two strategies that economist can follow in addressing the appeal for commodity price stabilisation. Firstly, they say that one obvious objection to the competitive market equilibrium is that it is inequitable and then the government could offer lump sum transfer or subsidies to the domestic producers and alter the level of domestic prices relative to rest-of-world prices. This method is known as first moment policies. The other approach (second moment policies) is to protect the domestic producers and consumers from world market by freezing domestic prices when rest of world prices swing about. Bellemare et al. (2013) also discuss that the urge toward state interventions to stabilise domestic commodity prices commonly arise because i) households are widely believed to value price stability and ii) the poor are widely perceived to suffer disproportionately from commodity price instability.

Nash and Knudsen (1990) discuss the topic of domestic price stabilisation programmes in a comparative cross country context and argue that government throughout the developing world have established mechanism to protect domestic commodity markets from the impulses of international price movements to promote macroeconomic stability. However, the desirability of price stabilisation from standpoint of welfare has long been debated in economic literature (Peng, 1992). If attention is focused on price stabilisation, then the welfare and income effects of price stabilisation on producers and consumers should be carefully considered.

2.5 Macroeconomic Effects of Energy (Electricity) Market Reform

Energy (Electricity) market reform continues to be one of the most important and challenging tasks facing policymakers in the energy sectors of different countries in the world. The existing reform studies mainly use both qualitative and quantitative techniques to assess the impact of reforms and found mixed results in terms of macroeconomic indicators.

2.5.1 Empirical Contributions on Macroeconomic Effects of Energy (Electricity) Market Reform

It has been more than two decades since the extensive beginning of worldwide energy (electricity) sector reforms and restructuring. Energy (Electricity) sector reform has usually involved some combination of product market competition, privatisation and regulation (Zhang, et al., 2008). In developed countries, the process of reform in the electricity sector has been well documented and appears to have been reasonable successful (Pollitt, 2008). However, the empirical evidence on the macroeconomic performance of reforms across developing countries needs to be examined considering the sizable gap in the energy economics literature (Jamasb et al., 2014). Most of the empirical literatures on energy (electricity) reform are biased on micro level studies. For macro level studies, still the theoretical methodology (Social Cost Benefit (SCB) analysis, CGE model etc.) dominates over its empirical counterpart.

Single or multi-country case studies are often preferable when in-depth examination or qualitative study is needed. This is because some reform factors are inherently difficult to capture through statistical methods (Jamasb et al., 2005). Case studies can examine the issues that do not easily lend themselves to rigorous quantitative analysis or could not be analysed due to lack of comprehensive data (Jamasb et al., 2005). Hence, analysis based on case studies can also overcome the issues related with model specification and accuracy of variables in representing the appropriate feature of reform. Case studies involving single or multiple countries have been a popular method to examine the process and outcomes of energy (electricity) sector reforms in many developing and developed countries. For example, Jamasb et al. (2005, 2014) provided a detailed literature survey of empirical evidence on determinants and performance of electricity sector reform in developing countries by studying different studies based on econometric evidence, efficiency and productivity analysis, macro evidence and case studies. Since we do not stress on the empirical studies in this thesis, we suggest interested reader to read Jamasb et al. (2005, 2014) who provide a detailed literature review of empirical evidence on the performance of energy sector reform in developing countries even though the dominant focus of the existing literature is on power sector reforms. Parker and Kirkpatrick (2005) review the main empirical evidence on the impact of privatisation as a reform instrument on economic performance in developing economies at firm and sectoral level. The evidence suggests that if privatisation is to improve performance over the longer term, it needs to be complemented by policies that promote competition and effective state regulation, and that privatisation works best in developing countries when it is integrated into a broader process of structural reform.

Kessides (2012) also reports an empirical survey of country case studies (mostly for Latin American countries) of electricity sector reform and conclude that when well designed and implemented, a combination of institutional reforms-privatisation, unbundling and effective regulation can lead to significant improvements in several dimensions of operating performance and in a variety of country setting. However, he concerns about investment in transmission and generation capacity in liberalised electricity market.

Using a cross-sectional survey conducted in 2005 of some 20,000 households in rural Bangladesh, Khandker et al. (2012) studies the welfare impacts of households' grid connectivity. Based on rigorous econometric estimation techniques (Maximum Likelihood Probit Model, IV Estimation and Propensity Score Matching), they find that grid electrification has significant positive impacts on households' income, expenditure, and educational outcomes. For example, the gain in total income due to electrification can be as much as 30% and as low as 9%. Benefits go up steadily as household exposure to grid electrification (measured by duration) increases and eventually reach a plateau. They also find that rich households benefit more from electrification than poor households. Finally, estimates also show that income benefits of electrification on an average exceed cost by a wide margin.

Zhang et al. (2008) provides an econometric assessment of the effects of privatisation, competition and regulation on the performance of the electricity generation industry using panel data for 36 developing and transitional countries, over the period 1985 to 2003. This study is based on a data base especially created from a range of international sources to measure the effects of privatisation, regulation and competition on performance in electricity generation in developing countries. The empirical results reveal that privatisation and regulation do not lead to obvious gains in economic performance. Additionally, competition in electricity generation is more important than privatisation or the establishment of independent regulation in bringing about performance improvements. This result complements earlier research into electricity generation like Pollitt (1997) who conclude that in the absence of competition, effective regulation is crucial to the success of privatisation.

Nakano and Managi (2008) measures productivity in Japan's steam power-generation sector and examines the effect of reforms on the productivity of this industry over the period 1978–2003. They estimate the Luenberger Productivity Indicator, which is a generalisation of the commonly used Malmquist Productivity Index, using a data envelopment analysis approach. Factors associated with productivity change are investigated through dynamic Generalized Method of Moments (GMM) estimation of panel data. Their empirical analysis show that the regulatory reforms have contributed to productivity growth in the steam power generation sector in Japan.

Du et al. (2009) estimate the impact of regulatory reforms on production efficiency of fossil-fired generation plants using the plant-level national survey data collected in 1995 and 2004. Applying the econometric method of Differences-in-Differences, they estimate the effects of these reforms on the demand for inputs of employees, fuel and nonfuel materials. The results show that the net efficiency improvement in labour input associated with the regulatory reforms is roughly 29% and the gains in nonfuel materials are about 35%, while there is no evidence of efficiency gains in fuel input associated with the electricity reforms.

Andriamihaja and Vecchi (2007) employed Price Shifting Model to assess the distributional impact of higher energy price in Madagascar on households' real expenditure. They showed that a 17% rise in the price of energy products leads to a 1.75% average decrease in real expenditure. This percentage is higher for low-income households (2.1%) than for high income households (1.5%). The study concludes that the benefit of introducing price subsidies would be progressive; that is, in percentage terms, subsidy would benefit poor households' more than rich household. However, subsidising would involve substantial leakage in favour of high income households and there is an issue of identifying more cost-effective policies to protect poorest households.

Adagunodo (2013) examined petroleum products pricing reform and welfare in Nigeria and concluded that if implemented correctly, the removal of subsidy would save largest amount from government budget and the subsidy funds could lead to major development gains for the country. Nwafor et al. (2006) investigated the impact of removal of petroleum products subsidies on poverty in Nigeria. The study concluded that subsidy removal, without spending of the associated savings, would increase the national poverty level. This is due to the consequent rise in inputs' costs which is higher than the rise in selling prices of most firms. The key sectors which experience increased nominal output are the refined petroleum products which provide income for an extremely low number of households. Freund and Wallach (1995) examine the welfare effects of increasing energy prices in Poland and concluded that programmes that subsidising household energy prices in Poland as well as the other transition economies help the rich more than they help the poor. Not only do the wealthy consume more energy in absolute terms, but also spend a larger portion of their income on energy. Based on their results, they proposed that the first best policy would be to raise energy prices while targeting cash relied to the poor through a social assistance programme.

Coady et al. (2006) simulated both direct and indirect effects of fossil-fuel subsidy reform in Bolivia, Ghana, Jordan, Mali and Sri Lanka. They found that the direct effects of increased fossil fuel prices on aggregate real income ranged from 0.9% in Mali to 2.0% in Bolivia. However, in Ghana, Jordan and Sri Lanka they were regressive affecting the lowest income more than the highest. Indirect effect resulting from increases in the prices of other goods and services were higher, ranging from 1.1 to 6.7% but tended to be equally distributed across income quintiles. This reflects the higher proportion of their budgets that lower income quintiles must devote to energy as opposed to other goods and services.

Angel-Urdinola et al. (2006) examined the extent to which the poor did benefit from past subsidies in Rwanda, and to discover whether they would benefit from alternative implicit or explicit cross-subsidies. Because access rates to the network are very low among the poor, the share of the implicit subsidies that prevailed before the increase in tariff and that benefited the poor was also very low. They have concluded that previous subsidies were badly targeted. Another important result of their analysis was the finding that it would probably be better for poverty reduction to give priority to a subsidy mechanism for new connections to the network rather than a subsidy for consumption for those households that are already connected.

2.5.2 Theoretical Contributions on Macroeconomic Effects of Energy (Electricity) Market Reform

The literature based on Dynamic models for energy market, is more concentrated on energy (oil) price shocks rather than energy (electricity) market reform. Most of the dynamic models used to study the impact of energy (electricity) market reform on macroeconomy are CGE models or Dynamic General Equilibrium (DGE) models ignoring the stochastic shocks. Since the focus of this thesis is stochastic in nature, we will not explain the models in details; will just briefly mentions the overview of few selected models and highlight the effects of energy (electricity) market reforms.

Oktaviani et al. (2007) used a CGE model to analyse the elimination of fuel subsidies in Indonesia, which occurred in three stages over the period 2000-2005 (prices were increased by 21% in 2000, 30% in 2001 and 29% in 2005). They concluded that the short to medium term macroeconomic performance of the economy was adversely affected by the removal of the subsidies, due to reduction in household incomes and increase in domestic prices. Furthermore, the reduction of fuel subsidies increased overall impact of poverty in Indonesian economy from 8.9% to 12.9% of population, with rural areas worst affected. However, **Gibson and Olivia (2008)** used the Marginal Social Cost approach to evaluate the equity and efficiency of subsidy reform in Indonesia and concluded that large subsidies on kerosene should be reduced.

Kpodar and Djiofack (2009) assessed the distributional effects of a rise in various petroleum product prices in Mali using a standard CGE model. Their results suggest that higher diesel prices primarily affect richer households, while the poorest ones tend to suffer more from higher kerosene and gasoline prices. Overall, the impact of fuel prices on household budgets shows a U-shaped relationship with expenditure per capita. Regardless of the oil product considered, high-income households benefit disproportionately from oil price subsidies. This suggests that petroleum price subsidies are ineffective in protecting the income of poor households compared with a targeted subsidy.

Manzoor et al. (2012) study the impacts of reducing implicit and explicit energy subsidies(which entails a huge increase in domestic energy prices) in Iran as an oil producing countries where government supply energy at a very low price which is treated as an implicit subsidy on the oil and gas input to the economy's production sectors. Their CGE model is based on a Modified Micro Consistent Matrix table which includes implicit subsidies and sector specific capital. The model consists of 36 commodity goods and 18 production activities. Their findings suggest that, except for energy and services, overall economic activity declines and the consumer faces a lower level of welfare after subsidy reduction. Energy exports would increase and non-energy exports decline. Domestic energy demand by households and producers would decline as well. On the demand side, the results show a crowding out effect on public goods and services. With sensitivity analysis, in which they consider different elasticity parameters in production, robust results are found.

Bouakez et al. (2008) consider a small open economy, which consists of households, firms, a government, and a monetary authority. Each household supplies a differentiated labour supply for which it sets a nominal wage in a monopolistically competitive labour market. Wages are costly to change and are thus sticky. There are four types of goods: a final good, a composite non-oil good, oil, and intermediate goods. The final good, which serves consumption and investment purposes, is produced by perfectly competitive firms using oil and a non-oil composite good as inputs. The non-oil composite good is produced by mixing domestically produced and imported intermediate goods. Domestic intermediate goods are produced by monopolistically competitive firms that use domestic labour and capital as inputs. Domestically produced intermediate goods are also exported to the rest of the world. Export prices are determined at the world market and are exogenous to the economy. Foreign intermediate goods are imported by monopolistically competitive firms at the world price. These goods are then sold to local firms at domestic-currency prices. Prices set by monopolistic firms for the domestic market are subject to adjustment costs.

Oil used to produce the final good is imported by the government, who plays the role of an intermediary, buying oil at the world price, and reselling it to domestic firms at the domestic price. These two prices need not be identical even after converting the world price to domestic currency. Depending on the way in which the government sets domestic price, pass-through from the world price to the local price of oil can be full or incomplete. In the model, the government follows a pricing rule that can yield any degree of pass-through between 0 and 100%. The monetary authority is assumed to set the nominal interest rate according to a Taylor-type rule, which nests strict CPI inflation targeting and fixed exchange rates as special cases.

The objective of the paper is to determine whether, and to what extent, government intervention in the oil market is warranted in an economy characterised by nominal rigidities in the goods and labour markets. More specifically, they investigate whether limiting the degree of pass-through of oil prices in such an environment could be welfare improving relative to a full-pass-through policy.

They compute the welfare-maximising level of pass-through of oil prices in an artificial oil importing economy characterised by nominal price rigidities. They also find that, to the extent that monetary policy is capable of stabilising the economy, government intervention in the oil market should be avoided. On the other hand, when complete stabilisation is not attainable, as is the case under CPI inflation targeting, the government can improve social welfare by limiting the degree of pass-through of oil prices. They find, however, that the welfare gain from pursuing such a policy is negligible.

Plante (2011) develops a small open economy that produces a composite traded good and a non-traded good. Both goods are produced using labour and oil and one sector may be more or less oil-intensive than the other. The traded good is the numeraire and for convenience its price is fixed at unity. The traded good is either consumed by households or used to purchase oil from the rest of the world. The economy is small in that it has no effect on the world price of the traded good or the world price of oil.

In the benchmark model, Plante (2011) assume that household activity is controlled by a representative agent who derives disutility from working and utility from consumption of a traded good, consumption of fuel products, and from holdings of real money balances. Total labour supply is divided to traded and non-traded sector. The agent also derives utility from the use of fuel products. The representative households do not pay the world price Po; however, but instead face a subsidised price, Ps. As with traded goods, the economy is small and does not affect the world price of oil.

Production of the traded good is done by a representative firm operating under perfect competition using the CES technology. The representative firm uses labour and oil to produce the final good; capital is not considered in the model. The government provides a subsidy on fuel products and earns revenue from levying lump sum taxes and from the inflation tax. He assume that the government purchases oil at the world price of Po and then sells it at the subsidised price Ps, with $Ps \leq Po$. The steady state government budget constraint is:

$$T + \chi m = (Po - Ps)\,(O_H + O_T)$$

Where the left hand side is the total revenue available is to the government (T, is the lump sum taxation and χm is the seigniorage revenue), while the right hand side is the total expenditures made by the government. This equation makes clear that lowering Ps requires government to increase revenue either increasing lump sum taxes, or by increasing seigniorage revenue through in the steady state rate of inflation, χ. In the above equation, m is the agent's holding. Plante (2011) investigates the long run implications of subsidies of fuel products (by changing the value of Ps) on economy. He then extends the same model for non-traded goods. The main contribution of his paper to the literature is a set of analytical and numerical results that show how the economy's steady state is distorted when the domestic price of oil is permanently reduced below that of the world price of oil. These results show that fuel subsidies have important effects on a number of macroeconomic variables above and beyond just promoting over-consumption of fuel products.

For an economy that produces only traded goods, analytical results showed that the subsidy drives up wages in the economy, leads to inefficiently high labour supply, and increases production of the traded good to pay for the over consumed oil. There is also a distinct possibility that non-oil consumption could be crowded out depending upon how elastic labour is supplied. A number of similar results hold for an economy that also produces non-traded goods. As before, the subsidy drives up wages and leads to an oversupply of labour. In addition, it distorts the allocations between the traded and non-traded sectors, generally leading to an overemphasis on producing traded goods to pay for the increased consumption of fuel products. This occurs regardless of whether or not the relative price of the non-traded good rises or falls in the economy. When the inflation tax is used to finance the subsidy, there are also significant impacts on monetary variables as well. All of these results highlight impacts of these subsidies that are usually ignored when considering the pros and cons of fuel subsidies in the countries used in this study. While households certainly benefit from extra consumption of fuel products, this comes at the indirect cost of working more, potentially reduced consumption of other goods, and inefficient allocation of resources towards the traded sector.

Glomm and Jung (2013) construct a DGE model to analyse the effects of large energy subsidies in a small open economy. The model includes domestic energy production and consumption, trade in energy at world market prices, as well as private and public sector production. They consider an overlapping generation economy with heterogeneity individuals. Within each period of their lives agents value a numeraire consumption good, energy and leisure. They divide the capital between physical capitals used in the production of final consumption goods and services and physical capital used in the production of energy. Final consumption and services are produced from four inputs: a public good, physical capital stock, effective labour in the private sector and energy. Government finances investment in public capital. The remainder of government expenditure is government consumption. The government uses public capital and hires labour to produce public goods. Government also runs two separate pension programmes. The government collects labour income taxes from all workers in the public and private sector as well as social security taxes. The government also taxes consumption, fuel consumed by households and fuel used in firm. In addition, government collects a tax on capital.

The model is calibrated to Egypt (a net exporter of oil) and used to study reforms such as reductions in energy subsidies with corresponding reductions in various tax instruments, or increases in infrastructure investment. They calculate the new steady states, transition paths to the new steady state and the size of the associated welfare losses or gains. In response to a 15% cut in energy subsidies, GDP may fall as less energy is used in production. Excess energy is exported and capital imports fall. Welfare in consumption equivalent terms can rise by up to 0.6% of GDP. Gains in output can be realised only if the government reinvests into infrastructure. The overall findings that emerge from this analysis are: a 15% reduction of energy subsidies to households and firms can either lead to decreases of GDP by 3% or increases of GDP by a similar amount. The expansionary or contractionary effect is mainly determined by the government policy that reacts to the subsidy cut and clears the government budget constraint. If infrastructure investments are increased after the subsidy cut, then growth effects can be realised. If subsidy cuts are handed back to households via lower taxes, no such growth effects will result as households simply consume the extra income and excess energy is exported at fixed world market prices. More severe cuts of energy subsidies amplify all effects monotonically. Overall, they find that welfare gains for most generations along the transition path can be realised. Only in the case with lower labour taxes in reaction to the subsidy cuts do we observe welfare losses by generations that are already retired when the reform takes place. These cohorts are not able to benefit from the lower taxes. They also find that energy cuts to producers lead to more direct growth effects. In addition, positive welfare effects are also larger as consumers do not suffer from higher (unsubsidised) energy prices and are therefore able to maintain their prior levels of energy consumption.

Pereira and Pereira (2011) examines the environmental, economic and budgetary impacts of fuel prices using a DGE model of the Portuguese economy which highlights the mechanisms of endogenous growth and includes a detailed modelling of the public sector[1]. As to the budgetary impact, higher fuel prices lead to higher tax revenues, which, coupled with a reduction in public spending translates to lower public deficits. In addition, and from a methodological perspective, their results highlight the importance of endogenous growth mechanisms. A scenario of higher fuel prices would, under exogenous economic growth assumptions, result in larger baseline emissions growth scenarios, substantially smaller economic effects, and rather different budgetary effects. Finally, and from a policy perspective, their results highlight the impact of fossil fuel prices in defining the level of

[1] For the model structure, please see Pereira and Pereira (2012), "DGEP-A Dynamic General Equilibrium Model of the Portuguese Economy: Model Documentation".

policy intervention required for compliance with international and domestic climate change legislation. As a corollary, they argue that it is critical for both international comparisons and international policy negotiations to define baseline emission targets in function of steady state economic projections under stable price assumptions.

Mehran and Payam (2014) set up a DGE model to analyse the short-run effects of energy subsidy reform in Iran. The model consists of 3 sectors: Household, firm and government. There is one representative firm, which demands for energy, as well as capital and labour. The firm buys energy from the government, which sets the price of energy, of course below the price of foreign energy market. Households take utility from consuming energy. Like firms, households they take the price of energy as given. Household maximises the combination of consumption and money in infinitive period. In the model, government collects proportional taxes from consumption, wage, capital and profit of households, and transfers lump sum payment to the households.

The non-energy supply side of economy has two sectors: final-goods and intermediate goods sector. Final good sector produces non-energy goods, using intermediate goods and sell it in a competitive market to the households, to be consume or transfer to capital without any cost. Intermediate sector firms, hire labour, rent capital and buy energy to produce continuum of intermediate goods and sell their output in a monopolistic competition market to the final sector firms. An intermediate sector firm hires labour and rents capital from households and buys energy from government to produce non-energy intermediate goods, given the demand function of final sector firms for his product.

In this model they assume that government expenditures are assigned to providing public goods, public investment and transfer payments, and it does not contribute to making output, i.e. GDP. Public good and investment is not introduced explicitly in the model. It is assumed that government consumption and investment are perfect substitute for private consumption and investment. So, they express government expenditures in term of lump-sum transfers. In this framework, there is no difference between transferring the increased revenue of the government (as a consequence of removing energy subsidies), to the household and using them as new resources for government expenditures.

Government has three kinds of revenue; the first is taxes on capital, labour, profits of the intermediate firms and consumption. The second, which is important in the model, is energy carrier resources. It is assumed that all of the resources like oil are owned by government. The government sells part of them in domestic market to households and firms in intermediate sector, of course with price that is less than foreign price. The remaining part is exported with exogenous foreign price of energy. The third source of government revenue is seigniorage. In this model, government sets energy prices for firms and households, so the amount of transfer payment (which contains government expenditures and lump-sum subsidies for compensating energy subsidies reforming) is obtained endogenously.

The calibrated model shows surprising results. To decide whether to reform subsidy or postpone it to the near future, when the economy will recover after the recent inflationary recession, policy makers should be concerned about output losses, rather than about high inflation. It is found that a rise of domestic prices of energy up to 100% will not end at higher price levels if the increased revenue is repaid to households. In spite of that, during this period the policy has had a great impact on the level of total output, about -3% to -2% on average, both/equally in the case of sticky prices and flexible prices. It is shown that after a quarter of reform, Calvo-type price stickiness has negligible effect on the macro variables.

In the literature, IMF, define lots of researches on subsidies in energy market. For example, Anand et al. (2013) evaluates the fiscal and welfare implications of fuel subsidy reform in India. Their result show that these subsidies are inefficient and inequitable and subsidising will makes the ratio of energy consuming to GDP from 0.8 to 1.9% in less than 2 years. In other work, Coady et al. (2012) conduct a research on the world data to realise the increasing fuel subsidies in lots of country. They confirm that the best solution is liberating market. In addition they suggest, changing price setting regime, from fix prices to adjusting regularly.

2.6 Conclusions

The survey of the theoretical models on the relationship between energy (oil) price shocks and macroeconomy undertaken in Chapter 2 has shown that most of the DSGE models treat the developed countries in a much aggregated manner. There are also relatively few studies focusing on dynamic models to examine the macroeconomic consequences of energy (electricity) market reform. These consequences are complex and require an explicit DSGE modelling approach. Moreover, in many developing oil importing developing countries, government controls electricity and fuel prices and provides subsidies to the households and firms. However, to the best of our knowledge, this price controlling mechanism feature is not incorporated in the DSGE applications till now. Additionally, the feature of inter fuel substitution in electricity generation sector is also missing in most of the DSGE literature. So, relatively little attention is given to developing a model for a mixed economy where government still control electricity and fuel prices and electricity is produced using different fuels and supplied by both public and private companies. The absence of these features makes it difficult for the extension of energy related policy research for the developing and less developing countries.

In light of these limitations, this thesis aims to contribute to the theoretical side of the energy research by developing a DSGE model for a mixed economy like Bangladesh where government still control electricity and fuel prices and electricity and fuel enters both in production and utility functions. The main goal is to develop a model for mixed economy where government still controls electricity and fuel price considering a detailed disaggregation of electricity sector as a further step forward in the theoretical efforts to model energy in the macroeconomy and try to examine i) how important aggregate energy price shocks are to explain business cycle fluctuations in Bangladesh economy (**Chapter 4**) since no such study is done for Bangladesh economy and RBC is the first step of developing a DSGE model, ii) how would oil price shocks affect the macroeconomy of Bangladesh economy in the presence of government price controlling mechanism (**Chapter 5**) and iii) the outcomes of liberal electricity price reforms policies at macro level as a move towards the free market economy (**Chapter 6**).

APPENDIX 2

Table 2.1: A Synopsis of the Energy Augmented DSGE Models

Model	Country	Utility Function	Production Function	Model Shocks	Government Sector (Taxes/Subsidy)	Foreign Sector	Welfare Estimation	Energy in the Model	Main Findings
Miguel, Manzano and Moreno (2003)	Spain	U=$\frac{1}{1-\sigma}[(c_t-\psi n_t^{v})^{1-\sigma}-1]$	F=$n_t^{\theta}[(1-\alpha)k_t^{-v}+\alpha e_t^{-v}]^{-\frac{1-\theta}{v}}$ (CES)	Ln Pt = ṕ +ρP_{t-1}+ϵ_t	No	YES	Yes	Technology and Shock	High Oil Prices have a negative welfare effect on Spanish economy
Miguel, Manzano and Moreno (2005)	EU	U=$\frac{1}{1-\sigma}[(c_t-\psi n_t^{v})^{1-\sigma}-1]$	F=$n_t^{\theta}[(1-\alpha)k_t^{-v}+\alpha e_t^{-v}]^{-\frac{1-\theta}{v}}$ (CES)	Ln Pt = ṕ +ρP_{t-1}+ϵ_t	No	YES	Yes	Technology and Shock	High Oil Prices have a negative welfare effect in Southern European countries.
Manzano and Rey (2012)	Spain	U=$\frac{(A_t^{1-\mu}(1-n_t)^{\mu})^{\sigma}}{\sigma}$	F=$n_t^{\theta}[(1-\alpha)k_t^{-v}+\alpha e_t^{-v}]^{-\frac{1-\theta}{v}}$ (CES)	Ln Pt = ṕ +ρP_{t-1}+ϵ_t	No	YES	Yes	Technology and Shock	High Energy Prices have a negative welfare effect on Spanish economy
Kim and Loungani (1992)	USA	U= log c + A log (1-h)	F=$\tau h^{\theta}[(1-\alpha)k_t^{-v}+e_t^{-v}]^{-\frac{1-\theta}{v}}$ (CES)	$\tau_t=\alpha_0+\alpha_1\tau_{t-1}+\epsilon_t$ $P_t=\gamma_0+\gamma_1 P_{t-1}+\phi_t+\eta\phi_{t-1}$	No	YES	No	Technology and Shock	Support the views of macroeconomists who downplay the impact of energy shocks on the economy
Tan (2012)	USA	U=$\varphi\log[\alpha(u_t d_t)^{\rho}+(1-\varphi)n_t^{\rho}]^{\frac{1}{\rho}}+(1-\varphi)\log(1-h_t)$	$y_{d,t}=\exp(A_t)k_{d,t}^{y_d}h_{d,t}^{y_d}$ $y_{n,t}=\exp(A_t)k_{n,t}^{y_n}h_{n,t}^{y_n}$ $y_{e,t}=\exp(A_{e,t})k_{e,t}^{y_e}h_{e,t}^{y_e}$ (CD)	$A_t=\rho_A A_{t-1}+\varepsilon_{A,t}$ $A_{e,t}=\rho_e A_{e,t-1}+\varepsilon_{e,t}$	No	No	No	Utility. Technology and Shock	Emphasises the role of energy on economy as higher energy prices seem to have adverse consequences.

Dhawan and Jeske (2007)	USA	$U=\varphi \log N_t^{\gamma}[\theta(D_{t-1}^{\rho})^{\rho} + (1-\varphi)E_t^{\rho}]^{\frac{1-\gamma}{\rho}} + (1-\varphi)\log(1-h_t)$ $U=\varphi \log C_t^A + (1-\varphi)\log(1-h_t)$ $C_t^A = N_t^{\gamma}[\theta(D_{t-1}^{\rho})^{\rho} + (1-\varphi)E_t^{\rho}]^{\frac{1-\gamma}{\rho}}$	$F=Z_t[\eta k_{t-1}^{\psi} + (1-\eta)e_t^{\psi}]^{\frac{\alpha}{\psi}}h_t^{1-\alpha}$ (CES)	$Z_t = \rho_Z Z_{t-1} + \varepsilon_{Z,t}$ $P_t = \rho_P P_{t-1} + \varepsilon_{P,t} + \rho_{\epsilon}\varepsilon_{p,t-1}$	No	No	No	No	Energy Price shocks are not a major factor for business cycle fluctuations
Finn (2000)	USA	$U=\frac{[c_t^{\varphi}(1-l_t)^{1-\varphi}]^{(1-\alpha)}-1}{(1-\alpha)}$	$y_t = (Z_t l_t)^{\theta}(k_t u_t)^{(1-\theta)}$ (CD)	-	No	YES	No	Production and Capital Utilisation	Higher energy price works much like an adverse technology shock to induce contraction in economic activity when one models energy use as a function of capital utilisation.
Schmidt and Tobias (2005)	German	$U=\frac{1}{1-\sigma}[(c_t - \theta n_t^{v})^{1-\sigma} - 1]$	$F=n_t^{\alpha}[(1-\psi)k_t^{-v} + \psi e_t^{-v}]^{-\frac{1-\alpha}{v}}$	$\ln p_t = \gamma_0 + \gamma_1 \ln p_{t-1} + \varepsilon_t^{\rho}$	No	YES	No	Technology and Shock	German economy is vulnerable to energy price shocks

Source: Compiled by Sakib B. Amin (2015)

Chapter 3
Energy Scenario in Bangladesh

3.1 Introduction

Access to energy has become essential to the functioning of modern economies and the government of Bangladesh has been putting its best efforts to develop the indigenous energy resources, which ultimately plays a vital role in the socio-economic development of the country. Total energy consumption in Bangladesh in 2012 was 1.0937 Quadrillion BTU, which is only 0.20% of world consumption (US Energy Information Administration, USEIA, 2015). Energy use in Bangladesh is quite low when compared to other peer developing countries (**Table 3.1**). According to World Bank definition, energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. However, the annual growth rate of energy use was about 5% during 2000-2010, which is a lot faster than the other neighbouring countries in South Asia (**Table 3.2**). Domestic natural gas and solid biomass and waste account for the majority of Bangladesh's total primary energy consumption with the remainder being oil, coal, and hydropower. In 2015, Bangladesh’s primary energy consumption is estimated 62% natural gas, 12% traditional biomass and waste, 21% oil, 2.5% coal, and 2.5% hydropower and solar (BPDB, 2015).

3.2 Different Types of Energy used in Bangladesh

Fossil fuels and electricity are vital for economic development and a key ingredient to improving the socioeconomic condition of the population and reducing poverty. Fossil fuel comprises coal, oil, petroleum, and natural gas products represent more than 90% of total energy consumption in Bangladesh. In Bangladesh, electricity is one of the most widely used forms of energy. The main energy resources of Bangladesh are non-commercial resources (Biomass etc.) and commercial energy resources (Gas, oil etc.). In the early 1980's biomass dominated energy requirement of the country. Although with the increase of commercial energy use, the contribution of biomass is decreased, still it is the principal source of energy for the rural population and comprise almost one-sixth of the total primary energy consumption.

Natural gas has the largest share of primary energy consumption, which is possible because of its local availability. Imported petroleum constitutes almost one-fifth of the total consumption, whereas coal and hydro (and recently some solar PV) contribute approximately 5%. In 2013, Bangladesh produced almost 4500 barrels per day of total oil while consuming nearly 119000 barrels per day (USEIA, 2015).

3.2.1 Natural Gas

Bangladesh gas sector started its journey in the 1960s. However, following the sharp increase in oil prices in the early 1970's, Bangladesh also started feeling the burden of increasing oil import bills and decided to switch fuel. The gas sector started its rapid expansion and gas becomes the energy of choice now and plays a key role to national development in Bangladesh. Electricity generation in Bangladesh is almost entirely dependent on natural gas and the whole of the urea fertiliser manufacturing are based on natural gas. Power plants, fertiliser factories, other industries (e.g. brick factories, tea processing plants, steel mills and textile factories), commercial organisations (e.g., offices and business centres) and the domestic sector are the end users of natural gas in the country. Natural gas is also used as a feedstock for petrochemicals, as Compressed Natural Gas (CNG) for vehicles. The electricity sector and industry are the two biggest consumers of natural gas.

Natural gas plays a vital role in the development of the economy in Bangladesh. Bangladesh, the seventh largest natural gas producer in Asia in 2012, produced 772 billion cubic feet, all of which was domestically consumed. Natural gas production in Bangladesh has increased by an annual average of 7% over the past decade, from 2002 to 2012. However, Bangladesh is facing acute gas supply shortages especially in the electricity sector. These shortages, in turn, have led to rolling blackouts of electricity (USEIA, 2015).

Bangladesh's natural gas resources were first exploited by the national public energy company, PETROBANGLA. More recently, International Oil and Gas Companies (IOCs) have established exploration and production activities. Till now, only about 79 exploration wells have been drilled and 24 natural gas fields have been discovered in Bangladesh. Of the exploration wells, 18 are in the offshore with 2 discoveries and the rest 61 are onshore with 22 discoveries. It is also to be noted that all the major gas fields in the country were discovered by IOCs.

The use of gas keeps increasing till 2008. However, Bangladesh lost the opportunity to raise the gas price to the level of price of the fuel it was replacing. For example, it supplied it at one-sixth of the replaced fuel price (1985 oil price is the average for the decade) and hence the beginning of subsidy. The gas price has remained virtually constant since 1990. So, the import bill was reduced at the expense of higher use of gas in the economy. It also may be noted that, like petroleum products and electricity, the government also subsidises natural gas, although indirectly. The fertilizer industry, household consumers and the electricity sector are the major beneficiary groups of these subsidies. The government offers natural gas to these sectors at a price lower than the supply cost. According to World Bank, the administrated price of domestically produced natural gas is fixed at a level considerably below that of the international market (PLATTS, 2014). This does not only cause government to incur losses, but also send wrong price signals which leads to inefficiencies in allocation and gas use.

Bangladesh's natural gas reserves are expected to last till 2031 at current production and extraction rate which would endanger the energy security of Bangladesh (Ministry of Power, Energy and Mineral Resources, 2015). Available evidence suggests that natural gas is very inefficiently allocated across the country (Gunatilake and Ronald-Holst, 2013). Billah and Khan (2001) mention that the current gas extraction rate of Bangladesh is very fast and signifying the unsustainability of the economy. Moreover, the growth in gas demand will exceed supply in future. Thus, it would not be optimal to keep the extraction rate unchanged, if the reserve remains same. This situation has forced the government to shorten the supply to prioritise the industrial sector. In order to counteract the problem, PETROBANGLA, the Oil, Gas and Mineral Company of Bangladesh, gave priority to the exploration and search for reserves of gas in the Bay of Bengal and reassessment of old fields to attempt further extraction with newer technologies. According to PETROBANGLA (2015), recent reserve estimation, current gas production and consumption rates and future demand projections suggest that known recoverable reserves of gas will not be able to cater the growing energy needs of the country and Bangladesh is now on the threshold of a critical stage. Chevron's already initiated the Bibiyana Expansion Project in the north-eastern part of the country in 2014. The project includes an expansion of the existing gas plant to process increased natural gas volumes, additional development wells to boost natural gas production in future.

3.2.2 Petroleum Products

The use of petroleum products is varied; octane, petrol and diesel are the major fuels for transportation. Diesel is also widely used for irrigation and kerosene is mostly used for lighting, especially in rural households with no electricity. Kerosene and diesel has always been subsidised in Bangladesh like many other developing countries. In 1991, around 84.73% of all households in Bangladesh used kerosene for lighting. However, in 2011, the number decreased to 39.5% (Bangladesh Bureau of Statistics, BBS, 2015). Although the percentage of kerosene uses has reduced during the last two decades, the absolute numbers of kerosene users remain same. The transport sector (both public and private) dominates in terms of petroleum product usage, consuming around 44.80% of total sales in 2014. Most of the petroleum demand is met by imports in Bangladesh which is mainly used in the transportation sector although the importance of petroleum in this sector has been decreasing since the government policy of encouraging CNG as a transportation fuel. However, still a major share of all petroleum consumption in the country is by the transport sector. Around 10% of the total energy in 2010 came from diesel and furnace oil (Bangladesh Power Development Board, BPDB, 2011). There have been some structural changes beginning in 2012. The electricity sector has been rapidly increasing its share of oil in total consumption, which increased from around 6 to 8% up to in 2011 but then rapidly to 19% in 2012 and 28.38% in 2015 (Bangladesh Petroleum Corporation, BPC, 2015). The use of furnace oil (as well as diesel) by the power sector, especially by the private rental power plants, is the major reason for this drastic upsurge in consumption. Lack of reliable gas supply recently has also forced some entrepreneurs to use diesel based generators for power. Agriculture is the third most dominant sector. Sales of petroleum by agricultural sector represent 18.09% of total petroleum sales in Bangladesh. The consumption trend of different petroleum products is given in **Table 3.3**.

Bangladesh's only oil deposits, discovered in 1986 and located at Haripur in the district of Sylhet, have an estimated reserve of 1.4 Mtonne of which 0.84 Mtonne are believed to be recoverable In Bangladesh, oil is used mainly as a transport fuel, for electricity generation and for industrial heating.

3.2.3 Biomass

Biomass as a versatile source of energy is primarily used in rural areas to meet the energy needs for cooking. The traditional biomass sources include agricultural residue (rice husks, rice and jute stalks, sugarcane bagasse, etc.), animal waste (mainly dried form, but some biogas plants, too), scrub wood and fire wood (Miah et al., 2010). These renewable biomass resources are considered to have significant potential to meet the energy demand, especially in the rural areas (Hossain and Badr, 2007; Islam et al., 2006). In the early eighties biomass contributed more than 55% of the entire energy requirement of the country. With the increase of commercial energy use that contribution has come down to 15% now.

3.2.4 Coal

Although substantial amounts of coal reserves in seven fields have been discovered in the north-western part of the country, still the coal sector of Bangladesh is quite underdeveloped. The major coal deposits are at Jamalgonj (in the Jaipurhat district), Baropukuria (in the Dinajpur district) and Khalashpir (in the Rangpur district). The total amount of coal reserve is estimated at 1.756 Gtonne. Mining work has started only at Baropukuria. The Baropukuria coal mine was discovered in 1985 by the Bangladesh Geological Survey Department. This is the first and only operating coal mine in Bangladesh. The Government was in the process of reviewing the country's coal policy, which would set the regulations for the development of the coal industry and help establish a reliable source of energy for the country through the use of coal as the primary fuel for power generation. In 2012, Bangladesh produces 1.1 MT coals/year and consumes some 2.2 MT coals/year. Thus, 1.1 MT coals/year is imported from Meghalaya, India in 2012. Indigenous coal, developed in a sustainable manner with social and environmental safeguards, can supply a vital part of the total energy and electricity demand in the mid to long term future as coal based power plant takes 3-5 years for installation.

3.2.5 Renewable Energy

Renewable energy helps in reducing poverty, aid in energy shortage and environmental degradation such as desertification, biodiversity depletion and climate change (Power

Division, 2015). At present, Bangladesh receives energy supply from both renewable and non-renewable sources. However, by using more renewable energy it is possible to ensure energy security, because there is a shortage of non-renewable energy as the source of fuel. At the same, as the renewable energy is environmental friendly, it is necessary to preserve the environmental balance by expanding the use of renewable energy and lessening the dependency on non-renewable energy. Over-exploitation of biomass in meeting the need of energy in the rural areas is causing environmental degradation. Renewable energy helps to solve those problems if it is widely used in the rural Bangladesh where people primarily depend on biomass energy. Moreover, the expansion of the use of renewable energy might reduce the import of energy and this may bring a positive impact on the reserve of foreign currency and the balance of payments. Considering these issues, the government has taken up some initiatives for the development of renewable energy.

Renewable energy is energy, which comes from natural resources such as sunlight, wind, rain, tides and geo thermal heat which are renewable. Renewable energy generates 3.47% of total electricity demand globally (Tamim et al., 2013). However; it represents only 1.5% in Bangladesh. Electricity generation in Bangladesh was almost mono-fuel dependent, i.e. indigenous natural gas considering its apparent huge availability. About 87% of electricity comes from natural gas and the rest is from liquid fuel, coal and hydropower till 2008.

Recently, the importance of renewable energy has gained momentum as the supply of natural gas has been at stake due to depleting existing gas reserves. The uncertainty has been constraining development of further gas based power generation expansion programme. Excessive use of oil also cause fiscal burden. Taking this into cognizance the government has prepared "Power System Master Plan 2010" to develop energy balanced sustainable power system in the country. Development of renewable energy is one of the important strategies adopted as part of fuel diversification programme. According to the plan, 15% of total electricity generation will come from renewable and new energy sources in future.

Commercial use of renewable energy in sustainable manner is still a great challenge for Bangladesh as in other part of the world. Government of Bangladesh has taken a systematic approach towards renewable energy development. The initiative includes development of awareness, legal and regulatory framework, institutional development and financing mechanism to drive the sector. The renewable energy policy passed in December 2008 aims at exploring the country's electricity generating potential from renewable energy resources to meeting the nagging electricity crisis across the country. The policy encourages the private and public sectors to investment in renewable energy projects to substitute indigenous non-renewable energy supplies and scale up contributions of existing renewable energy based electricity productions. The policy envisions 5% of total generation from renewable sources by 2015 and 10% of the same by 2020.

Regarding the institutional development, government power utilities like Bangladesh Power Development Board (BPDB), Rural Electrification Board (REB), Local Government Agency like Local Government Engineering Directorate (LGED) and a significant number of private sector agencies including NGOs are already involved in renewable energy development. Noted public universities and their affiliated Institutes are involved in research and development of renewable energy applications. A nodal agency, i.e.

Sustainable and Renewable Energy Development Authority (SREDA) as envisioned in the Renewable Energy Policy is established and in the process of manning this organisation so that it can work according to the desire of the people. This organisation will provide policy support to the government as well as work to promote, expand and develop the renewable energy and to enhance energy efficiency both in public and private sector. Moreover, this organisation facilitate private sector to get involve in renewable energy and energy efficiency business.

Electrification of villages in remote areas generally requires huge investment and leads to power losses associated with transmission and distribution networks. Additionally, at the current annual rate of growth of consumption of 10% the natural proven reserve of natural gas may not last more than 15-20 years. One of the great promises offered by the renewable energy technologies is their potential to provide electricity in areas not served by national power grids. There is no doubt about the fact that renewable energy will take a crucial role not only for off grid electrification in the country but also for future electricity generation as a whole.

Bangladesh is expected to have enormous potentiality in renewable energy development. Among the renewable energy sources, hydropower currently represents less than 5% of total installed electricity generation capacity. Since the country is a flat one, opportunities for installing further hydropower plants is negligible, although micro hydro and mini hydro have limited potential in Chittagong Hill Tracts.

However, the country is blessed by considerable solar radiation. Bangladesh receives an average daily solar radiation of 4-6.5 kWh/m2. Solar photovoltaic (PV) are gaining acceptance for providing electricity to households and small businesses in rural areas where electricity is not available from national grid.

Despite their higher prices, solar PVs were made affordable by the micro credit opportunities. Bangladesh currently has 14 MW installed capacity in solar electricity, although it represents a negligible share of total primary energy consumption (Power Division, 2015). Solar power does have the potential to have a significant market share in the future because of the availability of sunlight and further reduction in costs.

According to a survey, there is an existing market size of 6 million households for Solar Home Systems (SHS) on a fee-for-service basis in the off-grid areas of Bangladesh. At present, the national grid is serving 69% of our total population. Nearly 10,000 rural markets and commercial centers in the country are still out of grid which is excellent market for centralised solar photovoltaic plants. Throughout the country, different government administrative offices, NGO offices, health centers, schools, banks, police stations etc. are functioning. In the off-grid locations, these offices are either using traditional means (lantern, candles, kerosene wick lamps etc.) or operating their own diesel generator to cater there lighting needs.

The first significant PV-based rural electrification programme was the Norshingdi project initiated with financial support from France. Since the introduction of SHS in 1996, it has become now the biggest renewable energy programme in Bangladesh so far installed 3 million units and ever increasing due to an integrated programme undertaken by the government through its financial institution IDCOL. IDCOL's programme is considered as a successful model for installation of SHSs in the world.

However, potential of other renewable resources is still at the exploration stage. Potential of wind energy is mainly in coastal areas and offshore islands and to determine extent of potential wind resource mapping project is in process. Some of the development partners and companies come forward for wind mapping in different parts of the country. Bangladesh has strong potential for biomass gasification based electricity. More common biomass resources available in the country are rice husk, crop residue, wood, jute stick, animal waste, municipal waste, sugarcane bagasse etc. Exploration of these resources for electricity generation is still at preliminary stage. Potentials for utilising biogas technologies derived mainly from animal, kitchen and municipal wastes may be one of the promising renewable energy resources for Bangladesh.

Other renewable energy sources include bio-fuels, gasohol, geothermal, river current, wave and tidal energy. Potentialities of these resources are yet to be explored. Government utilities are involved in large scale grid connected renewable energy based power project development. On the other hand, private sector is involved with off-grid home-based renewable energy solutions.

According to the Renewable Energy Policy, the government aims to produce 500 MW of electricity from the renewable energy by 2015. Till now, national capacity of renewable energy based power is approximately 403 MW, as shown in **Table 3.4**. In a developing country like Bangladesh where meeting generation shortage is the primary priority, least cost generation technologies always rule the generation planning. Unfortunately, renewable energy cannot compete to achieve grid parity at the moment. Government incentives like Feed in Tariffs (FiT) can enhance the development process, but it is always difficult to source fund for such incentives especially under present tariff rationalisation structure. Only a comprehensive large scale programme with support to buy-down the cost of intervention can pave the way for renewable energy development. Realising the future energy need and to ensure energy security, government put due emphasis to mainstreaming the renewable energy. In line with the development of solar and wind energy government also initiated a feasibility study on hydro potentiality. Initially few locations were identified where hydro potentialities exist. But it need further study to make it possible. Additionally, Government has given number of financial and fiscal incentives in renewable energy and energy efficiency investment. Government has exempted income tax for next 5 years from commercial production of renewable energy. Dedicated funding support has also been extended through government financial institutions like Bangladesh Bank and IDCOL as well as through private commercial banks. Moreover, government has extended fiscal incentives including duty exemption on certain renewable energy products, e.g. solar panel, solar panel manufacturing accessories, LED light, solar operated light and wind power plant.

3.3 Environmental Impacts from Energy Systems

Bangladesh is considered as a country at high risk from the negative impacts of global warming. In order to reduce dependency on fossil fuel and to explore renewable energy sources in addition to generating power from commercial sources, the Government has formulated 'Renewable Energy Policy 2010' for the generation of environment-friendly power from renewable energy sources. Like the other countries of the world, Bangladesh has also a number of environmental problems such as a reduction of agricultural land due to soil erosion and land used for residential purpose, water pollution and salinity, loss of biodiversity and natural disasters. Additionally, negative environmental and social impacts associated with the large scale hydropower (>40 MW) generation have occurred as resettlements of a large numbers of people and loss of agricultural lands and habitats. Social acceptance of long-term environmental impacts from the planned 500 MW coal-fired power plant using coal obtained from open-cut mining at Phulbari (in northern-eastern part of Bangladesh) are yet to be confirmed. However, this project already received environmental clearance from the Government of Bangladesh notwithstanding emissions including those of greenhouse gases. However, Bangladesh's contribution to global climate change via emissions of CO2 from energy systems is insignificant compared with many industrialised nations. Bangladesh shares around 0.19% of global emissions of CO2 compared with 16.31% of the USA, 0.45% of Pakistan, 5.67% of India and emits about 63.49 Million Metric Tons of CO2 in 2012 (USEIA, 2015).

Due to lack of clean energy access for cooking and small industrial applications, traditional energy meets these important energy demand (Bhattacharya, 2006). However, burning of wood, dung and crop residues results in indoor air pollution and causes severe human health impacts directly to the users especially rural women (Sarkar et al., 2003). Most Bangladeshi households in rural areas (99%) as well as urban areas (60-66%) use biomass such as wood, cow dung, jute sticks or other agricultural wastes for cooking. Inefficient and poorly ventilated clay stoves produce fine particles, polycyclic aromatic hydrocarbons, carbon monoxide, dioxins and other carcinogens. Housewives are exposed to high levels of these toxins between three and seven hours a day. Research revealed that this Indoor Air

Pollution (IAP) occurs not only in the kitchen but only slightly lower in the living area therewith affecting also other family members such as children.

Bangladesh is also known as a disaster prone country and likely to be one of the most vulnerable countries in the outcome of climate change. Ali (1999) discusses the possible impacts of climate change in Bangladesh through tropical coastal cyclones, storm surges, coastal erosion, floods and droughts and reveals that natural disasters cause heavy loos of life and property and threatening the development activities in Bangladesh. Brouwer et al. (2007) investigates the complex relationship between environmental risk in Bangladesh and show that households with lower income face higher exposure to risk of flooding.

A number of studies examine the impact of global climate change towards world economy. Goulder and Pizer (2006) survey that the literatures on the economics of climate change and claim that global climate change poses a threat to the well-being of humans and other living things through impacts on ecosystem functioning, biodiversity, capital productivity and human health. Dell et al. (2014) discuss recent panel studies about climate-energy linkages and highlight that there is a wide range of channels through which whether shocks affect economic outcomes. For example, shocks, especially, temperatures affect agricultural output, industrial output, energy demand, labour productivity, health, conflict, political stability and economic growth. Desmet et al. (2015) study the relationship between geography and growth to evaluate the economic impact of coastal flooding due to climate change and show that a 6 meter rise in sea levels would flood 1% of land, home to 6.6% of the world's population and cause welfare losses of around 8%. Moreover, Stern (2008) highlights that the economic costs of doing nothing to combat climate change could be up to 20 times greater than taking action now to avoid catastrophic climate change in the future. If immediate action is taken, climate change will cost around 1% of global GDP per year on prevention and adaptation. Stern (2008) further claims that tackling climate change is the pro-growth strategy; ignoring it will ultimately undermine economic growth. Environmental considerations should also need to be considered in the energy policy; and energy development programmes should be so designed as to minimise the energy sector's contribution to environmental pollution. Thus, energy security calls for a mix of diverse energy sources that balance costs, availability, and environmental impact, which may be ensured by a combination of domestic production and importation with due regard to in-country options and economic considerations.

3.4 Energy Security

Energy services are fundamental to development and economic growth (UNDP, 2004) and at the level of the individual, modern services can transform people's lives for the better (World Bank, 2000). Energy security is a part and parcel of sustainable development for both industrialised and developing nations. Energy security for a country may be conceptualised as the country's access to energy sources of various types consistent with its energy needs for various purposes and for different segments of society at any point of time. Obviously, the total energy needs of a country are related to the level and structure of its economic and social development and the underlying technology regime. Energy security is indeed a dynamic concept; availability of energy of various types would increase overtime with reference to the pace, pattern and directions of development that the country is embarked upon. A poor country consumes a very low amount of energy per capita, given its low level of socio-economic and technological development. Also, generally its dependence on biomass is very high and access to commercial energy (For example, electricity, petroleum, gas) is very low. The former is used by the mass of the people, while the latter by the richer minority. Equity would demand that adequate (depending on the particular socio-economic circumstances faced at a given time) access to quality energy is ensured for various segments of society (Ahmad et al., 2004).

In Bangladesh, security of energy supply is threatened due to number of reasons including lack of domestic energy resources, high dependence on imported transportation fuels and poor energy infrastructure. Bangladesh has substantial natural gas reserves which provide more than two-thirds of the nation's commercial fossil fuel supply. Even though Bangladesh has these natural gas reserves and recently discovered coal resources, efficient use of these resources is limited due to lack of exploitation and distribution facilities. Also, though its proven oil reserves are estimated to be 56.9 million barrels, Bangladesh meets over 90% of its oil demands through imports (Kumaraswamy and Datta, 2006). Due to the nation's flat terrain and potentially large social and environmental impacts, further exploitation of hydropower is expected to be limited to small and mini-sized hydropower plants with an estimated potential of about 250 MW.

Among others, the following steps should be considered for energy development and energy security are presented below:

1. Political Consensus: Political consensus should be reached among the political parties on long term energy development programme so that the decisions are not frequently changed with the periodic change of political government through elections.

2. Energy Conservation: Although there is a good potential to reduce energy demand through energy conservation, serious actions have not been taken in the past to achieve success. It is cheaper to save one unit of energy than to supply an additional unit. In future, energy conservation measures should be considered as an integral part of national energy development programme (**See Figure 3.1**).

3. Imported Energy Supplies: Possibility of natural gas import (via pipe line and or LNG) should be considered to ensure long-term energy security of country beyond 2020.

4. Capacity Building: Adequate attention should be given to develop and strengthen national capabilities in the planning and management of energy sector programmes. This would involve initiation of appropriate educational programmes in universities, recruitment of qualified personnel and training of recruited personnel on a continuing basis. In certain cases it may be necessary to recruit expatriate Bangladeshis as well as foreign nationals to meet the need of competent experts in specialised fields.

3.5 Electricity Sector in Bangladesh

The market for electricity includes households, agriculture, industries, and transport. In Bangladesh, about 69% of the population currently has access to electricity. The remaining 31% represents the market yet to be brought under the national grid. The present generation capacity of 10416 MW cannot be realised to its fullest due to forced outage, maintenance activities and particularly fuel constraints i.e. gas supply shortage. One-fourth of the generation plants of the power system are more than 20 years old, which causes higher maintenance costs and regular plant outages. In addition, gas supply shortfall forced the power plants to operate at a reduced capacity in recent years. Hence, even the demand originating from within the grid remains unmet. Against the demand of 7518 MW in the year 2012, the actual generation capacity falls short by 1,000-1,200 MW, which reaches around 2,000 MW during the summer months.

A Single Buyer System prevails in the power sector making. Most of the electricity generated is either produced or purchased by BPDB making it the sole customer of power generation companies. Nevertheless, a small portion of electricity produced by rather small IPPs are directly synchronised to the 33kV distribution line of selected Palli Biddyut Samity (PBS) of the Rural Electrification Board (REB). Unless a cost-based or economic tariff structure is operational in the country, an open market system or other improved methods for trading electricity is not likely to be introduced in Bangladesh anytime soon. As such, the buyer-seller dynamics is expected to remain the same.

It is recognised that the pace of electricity sector development has to be accelerated in order to achieve overall economic development of the country. To upgrade the socio-economic condition and to alleviate poverty, electricity sector has been prioritised by the government. Nearly 90% of the population is urban and only about 42% of the rural households have access to grid electricity (BBS, 2010). The current rate of expansion in electrification is only about 400,000 new households gaining access every year and at such rate it would take more than 40 years to reach all households. Providing access to affordable and reliable electricity to all citizens by 2020 is a befitting national goal of the Government of Bangladesh. Rural electricity access rates have to increase dramatically to accomplish the Government's stated goal of providing universal electricity access by 2020. Government has encouraged implementing off-grid renewable energy technologies, such as

Solar Home Systems (SHS) and micro-wind power systems in coastal areas and mini-hydro projects in the mountainous regions as a priority. It has been estimated that power outage in Bangladesh results a loss of annual industrial output of $1 billion (Chowdhury et al., 2014). Electricity is one of the major reasons of slow GDP growth and the government of Bangladesh has recognised the electricity sector as a priority sector. Government has decided to build more power projects through private sector and public private partnership. The electricity supply in terms of capacity has increased by 37% from 2010 to 2014. The number of connections also increased by 1.5 million in that time frame. As a result, the access to electricity for the country increased from 48.4% in 2010 to 69% in 2015. However demand and supply imbalance still remains. The generation capacity along with actual generation increased recently with the installation of rental power plants.

In spite of financial constraints and gas supply shortages, the government designed a strategy to overcome the crisis and at the same time meet the ever increasing demand for electricity. It launched immediate, short, medium and long term programmes to increase electricity supply through introduction of fuel mix (gas, coal, liquid fuel, nuclear energy and renewable), demand side management, energy efficiency and conservation. The year-wise commissioned and planned of the additional electricity generation programmes, both in public and private are listed in **Table 3.5. Table 3.6** represents the electricity sector in Bangladesh at a glance and also presents an update of comparative data from which steady development in the electricity sector can be easily understood.

3.5.1 Electricity Consumption in Bangladesh

In Bangladesh, households and industry are the two biggest consumers of electricity. According to BPDB, the per capita electricity consumption of Bangladesh now is at 232 KWH/capita as of December, 2014. Share of electricity consumed from the national grid by households has gone up from 40% in 2001 to 49.94% in 2013. On the contrary the share of electricity consumed from the grid by industries has gone down from 47% in 2001 to 35% in 2013. This is a cause for concern as new industries have been finding it harder to get new electricity connections while existing ones have found it difficult to increase their electricity supply. Though the number of connections for industries is lower but they consume a lot more on average and hence the average bill per user was the highest for Industrial connections. The consumption in commercial sector is relatively low in comparison to that in the industrial sector, i.e., only 10.48% of the total electricity consumption. In contrast, this sector has the largest GDP share, i.e., 53.9% in 2013.

Agriculture is a seasonal industry and therefore the demand for energy fluctuates throughout the year. Agriculture sector consumes only 4.61% of overall electricity consumption in Bangladesh as of 2013. Diesel oil and electricity are two major sources of energy in this sector. The total demand of electricity for agriculture has increased over the years, but the relative percentage of consumption has changed little in the past years. Due to shortage of electricity, the government has recently stopped the extension of new electricity connection lines for the rural residential sector but continues to maintain the connections to irrigation pumps.

Electricity for other sectors consists of street lighting, water pumps for domestic water, mosques, etc., and plays only a minor role in the overall electricity consumption. Its share of total electricity consumption in 2005 was about 2%. The GDP share has hardly changed in recent years, although a slight decrease has been observed.

Consumption of electricity and commercial energy as a whole is increasing in the residential sector for several reasons. There has been a steady shift from non-commercial to commercial energy use. Population increase and access to electricity coupled with higher income and increased numbers of electrified households are some of the reasons for this change. The government has undertaken a major programme to address electricity shortages and aimed to raise the electricity coverage in Bangladesh. According to annual report of BPDB (2007-2015), the population's access to electricity was only 15% in 1996, but grew to 69% by 2014 (**Table 3.7**). Between 1995 and 2005, electricity consumption in this sector grew at an annual rate of 11.2%. It is worth noting that, in order to materialise the government vision of 100% electricity access by 2021, at the end of 2009, the government has changed its planning perspective and BPDB has started to revise the generation expansion plan by allowing QR firms.

The lighting service demand in the urban and rural electrified residential sectors is satisfied solely by electricity. Consumption for lighting alone is around 40% of the total consumption in the residential sector in urban areas and 48.2% in rural areas in 2005 (Islam, 2006).

The tropical climate in Bangladesh requires cooling, which is satisfied mainly by cooling fans. Only few high-income urban households have air-conditioning systems. Electricity for refrigeration also represents an important fraction (about 22% in 2005) of the urban residential load. In addition to refrigerators, households use miscellaneous electrical appliances namely irons, televisions, computers, etc. Consumption depends on how well equipped the household is with such appliances and also on the technical characteristics of the appliances.

3.5.2 Electricity Generation in Bangladesh

Generating and supplying enough electricity for demand remains an unresolved challenge for Bangladesh. Significant efforts aimed at adding new generation capacities characterised the electricity sector of Bangladesh in recent years. As a result, electricity generation have achieved some success. During 1992, the country's total installed capacity of electricity generation was 2,350 million watts (MW), while the derated capacity was 1,719 MW. The installed capacity increased to 4,680 MW in 2002 and further to 10416 MW in 2014, with the corresponding derated capacities of 3,428 MW and 9821 MW respectively (**Table 3.8**). That means, the addition in installed capacity is not reflected in terms of proportional increase in electricity generation. There are many factors that contribute to the difference between the installed capacity and the maximum available generation (derated capacity). For example, some plants may remain out of operation for maintenance, rehabilitation and overhauling, and the capacity of some plants may be derated due to aging. However, the shortage of natural gas, which is the major fuel used for electricity generation, is the most important factor for low-capacity utilisation in Bangladesh.

The electricity generation peak in 2014 increased to 7356 MW compared to 4,162 MW in 2009, a 76% increase. The increase in production, however, was not enough to meet the rapidly rising demand for electricity resulting in increased load shedding and adoption of other measures of demand management. The situation was further aggravated by the antiquation of a number of generation units and a shortage in gas supply, forcing them to operate at reduced capacity.

The quick improvement in electricity generation came from quick rental power plants. Quick rental power plants are privately owned plants for electricity generation. The government has allowed the private sector to generate electricity for short-term contracts (three to five years) in order to mitigate the acute electricity crisis of 2009-2010. Most of these quick rental power plants were powered by liquid fuel (Diesel, High Speed Furnace Oil). With the increase in liquid fuel based power plants (the total contribution of liquid fuels in electricity generation to 21% cent in 2014, up from 12% in 2011 and only 5% in 2010), the average fuel cost per KWH of electricity increased from BDT 2.53/KWH in 2009 to BDT 5.88/KWH in 2014. Moreover, the addition in installed capacity has not been fully reflected in a proportional increase in electricity generation, since many older power plants have become non-operational in recent years. This underproduction has resulted in huge gap between derated capacity and evening peak generation, especially since 2006. Most of the liquid fuel-based electricity has come from rental, quick-rental and peaking plants that were fast-tracked to address the electricity crisis.

The responsible authorities for generation of electricity in Bangladesh are Bangladesh Power Development Board (BPDB) along with its subsidiaries, Rural Power Company Limited (RPCL), Independent Power Producer (IPP) and Quick Rental (QR) companies (**Table 3.9**). Government power plants used to monopolise electricity production in

Bangladesh. In April 2010, about 60% of total electricity production used to be generated by the government power plants; of which, BPDB's share was 76%. A competitive market environment has been created in electricity generation by reducing dependence on public sector power plants as well as BPDB. Recently, nearly 56% of total electricity production originates from public sector power plants, whereas the private sector provides the rest 44%. By 2016, the private sector is expected to take the lead and generate nearly 58% of the total electricity produced.

The fuel mix for electricity generation has reshaped since 2008. The share of furnace oil has significantly gone up from 4% in 2008 to almost 20% in 2013. The share of gas to generate electricity has brought down to 64.5% in 2013 from 87% in 2008 (**Table 3.10**). In 2010, due to shortage of gas supply approximately 500-800 MW electricity could not be produced. In this context, it has been planned to reduce over-dependence on natural gas and to increase use of diesel, furnace oil and coal for electricity generation. Besides, importance is also given to generate electricity from renewable energy.

3.5.3 Cost and Tariff

The change in the fuel mix of electricity generation has significant implications for the cost structure and total subsidy cost. The use of liquid fuel high speed diesel and furnace oil has increased significantly in the last two years, which has, in turn, increased the per-unit generation cost of electricity in 2011 and 2012 (**Table 3.11**).

With furnace oil and diesel now accounting for around 21% of fuel mix for electricity generation, the average cost for bulk supply stands at BDT 5.88/KWH in 2014. This was BDT 5.36/KWH in 2012. The increase in generation cost is due to the increase in share of liquid fuel based power plants and also the increase in prices of liquid fuel (**Table 3.12**). Bangladesh has adopted several tariff structures at various times to adjust its selling price with changes in the production cost of electricity. The tariff rates have been changed six times between 2007 and 2012 (**Table 3.13**).

Cost to generate electricity with the use of High Speed Diesel (HSD) is BDT 18-20/ KWH and that with Furnace Oil (FO) is BDT 13-14/KWH. Generating electricity with coal now cost around BDT 5/KWH and that with hydro-power plant comes to around BDT 1/KWH. But the country can only generate up to 200 MW with the hydro plant. Generating electricity with gas is much cheaper and is around BDT 2.5-3.0/KWH. Hence gas based plants are used throughout the year to maintain base load, and fuel based plants are brought to operation to meet peak loads only. Consequently the average cost of generating electricity drops down to BDT 5/KWH in winter starting from November and goes up to BDT 6.5/KWH in the summer when fuel based power plants come into generation to meet peak demands.

As the gas supply to the power plants is already not meeting up with the requirements for electricity generation, the dependence on fuel based power plants is increasing. This is increasing the cost of generating electricity. Take for example, the day on August 4, 2012, 16% of the total day's generation came from fuel oil but shared 74% of the total cost of fuel that day. As soon as the liquid fuel based quick rental power plants came into operation from the year 2010 the average cost of generating electricity started picking up. As a result the government was forced to increase electricity tariff. In six hikes the bulk tariff has gone up by 79% from February 2011 till September 2012.

3.5.4 Energy Utilities and Related Organisations in Bangladesh

Electricity (Power) Sector Structure

Power Division is responsible for formulating policy relating to electricity and supervises controls and monitors the developmental activities related to electricity generation, transmission and distribution of the country. The division is responsible to i) manage all matters and policies related to the electricity sector; ii) expand, rehabilitate and modernise electricity generation, transmission and distribution services in line with the increasing national demand and prepare action plans and programmes accordingly; iii) encourage private and joint venture investment in the electricity sector in addition to the government investment; iv) improve the standard of living of the rural poor through rural electrification and the introduction of renewable energy; v) monitor revenue earnings and commercial activities of the utilities and vi) to promote renewable energy and energy efficiency through formulation of policy/regulation, different incentive mechanism and R&D.

To implement its mandate the Power Division is supported by a number of organisations, related with generation, transmission and distribution. The organisational linkage is as follows:

Governmental Institution

Office of the Electrical Advisor & Chief Electric Inspector and Energy Monitoring Unit

The office of the Electrical Advisor and Chief Electrical Inspector (EA & CEI) emphasises on thrift, simplicity and safety. It has been established, in order to ensure proper control of life and property in generation, transmission and distribution of electricity. Main responsibility of this office is to inspect installations, substations and lines as well as to grant license for high tension and medium tension consumers. Besides, it issues license to electrical contractors, engineers and electricians. The Energy Monitoring Unit (EMU) is a sub-unit under this office. The objective of EMU is to ensure efficient use of energy in industries and to induce energy conservation.

Power Cell

The Power Cell was established in 1995 in order to assist the Power Division in developing design and strategies, facilitating and monitoring various reform measures so that the electricity sector can achieve desirable consumer satisfaction and reach optimum growth. It basically acts as a technical unit of the Power Division. Since inception, Power Cell has played a pivotal role in reforming the private electricity generation, electricity tariff evaluation and establishing regulatory commissions. Power Cell is headed by a Director General, appointed by the government and is assisted by a number of directors. In the recent past a number of generation and distribution companies have been created under its reform programmes.

Electricity (Power) Generation Utilities and Related Organisations in Bangladesh

Bangladesh Power Development Board (BPDB)

Bangladesh Power Development Board (BPDB) was established in 1972 as an integrated utility, responsible for electricity generation, transmission and distribution. The BPDB, which is a statutory body, is responsible for major portion of generation and distribution of electricity mainly in urban areas except Dhaka and West Zone of the country. The Board is now under the Power Division of the ministry of Power, Energy and Mineral Resources. Today, BPDB consists of a Chairman and six members, all appointed by the government.

BPDB incurs its own cost of production for electricity. It also purchases electricity as a single buyer from IPPs, RPCL, Rental power plants, EGCB and Ashuganj power station company limited. BPDB is selling electricity to the bulk consumers (DPDC, DESCO and REB) and retail consumers under its distribution area at the tariff rate fixed by the Government. Due to the increasing demand for electricity, BPDB has taken steps to install new power plants and to purchase electricity from Rental and IPP to meet up emergency demand.

Ashuganj Power Station Company Ltd. (APSCL) is the second largest power station in Bangladesh. As a part of the electricity (power) sector development and reform programme of the Government of Bangladesh (GOB), Ashuganj Power Station Company Ltd. (APSCL) has been incorporated under the Companies Act 1994 on 28 June 2000. All the activities of the company started formally on 01 June 2003. According to the Articles of Association of the Company, 51% of total shares are held by BPDB and the rest 49% is distributed among Ministry of Finance, Ministry of Planning, Power Division, MOPEMR & Energy Division, and MOPEMR of GOB. Electricity generated in this power station is supplied to the national grid and it is distributed to the consumers throughout the whole country through the national grid. This power station plays a significant role in the national economic development by generating more than 10% of total demand for electricity in the country. In this power station, natural gas from Titas Gas Transmission & Distribution Company Ltd. is used as fuel. (Subsidiaries of BPDB)

Electricity Generation Company of Bangladesh (EGCB) Ltd. (An Enterprise of Bangladesh Power Development Board) was incorporated with Registrar of joint stock companies on February 16, 2004 to produce and sale of Electricity. EGCB has a plan to become a leading electricity generation company across the country. Electricity generation related business services are among the fastest growing and key area of the economy, EGCB intends to capitalise on the opportunity in that area. The company's major share is currently held by BPDB. (Subsidiaries of BPDB)

North West Power Generation Company Limited (NWPGCL) is an enterprise of BPDB. This company was created as a part of reform programme in order to meet the prevailing demand of electricity and to solve the low-voltage problem the in the North-West region of the country. In pursuance of the above, with a view to meeting the growing demand of electricity in the North-West region of the country, NWPGCL has been formed, incorporated and registered in August, 2007 under the framework of the Government Power Sector Reforms Policy and the provision of the Companies Act, 1994. (Subsidiaries of BPDB)

Rural Power Company Limited (RPCL) is committed to reliable power generation for rural development and also to take part in social & economic development for rural people of the country. RPCL was the first IPP of Bangladesh and the first non-Bangladesh Power Development Board (BPDB) entity to be licensed to take up power generation. Rural Power Company Limited is registered as a public limited company under company ACT 1913, was incorporated on 31st December, 1994 under the company laws to build, own and operate electricity generation projects with business philosophy and principles. Rural Power

Company Limited has opened a new dimension of electricity generation in private sector of Bangladesh, because the 100% equity investment is mobilised locally. This is absolutely a national company in the private sector. This will raise the confidence of investors in the private electricity generation sector. Rural Electrification Board (REB) owns 20% share and the rest 80% is owned by 9 Palli Biddyut Samity (PBS).

Electricity (Power) Distribution Utilities and Related Organizations Bangladesh

Because of major reforms, restructuring and corporatisation process of Bangladesh electricity sector, a number of distribution entities were formed with the objective of bringing commercial environment including increase of efficiency, accountability and dynamism with the aim of reaching electricity to all citizens by 2021.

In order to increase and improve electricity generation and customer service with an aim to bring a greater mass under electrification, major integrated electricity distribution programmes have been undertaken. Presently the following five organisations are responsible for the distribution of electricity (**Table 3.14**):

1. Bangladesh Power Development Board (BPDB)
2. Rural Electrification Board (REB)
3. Dhaka Power Distribution Company (DPDC)
4. Dhaka Electric Supply Company (DESCO)
5. West Zone Power Distribution Company (WZPDC)

BPDB is responsible for distribution of electricity in most of urban areas in Bangladesh except Dhaka Metropolitan City and its adjoining areas under DESA and DESCO, areas under West Zone Power Distribution Company Limited (WZPDCL) and some of the rural areas under Rural Electrification Board (REB). Followings of the Distribution Zones of BPDB: Chittagong, Comilla, Sylhet, Mymenshing, and Rajshahi and Rangpur.

Dhaka Power Distribution Company Limited (DPDC) is the largest electricity distribution company in Bangladesh. As a part of the Power Sector Development and Reform programme of the Government of Bangladesh (GOB) Dhaka Power Distribution Company Limited (DPDC) had been incorporated on 25th October, 2005. DPDC started functioning from 14th May 2007 and later on 1st July 2008 taken over the distribution management system from the then DESA along with all the assets and liabilities of DESA. The company was created to provide electricity to the consumers of Dhaka city corporation area (excluding DESCO area) and also includes Narayanganj town, Siddirganj, Fatullah and Mokterpur under Narayanganj district. DPDC distribution area comprises 350 sq. kms of Dhaka and Narayanganj. DPDC Board of Directors consists of Chairman and 10 members.

As a part of ongoing power sector reforms programme by the way of unbundling the electricity sector and increasing efficiency in the area of generation, transmission and distribution, **West Zone Power Distribution Co. Ltd. (WZPDCL)** was constituted as an electricity distribution company in November 2002 under the Companies Act 1994 as a Public Limited Company. The manpower of the Distribution Western Zone (Khulna Division, Barisal Division and Greater Faridpur comprising of 21 districts and 20 upazillas excluding REB area) of erstwhile Bangladesh Power Development Board (BPDB), put under Lien being the employees of WZPDCL in October 1, 2003 (Subsidiaries of BPDB). In fact, WZPDCL is responsible for electricity distribution in 21 districts of Khulna and Barisal Division and greater Faridpur district. It had started its function from March, 2005.

Rural Electrification Board (REB) was established in 1977 as a semi-autonomous government organisation reporting to the Ministry of Power Energy and Minerals Resources and has been providing service to rural member consumers since then. It is responsible for electrification in rural areas. Since its inception, the purpose of the programme has been to use electricity as a means of creating opportunities for improving agricultural production and enhancing socio-economic development in rural areas, whereby there would be improvements in the standard of living and quality of life for the rural people. As of today, there are 70 operating rural electricity co-operatives called Palli Bidyuit Samity (PBS), which bring service to approximately 7,900,000 connections. REB has expanded its distribution networks significantly in past years and has thus made immense contribution in increasing agricultural products and rural development. REB consists of a Chairman, four full time members appointed by the government and four part time members nominated from relevant departments. Continued support from the government of Bangladesh, the donor community, consulting partners and the valuable consumer members will help this programme to continue and expand, providing electricity to millions of Bangladeshi households, businesses and industries.

Dhaka Electric Supply Co. Ltd (DESCO) is the first electric distribution company which is registered under companies Act, 1994, and established on November, 1996 to provide uninterrupted & stable electricity supply, better consumer service, improve system loss. DESCO has started its operational activity since September 24, 1998 by taking over of Mirpur area from DESA. Its distribution comprises 220 sq. kms. of Dhaka Mega City area namely, Mirpur, Pallabi, Kafrul, Kalyanpur, Cantonment, Gulshan, Banani, Uttara, Uttarkhan, Dakkhinkhan, Badda, Baridhara and Tangi. DESCO Board of Directors consists of Chairman and 9 members.

North West Zone Power Distribution Company Ltd (NWZPDCL)

North West Zone Power Distribution Company Ltd (NWZPDCL) was registered on August 3, 2005. Its distribution area is entire Rajshahi Division.

South Zone Power Distribution Company Ltd (SZPDCL) South Zone Power Distribution Company Ltd (SZPDCL) was established on 6 May, 2008.

Electricity (Power) Transmission in Bangladesh

Power Grid Company of Bangladesh (PGCB) is responsible for operation, maintenance and development of the transmission system of the country for distribution of generated electricity. PGCB was created in November, 1996 under the restructuring process of electricity sector in Bangladesh with the objective of bringing about commercial environment including increase in efficiency, establishment of accountability and dynamism in accomplishing its objectives. It was entrusted with the responsibility to own the national power grid to operate and expand the same with efficiency. Pursuant to Government decision to transfer transmission assets to PGCB from Bangladesh Power Development Board (BPDB) and Dhaka Electric Supply Authority (DESA), PGCB completed taking over of all the transmission assets on 31.12.2002. Since then, PGCB is operating those efficiently and effectively. It is a public limited company which is incorporated through sponsorship of chairman, BPDB and its six members where 76.25% ownership with BPDB & 23.75% with general public.

The main operating function of PGCB is wheeling of energy from BPDB power stations and generation companies to distribution entities utilising transmission network. PGCB gets its energy wheeling charge from its clients (distribution entities) at the rate fixed by Bangladesh Electricity Regulatory Commission (BERC). The company has taken infrastructure development projects for further development of its operation. After successful completion of the projects the capacity of PGCB transmission network will enhance significantly.

Bangladesh Energy Regulatory Commission (BERC)

Bangladesh Energy Regulatory Commission (BERC) was established on April, 2004 under an Act. BERC frames all rules and regulation to ensure transparency in the management, operation and tariff determination in the electricity, gas and petroleum sector. The commission protects consumers and promotes competitive market environment. The commission consists of a Chairman and 5 members.

The key private companies, enterprises, NGOs involved in Bangladesh electricity sector are Summit Power Company, EnergyPac, Rahim Afrooz, Infrastructure Development Company Limited (IDCOL), Grameen Shakti (GS), Bangladesh Rehabilitation Assistance Committee (BRAC), SZ Consultancy Services Ltd. (SZCSL), Rural Services Foundation (RSF), Palli Karma Sahayak Foundation (PKSF), The Village Education Resource Centre (VERC) and The Bangladesh Solar Energy Society (BSES).

Activities of other Donors

Asian Development Bank (ADB): The ADB as the major donor took the coordinating role and acts as the chief negotiator with the Government of Bangladesh. All international donor activities in the energy sector are coordinated by the local consultative group led by ADB. ADB is also providing funds to the Rural Electrification and Renewable Energy Development (RERED) programme implemented by IDCOL.

The World Bank (WB): The World Bank is providing funds to the Government of Bangladesh to increase the electricity generation, transmission and distribution capacity. The WB initiated the SHS RERED programme. It recently announced that it will scale up its support for the Solar Home System (SHS) programme by adding US$ 78.4 million in IDA credits to the Bangladesh Rural Electrification and Renewable Energy Development II (RERED II). This funding shall help install an additional 480,000 solar home systems in areas without grid access to electricity.

Japan International Cooperation Agency (JICA): JICA is helping Bangladesh in the generation of electricity. Currently, JICA is also providing funds to RERED programme.

Global Environment Facility (GEF): GEF has supported REREDP from the very beginning and plans to undertake projects in the areas energy efficiency and improved brick kilns.

SNV: SNV is active in the field of biogas technology dissemination and is showing interest in improved cook stoves.

Urban Partnership for Poverty Reduction (UPPR): Under UNDP initiated UPPR is collaborating with SED in the cook stove sector and is also open for cooperation in biogas plants in urban settings.

U.S. Agency for International Development (USAID): USAID has been supporting rural electrification programme of Bangladesh for the last 35 years. Currently, USAID has approved a 50 million USD programme for energy. 35 million are foreseen for energy efficiency measures and 15 million for improved cook stoves.

Practical Action (PA): PA is mostly active in infrastructure and livelihood improvement in poor urban areas. As part of their efforts to provide energy access to the poor, they are interested to cooperate with SED in the promotion of improved cook stove as well as related monitoring and evaluation activities.

Swedish International Development Agency (SIDA): SIDA is involved in improved cook stove activities in Bangladesh. It is also working on renewable energies and energy efficiency in cooperation with GIZ.

UK Department for International Development (DFID): DFID has made tremendous funds available for electrification projects. They have indicated strong interest in SHS/SSHS, PicoPV as well as improved cook stove activities. Also they will be active in the field of political advisory, e.g. they are working on the topic of reallocation of subsidies for energy services and fuels.

Climate and Clean Air Coalition (CCAC): CCAC is a new partnership represented by the USA, Canada, Sweden, Mexico, Ghana and Bangladesh. This group is focussing on the reduction of short lived pollutants such as black carbon and methane by promoting new environmentally friendly technologies and processes like improved cook stoves, brick kilns and rice parboiling system. Detailed discussions for cooperation have taken place in Toronto and Paris recently.

Kreditanstalt für Wiederaufbau (KfW): Besides their efforts in rehabilitation of old power plants and grid efficiency, KfW has been a strong promoter and supporter of the SHS and SSHS dissemination under IDCOL. Further cooperation can be envisaged also for PicoPV.

Global Alliance for Clean Cook stove (GACC): GACC, an UN Foundation, is now start working in Bangladesh and developing a Country Action Plan (CAP) which will give the whole cook stove sector participants a common platform.

3.6 Energy and Electricity Reform Policies in Bangladesh

Energy is a strategic input for socio economic development. Energy has direct linkages with economic security, food security, and environment sustainability. However, energy security as well as economic stability in Bangladesh is threatened by spiralling population growth, scarcity of fossil fuel resources, high frequency of climatic events and decision making processes that often lack transparency (Uddin and Taplin, 2008). Bangladesh is currently unable to ensure necessary energy supplies to meet the energy demand of the country. In fact energy crisis is one of the major problems in Bangladesh since its independence which is becoming more acute now a day as the gap between demand and production is increasing.

While demand is increasing as a result of economic, social and technological expansion, the supply remains sticky. It should be noted that energy crisis in Bangladesh has also exaggerated due to lack of attention of all previous governments because of i) Lack of experience, ii) Frequent changes of key policy makers and decision makers; iii) Lack of political commitment to maintain continuity of policy; iv) Lack of rational tariff policy; v)

Lack of trained manpower; vi) Lack of appropriate organisational structure & character; vii) Corruption; viii) Politicisation to the system.

It is therefore, essential to take steps to ensure necessary energy supplies and their proper distribution to all uses and users throughout the country to support steady socio-economic development in the country. For a developing country like Bangladesh, the energy security issue needs to be considered in the context of sustainable human development under long term perspective to meet the energy needs of the future generations.

The conceptual framework of National Energy Policy (NEP) is shown in **Figure 3.1**. The major objective of NEP is to ensure the equality between energy demand and energy supply for different zones of Bangladesh. Shortage of supply in comparison to demand causes energy crisis. There is certain degree of uncertainty to maintain reliable supply from imported sources. In order to ensure energy security, both developed and developing countries always give priority to meet the demand by indigenous energy sources.

Additionally, development of the energy sector has been prioritised via the Five-Year Development Plans of Bangladesh. The objectives and targets set out for the energy sector for the Sixth Five Year Plan (SFYP) 2011-2015, in line with the Vision 2021 a national development plan, are as follows:

1. Accelerated exploration, appraisal and development of existing and new gas fields, the upgrade of possible gas resources into proven reserves, and balanced expansion of the transmission and distribution network;

2. Integrated reservoir management in both public and private gas companies, and where possible, the provision of standby wells for supply security and reservoir data collection;
3. Institute administrative, financial and legal reform in Petro Bangla and companies;
4. Reduce system losses and improve energy use efficiency;
5. Encourage public-private partnerships for LNG import and marketing;
6. Encourage public-private partnerships in the exploration and distribution of indigenous oil and gas;
7. Expand LPG use for domestic consumption to discourage piped gas.

To set out the overall framework for the improved performance of this sector, the NEP was prepared and adopted by the government in 1996, followed by a revised version in 2004. The fundamental objectives are as follows:

a. To provide energy for sustainable economic growth so that the economic development activities of different sector are not constrained due to shortage of energy- **Development of Energy Infrastructures.**

b. To meet the energy needs of different zones of the country and socio-economic groups- **Development of Energy Infrastructures.**

c. To ensure optimum development of all the indigenous energy sources (e.g. commercial fuels, biomass fuels and other renewable energy sources)-**Increase Indigenous Energy Supply.**

d. To ensure sustainable operation of the energy utilities-**Institutional and policy reforms.**

e. To ensure rational use of total energy sources-**Energy conservation and efficient use.**

f. To ensure environmentally sound sustainable energy development programmes causing minimum damage to environment-**Protection and improvement of environment.**

g. To encourage public and private sector participation in the development and management of the energy sector-**Implementation strategies.**

h. Electricity to all by 2020-**Development of power infrastructure.**

i. Rational energy tariff-**Policy reform.**

j. Regional energy market - **Policy reform and energy infrastructure development.**

However, the government has adopted the following policy measures:

- Private Sector Power Generation Policy of Bangladesh, adopted in 1996,
- Policy Guidelines for Small Power Plants (SPP) in the Private Sector in 1998,
- Guidelines for Remote Area Power Supply Systems (RAPSS) in July 2007,
- Policy Guidelines for Enhancement of Private Participation in the Power Sector in 2008,
- Renewable Energy Policy of Bangladesh, adopted in January 2009. This policy has the following objectives:

i. to harness the potential of renewable energy resources and the dissemination of RETs in rural and urban areas;

ii. to enable, encourage and facilitate public and private sector investment in RE projects;

iii. to develop sustainable energy supplies to substitute indigenous non-renewable energy supplies;

iv. to scale up the contribution of RE to electricity production;

v. to facilitate the use of renewable energy at every level of energy usage;

vi. to promote development of local technology in the field of RE;

vii. to promote clean energy for the Clean Development Mechanism (CDM).

3.6.1 Achievements of National Energy Policy of Bangladesh till 2014

Along with the other policies in 1998, Bangladesh also experienced institutional reforms in the energy sector by dividing MOPEMR in to two divisions a) Energy and Mineral Resources (EMR) Division and b) Power Division and so far has the following achievements:

1. International Oil Companies (IOC) operates Production Sharing Contract (PSC) in 11 blocks out of 23 blocks.
2. IOC discovered three gas fields.
3. Bangladesh Petroleum Exploration and Production Company Limited (BAPEX) transformed to an Exploration and Production (E & P) company.
4. Independent Power Producers (IPP) involved in electricity generation.
5. Separate companies of Bangladesh Power Development Board (BPDB) for power generation, transmission and distribution.
6. Bangladesh Petroleum Corporation (BPC) ensures petroleum supply during irrigation.
7. Bangladesh Energy Regulatory Commission (BERC) was established in 2004.

8. BERC has started making decisions on energy (petroleum, gas, electricity) tariffs from 2008 in place of Government administered tariffs. However, originally the prices are still determined by government and BERC acts as a government agent to make it public.
9. Access to electricity has been raised from 47% to 69% (including RE) and per capita electricity generation improved dramatically (from 220 kWh to 321 kWh) between 2009 and 2014. 3.45 million people have newly been connected and system loss (distribution) reduced from 15.67% to 12.03% between the same years.
10. Government has already initiated different energy saving measures and demand-side management programme to save power and energy. One such programme is the distribution of energy efficient CFL at free of cost. 10.5 million have already been distributed through this programme. Mass awareness raising programmes have been undertaken. Inclusion of energy efficiency in the school curricula, essay competition amongst the school students on energy efficiency issues, use of electronic and print media are some of them.
11. Considering the country's future energy security and low-carbon emission strategy, programmes have been undertaken to promote use of renewable energy. Government has formulated pro-investment policy to encourage private sector investment in Renewable Energy (RE) Sector.
12. Sustainable & Renewable Energy Development Authority Act-2012 has been enacted to set up nodal organisation for renewable and energy efficiency issues.

13. Customers can now pay utility bills on-line and through mobile phones which have been hailed by the public.

The electricity sector in Bangladesh has been undergoing a process of significant institutional change. Since 1972 the operation of the electricity sector has been the responsibility of the BPDB, reporting to the MPEMR. This responsibility has been subdivided over the years, initially with the setting up of the REB in 1978, and the subsequent creation of a co-operative based model for expansion of access, the cooperatives being known as PBS. Under the reform programme, Dhaka Electric Supply Authority (DESA) was created for the better management and efficient electricity supply in Dhaka city and its adjoining districts in 1990 and after that, DESA was reformed as Dhaka Power Distribution Company Ltd. (DPDC) in 2008. Dhaka Electric Supply Company Ltd. (DESCO) was created in 1997 as a part of DESA. Since the mid-1990s, the Government of Bangladesh has continued with the vertical unbundling of the sector, through the creation of separate publicly owned entities for generation, transmission and distribution, and the development of a Single Buyer Market (SBM) model. This has led to the entry of a number of Independent Power Producers (IPPs) into the market. The unbundling has led to the creation of a number of independently managed entities which are gradually taking over the operational responsibility previously vested with BPDB, thereby changing its status to that of a holding company, with management control being decentralised into the business unit. As part of the ongoing programme of electricity sector reform, a regulatory body, the BERC (Bangladesh Energy Regulatory Commission) has been set up, and a unit called Power Cell has been set up within the MPEMR to drive the reform process forward. Under the Companies Act of 1994, Power Grid Company of Bangladesh (PGCB) was created in 1996 to oversee the transmission system. In the recent past, a number of generation companies have been created under the reforms programme. Following the reform activity, Ashuganj Power Station Complex has been converted into Ashuganj Power Station Company Ltd (APSCL) in 1996. Additionally, as a part of reform activities, Electricity Generation Company of Bangladesh (EGCB) was formed in 2004 and the North West Zone Power Generation Company Limited (NWZPGCL) was also formed in 2007.

Under the Companies Act of 1994, Power Grid Company of Bangladesh (PGCB) was created in 1996 to oversee the transmission system (See **Table 3.15 for** Detailed of Reform Policy in Bangladesh).

In fact, Bangladesh government has adopted a comprehensive electricity development strategy for exploring supply side options along with demand management that conserves electricity and discourages its inefficient use. The thrust of the government's policy is to treat electricity as a private good such that its price reflects the cost of production and a fair return is generated on the electricity investment. The policy maintains that "social objectives like reaching out to the poor and rural community could be achieved through cross-subsidisation as well as explicit budget subsidies" (Planning Commission, 2011). As such, a key policy reform for the government is to ensure proper pricing of electricity and power based on international best practices.

3.6.2 Main Reasons behind Electricity Sector Reform in Bangladesh

Based on different literature (Mujeri et al., 2013, Tamim et al., 2013 and BPDB, 2014), the main reasons behind electricity sector reform in Bangladesh can be listed as follows:

i. A poor performance of the electricity sector such as poor conditions of generation and distribution equipment
ii. Inadequate operational and maintenance performance
iii. High level of technical and non-technical losses
iv. A rapidly growing demand for electricity with the expansion of agricultural and industrial activities
v. A low number of electricity plants
vi. Technical constraints and organisational problems
vii. Poor sector financing with low electricity tariff which is below the long run marginal costs of production or even below average operating costs
viii. Only 15% of households had access to Grid electricity in 1996
ix. Inadequate planning and investment decisions
x. Misuse of subsidies

3.6.3 Future programmes

With new generation addition, the total generation capacity would be 17,000 MW by 2016. By that time some power plants will be derated, contracts of some rental power plants will be over and the dependable capacity would be around 13,000 MW. A long term comprehensive and integrated energy (electricity) policy along with appropriate strategies should be formulated to ensure energy security over short, medium, and long terms of the country. The policy should ensure tapping of all possible sources of energy, adequate supplies of energy to its various uses and equitable access of energy to all segments of the society.

Use of renewable energy should be given due importance and extensive R&D on technologies for commercialisation of renewable energy should be conducted. Energy sector must be made efficient through the improvement of management and operational aspects relating to generation, transmission, and distribution. In this context it is essential to curb the system loss and pilferage, improve transparency and accountability, remove financial constraints, and introduce proper billing system and collection procedures.

Coal will be the dominating fuel in the future generation. Two big coal fire plants with capacity of 1320 MW each will be set up, one in Khulna and other in Chittagong. The Khulna plant will be set up in joint venture with BPDB of Bangladesh and NTPC of India. Besides, other coal fired plants will be set up in different locations of Khulna, Chittagong, Matarbari and Moheshkhali.

Transmission and distribution system will be improved accordingly in line with generation increase. The old plants will be rehabilitated phase-wise into combined cycle plants for energy efficiency and reduction of emissions.

Sustainable & Renewable Energy Development Authority (SREDA), as a nodal agency for renewable energy, energy efficiency and energy conservation, will be set up. The act has already been passed by the Parliament and have made effective from 22nd May, 2014. Steps are going on to operationalise SREDA. Another organisation in the name of Bangladesh Energy Research Council will be formed for R&D in power and energy sector. In order to promote solar energy, recently government has initiated 500 MW Solar Power Development Programmes. The plan envisages with the provision of solar power in the remote and hard to serve areas, community clinics, rural schools, union-information centers and irrigation pumps which would not only enhance quality of life and productivity in the rural areas but also contribute to reduction of infant and child mortality, improvement of maternal health, reduction of malnutrition and empowerment of women. In order to explore the wind potentials in Bangladesh, a number of wind mapping programmes has been initiated all over the country. Along with wind mapping, a flag ship wind power project with capacity of 15 MW will be implemented within 2 years.

Cross-border electricity trading is going on with India which will carry forward further. Possibilities of trading of hydro power from Nepal, Bhutan and Myanmar are being explored. Human Resource Planning in line with Power Sector Master Plan 2010 is being designed; Extensive use of ICT will be made to improve the institutional capacity of the electricity sector and service delivery to the customers.

3.7 Energy and Electricity Subsidy in Bangladesh

Following the internationally accepted definition of "subsidy," one can identify two major types of subsidies that are provided by the government: i) subsidies designed to reduce the cost of consuming energy (electricity) and ii) fuel subsidies aimed at supporting domestic production (Ellis, 2010). Similarly, subsidies in the energy sector may encompass various forms, such as direct financial transfers; retail prices set at below-market prices; providing credit at below-market interest rates; government loan guarantees; preferential tax treatments; accelerated depreciation on energy machineries and equipment; provision of energy-related services at less than full cost; imposing trade restrictions (e.g., tariff and nontariff barriers); and imposing regulatory regimes on the energy sector, such as price controls, purchase guarantees and preferential market access.

There are two types of electricity subsidies. The first type of subsidy lowers the production cost through subsidised fuel (e.g., natural gas, coal, diesel, furnace oil, etc.) in electricity generation. The second type offers electricity tariffs for groups of consumers (including residential customers and farmers) that are lower than the production costs. As a result, the BPDB, which generates around 60% of the country's total electricity, has persistently incurred losses due to selling electricity at prices lower than the break-even point. These losses are adjusted mainly through budgetary transfers by the government every year.

Bangladesh's total on-budget subsidies between the years of 2009 and 2013 are given in **Table 3.16**. This table shows a substantial shift in the sectoral composition of subsidies. In 2010, agriculture accounted for 54% of the total subsidy, while the shares of fossil fuels and electricity were 14% cent and 9% respectively. The share of agriculture declined to 22% of the total in 2013, while the shares of fossil fuels and electricity rose to 30% and 22% respectively. Thus, the energy sector as a whole now accounts for 52% of the total budgetary subsidy of the government compared with only 23% three years ago. These figures indicate how fast energy subsidies are rising and the urgent need for energy subsidy reform in Bangladesh.

A summary of the estimates of overall energy subsidies (including both on-budget and off-budget subsidies) by different energy products is given in **Table 3.17**. It shows that total energy subsidies increased sharply to BDT 126 billion in 2011 from BDT 9.8 billion in 2010 and further increased to BDT 149 billion in 2012. Total subsidies have escalated due to a rapid increase in energy consumption levels and rising import prices for energy products, especially in 2012.

In Bangladesh, the government imports most of the fossil fuels and petroleum products. The BERC periodically fixes the prices of these products in the market. Thus, all petroleum products, including electricity, are sold under an administered price regime, which is controlled by the government. As such, energy subsidies in Bangladesh mostly result from setting retail prices for fuel and electricity at lower than their "true market prices." Although the government periodically adjusts energy prices to bring them closer to world market prices, subsidies remain substantial due to the government's policy of subsidising energy to support access for the poor. Energy subsidies are also considered important for several key production sectors of the economy, including agriculture (e.g., using subsidised diesel for irrigation by small and marginal farmers).

Bangladesh is fully dependent on imported crude oil and also imports refined petroleum products. Furnace oil, lubricant oil (lube), high-speed diesel, kerosene and petrol are some of the imported refined products.

Although the domestic prices of petroleum products follow the general trend of world prices, prices in the domestic market are much less volatile than those in the world market. The government absorbs significant portions of the price volatility by providing subsidies on petroleum products. As expected, rising trends in international prices result in a higher import cost for petroleum products in Bangladesh. The world financial crisis in 2008 led to a sharp fall in petroleum prices in FY2009. Since then, petroleum prices have risen continuously in the world market, leading to an increasing import cost for Bangladesh. (**Table 3.18**)

The subsidy on petroleum products can be residually estimated by the difference between the import price and the administrative price of different petroleum products in the domestic market (Mujeri et al., 2013). The subsidisation of petroleum prices has resulted in significant losses for the BPC (the public sector oil company with a monopoly on imports). The BPC's operational losses are covered by loans from state-owned commercial banks, direct budgetary transfers and net lending by the government. These loans are provided with an interest rate that is lower than the market rate.

The difference between the import costs and selling revenues of imported petroleum products-namely, diesel, kerosene and furnace oil-has given rise to huge subsidies over the last three years. The subsidies on these three petroleum products were estimated at BDT 1.84 billion in 2010, which then increased sharply to BDT 73.28 billion in 2011, and decreased to BDT 68.71 billion in 2012 (**Table 3.19**). Two factors have contributed to the jump in subsidy in 2011. First, unit costs were higher due to the higher import prices of different petroleum products in the world market; second, consumption of diesel and furnace oil rose rapidly, particularly for liquid fuel-based electricity generation from rental/quick rental power plants to meet the ongoing electricity crisis.

The electricity tariff structures differ across sectors and levels of consumption. Industrial and commercial sectors pay higher tariffs while domestic and agriculture sectors pay low, subsidised tariffs. Thus, the domestic and agriculture sectors are partially cross-subsidised by the industrial and commercial sectors. Bangladesh imposes one of the lowest electricity tariffs of many of its neighbors when both domestic and agricultural usages are considered (**Table 3.20**).

Estimates of Electricity Subsidies

BPDB is responsible for generating electricity and selling it to different distribution companies, such as Dhaka Power Distribution Company Limited (DPDC), West Zone Power Distribution Company Limited (WZPDCL), Rural Electrification Board (REB) and Dhaka Electric Supply Company Limited (DESCO). BPDB sells electricity to these distribution companies at a rate that is lower than the generation cost, leading to huge losses for BPDB. The government provides loans to BPDB at interest rates lower than market interest rates to mitigate these losses. As these loans are provided at subsidised interest rates, the process involves the provision of implicit subsidies. The low selling price of BPDB to the distribution companies' results in losses per unit of electricity generated. These estimated costs are shown in **Table 3.21.**

Despite the lower price paid to BPDB, the distribution companies also incur losses because electricity is provided to final consumers at subsidised rates. This per-unit subsidy can be estimated by calculating the difference between the per-unit supply cost of the distribution companies and the per-unit selling price to final consumers (**Table 3.22**).

Appendix 3

Table 3.1: Per Capita Energy Use in Different Region in 2009	
Region	**Per Capita Energy Use (Kilograms of Oil Equivalent)**
Bangladesh	205
India	615
Nepal	381
Pakistan	487
Srilanka	477
South Asia	555
World	1890
Source: World Development Indicator (WDI), 2015	

Table 3.2: Energy Growth Rate of Bangladesh and Neighbouring Countries		
Growth Rate	**1980-2010**	**2000-2010**
Bangladesh	4.3%	4.8%
Srilanka	2.5%	1.6%
Pakistan	4.0%	2.6%
Myanmar	1.3%	0.8%
Nepal	2.6%	2.1%
India	4.0%	3.8%
Source: World Development Indicator (WDI), 2015 and Tamim et al., 2013		

Table 3.3: Consumption of Petroleum Products (In Million Litres)							
Product	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Octane	90.02	78.26	85.54	97.26	107.15	110.85	117.45
Petrol	124.82	115.38	127.25	141.49	158.71	169.71	178.67
Kerosene	405.10	342.70	376.65	397.21	358.44	314.87	289.87
Diesel	2333.6	2301.3	2568.2	3239.3	3240.4	2964.60	3242.55
Furnace Oil	289.60	164.47	194.17	544.62	883.74	1076.42	1202.50
Lube	17.29	15.02	15.92	17.95	17.52	15.90	17.82
Others	366	310	390	430	448	443.65	435.09
Total	3626	3327	3257	4868	5214	5086	5484
Source: Bangladesh Petroleum Corporation (BPC), 2015							

Table 3.4: Achievement of Electricity Generation from Renewable Energy till 2014	
Classification	**Generation (MW)**
Solar Home Systems (SHS)	150
Solar Irrigation	1
Roof Top solar PV at Government, Power sector office buildings and at newly constructed buildings	14
Wind Energy	2
Biomass based Electricity	<1 MW
Biogas based Electricity	5 MW
Hydro Power	230 MW
Total	403 MW
Source: Power Division, Government of the People's Republic of Bangladesh, 2015	

Table 3.5: Year wise Additional Electricity Generation in Bangladesh									
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Public	255	800	607	587	225	1293	1475	2131	1320
Private	520	963	344	76	1024	1218	1014	640	630
Total	775	1763	951	663	1249	2511	2489	2771	1950
Source: Power Division, Government of the People's Republic of Bangladesh, 2015									

Table 3.6: Updated Comparative Data of Bangladesh Electricity Scenario						
Subject	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Installed generation capacity	5719	5823	7264	8716	9151	10416
Derated generation capacity	5166	5271	6639	8100	8537	9821
Generation (MW)	3589	3883	3962	4805	5010	5320
Highest generation	4162	4606	4890	6066	6434	7356
Electricity Demand (peak demand)	6066	6454	6765	7518	8349	9268
Access to Electricity	47	48.5	49	53	62	69
Per capita electricity Generation	183.26	200.32	211.86	231.65	248.89	270.83
Per capita electricity Consumption	165.32	170.27	180.08	197.72	213.15	232.56
Transmission Lines(km)	8305	8500	8600	8949	9328	9500
Distribution Lines(km)	256143	266460	270000	281123	301654	303000
Load Shedding	1269	1459	1355	1058	1048	932
System Loss	13.57	13.10	13.06	12.15	11.95	11.89
Source: Power Division, Government of the People's Republic of Bangladesh, 2015						

Table 3.7: Access to Electricity (% of Population) between 1996-2014										
Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Access to Electricity	15%	17%	19%	20%	23%	25%	30%	32%	35%	38%
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015 (June)**
Access to Electricity	40%	42%	45%	47%	48.5%	49%	53%	62%	69%	74%
Source: Power Division, Government of the People's Republic of Bangladesh, 2007-2015										

Table 3.8: Electricity Generation in Bangladesh		
Year	Capacity(MW)	
	Installed	Derated
2006	5245	3782
2007	5202	3717
2008	5201	4130
2009	5719	5166
2010	5823	5271
2011	7264	6639
2012	8819	8149
2013	9151	8537
2014	10416	9821
Source: Bangladesh Power Development Board (BPDB), 2015		

Table 3.9: The Responsible Authorities for Generation of Electricity in Bangladesh (as of Jan,2015)	
Public Sector (54%)	
Companies	Generation Share
BPDB	38.14%
APSCL	6.35%
EGCB	5.75%
NWPGCL	3.40%
RPCL	0.71%
Private Sector (46%)	
IPP	18.17%
SIPP	3.23%
Quick Rental	18.06%
15 Year Rental	1.54%
Power Import	4.62%
Total	100
Source: Bangladesh Power Development Board (BPDB), 2015	

Table 3.10: Electricity Generation by Fuel Type in Terms of Percentage					
Generation Source	**2008**	**2010**	**2012**	**2013**	**2014**
Natural Gas	87%	84.02%	79%	64.50%	61.76%
Diesel	1%	5.15%	4%	6.69%	7.89%
Furnace Oil	4%	4.42%	12%	19.22%	21.28%
Coal	4%	2.19%	3%	2.45%	2.31%
Hydro	4%	4.23%	2%	2.25%	2.13%
Power Import				4.90%	4.62%
Source: Bangladesh Power Development Board (BPDB), 2015					

Table 3.11: Per Unit Average Cost of Electricity Generation in Bangladesh							
Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Per Unit Cost (BDT/kWh)	2.33	2.53	2.58	4.20	5.36	5.73	5.88
Source: Bangladesh Power Development Board (BPDB), 2015							

Table 3.12: Historical Fuel Prices for Bangladesh				
	Gas (BDT/1000 Cft)	**Furnace Oil (BDT/Liter)**	**Diesel (BDT/Liter)**	**Coal (USD/Ton)**
2009	79.82	26	43	71.5
2010	79.82	26	43	84
2011	79.82	60	61	84
2012	79.82	60	61	105
2013	79.82	60	68	105
2014	79.82	60	68	105
Source: Bangladesh Power Development Board (BPDB), 2015				

	Table 3.13a: Bangladesh Electricity Tariff from 2007-2012(Retail)							
Consumer Category	**Range**	**Rate/Kwh**						
		Mar, 2007	Mar, 2010	Feb, 2011	Dec, 2011	Feb, 2012	Mar, 2012	Sep, 2012
A: Residential Light and Power(Domestic)	000-100 kwh 101-400 kwh 400 and above	Taka 2.50 Taka 3.25 Taka 5.25	Taka 2.60 Taka 3.30 Taka 5.65	Taka 2.60 Taka 3.46 Taka 5.93	Taka 2.73 Taka 3.81 Taka 6.88	Taka 2.87 Taka 4.04 Taka 7.43	Taka 3.05 Taka 4.29 Taka 7.89	00-75 kwh-3.33 Tk 76-200 kwh-4.73 Tk 201-300 kwh-4.83 Tk 301-400 kwh-4.93 Tk 401-600 kwh-7.93 Tk 600 above-9.38 Tk
B: Agricultural Pumping	Flat	Taka 1.93	Unchanged	Unchanged	Taka 2.03	Taka 2.13	Taka 2.26	Taka 2.51
C: Small Industry	Flat Pick Off-Pick	Taka 4.02 Taka 5.62 Taka 3.20	Taka 4.35 Taka 5.95 Taka 3.50	Taka 4.56 Taka 6.24 Taka 3.67	Taka 5.27 Taka 6.75 Taka 4.41	Taka 5.67 Taka 6.90 Taka 4.86	Taka 6.02 Taka 7.33 Taka 5.16	Taka 6.95 Taka 8.47 Taka 5.96
D: Non Residential Light and Power	Flat	Taka 3.35	Unchanged	Unchanged	Taka 3.52	Taka 3.69	Taka 3.92	Taka 4.53
E: Commercial	Flat Pick Off-Pick	Taka 5.30 Taka 8.20 Taka 3.80	Taka 5.58 Taka 8.45 Taka 4.05	Taka 5.85 Taka 8.87 Taka 4.25	Taka 6.80 Taka 9.31 Taka 5.23	Taka 7.33 Taka 9.66 Taka 5.88	Taka 7.79 Taka 10.26 Taka 6.25	Taka 9.00 Taka 11.85 Taka 7.22
F: Medium Voltage General (11 KV)	Flat Pick Off-Pick	Taka 3.80 Taka 6.73 Taka 3.14	Taka 4.17 Taka 7.12 Taka 3.43	Taka 4.17 Taka 7.12 Taka 3.43	Taka 5.14 Taka 7.55 Taka 4.40	Taka 5.55 Taka 7.60 Taka 4.86	Taka 5.90 Taka 8.08 Taka 5.16	Taka 6.81 Taka 9.33 Taka 5.96
G 2:Extra High Voltage(132 KV)	Flat 23.00-6.00 6.00-13.00 13.00-17.00 17.00-23.00	Taka 2.82 Taka 1.49 Taka 2.48 Taka 1.66 Taka 5.52	Taka 3.10 Taka 1.63 Taka 2.72 Taka 1.82 Taka 5.94	Taka 3.25 Taka 1.71 Taka 2.85 Taka 1.91 Taka 6.23	Flat-4.59 Tk Pick-6.90 Tk Off-Pick-4.04 Tk	Flat-5.02 Tk Pick-7.07 Tk Off-Pick-4.54 Tk	Flat-5.33 Tk Pick-7.51 Tk Off-Pick-4.82 Tk	Flat-6.16 Tk Pick-8.67 Tk Off-Pick-5.57 Tk
H: High Voltage General(32 KV)	Flat Pick Off-Pick	Taka 3.58 Taka 6.45 Taka 3.03	Taka 3.92 Taka 6.82 Taka 3.33	Taka 4.11 Taka 7.16 Taka 3.49	Taka 4.88 Taka 7.34 Taka 4.30	Taka 5.28 Taka 7.44 Taka 4.78	Taka 5.61 Taka 7.91 Taka 5.08	Taka 6.48 Taka 9.14 Taka 5.87
J: Street Lights and Water Pumps	Flat	Taka 3.86	Taka 3.98	Taka 4.17	Taka 4.90	Taka 5.28	Taka 5.61	Taka 6.48

	Table 3.13b: Bangladesh Electricity Tariff from 2007-2012(Bulk)							
Consumer Category	**Range**	**Rate/Kwh**						
		Mar, 2007	Feb, 2011	Aug, 2011	Dec, 2011	Feb, 2012	Mar, 2012	Sep, 2012
G-1: DESA/DPDC	132 KV	Taka 2.34	Taka 2.75	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.78	Taka 2.96	Taka 3.60	Taka 4.24	Taka 4.57	Taka 5.40
I-1: REB/PBS	132 KV	Taka 2.34	Taka 2.75	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.78	Taka 2.63	Taka 2.91	Taka 3.17	Taka 3.42	Taka 4.03
I-2: DESCO	132 KV	Taka 2.34	Taka 2.34	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.39	Taka 2.96	Taka 3.60	Taka 4.24	Taka 4.57	Taka 5.40
I-3: WZPDCL	132 KV	Taka 2.34	Taka 2.34	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.39	Taka 2.81	Taka 3.15	Taka 3.47	Taka 3.74	Taka 4.43
I-4: BPDB	132 KV	Taka 2.34	Taka 2.34	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.39	Taka 2.84	Taka 3.42	Taka 3.98	Taka 4.25	Taka 4.97
I-5: NWZPDCL	132 KV	N/A	Taka 2.34	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV		Taka 2.39	Taka 2.84	Taka 3.42	Taka 3.98	Taka 4.25	Taka 4.97
I-6: Future Distribution Company	132 KV	Taka 2.34	Taka 2.34	Taka 2.94	Taka 3.56	Taka 4.20	Taka 4.53	Taka 5.32
	33 KV	Taka 2.39	Taka 2.39	Taka 2.84	Taka 3.42	Taka 3.98	Taka 4.25	Taka 4.97
Source: Bangladesh Power Development Board (BPDB), 2015								

Table 3.14: Power Distribution Company in Bangladesh (Areas Wise Distribution)	
1. **BPDB**	Most of Urban Areas(like Chittagong, Comilla, Sylhet, Mymenshing, Rajshahi, Rangpur) in Bangladesh except Dhaka city and its adjoining areas under DESCO, DPDC, WZPDCL and some of the rural areas under REB.
2. **DPDC**	Dhaka city corporation area (excluding DESCO area) and some towns (Siddirgonj, Fatullah and Mokterpur) under Narayanganj district.
3. **WZPDCL**	Khulna Division, Barisal Division and Greater Faridpur comprising of 21 districts.
4. **REB**	Rural areas of Bangladesh
Source: Bangladesh Power Development Board (BPDB), 2015	

Table 3.15: History of Energy and Electricity Sector Reforms in Bangladesh

Year	Reform
1972	Bangladesh Power Development Board (BPDB) was established in 1972 as a public sector organisation with the responsibility for power generation, transmission and distribution of electricity throughout the country. The BPDB (now under the power Division of the ministry of power, Energy and Mineral Resources) is responsible for major portion of generation and distribution of electricity mainly in urban areas of the country except Dhaka and West Zone of the country.
1978	Creation of Bangladesh Rural Electrification Board (REB) from Bangladesh Power Development Board (BPDB) to fulfill the power demand for village people. REB was mainly responsible for electrifying rural Bangladesh. After the establishment of REB now all most 50% of the villages are being electrified. REB is a semi-autonomous government agency.
1985	Liberalisation of Government policy with more private opportunities.
1991	New Public Sector Utility Dhaka Electric Supply Authority (DESA) was created to operate and develop the distribution system in and around Dhaka and bring about improvements in customer service, collection of revenue and lessen the administrative burden on BPDB. (Unbundling the Electricity Sector).
1993	Power Sector Reform in Bangladesh (PSRB) was constituted recommending unbundling of the sector according to functional lines, corporatisation of sector entities and establishment of an Independent Regulatory Commission.
1995	Legalisation of Private Participation under a new Energy Policy which aims vertical separation of existing utility in functional line i.e. Generation, Transmission Distribution and Commercialisation

1996	1) Creation of Power Grid Company of Bangladesh (PGCB) for operation, maintenance and development of transmission system in the country. A separate Electricity Transmission Utility under Public Sector. (Unbundling from BPDB) 2) Dhaka Electric Supply Company Limited (DESCO) was established. As part of reform programmes, the distribution area of DESA has been re-defined, with some area being allocated to DESCO for better management (1 and 2 is the outcome of the implementation of PSRB). 3) "Private Sector Power Generation Policy of Bangladesh" was adopted and power generation and distribution were opened to both national and foreign private investments. The involvement of Independent Power Producers (IPPs) was made effective after October 1996. 4) The National Energy Policy was adopted in 1996 which recommended among others i) Sector unbundling ii) Private sector participation and iii) Establishment of an Energy Regulatory Commission.
1998	1) Policy Guidelines for Small Power Plants (SPP) in the private sector adopted. 2) The country's first private power plant (with an 110MW installed capacity) started feeding power to the national grid in October 1998. 3) Along with the other policies in 1998, Bangladesh also experienced institutional reforms in the energy sector by dividing MOPEMR in to two divisions a) Energy and Mineral Resources (EMR) Division and b) Power Division
2001	Corporatisation of BPDB owned Ashuganj Power Station as a public limited company (APSCL).
2003	1) Corporatisation of Distribution system of 19 administrative District of Western areas named "West Zone Power Distribution Company Limited". 2) The Bangladesh Energy Regulatory Commission was established on March 13, 2003 through a legislative Act of the Government of Bangladesh.
2007	Guidelines for Remote Area Power Supply Systems (RAPSS) adopted.
2008	1) DESA converted into new company: Dhaka Power Distribution Company(DPDC) and 2) Policy Guidelines for Enhancement of Private Participation in the Power Sector. 3) BERC has started making decisions on Energy (Petroleum, Gas and Electricity) Tariffs in place of Government Administrative Tariffs.
2009	Renewable Energy Policy of Bangladesh, adopted a) to harness the potential of Renewable Energy resources and the dissemination of Renewable Energy Technologies (RETs) in rural and urban areas, b) to enable, encourage and facilitate public and private sector investment in Renewable Energy (RE) projects, c) to develop sustainable energy supplies to substitute indigenous non-renewable energy supplies, d) to scale up the contribution of RE to electricity production, e) to facilitate the use of RE at every level of energy usage, f) to promote development of local technology in the field of RE and g) to promote clean energy for the Clean Development Mechanism (CDM).
Source: Compiled by Sakib B. Amin from different Literature	

Table 3.16: Subsidies in the Government Budget, 2010-2013				
	2010	2011	2012	2013
Total Subsidy, billion BDT	107.7	95.3	162.9	298.1
By broad sector, billion BDT				
Agriculture	58.2	41.9	50.5	65.6
Fossil Fuels	15.1	8.6	40.7	89.4
Electricity	9.7	12.4	40.7	65.6
Others	24.7	32.4	31.0	77.5
Total Subsidy as % of GDP	1.8	1.4	2.0	3.3
Total Subsidy as % of Total Tax Revenue	20.5	15.4	20.6	30.9
Source: Ministry of Finance, Government of the People's Republic of Bangladesh, 2015				

Table 3.17: Energy Subsidies in Bangladesh				
Energy Products		2010	2011	2012
Subsidies on Electricity (Million BDT)	Generation Level	5952	47187	64108
	Distribution Level	2056	5488	16032
	Total	8008	52675	80140
Subsidies on Petroleum Products(Million BDT)	Total	1839	73277	68714
Total Energy Subsidies (Million BDT)	Total	9847	125952	148854
Energy Subsidies as a percentage of GDP	Total	0.14182	1.58091	1.627208
Source: Mujeri et al., 2013				

Table 3.18: Total Import and Import Cost of Petroleum Products in Bangladesh								
	Crude Oil		Refined Products		Lube-Based Oil		Furnace Oil	
Year	Import in (MT)	Value (Crore Tk)	Import in (MT)	Value (Crore Tk)	Import in (MT)	Value (Crore Tk)	Import in (MT)	Value (Crore Tk)
2009	860.88	3431.4	2507.82	10945.24	4.83	23.63	29.92	60.38
2010	1136.57	4701.54	2634.21	12028.18	7.26	52.03	-	-
2011	1409.30	7037.00	3259.34	20280.52	4.75	43.75	230.43	1123.17
2012	1083.47	7053.51	3409.93	27111.24	4.98	53.11	680.98	3819.07
2013	1292.10	8536.70	2827.16	219493.10	4.85	38.56	803.60	4367.26
2014	1176.70	7957.29	3158.34	23485.56	-	-	1016.10	5144.68
Source: Bangladesh Petroleum Corporation (BPC), 2015								

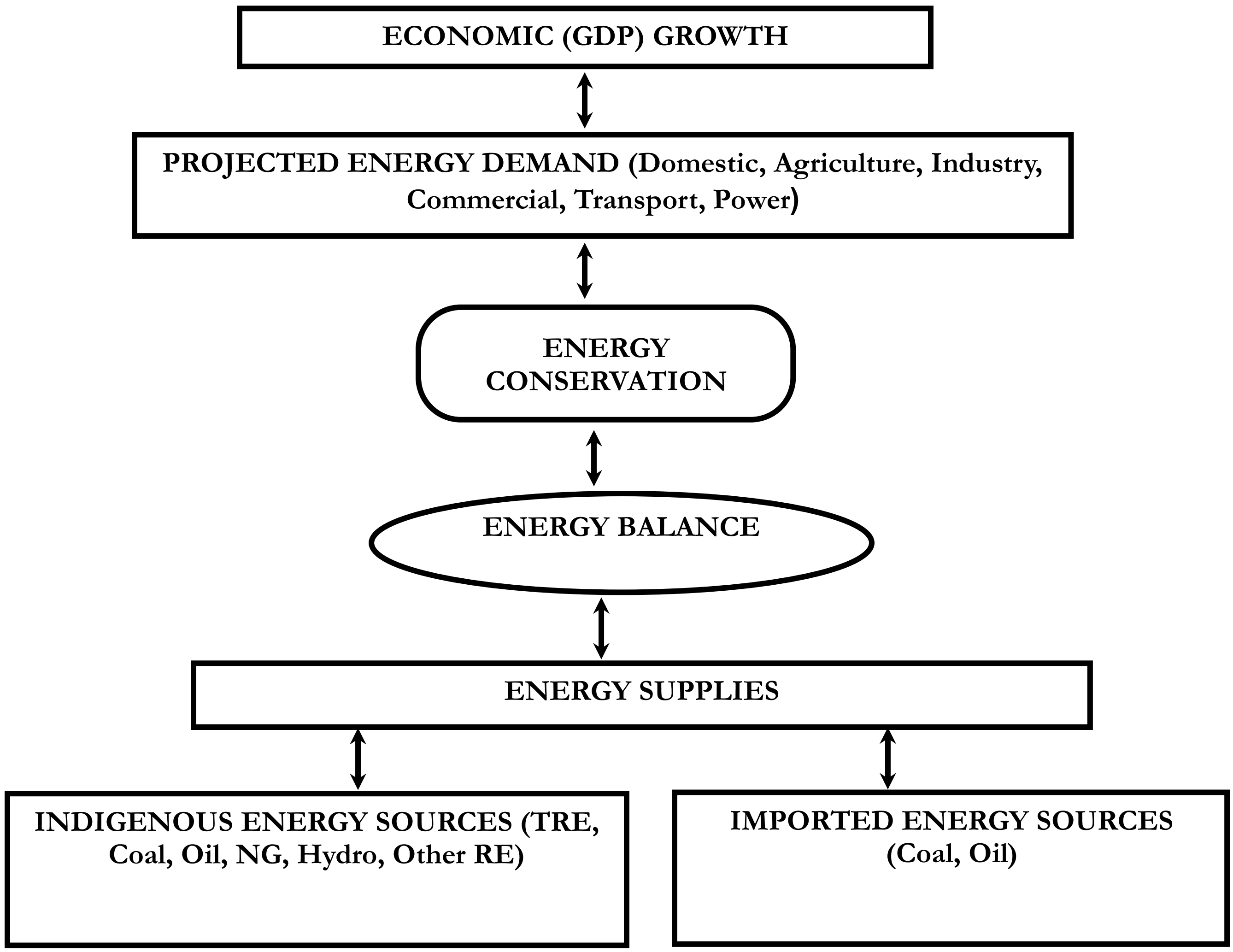
Table 3.19: Subsidies For Refined Imported Petroleum Products					
	Sales (Million Litres)	Per Unit Supply Cost(BDT/Liter)	Selling Price (BDT/Litre)	Per Unit Subsidy (BDT/Litre)	Total Subsidy (Million BDT)
2009-2010					
Diesel	3045.89	45.22	44	1.22	3715.99
Kerosene	477.58	46.95	44	2.95	1408.87
Petrol	181.07	50.53	74	-23.47	-4249.77
Octane	117.02	51.53	77	-25.47	-2980.5
JET-1	363.83	51.22	45	6.22	2263.06
Furnace Oil	210.08	38.00	30	8.00	1681.23
Total					1838.9
2010-2011					
Diesel	3481.78	62	46	16	61468.56
Kerosene	503.66	62.74	46	16.74	8431.28
Petrol	201.34	64.33	76	-11.67	-2349.66
Octane	133.05	65.33	79	-13.67	-1818.89
JET-1	425.70	62.12	67	-4.88	-2077.46
Furnace Oil	589.27	58.33	42	16.33	9622.87
Total					73276.71
2011-2012					
Diesel	3843.05	77.45	61	16.45	63218.24
Kerosene	454.49	74.65	61	13.65	6203.88
Petrol	225.84	79	91	-12	-2710.08
Octane	146.58	79	94	-15	-2198.72
JET-1	395.47	73.13	87	-13.87	-5485.26
Furnace Oil	956.20	65.13	55	10.13	9686.31
Total					68714.38
Source: Power Division, Government of the People's Republic of Bangladesh, 2015					

Table 3.20: Tariff Rates in Bangladesh and its Neighbours		
Country/Region	**0-100 Unit Residential (BDT/KWH)**	**Agriculture (BDT/KWH)**
Bangladesh	3.68 (up to 75 unit: 3.33)	2.51
West Bengal, India	3.88(Rural);3.90(Urban)	Off Peak:2.34; Peak:9.06
Karachi, Pakistan	5.90	Flat: 11.00
Nepal	6.79	-
Srilanka	3.88	-
Source: Bangladesh Power Development Board (BPDB), 2012		

Table 3.21: Estimated Electricity Subsidies at Generation					
	Total Bulk Sales (MKWH)(A)	**Per Unit Supply Cost (BDT/KWH)(B)**	**Per Unit Selling Price to Distribution Companies (BDT/KWH)(C)**	**Per Unit Subsidy (D=B-C)**	**Total Subsidies (Million BDT) (E=D*A)**
2010	28341	2.58	2.37	0.21	5952
2011	30443	4.2	2.65	1.55	47187
2012	34100	5.35	3.47	1.88	64108
Source: Bangladesh Power Development Board (BPDB), 2012					

Table 3.22: Estimated Subsidies in the Electricity Sector at the Distribution Level, 2010-2012						
	Total Sales (MWKH)(A)	Per Unit Supply Cost(BDT/KWH)(Per Unit Price Paid by Distribution Companies to BPDB+TransmissionCharge+Distribution Cost=Total Supply Cost Per Unit)(B)	Per Unit Selling Price (BDT/KWH)(C)	Per Unit Subsidy (BDT/KWH) (D=B-C)	Total Subsidies (Million BDT) (E=A*D)	Total Subsidies in Electricity (Sum of Generation and Distribution Subsidies) (Million BDT)
2010						
Domestic	11623	3.93	3.19	0.74	8601	
Agriculture	1229	3.93	2.9	1.03	1266	
Industry	9002	3.93	4.35	-0.42	-3781	
Commercial	2336	3.93	5.61	-1.68	-3925	
Others	406	3.93	4.19	-0.26	-106	
Total	24596	3.93	-		2056	8008
2011						
Domestic	12757	4.24	3.39	0.85	10843	
Agriculture	1269	4.24	2.88	1.36	1725	
Industry	7713	4.24	4.41	-0.17	-1311	
Commercial	2574	4.24	5.96	-1.72	-4427	
Others	2276	4.24	4.83	-0.59	-1343	
Total	26587	4.24	-		5488	52675
2012						
Domestic	14678	5.15	3.9	1.25	18348	
Agriculture	1492	5.15	3.18	1.97	2939	
Industry	10579	5.15	5.11	0.04	423	
Commercial	2751	5.15	7.14	-1.99	-5474	
Others	473	5.15	5.58	-0.43	-203	
Total	29973	5.15			16032	80140
Source: Mujeri et al., 2013						

Figure 3.1: The Framework of National Energy Policy



PART II: DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM (DSGE) MODEL WITH ENERGY

Chapter 4
Energy Price Shocks and the Real Business Cycle Model: The Case of Bangladesh

4.1 Introduction

Energy is considered to be one of the key elements in the socio-economic development of a country. It helps to improve the living standards of the society through an increase in economic output. Energy plays a vital role not only on the demand side but also on the supply side of the economy. On the demand side, energy is one of the goods a consumer decides to buy in order to maximise his utility. Conversely, on the supply side, energy is a key factor of production in addition to labour, capital, and other raw materials. Therefore, understanding the linkage between energy and economic development is extremely significant because energy policy implications mostly depend upon what kind of relationship exists between them. The importance of energy in the economy became prominent after the oil crisis of the 1970s which provides one major example of the consequences of oil price turbulences on the macroeconomy.

The measure of growth in the developing countries like Bangladesh is synonymous with the level of energy use. Bangladesh also considers energy as a pre requisite for its technological, societal and economic growth as the country has lot of potentials in terms of energy specifically natural gas and coal because of its local availability. In terms of renewable energy, solar power does have the potential to have a significant market share in the future because of the availability of sunlight. However, Bangladesh is currently unable to ensure necessary energy supplies to meet the energy demand of the country. In fact, energy crisis is one of the major problems in Bangladesh since its independence which is becoming more acute as the gap between demand and production is increasing. It is therefore, essential to take steps ensuring necessary energy supplies and their proper distribution to all uses and users throughout the country to support steady socio-economic development in Bangladesh. Additionally, the energy related constraints like energy price shocks needs to be considered in the context of business cycle fluctuations to examine the importance of energy for development process and advocate policy suggestions.

In light of the limitations, this chapter presents a standard RBC model with energy in the spirit of a DSGE model for the Bangladesh economy which has become a standard tool in quantitative economics. DSGE modelling mainly began with work in RBC analysis (Kydland and Prescott, 1982; Long and Plosser, 1983). Therefore, we focus on the RBC model in this chapter (Chapter 4) because it constitutes a useful benchmark framework as a vehicle for developing DSGE model to address the source of fluctuations and the behaviour of different macroeconomic variables for policy analysis (Chapter 5 and Chapter 6). The basic building blocks of the model are standard in the literature. The main goals of this chapter are about the examination and validation of the basic RBC model with regard to its performance in terms of the common RBC properties and to see how important productivity shocks are to the basic RBC model, once the model is extended to allow for energy price shocks. Put in different words, we would like to explore the extent to which aggregate energy price shocks can help explain business cycle fluctuations in Bangladesh. We attempt to calibrate the RBC model to explain the quantitative business cycle properties of macroeconomic variables in Bangladesh economy. Then we examine how the fluctuations of key economic variables such as consumption and output are explained by the exogenous shocks. The model's ability to describe the dynamic structure of the Bangladesh economy is analysed by means of Impulse Response Functions (IRFs) which yield useful qualitative and quantitative information.

Energy is explicitly modelled in the household's utility function where the representative household derives utility from the consumption of energy oriented goods, non-energy oriented goods and from their leisure. The model also considers energy as an additional productive input along with labour and capital. That means, all economic agents in the economy rely on energy either for household's consumption or for production of various goods. Aggregate energy price is modelled as an exogenous random process in addition to productivity shocks. The model is calibrated based on microeconomic evidence and also on long run considerations and try to examine the strength of the model to replicate the quantitative business cycle properties. Before the statistics were calculated, all the data were log-differenced and detrended using the HP filter so that the actual growth rates are displayed (Prescott and Hodrick, 1997; Uhlig and Morten, 2002).

Our result shows that the basic RBC model does a modest job of replicating some of the broad features of annual data of 1990-2010 in Bangladesh. We show that energy price shock does not explain the business cycle fluctuations in Bangladesh. Consequently, output fluctuations in Bangladesh are mainly driven by productivity shock. Our results further reveal that exogenous shock's impact on endogenous system variables are in the right direction.

However, the model is still rather stylised. It abstracts from many of the channels through which energy prices may affect the macro economy. First, many of the studies that derive strong impacts of energy on real variables do so by assuming some rigidity in the response of wages and (non-energy) prices to the energy price shocks [Gordon(1975), Phelps(1978), Mork and Hall(1980), and Black(1985)]. Second, it abstracts from the presence of government sector as well as taxes, subsidy etc. Finally, the model represents a centralised economy where a representative economic agent (Household) makes every economic decision regarding consumption, savings, leisure, investment and capital instrument. Put in different words, the model presented in this chapter can be defined as a representative agent model where both firms and households are identical.

The chapter is organised as follows. Section 4.2 focuses on the literature review. The model is presented in section 4.3; calibration and estimation of the parameters are discussed in section 4.4. The results are analysed in the section 4.5 and finally, in the last section, we present the conclusions.

4.2 Literature Review

Economic theory has long struggled in attempting to explain the energy-macroeconomic relationship (Finn, 2000). Researchers investigated the theoretical relationship between the use of energy (electricity, natural gas and petroleum products) and macroeconomy through different possible channels. However, the earlier macroeconomic models did not consider energy as an essential input in the production process. For example, Tsani (2010) mentions that energy is simply considered as an intermediate input of production. Bartleet and Gounder (2010) argue the presence of certain mechanisms by which economic growth could exist in spite of a limited source of energy resources. Proponents of this view focus on the possibility of technological change and substitution of other physical inputs for energy to use existing energy resources efficiently, and to generate renewable energy resources that are not subject to binding supply constraints (Solow, 1974, 1997; Stiglitz, 1974). The advocates of this theory support the ‘neutrality hypothesis’ and the ‘conservation hypothesis’. These hypotheses imply that energy would not have any negative effect on economy. Thus, the government can simultaneously adopt energy conservation and macroeconomic policies (Bartleet and Gounder, 2010).

The classical economists assume the limits which land (nature) impose on economic activities, especially in agriculture in three steps (Alam, 2006). First, they broke down the economy into two sectors, agriculture and manufacturing. Second, they defined the distinctness of agriculture by recognising that labour and capital in this sector worked with land, a third factor of production. Third, they assumed that land was available in fixed quantities, and, in some formulations, its quality was variable. The fixed supply of land produced a tendency towards diminishing returns to capital and labour in agriculture. The presence of diminishing returns to labour and capital in agriculture sums up the constraints that nature imposes upon the organic economy.

In contrast, the ecological economic theory states that energy consumption is a limiting factor to economic growth. Ecological economists judge that technological progress and other physical inputs could not possibly substitute the vital role of energy in the production process (Stern, 1993, 2000, 2004, 2010). They even consider energy as the prime source of value because other factors of production such as labour and capital cannot perform without energy (Belloumi, 2009). The advocates of this theory highlights the so-called ‘growth hypothesis’. They advise that any shock to energy supply will ultimately have an adverse effect on economic growth. Consequently, they stand against the energy conservation policies.

In modern macroeconomics, the economy is described as a Dynamic Stochastic General Equilibrium (DSGE) system that reflects the collective decisions of rational individuals over a range of variables that relate to both the present and the future (Wickens, 2008). A fundamental point of departure of a dynamic CGE model from a static one is the incorporation of intertemporal structure of consumption and investment decision in the dynamic model. A standard static CGE model examines one period sectoral reallocation of resources, while, in contrast, a dynamic CGE model allows us to analyse the path of a transitional dynamics toward a new steady state after an initial shock. Moreover, in contrast to a static CGE model, a dynamic counterpart is characterised by the inclusion of a driving force to move the economy from period to period. This driving force may be the growth in the underlying labour force and/or a change in the level of productivity in one or more sectors of the economy. DSGE models have been around for a long time, beginning with the planning models of the 1970s (Blitzer et al., 1975), through the energy and natural resource oriented models of the 1980s (Jorgenson and Wilcoxen, 1983; Martin and Van Wijnbergen, 1988), to optimal borrowing models (e.g., Kharas and Shishido, 1987). However, recently these models have earned a great deal of attention from researchers and policy makers. During the last decade, a few energy augmented DSGE models was developed.

Apart from the extensive empirical literature examining energy-economic activity, there is another kind of literature, which has analysed the energy price shocks on economic variables using Real Business Cycle (RBC) models. McCallum (1989) was responsible for carrying out the incorporation of energy price shocks into the RBC models with concrete credibility. The RBC model is considered as a simple neo-classical growth model which is the building block of almost all modern DSGE models. The RBC theory also assumes that exogenous technological shocks identified through Solow residual, are the main sources of aggregate fluctuations in the economy which has often been criticised (De Miguel et al., 2003). They argue that there is a lack of discussion on the nature of technological shocks, which are unobservable, and based on the idea that they are just the result of the convergence of other kinds of factors that are not specified in the model. However, one of the identifiable sources of shocks that have claimed the attention of many economists is energy price shocks which, according to some researchers, is equivalent to adverse productivity shocks and thus, induce significant contractions in economic activity. In fact, using US data, Hall (1988) finds that a standard measure of technology, the Solow residual, systematically tends to fall whenever energy price increases.

There are two main branches in RBC/DSGE research. On one side, empirical research concentrates mainly on getting the appropriate measures of energy (oil) price increases and quantifying the real impact of energy (oil) price increases on GDP. In this area most prominent are works by Hamilton (1996, 2003, 2009), Bernanke et al. (1997) and Kilian (2008).

On the other side, theoretical research tries to keep up with its empirical counterpart by devising theoretical models with energy to replicate empirical findings and finalise the role of energy in a theoretical economic model. Authors such as Kim and Loungani (1992), Finn (2000), Rotemberg and Woodford (1996), Dhawan and Jeske (2007), De Miguel et al. (2003, 2005), Tan (2012) investigates the effect of energy (energy price) shocks on the variation of output in RBC framework. But, most of the authors find that such energy (energy price) shocks offer very little help in explaining the US business cycle which in fact support to the views of macroeconomists who downplay the impact of energy shocks on the economy. For instance, Tobin (1980) has argued that the share of energy in US GDP is so small that it would require implausible parameter values to generate strong aggregate impacts from energy price shocks.

However, De Miguel et al. (2003, 2005) mentions that the case of the US economy does not seem to be applicable to the rest of the oil importing countries whose economies depend heavily on energy especially, oil. They show that the ability of the RBC model to reproduce the cyclical path of the Spanish economy, especially in those periods when oil price shocks were most dramatic. They further mention that oil shocks can account for a significant percentage of GDP fluctuations in many of the European countries, but the explanatory power is quite smaller for others which can be explained by differences in the strength of monetary policies. Rotemberg and Woodford (1996) showed that effect of an energy (oil) price is stronger in imperfect competition than perfect competition. Finn (2000) further reveals that one can increase the economy's response to an energy price shock even under perfect competition when one models energy use as a function of capital utilisation.

The common features in most of the aforementioned models are that energy (oil) prices are taken as exogenous stochastic process and energy (oil) is considered mainly in the production function. However, the importance of energy (oil) in the household's utility function remains less focused. As far as we have been concerned, most of those models are calibrated for the developed countries perspective and no researcher has calibrated an energy augmented RBC model for Bangladesh economy (as an example of a developing country) to investigate the interactions between energy and the overall economy.

4.3 The Model

Our research attempts to construct a simple DSGE model by extending Kydland and Prescott's (1982) analysis of an RBC model to understand the business cycle fluctuations in Bangladesh caused by energy price shocks in addition to productivity shocks. The main motivation of considering an RBC model in this chapter is that it is considered as a simple neo-classical growth model which is the building block of almost all modern DSGE models and functional to study how real shocks to the economy might cause business cycle fluctuations and allow for welfare analysis. Additionally, one of the novelties of the RBC approach is that it takes a model that is (a) designed to explain the long run; (b) picked parameters designed to explain the long run but then, (c) used that model and those parameters to explain the short run (Sims, 2012).

We have initially considered a stylised model (The Benchmark Model) of the economy in which a single economic agent makes every decision: consumption, saving, leisure, work, investment and capital accumulation. An alternative interpretation is that a central planner is making all of these decisions for each person in the economy in the light of individual preferences and is taking the same decision for everyone so that we have a single household or, more generally, representative economic agent. It is also called a representative agent model when all economic agents are identical and act as both a household and a firm. Aggregate energy enters into our production function as other physical inputs could not possibly substitute the vital role of energy in production process. Output is produced according to Constant Returns to Scale (CRS) production function that is subject to productivity and energy price shocks. The final good is consumed, invested and used to purchase energy related products for household and production purposes. The typical RBC model is based upon an economy populated by identical infinitely lived households and firms, so that economic choices are reflected in the decisions made by a single representative agent.

The present model may be described as follows. Today's output can either be consumed or invested and the existing capital stock can be consumed today or used to produce output tomorrow. Today's investment will add to the capital stock and increase tomorrow's output. The problem to be addressed is how best to allocate output between consumption of energy and non-energy goods today and investment (accumulating capital) so that there is more output and consumption tomorrow. These choices are made in order to maximise the expected value of lifetime utility.

We can also generalise this model into a decentralised model by introducing a distinction between households and firms. It is assumed that all markets are characterised by perfect competition. In order to coordinate the separate decisions of households and firms, we also need to introduce product, labour, and capital markets. Households take consumption decisions, they own firms (and will therefore receive dividend income from firms), and they save in the form of financial assets. Households also sell capital to firms at the rental rate of capital and sell labour at the real wage rate. Firms act as the agents of households. In each period, firms choose capital, labour and aggregate energy following a production function to maximise profits. They make output, investment, and employment decisions, determine the size of the capital stock, borrow from households to finance investment, pay wages to households, and distribute their profits to households in the form of dividends. In separating the decisions of households and firms, one can introduce a number of additional economic variables. However, Wickens (2008) mentions that the behaviour of the decentralised economy when in general equilibrium is remarkably similar to that of the centralised economy. Additionally, the basic RBC model assume perfectly functioning competitive markets, so outcomes generated by decentralised decisions by firms and households can be replicated as the solution to a social planner problem.

Energy is explicitly modelled in the household's utility function where the representative household derives utility from the consumption of energy oriented goods, non-energy oriented goods and from their leisure. Following Finn (2000), we measure energy oriented goods as the sum of electricity, coal, natural gas and petroleum. Non-energy oriented goods include all the durable and non-durable goods excluding energy goods. Each household's endowment of time is normalised to 1 so that leisure is equal to (1-l) where l represents the number of working hours.

Household consumes a CES aggregation of energy consumption and non-energy consumption, and also derives utility from leisure. Thus for the household, in each period it decides on how much energy goods to consume (e_t), how much non-energy goods to consume (c_t) and how much time to devote to labour (l_t) in order to maximise its lifetime expected utility.

Max E_t $(\sum_{t=0}^{\infty} \beta^t u_t)$

With a utility function of the following form:

(1) $u_t = \varphi \log \left[\theta c_t^{\rho} + (1-\theta) e_t^{\rho}\right]^{\frac{1}{\rho}} + (1-\varphi)\log(1-l_t)$

Utility function exhibits the commonly assumed properties like u_c>0, u_{cc}<0, $\lim_{C\to 0} = \infty$ and $\lim_{C\to\infty} = 0$. That means, additional consumption and leisure increases utility but does so at a diminishing rate.

Here, φ represents the share of consumption in the household's utility where $\varphi \sim (0, 1)$. θ is the share of non-energy consumption in the household's aggregator where $\theta \sim (0, 1)$. With this aggregation function, the elasticity of substitution between energy and non-energy goods is $\sigma = 1/1\text{-}\rho$. When $\rho = 0$ and $\sigma = 1$, the CES function becomes Cobb Douglas (CD) function. It is rational to choose $\rho < 0$, which implies that the goods are somewhat complementary.

Following Kim and Loungani (1992), the production technology of firm is described by a Cobb-Douglas production function with CRS by combining energy as an additional input along with capital and labour.[2]

(2) $Y_t = A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma}$

Where α and γ is the fraction of aggregate output that goes to the capital input (k_t) and labour input (l_t) respectively, and $1\text{-}\alpha\text{-}\ \gamma$ is the fraction that goes to the energy input (g_t). That means all the economic agents rely on energy either for household's consumption or for production of various goods. Additionally, energy price is modelled as an exogenous random process in addition to productivity shock.

Just as Cooley and Prescott (1995), the stochastic productivity shock A is assumed to be:

$Ln\, A_t = \omega A_{t-1} + u_t$; where $u_t \sim N\ (0, \sigma^2)$.

As in a neoclassical growth model, capital stock depreciates at the rate δ and households invest a fraction of income in capital stock in each period. So, capital accumulates according to law of motion:

(3) $k_{t+1} = (1-\delta)k_t + I_t$ with $0 < \delta < 1$

[2] One could model technology using CES production function as in Kim and Loungani, 1992. However, in this benchmark model, for computational purposes, we have used Cobb Douglas Production function.

The price of energy used in the economy, p, is exogenously given and follows AR (1) process:

$Ln\, P_t = \Psi P_{t-1} + v_t$; where v_t is normally distributed with standard deviation τ and zero mean. As energy is consumed both by the consumers and the producers in this model, the economy's resource constraint for period t is given by:

(4) $Y_t = c_t + I_t + P_t\,(e_t + g_t)$

So, the objective of the social planner is to maximise the utility of the representative households subject to feasibility, i.e.

Max $E_t\,(\sum_{t=0}^{\infty} \beta^t u_t)$

s.t.

$Y_t = c_t + I_t + P_t\,(e_t + g_t)$

$k_{t+1} = (1-\delta)k_t + I_t$

$Ln\, A_t = \omega A_{t-1} + u_t$

$Ln\, P_t = \Psi P_{t-1} + v_t$

The Lagrangian constrained for the household can be defined as follows:

$$(5)\ L = \sum_{t=0}^{\infty} \beta^t \left(\varphi \log\, [\theta c_t^{\rho} + (1-\theta) e_t^{\rho}]^{\frac{1}{\rho}} + (1-\varphi)\log(1-l_t)\right) + \lambda_t [A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma}$$
$$+ (1-\delta)k_t - c_t - P_t\,(e_t + g_t)]$$

Where λ_t is the Lagrange multiplier and the function is maximised with respect to c_t, k_{t+1}, e_t, l_t, g_t and λ_t.

The subsequent Euler equations are as follows:

$$(6)\ \frac{c_{t+1}}{c_t} = \beta.\,[A\alpha\, K_{t+1}^{\alpha-1} l_{t+1}^{\gamma} g_{t+1}^{1-\alpha-\gamma} + (1-\delta)]\, \frac{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_t^{\frac{\rho}{\rho-1}}}{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_{t+1}^{\frac{\rho}{\rho-1}}}$$

(7) $\frac{c_t}{1-l_t} = \frac{\varphi}{1-\varphi} \cdot \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}} . P_t{}^{\frac{\rho}{\rho-1}}} \cdot [A\, K_t^{\alpha} \gamma\, l_t^{\gamma-1} g_t^{1-\alpha-\gamma}]$

The Euler equation interprets that the marginal disutility of reducing consumption in current period should be equal to the discounted utility from future consumption. The Euler equation in relation to leisure interprets that the disutility from additional working hour should be compensated by an increase in utility due to producing extra output.

Additionally, after eliminating the Lagrange multiplier, the equilibrium condition is described by the following system of differenced equations that fully characterises the cyclical properties of the model economies.

(8) $\frac{e_t}{c_t} = (P_t . \frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}$

(9) $P_t = A\, k_t^{\alpha} l_t^{\gamma} (1-\alpha-\gamma) g_t^{-(\alpha+\gamma)}$

(10) $c_t + k_{t+1} + P_t\, (e_t + g_t) = A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma} + (1-\delta) k_t$

(11) $Y_t = A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma}$

(12) $Ln\, A_t = \omega A_{t-1} + u_t$

(13) $Ln\, P_t = \Psi P_{t-1} + v_t$

4.4 Calibration

Before examining the model's performance to evaluate the empirical data, model calibration is required. In this section, we use the term calibration for the process by which researchers choose the parameters of their DSGE model from various sources. For example, Cooley and Prescott (1995) calibrate their model by choosing parameter values that are consistent with long run historical averages and microeconomic evidence. So, calibration means choosing "suitable" or "empirically relevant" parameter values. However, there is also a substantial body of more recent work, that employs econometric techniques-such as moment and likelihood based methods to estimate DSGE models. Since our focus is on numerical solutions, we refer the interested reader to the books by Jong and Dave (2007) and Canova (2007) that cover the application of econometric techniques to the estimation of DSGE models.

In fact, calibration has proven to be highly controversial within the field as it involves picking the model's parameters to match long run properties of the data. But calibrated models have become an important tool for economic research and policy analysis and researchers need to calibrate model because in some cases, there is no available data to estimate model's parameter (Canova, 2007). Dhawan and Jeske (2007) calibrate parameters to produce theoretical moments of model aggregates that reproduce as best possible the empirical moments obtained from the empirical data.

However, we have generally adopted three approaches in terms of calibrating parameters for our RBC model. Some of the parameters, for which estimation remained an issue due to lack of reliable and detailed data, are picked from existing RBC/DSGE literature for developing and developed countries (Choudhary and Pasha, 2013). Some of the parameter values are chosen by using steady state conditions of the model. Rest of the parameter values are directly considered from Bangladesh Bureau of Statistics (2015) and Bangladesh Household Income and Expenditure Survey (2015). Due to data constraints, all parameters in our model are calibrated for annual frequency.

There are 11 parameters in total with 7 structural and 4 shock related parameters in the model. Structural parameters can be categorised into utility and production function related parameters. It is important to have a good understanding of rationale behind picking different parameter values in order to properly evaluate the fit of the model. Let us briefly describe our procedure for selecting parameter values listed in **Table 4.1**.

Table 4.1: Parameters of the Economy	
β, discount factor	0.88
α, capital share of output in the production function	0.31
γ, labour share of output in the production function	0.65
δ, depreciation rate	0.025
φ, the share of consumption in the household's utility	0.41
θ, the share of non-energy consumption	0.8
σ, the CES parameter of household's utility function	-0.11
ω, persistence coefficient of productivity shock	0.95
Ψ, persistence coefficient of energy shock	0.95
ζ, standard error of productivity shock	0.01
τ, standard error of energy shock	0.01
Source: Bangladesh Household Income and Expenditure Survey (2015), Bangladesh Bureau of Statistics (BBS, 2015)	

First of all, we discuss parameters related to production. Alpha (α), Gama (γ) and Depreciation (δ) are the main parameters related to production. Following Rahman and Yusuf (2010), we set alpha equals to 0.31 which implies capital's share of national income in Bangladesh is slightly less than a third. This is fairly close to the computed aggregate capital share which is 0.36 as calculated by Tan (2012). However, the average of capital shares of other developing countries is around 0.45 as reported by Liu (2008). According to Bangladesh Household Income and Expenditure Survey (2010), the labour share of output in Bangladesh varies from 0.65 to 0.70. We decided to use a value of 0.65 to make it consistent with the Cobb-Douglas production function used in our model. Finn (2000) also mentions that the measures of labour's output share range from 0.64 (Prescott, 1986) to 0.76 (Lucas, 1990).

Depreciation rate is usually very low in the developing countries. Thus, depreciation rate, delta has been set at 0.025 implying that the overall depreciation rate in Bangladesh is 2.5% annually. This value is equally realistic from the perspective of the developing countries economic condition (IMF, 2001 and Bu Yisheng, 2006). The capital output ratio in Bangladesh is borrowed from Rahman and Rahman (2002) who estimated that the trends in capital output ratio in Bangladesh over the period of 1980/81 to 2000/01 is equal to 2.

Now, we discuss parameters related to household utility. Given, α, δ, capital-output ratio and considering the value of steady state level of price is P=1 (Mean zero in the log implies a mean of utility in the level), the value of discount factor beta, β, is obtained from equations 6 and 11 calculated in steady state in the following ways:

$$\frac{c_{t+1}}{c_t} = \beta.\left[A\alpha\, k_{t+1}^{\alpha-1} l_{t+1}^{\gamma} g_{t+1}^{1-\alpha-\gamma} + (1-\delta)\right] \frac{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_t^{\frac{\rho}{\rho-1}}}{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_{t+1}^{\frac{\rho}{\rho-1}}}$$

$$\frac{c}{c} = \beta\left[A\alpha k^{\alpha-1} l^{\gamma} g^{1-\alpha-\gamma} + (1-\delta)\right] \frac{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P^{\frac{\rho}{\rho-1}}}{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P^{\frac{\rho}{\rho-1}}}$$

$$1 = \beta\left[\alpha\frac{y}{k} + (1-\delta)\right]$$

$$\beta = \frac{1}{\alpha\frac{y}{k} + (1-\delta)}$$

Our estimated value 0.88 is less compatible with the value of discount factor used in other existing literature for developing countries at annual frequency. Ahmad et al. (2012) estimate the long run discount factor for a group of developed and developing countries and find that the discount factor of most of the developing countries is relatively similar to that of developed countries. For example, they calculate the discount factor, β, equals to 0.94 for Philippines. As a robustness check, we have performed sensitivity analysis along three different discount parameters (β=0.88, β=0.96 and β=0.99) and confirm that our results are robust to a wide range of possible β values (see table 4.2). It is worth noting from table 4.2 that the steady state value of c shows odd pattern with low β values. In principle, lower β value should cause a reduction in consumption and vice versa. However, in this sensitivity analysis, we have also changed the value of δ which offset the changes observed in c for different β values. Thus, lower β value yields a higher value for c in our analysis. However, we have also run another sensitivity analysis keeping the value of δ to 0.025. Our results show that c is now smaller for lower β values. Due to unavailability of the data of working hours, we set l=0.33 with an assumption that people work about one-third of their time endowment which is a widely accepted value for RBC/DSGE analysis. For example, l is set equal to 0.30, consistent with the time-allocation measurements of Ghez and Becker (1975) for the US economy.

Certain standard parameters are calibrated following standard literature. The share of non-energy oriented consumption, θ, is set at 0.8. In this chapter, the household's utility function follows a general CES form, meaning that it cannot be used to model an elasticity of substitution of exactly 1. Here, it is set at 0.9 for the main analyses, and the CES parameter of the household's utility function, ρ, is therefore -0.11(1-(1/0.9)), which is negative and indicates that energy and non-energy consumption are somewhat complementary.

Table 4.2: Sensitivity Analysis for β (Benchmark Model)			
Variables	**β=0.88 and δ=0.025**	**β=0.96 and δ=0.12**	**β=0.99 and δ=0.14**
k	0.712689	0.820228	0.963403
y	0.370975	0.427755	0.466477
a	1	1	1
c	0.262911	0.242628	0.24319
l	0.331236	0.382276	0.402381
p	1	1	1
i	0.0178172	0.0984273	0.134876
e	0.0754072	0.0695897	0.069751
g	0.014839	0.0171102	0.0186591

φ reflects the share of energy consumption and non-energy consumption goods in the household's utility function and its value is calculated 0.41 as follows:

The intra-temporal efficiency condition (the labour-leisure) trade off implies that the marginal rate of substitution between labour and consumption must equal the marginal product of labour. That means,

$$\frac{U_l}{U_c} = F_l$$

$$\frac{\frac{1-\varphi}{1-l_t}}{\frac{\varphi}{\rho} \cdot \frac{\rho\theta c_t^{\rho-1}}{\theta c_t^{\rho}+(1-\theta)e_t^{\rho}}} = [A\, K_t^{\alpha}\gamma\; l_t^{\gamma-1} g_t^{1-\alpha-\gamma}]$$

$$\frac{\frac{1-\varphi}{1-l_t}}{\frac{\varphi}{\rho}.\frac{\rho\theta c_t^{\rho-1}}{\theta c_t^{\rho}+(1-\theta)e_t^{\rho}}} = [\gamma\frac{y}{l}]$$

$$\frac{1-\varphi}{\varphi}.\frac{l}{1-l_t}\left[1+\frac{(1-\theta)}{\theta}(\frac{e_t}{c_t})^{\rho}\right] = \gamma\frac{y}{l}$$

By using equation 8, we can calculate the steady state ratio of energy to consumption which yields a value of 0.28. Now, given the value of l, γ, θ and the ratio of $\frac{c}{y}$ and $\frac{e}{c}$, we can find the value of φ equals to 0.41.

Owing to the unavailability of data, following King, Plosser and Rebelo (1988), we set the persistence of our two exogenous shocks to 0.95 and standard deviation of the shocks to 0.01. Using different series, empirical literature get a range of estimates for persistence 0.85-0.95 and standard deviation 0.0095-0.01.

Although some DSGE literature calibrates not only the parameter values but also the fundamental steady state variables, we do not follow that procedure. The reason is that the software Dynare can solve models without setting up the steady state and by guessing initial values for the endogenous variables[3]. In the same fashion, the RBC model can be solved recursively by using initial value and given the Steady State (SS) results (Levine and Yang, 2012).

In context with the aforementioned discussions and following the initial steady state values used by Sims(2012), together with the normalisation of P and A, table 4.3 reports the initial steady values in comparison to the computed steady state values by Dynare. All the Dynare codes are given in Appendix **3**.

[3] Dynare, a preprocessor and a collection of MATLAB routines is used in this chapter to solve for the steady states, linearise the necessary conditions around steady states, compute the moments and calculate the impulse response paths once the necessary equations are transformed into Dynare codes (Griffoli, 2011).

Table 4.3 : Steady State Values of the Variables		
Variables	Initial SS value (by guess)	Dynare computed SS Values
K	1.5	0.712689
Y	0.8	0.370975
A	1	1
c	0.6	0.262911
l	0.4	0.331236
P	1	1
i	0.3	0.0178172
e	0.2	0.0754072
g	0.01	0.014839

We assume that productivity and energy price shocks follow a mean zero AR (1) process in its natural log, with an iid disturbance with some variance σ_u^2 and σ_v^2 . Mean zero in the log implies a mean of utility in the level, so, steady state level of productivity is A=1 and P=1.

4.5 Results

After calibration, to evaluate the performance of our model, we will compare steady state ratios from the models with their empirical counterpart. Furthermore, second order moments (such as standard deviation, contemporaneous correlation with output etc.) obtained from simulations will also be evaluated from our models and their fit with the actual data.

Our model shows that the relevant capital output ratio is equal to 1.92 which is fairly close to the actual data of 2 as explained in the previous section. Another important ratio of our model is the consumption-output ratio. The model does a good job at matching the model generated ratio of 0.70 to the actual consumption output ratio of 0.65-0.70 as showed in data. However, our model undershoots the value of investment output ratio (in percentage form) by a large extent. The model generated result 4.8% is far away from the average long run investment output ratio of 20%.

We would also like to verify the ability of the model to reproduce other empirical regularities of the Bangladesh business cycle. In order to do so, we proceed to the stochastic simulation of the model with the parameters obtained in the calibration section, where the source of fluctuations comes from the productivity and energy price shocks. Table 4.4 reports a selection of second moment properties for the HP filtered series corresponding to the Bangladesh data and the simulated economy respectively[4]. In other words, we would like to evaluate our model's performance by comparing the results with data. For this purpose, the following table reports some selected historical moments from data and their counterparts predicted by our models.

[4] We have used HP filtering data to make it consistent with Dynare generated data as it gives HP filtering data. However, considering the fact that HP filtering data might give rise to spurious cycles as criticised in some literature, we have also checked with Baxter and King (BK) filtering process but that does not make any significant differences.

Table 4.4: Actual and Predicted Moments				
	Data[1]	RBC Model		
Statistics	Estimate	Model 1 Productivity and Energy Price Shocks	Model 2 Productivity Shocks	Model 3 Energy Price Shocks
Standard Deviation				
Y	0.005488	0.004321	0.004335	0.000172
I	0.003155	0.002264	0.002270	0.000088
c	0.007593	0.001629	0.001637	0.000115
e	0.002546	0.000784	0.000470	0.000624
Standard Deviation Relative to Output				
I	0.57	0.49	0.52	0.51
c	1.38	0.38	0.38	0.67
e	0.46	0.18	0.11	3.62
Autocorrelation				
Y	0.823	0.4815	0.4845	0.4841
I	0.824	0.4406	0.4437	0.4437
c	0.821	0.5777	0.5811	0.5230
e	0.821	0.4879	0.5811	0.4731
Correlation with Output (Y)				
I	0.9965	0.9545	0.9545	0.9550
c	0.9938	0.9457	0.9470	0.9890
e	0.9967	0.5238	0.9470	0.9986

1 The statistics are based on log-differenced and HP filtered for the period 1990-2010 to reflect the actual growth rates.

Our model performs well to capture the actual volatility of output and investment when we consider both the productivity and energy price shocks together as well as when we take into account the productivity shock alone. However, considering only energy price shocks, we observe a very gloomy picture. A shock to the energy sector or a policy pertaining to that sector would have significant impact on the rest of the economy. However, energy price shocks can account for only 3.29% of output volatility whereas productivity shocks can account for almost 83.52% of output volatility in our model. Investment also follows more or less the same pattern as output. However, the model does a poor job in replicating the variation of consumption of energy and non-energy goods. The situation is more severe in the consumption of non-energy goods when we just consider energy price shocks. Therefore, energy price shocks are a less important source of aggregate fluctuations in Bangladesh economy. Our results reveal from the long run data that energy input is well substituted by other inputs (capital and labour) in the production function when there is any shock in energy price. In fact, the results indicate that there are some mechanisms by which macroeconomic variables could be stable in spite of a limited source of energy inputs as argued by Bartleet and Goulder (2010). Additionally, our RBC model shows that the series are not strongly persistent and robust in the sense of having a large first order autocorrelation coefficient and matching the historical data. The highest persistent series is capital which is 0.74 whereas the autocorrelation of the remaining series are typically in the neighborhood of 0.45 compared to their empirical counterpart of a range around 0.82.[5] The policy and transition function reveals that the exogenous shock's impacts on endogenous variables are in the right direction. Lastly, the model captures the fact that most of the series are quite pro-cyclical with output.

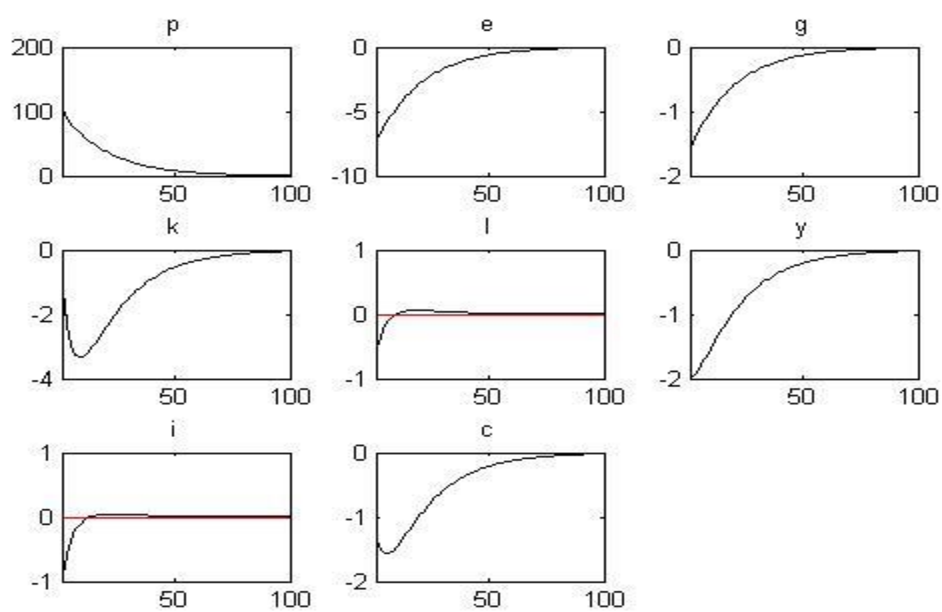
After considering the steady state ratios and second order moments for our model with their empirical counterparts, finally we take a brief look at the impulse response functions generated in response to the productivity and energy price shocks.

[5] The persistent of capital is not reported in the table as we mainly focus on consumption, investment and output in this table.

4.5.1 Transmission Mechanisms of Energy Price Shocks

In this section, we describe the dynamic mechanism in which energy price shock is propagated. The shock is equal in size to the standard deviation of the normalised price. Figure 4.1 shows the response of the different endogenous variables of the model in presence to such a shock. When there is an increase in relative energy price (p), both the amount of energy consumption (e) and the amount of energy used (g) in the production decreases by 8% and 1.5% respectively. Because of the complementarity effects, the reduction in the use of energy in production decreases the amount of capital (k) by 1% and the amount of labour (l) by 0.5% approximately. The decrease in the productive inputs is translated into an output (y) decrease of 2% which would imply a negative association between output (y) and energy prices (p). Finally, consumption (c) exhibits a similar response to the output (y).

Figure 4.1: Impulse Responses to an Energy Price Shock



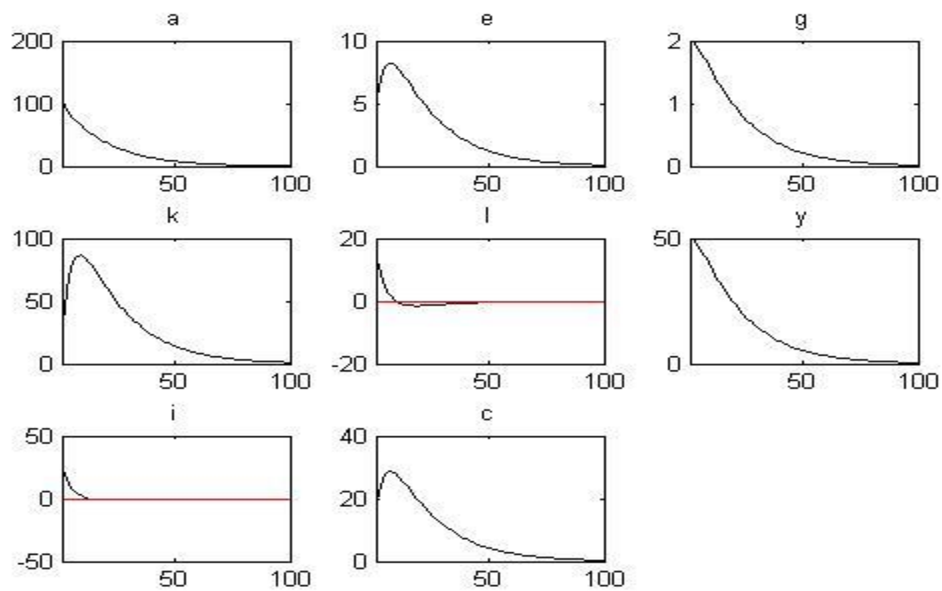
4.5.2 Transmission Mechanisms of Productivity Shocks

Although the focus of this thesis is not on the effects of productivity shocks, a productivity shock is still considered in our model as it would be of interest to compare the results of productivity shocks with those reported in the literature (Pesaran and Xu, 2011). Moreover, Dedola and Neri (2006) argue that in the standard RBC/DSGE model, productivity shocks play an important role in accounting for output fluctuations. Our results reveal that the productivity shock has more strong impact on the variables than the energy price shocks.

An increase in productivity (a) makes capital more productive in the future. Since future productivity is expected to be higher (as omega is close to 1), the social planner responds optimally by immediately building up the capital stock (k) by 40%. As a result of a positive productivity shock, investment (i) rises by 25% and output (y) by 50%. The IRF of consumption (c, e) displays a hump shape as is already documented in the literature. Investment (i) reverts back to original pre-shock levels just after a few periods compared to other endogenous variables.

It is worth noting that the behaviour of IRF for the endogenous variables are opposite in directions to their response to an exogenous productivity and energy price shock as the later shock acts as a negative productivity shock. Finn (2000) also finds that an energy price shock can be considered as an adverse productivity shock, since it causes capital (which embodies the technology) to produce at below capacity levels.

Figure 4.2: Impulse Responses to a Productivity Shock



4.6 Conclusions

In the introduction to this chapter we referred to McCallum's suggestion that RBC theory should explicitly model exogenous energy price changes. We made an attempt to implement this suggestion in the simplest possible way where energy is included both in the utility and production functions. Energy price shock is explicitly introduced in our model in addition to the productivity shocks. The model used in this chapter is based on the standard DSGE analysis which is a small first step in modelling energy price shocks in a RBC framework for Bangladesh economy.

Here it needs to be mentioned that, both the productivity and energy price shocks in this chapter are assumed to be exogenous. Contrary to the literature on endogenous growth, the idea that productivity and other shocks could be endogenous has recently been introduced to DSGE analysis (Baron and Schmidt, 2013). Acemoglu et al. (2012) introduces a two sector model of endogenous and directed technological changes to study the response of different types of technologies to environmental policies. They highlight the importance of endogenous shock process and show that when inputs are strong substitutes, under free market economy, a disaster will occur sooner with directed technological change than without. Popp (2004) also introduces directed innovation in the energy sector and presents a calibration exercise suggesting that models that ignore directed technological change might overstate the costs of environmental regulation. Moreover, early work by Bovenberg and Smulders (1995, 1996) and Goulder and Schneider (1999) study endogenous innovations in abatement technologies.

However, since the seminal work by Kydland and Prescott (1982) and Prescott (1986), RBC/DSGE models typically assume an exogenous shock process (mostly productivity shock). Gali (1999) argues that the exogenous variations in productivity is often justified by the ability of RBC/DSGE models to generate unconditional moments for a number of macroeconomic variables that display patterns similar to their empirical counterparts and to capture the economic fluctuations. These fluctuations have been interpreted by the DSGE economists as the equilibrium response to exogenous variations in productivity and energy price shocks, in an environment with perfect competition and intertemporal optimising agents, and in which the role of nominal frictions and monetary policy are secondary.

The main conclusion from our chapter is that energy price shocks are not a major factor for business cycle fluctuation in Bangladesh economy. This might be the case of the substitution possibility of energy with labour in the production function because of the cheap labour availability in the country. Kemfert and Welsch (2000) argue that labour is better substitutes for energy than capital. In practice, there may be a number of reasonable explanations for energy-labour substitutability. One possibility is that with higher energy prices more engineers are engaged, which search for and implement energy saving technologies (Koschel, 2000). Besides, different measures of underground economy of Bangladesh has pointed out that the informal economy had the size of 35% of the total official GDP which is a large value and sufficient enough to distort any macroeconomic outcomes (Schneider, 2004). However the impulse response function shows that energy price shocks have a negative impact on macroeconomic variables in the Bangladesh economy.

Therefore, it would require implausible parameter values to generate strong aggregate impacts from energy price shocks. Additionally, variance decomposition analysis shows that energy price shocks contribute a very small percentage to variations in overall output, similar to results obtained in Tan (2012), Dhawan and Jeske (2007) and Kim and Loungani(1992). It is also not surprising that a choice of functional forms and parameterisation may affect model dynamics and also changes the model's amplification and propagation mechanism (Kormilitsina, 2011). In fact, our results offer some support to the views of macroeconomists who downplay the impact of energy (energy price) shocks on the business cycle fluctuations. Overall, the RBC model developed in this chapter does a reasonable job to capture the qualitative changes of selected endogenous variable like consumption, output, investment etc. when the economy faces the exogenous shocks.

For further research, it would be interesting to generalise the model into decentralised economy by introducing a distinction between households and firms. We would also like to consider the involvement of government sector to perform the different fiscal policies like taxation, subsidies etc. Finally, we would also intend to extend the model by explicitly modelling the energy market for a mixed economy where government still controls energy prices so that energy policy reforms and their impact on the overall economy can be accurately analysed. We would also like to include the industrial and service sector in the model as these sectors represent major share of energy (electricity) consumption in the developing countries like Bangladesh.

Appendix 4A

Technical Appendix

Utility Function: $u_t = \varphi \log\ [\theta c_t^{\rho} + (1-\theta)e_t^{\rho}]^{\frac{1}{\rho}} + (1-\varphi)\log(1-l_t)$

Production Function: $Y_t = A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma}$

Resource Constraint: $Y_t = c_t + I_t + P_t\,(e_t + g_t)$

Lagrangian Function:

$$L = \sum_{t=0}^{\infty} \beta^t \left(\varphi \log\ [\theta c_t^{\rho} + (1-\theta)e_t^{\rho}]^{\frac{1}{\rho}} + (1-\varphi)\log(1-l_t)\right) + \lambda_t[A\, k_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma} + (1-\delta)k_t - c_t - P_t\,(e_t + g_t)]$$

First Order Conditions:

$$\frac{\partial L}{\partial c_t} = \beta^t.\varphi.\frac{1}{[\theta c_t^{\rho} + (1-\theta)e_t^{\rho}]^{1/\rho}}.\frac{1}{\rho}.(\theta c_t^{\rho} + (1-\theta)e_t^{\rho})^{\frac{1}{\rho}-1}.\theta.\rho.c_t^{\rho-1} - \lambda_t = 0$$

$$=> \beta^t.\varphi.\theta.(\theta c_t^{\rho} + (1-\theta)e_t^{\rho})^{\frac{1}{\rho}-1-\frac{1}{\rho}}.c_t^{\rho-1} = \lambda_t$$

$$=> \lambda_t = \beta^t \frac{\varphi.\theta.c_t^{\rho-1}}{\theta c_t^{\rho} + (1-\theta)e_t^{\rho}} \quad \textbf{(1)}$$

$$\frac{\partial L}{\partial k_{t+1}} = -\lambda_t + \lambda_{t+1}\left[A\alpha\, k_{t+1}^{\alpha-1} l_{t+1}^{\gamma} g_{t+1}^{1-\alpha-\gamma} + (1-\delta)\right] = 0$$

Assuming $M_{t+1} = A\alpha\, k_{t+1}^{\alpha-1} l_{t+1}^{\gamma} g_{t+1}^{1-\alpha-\gamma} + (1-\delta)$, we have

$$\lambda_{t+1} = \frac{\lambda_t}{M_{t+1}} \quad \textbf{(2)}$$

$$\frac{\partial L}{\partial e_t} = \beta^t.\varphi.\frac{1}{[\theta c_t^{\rho} + (1-\theta)e_t^{\rho}]^{\frac{1}{\rho}}}.\frac{1}{\rho}.\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1}{\rho}-1}.(1-\theta).\rho.e_t^{\rho-1} - \lambda_t P_t = 0 \quad \textbf{(3)}$$

Combining equation 1 and 3, we have

$$\beta^t.\varphi.(1-\theta).[\theta c_t^{\rho} + (1-\theta)e_t^{\rho}]^{\frac{1}{\rho}-1-\frac{1}{\rho}}.e_t^{\rho-1} = \lambda_t P_t$$

$$=> \beta^t.\frac{\varphi.(1-\theta).e_t^{\rho-1}}{\theta c_t^{\rho} + (1-\theta)e_t^{\rho}}. = \beta^t \frac{\varphi.\theta.c_t^{\rho-1}}{\theta c_t^{\rho} + (1-\theta)e_t^{\rho}}.P_t$$

$$=> \frac{1-\theta}{\theta}.(\frac{e_t}{c_t})^{\rho-1} = P_t$$

$$=> \frac{e_t}{c_t} = (P_t.\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}} \quad \textbf{(4)}$$

$$\frac{\partial L}{\partial g_t} = \lambda_t \left[A k_t^{\alpha} l_t^{\gamma}(1-\alpha-\gamma) g_t^{-(\alpha+\gamma)} - P_t\right] = 0$$

$$=> P_t = A k_t^{\alpha} l_t^{\gamma}(1-\alpha-\gamma) g_t^{-(\alpha+\gamma)} \quad \textbf{(5)}$$

$$\frac{\partial L}{\partial l_t} = \beta^t.(1-\varphi).\frac{1}{1-l_t}.(-1) + \lambda_t A k_t^{\alpha} \gamma l_t^{\gamma-1} g_t^{1-\alpha-\gamma} = 0$$

$$=> \beta^t.(1-\varphi).\frac{1}{1-l_t} = \lambda_t A k_t^{\alpha} \gamma l_t^{\gamma-1} g_t^{1-\alpha-\gamma}$$

$$=> \beta^t.(1-\varphi).\frac{1}{1-l_t} = \beta^t \frac{\varphi.\theta.c_t^{\rho-1}}{\theta c_t^{\rho} + (1-\theta) e_t^{\rho}} [A k_t^{\alpha} \gamma l_t^{\gamma-1} g_t^{1-\alpha-\gamma}]$$

Assuming $N_t = A k_t^{\alpha} \gamma l_t^{\gamma-1} g_t^{1-\alpha-\gamma}$, we have

$$\frac{1}{1-l_t} = \frac{\varphi.\theta}{1-\varphi}.\frac{c_t^{\rho-1}}{\theta c_t^{\rho} + (1-\theta) e_t^{\rho}}.N_t \quad \textbf{(6)}$$

Multiplying equation 1 with c_t, we have:

$$c_t \lambda_t = \beta^t \frac{\varphi.\theta.c_t^{\rho}}{\theta c_t^{\rho} + (1-\theta) e_t^{\rho}}$$

$$= \beta^t \frac{\varphi.\theta}{\theta + (1-\theta)(\frac{e_t}{c_t})^{\rho}}$$

$$= \beta^t \frac{\varphi.\theta}{\theta + (1-\theta)(P_t.\frac{\theta}{1-\theta})^{\frac{\rho}{\rho-1}}} \quad \text{(From Equation 4)}$$

$$c_t \lambda_t = \beta^t \frac{\varphi}{1 + (\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_t^{\frac{\rho}{\rho-1}}} \quad \text{(Dividing by } \theta)$$

$$c_t \lambda_t = \beta^t \frac{\varphi}{1 + (\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_t^{\frac{\rho}{\rho-1}}} \quad \textbf{(7)}$$

Similarly, we can write

$$c\lambda_{t+1} = \beta^{t+1} \frac{\varphi}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_{t+1}{}^{\frac{\rho}{\rho-1}}} \quad \textbf{(8)}$$

From equation 7, we get,

$$\lambda_t = \frac{\beta^t}{c_t}.\frac{\varphi}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_t{}^{\frac{\rho}{\rho-1}}} \quad \textbf{(9)}$$

Combining equation 8 and equation 2:

$$c_{t+1}.\frac{\lambda_t}{M_{t+1}} = \beta^{t+1}.\frac{\varphi}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_{t+1}{}^{\frac{\rho}{\rho-1}}}$$

$$\frac{c_{t+1}}{M_{t+1}}\left\{\frac{\beta^t}{c_t}.\frac{\varphi}{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_t{}^{\frac{\rho}{\rho-1}}}\right\} = \beta^{t+1}.\frac{\varphi}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_{t+1}{}^{\frac{\rho}{\rho-1}}} \quad \text{(From Equation 9)}$$

$$\frac{c_{t+1}}{c} = \beta.M_{t+1}.\frac{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}}.P_t{}^{\frac{\rho}{\rho-1}}}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_{t+1}{}^{\frac{\rho}{\rho-1}}} \quad (\textbf{Consumption Euler Equation})$$

Multiplying Equation 6 with C_t, we obtain

$$\frac{c_t}{1-l_t} = \frac{\varphi.\theta}{1-\varphi}.\frac{c_t^\rho}{\theta c_t^\rho + (1-\theta)e_t^\rho}.N_t$$

$$= \frac{\varphi.\theta}{1-\varphi}.\frac{1}{\theta + (1-\theta)(\frac{e_t}{c_t})^\rho}.N_t$$

$$= \frac{\varphi}{1-\varphi}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_t{}^{\frac{\rho}{\rho-1}}}.N_t$$

$$\frac{c_t}{1-l_t} = \frac{\varphi}{1-\varphi}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.P_t{}^{\frac{\rho}{\rho-1}}}.N_t \quad (\textbf{Euler Equation in relation to Leisure})$$

Appendix 4B

Dynare Codes for Model 1

```
var p a  e g k l y i c;
varexo u v;

parameters alpha  gama  beta delta phi theta rho omega sigmae psi tau ;

alpha = 0.31;
gama = 0.65;
beta = 0.88;
delta = 0.025;
phi = 0.41;
theta = 0.8;
rho =-0.11;
omega = 0.95;
sigmae = 0.01;
psi = 0.95;
tau = 0.01;

model;

1/c = beta*(1/c(+1))*(a*alpha*k^(alpha-1)*l(+1)^gama*g(+1)^(1-alpha-gama)+1-
delta)* (1 +(theta/(1-theta))^(1/(rho-1))* p^(rho/(rho-1)))/(1+(theta/(1-
theta))^(1/(rho-1))*p(+1)^(rho/(rho-1)));

c = (1-l)* (phi/(1-phi))*(a*k(-1)^alpha*gama*l^(gama-1)*g^(1-alpha-
gama))/(1+(theta/(1-theta))^(1/(rho-1))*p^(rho/(rho-1)));

e = c*(p*theta/(1-theta))^(1/(rho-1));

p=a*k(-1)^alpha*l^gama*(1-alpha-gama)*g^-(alpha+gama);

y = a*k(-1)^(alpha)*l^gama*g^(1-alpha-gama);

k = i + (1-delta)*k(-1);

y = c + i+p*g+p*e;

a = a (-1) ^omega*exp (u);

p = p (-1) ^psi*exp (v);

end;
```

```
initval;

k = 1.5;
y = 0.8;
a=1;
c = 0.6;
l = 0.4;
p=1;
i = 0.3;
e=0.33;
g=0.01;

end;

shocks;
var u = sigmae^2;
var v = tau^2;
end;

steady;
check;

stoch_simul (hp_filter=100, order=1, irf=100, relative_irf, periods=200);
```

Dynare Codes for Model 2

```
var p a  e g k l y i c;
varexo u v;

parameters alpha  gama  beta delta phi theta rho omega sigmae psi tau ;

alpha = 0.31;
gama = 0.65;
beta = 0.88;
delta = 0.025;
phi = 0.41;
theta = 0.8;
rho =-0.11;
omega = 0.95;
sigmae = 0.01;
psi = 0.95;
tau = 0;

model;

1/c = beta*(1/c(+1))*(a*alpha*k^(alpha-1)*l(+1)^gama*g(+1)^(1-alpha-gama)+1-
delta)* (1 +(theta/(1-theta))^(1/(rho-1))* p^(rho/(rho-1)))/(1+(theta/(1-
theta))^(1/(rho-1))*p(+1)^(rho/(rho-1)));

c = (1-l)* (phi/(1-phi))*(a*k(-1)^alpha*gama*l^(gama-1)*g^(1-alpha-
gama))/(1+(theta/(1-theta))^(1/(rho-1))*p^(rho/(rho-1)));

e = c*(p*theta/(1-theta))^(1/(rho-1));

p=a*k(-1)^alpha*l^gama*(1-alpha-gama)*g^-(alpha+gama);

y = a*k(-1)^(alpha)*l^gama*g^(1-alpha-gama);

k = i + (1-delta)*k(-1);

y = c + i+p*g+p*e;

a = a (-1) ^omega*exp (u);

p = p (-1) ^psi*exp (v);

end;


initval;
```

```
k = 1.5;
y = 0.8;
a=1;
c = 0.6;
l = 0.4;
p=1;
i = 0.3;
e=0.33;
g=0.01;

end;

shocks;
var u = sigmae^2;
var v = tau^2;
end;

steady;
check;

stoch_simul (hp_filter=100, order=1, irf=100, relative_irf, periods=200);
```

Dynare Codes for Model 3

```
var p a  e g k l y i c;
varexo u v;

parameters alpha  gama  beta delta phi theta rho omega sigmae psi tau ;

alpha = 0.31;
gama = 0.65;
beta = 0.88;
delta = 0.025;
phi = 0.41;
theta = 0.8;
rho =-0.11;
omega = 0.95;
sigmae = 0;
psi = 0.95;
tau = 0.01;

model;

1/c = beta*(1/c(+1))*(a*alpha*k^(alpha-1)*l(+1)^gama*g(+1)^(1-alpha-gama)+1-
delta)* (1 +(theta/(1-theta))^(1/(rho-1))* p^(rho/(rho-1)))/(1+(theta/(1-
theta))^(1/(rho-1))*p(+1)^(rho/(rho-1)));

c = (1-l)* (phi/(1-phi))*(a*k(-1)^alpha*gama*l^(gama-1)*g^(1-alpha-
gama))/(1+(theta/(1-theta))^(1/(rho-1))*p^(rho/(rho-1)));

e = c*(p*theta/ (1-theta)) ^ (1/ (rho-1));

p=a*k(-1)^alpha*l^gama*(1-alpha-gama)*g^-(alpha+gama);

y = a*k (-1) ^ (alpha)*l^gama*g^ (1-alpha-gama);

k = i + (1-delta)*k (-1);

y = c + i+p*g+p*e;

a = a (-1) ^omega*exp (u);

p = p (-1) ^psi*exp (v);

end;


initval;
```

```
k = 1.5;
y = 0.8;
a=1;
c = 0.6;
l = 0.4;
p=1;
i = 0.3;
e=0.33;
g=0.01;

end;

shocks;
var u = sigmae^2;
var v = tau^2;
end;

steady;
check;

stoch_simul (hp_filter=100, order=1, irf=100, relative_irf, periods=200);
```

Chapter 5

A Dynamic Stochastic General Equilibrium Analysis of Oil Price Shocks: The Case of Bangladesh

5.1 Introduction

Energy is a vital instrument for economy as it is used in some form almost in every activity. Consequently, analysing interactions of the energy sector and the overall economy has been the subject of much interest among the researchers. The conventional wisdom is that even though energy does not make up a major fraction of GDP, it plays a crucial role in economy since without energy nothing would be produced. The role of energy is important too on the consumer's side since many types of household products, especially durables are energy dependent (Tan, 2012). Thus, energy is a strategic determinant of economic progress. For example, the importance of oil in any economy, developed or underdeveloped, also became clear after the first oil shocks in 1973 which would have significant impact on the rest of the economy. Those oil shocks questioned the belief of having oil abundances across the world which would not affect the economy. In fact, given the pace of economic development in many countries and the increasing world population, the concern about oil keeps growing. Thus, since the beginning of the 80s, numerous researchers have tried to identify the channels through which such shocks impact economies.

Bangladesh has shown significant economic performances in recent past maintaining an average of 6.01% GDP growth rate since 2010. This strong performance mainly comes from rapid urbanisation, increased industrialisation, and development of microcredit, higher public investment and strong exports. Although the country has made remarkable progress achieving macroeconomic stability, Bangladesh continue to face challenges such as infrastructure deficits and energy (electricity) shortages. It is widely believed that the country could achieve even higher growth if it could provide better infrastructure including electricity. Energy is vital for economic growth in Bangladesh and also considered a key ingredient in improving the socioeconomic conditions. In Bangladesh, electricity is the most widely used form of energy and is the major source of power for most of the country's economic activities. However, since independence from Pakistan in 1971; the country has struggled to generate adequate electricity to meet demand. Generating and supplying electricity for the mass people remains and unresolved challenge for Bangladesh and government has implemented significant efforts to increase the electricity generation capacities. This is in line with government's commitment to provide reliable electricity for all citizens by 2021. As a result, electricity generation has increased some success over the last few years. The installed electricity generation capacity has increased to 11294 MW in 2015 compared to 5719 MW in 2009.

The recent improvement in power generation comes largely from the privately owned QR power plants. The government has allowed the QR power plants to generate electricity for short term contracts in order to mitigate the acute power crisis of 2009-2010. Most of these QR power plants were powered by imported oil. The other responsible authorities for generating electricity in Bangladesh are BPDB along with its subsidiaries and privately owned IPP companies. Both BPDB and IPP use natural gas to generate electricity. A competitive market environment has been created in Bangladesh for electricity generation and recently, nearly 54% of total electricity production originates from public sector power plants, whereas the private sector provides the rest of 46% as of January 2015 (BPDB, 2015). BERC is the responsible authority to fix the electricity prices for all the economic agents in Bangladesh.

Bangladesh is partly dependent on imported oil to generate electricity and international oil price has some effects on the QR power plants and rest of the economy through income and substitution effect. Any change in world oil market price is primarily faced by the government as the electricity generating firms enjoy a subsidised oil price. The domestic oil price follows the general trend of world prices after a while; however, prices in the domestic market are much less volatile than those in the world market. The government absorbs significant portions of the price volatility by providing subsidies on petroleum products. As expected, rising trends in international prices result in a higher import cost for petroleum products in Bangladesh. Nevertheless, the quantity of imports has continued to rise because of the QR firms' higher demand to generate electricity.

Moreover, private-public partnership is considered as a key instrument for the infrastructural development. The last 20 years have seen the rise to power of Public-Private Partnerships (PPPs) as a means of crowding in investment and expertise from the private sector to the delivery of public goods and services. PPPs are a mechanism that the governments regularly turn to in order to fulfil their responsibilities on public infrastructure and services (Colverson and Perera, 2012). According to World Bank (2007), private sector investment in infrastructure in developing economies grew steadily over the past decade. Energy, telecommunication and transport have mainly attracted larger share of investment. For example, Kenya's government has agreed to work with private investors to increase overall domestic electricity generating capacity by 5,000 MW by 2016. It is envisaged that this capacity will be made up of natural gas-fired plants (1,050 MW), geothermal (1,646 MW), wind (630 MW) and coal (1,920 MW).

In order to obtain quantitative results the usual practice is to calibrate models to a particular economy and we simulate the model for Bangladesh economy to analyse the impulse response functions to productivity and oil price shocks pertinent in Bangladesh economy. In particular, our model examines the macroeconomic impacts of international oil price shocks and higher productivity shocks in Bangladesh economy in a DSGE framework. Our results show that higher oil price have a negative effect on the economy through reducing all types of consumption and GDP. IRF from productivity shocks in different model variables shows that positive productivity shocks make the factors of production more productive and accordingly output, household welfare increases due to income effect.

In summary, the contribution of this chapter is the development of an energy augmented DSGE model for the oil importing developing countries that can be used to conduct different electricity policy related analyses. The main difference of this model and other energy models is the presence of government price setting mechanism, three different electricity generating sectors in addition to two production sectors which have not been experimented in energy literature till now. Our model further allows for fuel diversification which is highly realistic for a developing country's perspective and somehow overlooked in the literature. The inclusion of three electricity generating firms coupled with fuel mix options will help policymakers to distinguish between the role of private and public sector in the electricity generating firms. The model offer richness focusing on the fact that all the economic agents in the economy rely on energy either for household energy consumption or for firm's production. The model follows in the footsteps of computable general equilibrium modelling. It also serves as the groundwork for further research. Because the model enable deeper research into energy related matters such as electricity policy experiments and the role the macroeconomy of a developing country like Bangladesh.

The chapter is organised as follows. Section 5.2 focuses on the literature review. The DSGE model is presented in section 5.3; calibration and estimation of the parameters are discussed in section 5.4. Section 5.5 describes the solution algorithms. The results are analysed in the section 5.6. Finally, in the last section, we present the conclusions.

5.2 Literature Review

The effects of energy (oil) price changes on economic activity have been widely studied in economic literature. Although the term "energy" covers a wide range of products such as electricity, oil, natural gas, coal, biomass and other renewable sources, literature mainly focuses either on aggregate energy or oil (which is known as one of the most widely forms of energy) in investigating the energy macroeconomic relationship. Evidence from literature suggests that there exist multiple channels of transmission through which oil price shocks can affect the macroeconomy (Kilian, 2009). Sudden and prolonged oil price increases are generally accompanied by economic contractions and high inflation, as documented in Hamilton (1983, 1996, and 2003). Higher oil price generates income and substitution effect if oil is included in the consumption bundle of a typical household. This implies that an increase in oil prices slows economic development primarily through its effects on consumer spending. It is expected that higher oil prices reduce discretionary income, since consumers are left with less money to spend after having to pay for escalated energy bills. Higher oil prices are primarily driven by higher prices for imported energy goods. Changing oil prices may create uncertainty about the future path of the price of oil, causing consumers to postpone irreversible purchases of consumer durables (Bernanke, 2004 and 2006). Even when purchase decisions are reversible, consumption may fall in response to oil price shocks, as consumers increase their precautionary savings. This response may arise if consumers smooth their consumption because they perceive a greater likelihood of future unemployment and hence future income losses.

An oil price shock also affects a firm's decision regarding substitution of oil as an input to production with capital and labour hiring. The marginal costs of production faced by firms and their pricing decisions are affected because of higher oil price. In addition, substitution of oil with capital in the production process might influence decisions on capital accumulation, which may eventually lead to long run consequences. Shifts in expenditure patterns driven by the uncertainty effect and operating cost effect amount to allocative disturbances that are likely to cause sectoral shifts throughout the economy. Thus, an increase of oil price in world market tends to reduce the level of economic activity and if the economy is dependent on imported oil to generate electricity, it has several adverse consequences.

In the short run, higher oil price reduce country's economic output and increase inflation rate. In the medium and long run, industrial production is affected, consumption decreases due to the fall of purchasing power and investment also falls, affecting the cyclical position of the economy and household's welfare. Under these circumstances, negative world oil price shocks become one of the most important external uncertain sources of shocks which have intensive impact on the macroeconomy of a small developing oil importing country like Bangladesh.

There are some literature that focuses on the dynamic relationship between aggregate energy (oil), aggregate energy (oil) price and economic development. Since 1990, DGE models have been used to study the influence of fuel price on capital accumulation, economic development and welfare. Examples of this literature include Jorgenson (1998), He et al. (2010), Korhonen and Ledyaeva (2010), Tang et al. (2010), Backus and Crucini (2000), Brown and Yücel (2002), Medina and Soto (2005), Leduc and Sill (2004), Barsky and Kilian (2002), Blanchard and Gali (2007), Hamilton and Herrera (2004) and many others. Calibrated versions of these types of models have been used to assess the quantitative effects of energy (oil) price shocks on economic growth in different developed and developing countries. Alves and Pereira (2006) survey the literature on dynamic computational models with a focus on energy studies and reports their special features to identify and analyse the main areas of investigation in general equilibrium models applied to the environment and energy and to systematise and classify the existing bibliography in 2000s in a survey (between 1996 and 2006), since there are many surveys on previous literature already listed in Bhattacharya (1996).

Recent advances in the energy-macroeconomy literature show that the effects of higher oil price depend critically on the source of disturbance and the underlying cause of that disturbance. Following Cashin et al. (2014), one can identify two groups of explanatory factors as the main drivers of the evolution of oil prices: i) fast growing demand due to high global economic growth (Demand Shock); and ii) declining supply or expected production shortfalls in the future (Supply Shock). Each oil demand and oil supply shock has its own unique set of effects (Kilian, 2009). In the case of pure supply shocks, macroeconomic variables are affected by the oil supply disruption through higher oil prices. Hamilton

(1983) argues that exogenous oil price shocks were responsible for the post-war US recessions. However, if an increase in oil price is triggered by a demand shock, there might be additional transmission channels that affect the macroeconomic variables. For example, Unalmis et al. (2008) argue that the faster economic growth coming from higher productivity growth in developing countries ultimately raised oil demand of these countries, fostering the prices of oil in the world market which in fact, increased the import bills of the countries. Jang and Okano (2013) discuss how productivity shock in one country can affect another country (the shock transmission between two countries). They argue that in RBC/DSGE models, a foreign productivity can cause marginal cost to fall and natural level of output to increase in foreign country. This would reduce the price level in the short run and monetary authority would lower the nominal interest rate. Because of the cost channel, through which firms borrow money from financial intermediaries, a fall in the foreign interest rate increases domestic demand. It is also common to assume that the relationship between economic activity and oil prices is asymmetric (Herrera et al., 2015).

Hamilton (1983) first finds that most of US recessions were preceded by the increasing oil prices and accordingly he recommends that oil price shocks is the primary cause for recession. Kim and Loungani (1992) show that energy price shocks could explain about 20% of the output fluctuations in US economy. Rotemberg and Woodford (1996) argues that resultant large fall in output could be explained by an endogenous rise in the price mark up. Jian et al. (2010) reveal that the impact of oil price shocks in China's economy is one of the main sources of economic fluctuations and stronger than other economic shocks like monetary policy shocks, government spending shocks, tax rate shocks, consumer demand shocks and productivity shocks. De Miguel et al. (2003, 2005) show that the effect of oil price shocks can account for a significant percentage of GDP in most of the European countries where oil is included as an imported productive input. They further reveal that the increase in the relative price of oil has a negative effect on welfare, particularly in Southern European countries, which are historically associated with a lax monetary policy during oil crisis. Cuche-Curti et al. (2009) present a DSGE model of the Swiss economy. Negative of oil price shocks of 1% are found to create an immediate rise in quarterly inflation of 0.012%.

Finn (2000) shows that an increase in the price of energy works much like an adverse technology shock to induce contraction in economic activity. But the power and persistency of the force exerted by energy price shocks derives from the novel relationship between energy usage and capital services-energy is essential to obtaining the service flow from capital, and capital services play an important role in the economy. Pereira and Pereira (2011) find that increasing fuel prices lead to an increase in firm's operating costs in Portuguese economy which reduces energy consumption, employment and private investment and their results further indicate that higher fuel prices have a negative effect on long term growth. Tan (2012) observes significant effects of a supply-side shock to energy prices on the overall US economy confirming the important role of energy on both household side and producer side. However, Dhawan and Jeske (2007), Hooker (1996) and Schmidt and Zimmermann (2005) conclude that the modern economy, represented by the period after 1985, is very resilient to energy (oil) price increase. That means the actual hike in energy price has smaller impacts on inflation and economic activity than the oil price shocks of the 1970s.

Unalmis et al. (2008) argue that, among other reasons, one reason for the decline in the responsiveness of the economies of the oil price hikes could be offsetting positive effects of productivity increases on the negative effects of the rising oil price. Blanchard and Gali (2007) propose explanations for the observed change in the effects of the oil price shocks. First, they argue that labour markets are more flexible now than in the past, and hence some of the negative effects of the oil price shocks can be observed in the labour market. Second, more credible and stronger anti-inflationary stance of monetary policies may have kept inflation relatively stable.

One of the advantages of DSGE model is that one could isolate impacts of different exogenous shocks and answer some policy questions and accordingly these models have become more popular tool for macroeconomic analysis in recent years to evaluate economic fluctuations. Henceforth, this chapter presents a new energy augmented DSGE model, a complete structural analytical framework, to shed light on impacts of oil price shocks and sectoral productivity shocks on the developing economies like Bangladesh economy. A vast of energy literature shows that developing countries are facing more economic crisis than the industrialised countries because of higher oil price (Abeysinghe, 2011 and Anciaes et al., 2012). In many developing and emerging market economies, governments control electricity, oil and fuel prices and intervene to limit the degree to which oil-price increases are passed through to domestic fuel prices. Many of these policies sought to avoid the full pass-through of oil-price increases to domestic consumers by controlling retail fuel prices, providing explicit fuel subsidies, lowering fuel taxes, and reducing the profit margins of state-owned oil companies. According to World Bank (2007) and Baig et al. (2007), roughly half of the developing and emerging market economies surveyed have not fully passed through the increase in international fuel prices between the ends of 2003 and mid-2006. In contrast, in most industrialised countries, governments have abstained from intervening in the oil market, opting to maintain a full-pass-through policy.

Sectoral productivity has been included in our model since fluctuations in aggregate economic activity result from a wide variety of disaggregated phenomena such as process innovation, product innovation, and fundamental productivity changes etc. (Caliendo et al., 2014). Productivity changes are actually specific to a sector and a location. The heterogeneity of these potential productivity changes at the electricity firms implies that the particular sectoral and regional composition of an economy is essential in determining their aggregate impact.

Our DSGE model incorporates households, production sector, government sector and an energy sector. The model assumes a mixed economy where government controls the electricity and fuel prices. In addition, we distinguish between industrial and service production sector; household consumption in between electricity consumption, non-electricity consumption and service consumption. The model also considers public and private electricity generating firms in energy sector depending on their usage of fuel to produce electricity as we allow for fuel diversification in electricity generating firms.

These features are mainly significant for developing countries perspective as electricity supply in these countries comes from both private and public electricity generating companies and most of the developing countries now opt for fuel-mix options to reduce dependency on mono fuel to generate electricity. To the best of our knowledge, no previous DSGE literature has considered the feature of electricity and fuel price controlling mechanism (even in the case of USA). Furthermore, oil imports are explicitly modelled in the economy wide resource constraint and the domestic electricity production functions.

5.3 The Model

The model considered in this chapter is a Dynamic Stochastic General Equilibrium (DSGE) model of a small economy populated by a large number of infinite lived households and firms that need to import oil to generate electricity. Electricity is also generated by locally produced natural gas. There are four sectors in the economy- the production sector, the household sector, the energy sector and the government sector. All four sectors are interconnected through market equilibrium conditions. However, government needs to intervene in the market and fix the electricity and fuel price faced by the electricity generating firms and electricity consumers to clear the electricity market. Economic agents are price takers in all markets and are assumed to have perfect foresight. The economy is open and small in the sense that its behaviour does not affect the rest of the world. This implies that international price, the foreign interest rate and foreign demand are not affected by domestic agents' decisions. Considering the oil price as exogenous is the most sensible hypothesis in this context. Shocks in the price of oil and productivity across the sectors are main sources of fluctuation in the economy. The basic structure of the model in terms of technology is similar in its set up to Kim and Loungani (1992). Energy (electricity) enters in the model as consumption good for households and as a productive input for firms in the form of oil and natural gas.

Various well known functional forms, such as the Cobb Douglas (CD) function, the Constant Elasticity of Substitution (CES) function, are used frequently in economic modelling. Traditionally, these functional forms have been used to model the production side or consumption side of macroeconomic models. All of the estimated parameters in the CES and CD models have a behavioural interpretation. This means that if the model is not internally consistent, then these parameters are not describing a meaningful economic relationship. CD is widely used in economic literature as it gives simple closed form solutions to many economic problems. However, some economists believe that CES may be a more appropriate choice since empirical and theoretical work has often questioned the validity of the CD in a model (Miller, 2008). Additionally, the flexibility of the CES function to choose the value of the elasticity of substitution over the unitary has contributed to its popularity in DSGE modelling. We also assume a CES function to describe our utility and production function in this chapter.

We now turn to the discussion of the details of the model which are presented in **Table 5.1.**

5.3.1 The Production Sector

There are three production sectors in the model: a service sector and an industrial sector where final goods are being produced using electricity as an additional productive input which is produced in the third sector, the energy sector. Final output in each sector is produced with a CES technology, exhibiting Decreasing Returns to Scale (DRS) in the inputs-labour, capital and electricity in the industry and service sector. Since the firms face fixed fuel prices controlled by the government, DRS is more rational in this framework. Some DSGE studies also assume DRS in their production function (Rotemberg and Woodford, 1996 and Jaaskela and Nimral, 2011).

The representative firm uses labour (l), capital (k) and electricity (j) to produce the final good of the respective sector. The production function of the firms combines capital, electricity and labour. It is defined as: F (G (K_t, j_t) l_t) where G (.) is a CES function and F (.) a

Cobb Douglas production function, K_t the capital input, j_t the energy input, electricity, l_t the labour input. It is noteworthy that we follow Rotemberg and Woodford (1996) and do not allow the multiplier effect transiting through variable capital utilisation as explained by Finn (2000).

The production technology of the firms is described by a CES function with DRS:

$$F_i(l_{i,t}, k_{i,t}, j_{i,t}) = A_t^i . l_{i,t}^{\alpha_i}[(1-\Psi_i)k_{i,t}^{-\nu^j} + \Psi_i j_{i,t}^{-\nu^j}]^{-\frac{(\vartheta^i)}{\acute{\upsilon}^{jj}}}$$

Where A_t^i is the stochastic productivity shock, i= respective sectors (Y or X), j= electricity used by the respective sectors (g or s). α_i is the labour share, ψ_i represents the importance of electricity with respect to capital, $\acute{\upsilon}^{jj}$ implies the degree of homogeneity in the CES production function and $\frac{1}{1+\nu}$ is the elasticity of substitution between capital and electricity which determines the degree of substitutability of capital and electricity. In order to hold the DRS assumption, following two conditions need to be met[6]:

1. $\vartheta < 1 - \alpha$
2. $\frac{\nu}{\acute{\upsilon}} < 1$

Following Kim and Loungani (1992), we specify the production function in industry and service sector as follows:

$$Y = A_t^Y l_{Y,t}^{\alpha_Y}[(1-\Psi_Y)k_{Y,t}^{-\nu^g} + \Psi_Y g_t^{-\nu^g}]^{-\frac{\vartheta^Y}{\acute{\upsilon}^{gg}}} \quad \text{[Industrial Sector]}$$

$$X = l_{X,t}^{\alpha_X}[(1-\Psi_X)k_{X,t}^{-\nu^s} + \Psi_X s_t^{-\nu^s}]^{-\frac{\vartheta^X}{\acute{\upsilon}^{ss}}} \quad \text{[Service Sector]}$$

All the firms except for the government operate under perfect competition and maximises profits as following:

---

[6] See Technical Appendix 5B for the derivation.

$$\text{Max } \pi_{i,t} = P^i . A_t^i . l_{i,t}^{\alpha_i} [(1 - \Psi_i) k_{i,t}^{-\nu^j} + \Psi_i j_{i,t}^{-\nu^j}]^{-\frac{(\vartheta^i)}{\upsilon^{jj}}} - rk_i - wl_i - v^j . j$$

Where w is the wage rate, r is the capital interest rate and v is the market price of electricity. Wage and capital interest rate are assumed to be equalised across all the sectors. The price of the final good is normalised to 1, thus v^j can be considered as the relative electricity price.

From firm's maximisation problem, we obtain the following equilibrium conditions which state that the marginal productivity of labour, capital and electricity are equal to the wage, the interest rate and the electricity price respectively.

$$w_t = \frac{\partial F(l_t, k_t, j_t)}{\partial l_t}$$

$$r_t = \frac{\partial F(l_t, k_t, j_t)}{\partial k_t}$$

$$v_t = \frac{\partial F(l_t, k_t, j_t)}{\partial e_t}$$

On the other hand, Government faces the following cost minimisation function:

$$c_G = wl_G + rk_G + v^m . m_{G,t} - P^G . A_t^G l_t^{\alpha_G} [(1 - \Psi_G) k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\nu^{m,GG}}}$$

5.3.2 The Energy Sector

Energy enters in the model as electricity consumption for households and as a productive input for firms in the form of oil and natural gas. Additionally, three different electricity generating firms have been considered in the model for the case of Bangladesh. This represents 89% of the total electricity generated in Bangladesh. The three electricity generating companies are i) Bangladesh Power Development Board (BPDB) which represents government sector and mainly use natural gas to produce electricity, ii)

Independent Power Producer (IPP) which represents private sector and uses natural gas in electricity production and finally, iii) Quick Rentals (QR) which represents private sector and uses oil to produce electricity.

Similar to the production function used by Kim and Loungani (1992), we employ a CES production function for different electricity generating firms in this model. Each electricity generating firms transform the three factor inputs- labour, capital and energy (gas, m or oil, h) into electricity according to the following specification:

BPDB: G=$A_t^G l_t^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}}+\Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\nu^{m,GG}}}$

IPP: I=$A_t^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\nu^{m,II}}}$

QR: H= $A_t^H l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-\nu^h}+\Psi_H h_t^{-\nu^h}]^{-\frac{\vartheta^H}{\nu^{hh}}}$

The parameter ν^i (i=m, h) depends on the elasticity of substitution between capital and energy (gas or oil). Labour's distributive share is given by the parameter α_i(i=G, I, H) and Ψ_i(i=G, I, H) is the share of oil/gas in production aggregation where $\Psi \in(0, 1)$. A certain amount of electricity (x) is lost while transmitting by the distribution companies to the end consumers. So, equilibrium in electricity market:

$$e+s+g=A_t^G{}_{G,t}^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}}+\Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\nu^{m,GG}}}$$

$$+A_t^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\nu^{m,II}}}$$

$$+A_t^H l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-\nu^h}+\Psi_H h_t^{-\nu^h}]^{-\frac{\vartheta^H}{\nu^{h,h}}}-x(H+I+G)$$

5.3.3 The Household

In the model economy there are an infinite number of identical households and the representative household maximises the expected value of future utility. The household gets utility from consuming three types of consumption goods: electricity oriented goods (e), non-electricity oriented goods (c) and service goods(x) and all three types of goods are imperfect substitutes in the consumption basket. Electricity oriented goods, e, can be considered as the consumption of electricity which enhances other consumption in a non-perfect substitutable manner. Another way of thinking behind the rationality of introducing electricity oriented goods is to assume implicitly the presence of durable goods as household requires electricity to operate many durable goods. The household uses the following aggregator function to combine these three types of consumption into consumption aggregator:

$$c_t^A = X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}$$

Where $\theta \in (0, 1)$ and $\rho \leq 1$. With this aggregation function, the elasticity of substitution between c and e is $\frac{1}{1-\rho}$ and θ is the share of non-electricity oriented consumption in the household aggregator. The elasticity of substitution between services and the composite of electricity and non-electricity consumption is 1 in our model. The parameter γ represents the share of service consumption in the consumption aggregator. This is similar to the aggregator function used by Dhawan and Jeske (2007), who include consumption of nondurables and services excluding energy, the flow of services from the stock of durables goods and energy goods. So, we write the period t utility function as follows:

$$U\left(c_t^A, l_t\right) = \varphi \log c_t^A + (1-\varphi)\log(1-l_t)$$

Where $\varphi \in (0, 1)$. This log-utility specification is the same as in Kim and Loungani (1992). Notice that household's endowment of time is normalised to 1 so that leisure is equal to 1-l. The momentary utility function is assumed to have the usual properties of monotonicity and quasi concavity. The household has four primary sources of income: 1) the income derived from selling capital stock, 2) labour income, 3) The lump sum transfer payment ъ, it receives from the government and 4) dividends. Capital and labour income are taxed at the rates τ^k *and* τ^l respectively. The price of service goods and electricity are n and q^e respectively.

So, the household resource constraint is defined as follows:

$$k_{t+1} + c_t + n.X_t + q_t^e.e_t = (1 - \tau^l)wl_t + \text{ъ} + (1 - \tau^k)rk_t + (1 - \delta)k_t + \pi$$

Where δ is the depreciate rate.

Thus, the representative household maximises expected utility subject to the following resource constraint:

$$\text{Max } E \sum_{t=0}^{\infty} \beta^t \varphi \log\left[X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right] + (1-\varphi)\log(1 - l_t)$$

subject to

$$k_{t+1} + c_t + nX_t + q_t^e.e_t = \left(1 - \tau^l\right)wl_t + \text{ъ} + \left(1 - \tau^k\right)rk_t + (1 - \delta)k_t + \pi$$

Where β^t is the discount factor.

The Lagrangian constrained for the household can be defined as follows:

$$L = \sum_{t=0}^{\infty} \beta^t[(\varphi \log\left[X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right]) + (1-\varphi)\log(1 - l_t)] - \lambda_t[k_{t+1} + c_t + nX_t + q_t^e.e_t - \left(1 - \tau^l\right)wl_t - \text{ъ} - \left(1 - \tau^k\right)rk_t - (1 - \delta)k_t - \pi]$$

Where λ_t is the Lagrange multiplier and the function is maximised with respect to c_t, k_{t+1}, e_t, l_t, X_t and λ_t.

The subsequent Euler equations are as follows[7]:

$$\frac{c_{t+1}}{c_t} = \beta[(1-\tau^k)r_{t+1} + (1-\delta)]\frac{1 + (\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.q_t^{e\frac{\rho}{\rho-1}}}{1 + (\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.q_{t+1}^{e\frac{\rho}{\rho-1}}}$$

$$\frac{c_t}{1-l_t} = \frac{\varphi(1-\gamma)}{(1-\varphi)}.\frac{1}{1 + (\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}}.w(1-\tau^l)$$

The Euler equation interprets that the marginal disutility of reducing consumption in current period should be equal to the discounted utility from future consumption. The Euler equation in relation to leisure interprets that the disutility from additional working hour should be compensated by an increase in utility due to producing extra output.

5.3.4 The Government

The government earns revenue from taxing labour income, capital income, selling natural gas to other electricity generating firms and selling electricity to the national grid. On the expenditure sides, the government purchases labour, capital and gas for its own electricity production and makes a lump sum transfer to households. Capital taxes in the model are raised on asset returns of household and not on capital stock in the production sector as mentioned by Glomm and Jung (2013). Government provides subsidy to the electricity producer to fill the gap between the world oil price (v^e) and domestic oil price(v^h) faced by the producer. Additionally, there is also an extraction cost of gas (δ^C) which is the actual cost of true gas price to control the use of free resource (Natural Gas). The government, like any other entity in the economy, must satisfy a resource constraint.

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[7] The derivation is included in Technical Appendix 5B.

$$\tau^{l}.w.l + \tau^{k}.r.k + (v^{m} - \delta^{C})(m^{I} + m^{G}) + (v^{h} - v^{e})h$$

$$+ P^{G}A_{t}^{G}[l_{t}^{\alpha_{G}}(1 - \Psi_{G})k_{G,t}^{-\nu^{m,G}} + \Psi_{G}m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^{G}}{\nu^{m,GG}}} - rk_{G} - wl_{G} - v^{m}.m^{G} - ъ = b$$

Following the internationally accepted definition of subsidy, one can identify two major types of subsidies that are provided by government: subsidies designed to reduce the cost of consuming energy (electricity) and fuel subsidies aimed at supporting domestic production (Ellis, 2000). The IEA defines subsidy that lower the price consumers pay for oil products, natural gas, coal or electricity generated with one of those fuels. In this chapter, we assume that government has to provide subsidy as it purchases electricity from the electricity producers at a high price and distributes it at a low price among the consumers. So, the negative of total subsidy is:

$$-b = q^{e}.e + q^{s}.s + q^{g}.g - P^{H}.A_{t}^{H}l_{H,t}^{\alpha_{H}}[(1 - \Psi_{H})k_{H,t}^{-\nu^{h}} + \Psi_{H}h_{t}^{-\nu^{h}}]^{-\frac{\vartheta^{H}}{\upsilon^{hh}}}$$

$$- P^{I}.A_{t}^{I}l_{I,t}^{\alpha_{I}}[(1 - \Psi_{I})k_{I,t}^{-\nu^{m,I}} + \Psi_{I}m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^{I}}{\upsilon^{m,II}}}$$

$$- P^{G}A_{t}^{G}[l_{t}^{\alpha_{G}}(1 - \Psi_{G})k_{G,t}^{-\nu^{m,G}} + \Psi_{G}m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^{G}}{\upsilon^{m,GG}}}$$

Finally, combining household resource constraint, government resource constraint and the subsidy equation, the economy wide resource constraint can also be derived. (For more details of the derivation, please see Technical Appendix 5B)

$$k_{t+1} = A_{t}^{Y}l_{Y,t}^{\alpha_{Y}}[(1 - \Psi_{Y})k_{Y,t}^{-\nu^{g}} + \Psi_{Y}g_{t}^{-\nu^{g}}]^{-\frac{\vartheta^{Y}}{\upsilon^{gg}}} - c_{t} - v^{e}.h + (1 - \delta)k_{t} - \delta^{C}(m^{I} + m^{G})$$

5.3.5 Model Shocks

The basic model is driven by five different shocks: an oil price shock and productivity shocks affects the industrial and three electricity generating firms.

Just as Cooley and Prescott (1995), the stochastic productivity shock A^i across sectors is assumed to be:

$\ln A_t^Y = \text{'}\Omega^Y + \mu^Y \ln A_{t-1}^Y + \eta_t^y$ (Productivity Shocks in Industrial Sector)

$\ln A_t^G = \text{'}\Omega^G + \mu^G \ln A_{t-1}^G + \eta_t^G$ (Productivity Shocks in Government Sector)

$\ln A_t^I = \text{'}\Omega^I + \mu^I \ln A_{t-1}^I + \eta_t^I$ (Productivity Shocks in IPP)

$\ln A_t^H = \text{'}\Omega^H + \mu^H \ln A_{t-1}^G + \eta_t^H$ (Productivity Shocks in QR)

In all the cases, the residuals are normally distributed with standard deviation of one and zero mean.

The world price of oil imported in the economy, v^e, is exogenously given and follows AR (1) process:

$\ln v_t^e = \text{'}\Omega^v + \omega \ln v_{t-1}^e + \kappa_t$; where κ_t is normally distributed with standard deviation one and zero mean.

5.4 Dataset, Parameter Specification and Calibration

In order to obtain a numerical solution, model calibration is necessary. Hence, the model is calibrated following Kydland and Prescott (1982). The model is implemented numerically using detailed data and parameter sets. The dataset is reported in **Table 5.2** and reflects the variable values for 2011-2012. The data needed to calibrate the model for Bangladesh economy comes from Bangladesh Bureau of Statistics (BBS), Bangladesh Economics Review (BER), World Development Indicator (WDI), Bangladesh Labour Force Survey (BLFS), Bangladesh Power Development Board (BPDB), Bangladesh Petroleum Corporation (BPC), Summit Power Limited, Dutch Bangla Power and Associates Limited and Bangladesh Tax Handbook.

Parameter values are reported in **Table 5.3** and are specified in different ways. Wherever possible, parameter values are taken from the available data sources. This is the case, for example, consumer prices of electricity, producer prices of electricity, world and domestic market price of oil, domestic price of natural gas, extraction cost of natural gas, fraction of system loss in electricity and the different effective tax rates.

In some cases, the parameters are chosen freely from the literature and thus are not implied by the steady state restrictions. This is the case, for example, the discount rate, the elasticity of substitution and the persistent coefficient of the different shocks. Although free, these parameters have to be carefully chosen since their values could not affect the values of the remaining calibration parameters. Accordingly, they were chosen either using central values or using available data as guidance. The remaining parameters are obtained by calibration in a way that the real picture of the economy is extrapolated as the steady state trajectory.

There are 58 parameters in total with 32 structural parameters, 15 shock related parameters and 11 policy related parameters in our model. Structural parameters can be categorised into utility and production function related parameters. It is important to have a good understanding of the rationale behind picking different parameter values in order to properly evaluate the fit of the model. Let us briefly describe our procedure for selecting parameter values used in the chapter.

First of all, we discuss parameters related to production. Alpha (α), Psi (ψ), nu (ν) and depreciation (δ) are the main parameters related to production (**See Table 5.3**). Since the model has two different sectors namely industry and service sector and three different electricity generating firms, we need to calculate different alpha for each sector. The labour share is defined as the share of value added which is paid to workers (Schneider, 2011). Following Roberts and Fagernas (2004), we set the labour distributive share of industrial sector, α_Y equals to 0.2 using the following first order condition: $w = \alpha_Y . \frac{Y}{l_{Y,t}}$. The labour distributive share in the service sector, α_X-can be calculated using the first order conditions; considering share of labour in service sector from data and calculating the ratios of $\frac{wl}{Y}$ and $\frac{nX}{Y}$ as follows:

$$\frac{\omega_1^x}{\omega l} = \frac{nX}{Y} . \alpha_X . \frac{1}{\frac{\omega 1}{y}}$$

Given $\frac{\omega_1^x}{\omega l} = 0.719460$; $\frac{nX}{Y} = 1.658839$ and $\frac{\omega 1}{y} = 0.722841$, we can estimate α_X equals to 0.313505.

Given the value of total labour cost (wl_i) and total revenue in the IPP and QR, the labour distributive share of different electricity sector can be calculated as follows:

$$\alpha_I = \frac{wl_{I,t}}{p^I I} = 0.036183$$

$$\alpha_H = \frac{wl_{H,t}}{p^H H} = 0.004125$$

Here it is worth noting that, in chapter 4, we have considered a highly aggregated economy where labour share was considered 0.65 as observed in Bangladesh Household Labour Force Survey, 2015. However, in this chapter, we have focused on a multi sector economy and calibrated labour shares are significantly different from what we observed in previous chapter. Sonja and Roberts (2004) show that labour costs per employee in industry in Bangladesh are remarkably low. Moreover, energy sector in Bangladesh is less labour intensive as observed in Ahmed et al. (2009). Since the labour share calibration in this chapter is based on the sectoral employment data, these are dramatically different from chapter 4. Guerriero (2012) estimate the labour share of income around the world within a range of 0.035 and 0.9.

We estimate $\nu^{h}, \nu^{m.i}, \nu^{m,g}, \nu^{Y}$ and ν^{X} equals to 0.1 from Thompson and Taylor (1995). Here, ν^{i}= (1-1/η) where η is the elasticity of substitution between capital and electricity in the production function. Additionally, we also assume that $\acute{\upsilon}^{hh}$, $\acute{\upsilon}^{m.ii}$, $\acute{\upsilon}^{m,gg}$, $\acute{\upsilon}^{YY}$ and $\acute{\upsilon}^{XX}$ equals to 0.2 to fulfill DRS. $\acute{\upsilon}^{jj}$ implies the degree of homogeneity in the CES production function. Thus if $\acute{\upsilon}^{jj}<1$, we have DRS.

Calculation of ψ involves two different approaches for production sectors and the energy (electricity) sectors. The main variance of the approaches is due to differences in data in the calculation process. For example, the share of electricity used in industrial production, Ψ_{Y}, can be calculated by employing the first order conditions and DRS assumptions.

Decreasing Returns to Scale (DRS) in industrial production implies: $Y > rk^{Y}+wl^{Y}+ q^{g}.g$. This can be rewritten as $\frac{rk^{Y}}{Y} < 1-\frac{wl^{Y}}{Y}-\frac{q^{g}.g}{Y}$.

Now, given the value of $\frac{wl^{Y}}{Y}$, $\frac{q^{g}.g}{Y}$ we can estimate $\frac{rk^{Y}}{Y}$. From the first order conditions, we obtain:

$$r = (\vartheta^{Y}\frac{\nu^{g}}{\acute{\upsilon}^{gg}})\frac{(1-\Psi_{Y})k_{Y,t}^{-\nu^{g}-1}.Y_{t}}{(1-\Psi_{Y})k_{Y,t}^{-\nu^{g}}+\Psi_{Y}.g_{t}^{-\nu^{g}}}$$

Alternatively we can express it as:

$$\frac{rk^{Y}}{Y} = \frac{(\vartheta^{Y}\frac{\nu^{g}}{\acute{\upsilon}^{gg}})(1-\Psi_{Y})}{(1-\Psi_{Y})+\Psi_{Y}(\frac{k_{y,t}}{g_{t}})^{\nu^{g}}} \text{ where, } \frac{k_{y,t}}{g_{t}} = \frac{q^{g}}{r}.\frac{rk^{Y}}{Y}.\frac{Y}{q^{g}.g}$$

Now, given the value of $q^{g}, r, \frac{rk^{Y}}{Y}, \frac{Y}{q^{g}.g}, \alpha_{Y}, \nu^{g}$ and $\acute{\upsilon}^{gg}$, we can calculate the value of Ψ_{Y} equals to 0.073398. In the similar fashion we can also find Ψ_{X}=0.079017.

Then, let us move on to the calculation of share electricity used in energy (electricity) sector which have three different electricity generating firms. Here, we require the value of total revenue, total labour cost and total cost of sales to estimate Ψ_I, Ψ_H and Ψ_G. Using the first order condition and holding DRS assumptions, we obtain:

$$r = (\vartheta^I \frac{\nu^{m,I}}{\acute{\upsilon}^{m,II}}) \frac{p^I(1-\Psi_I)k_{I,t}^{-\nu^{m,I}-1}.I}{(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I.m_{I,t}^{-\nu^{m,I}}};$$

$$\frac{r\,K^I}{P^I.I} = \frac{(\vartheta^I \frac{\nu^{m,I}}{\acute{\upsilon}^{m,II}})(1-\Psi_I)}{(1-\Psi_I)+(\frac{K_I}{m_I})\nu^{m,I}} \text{where}$$

$$\frac{K_I}{m_I} = \frac{r\,K^I}{P^I.I}.\frac{P^I.I}{v^m.m}.\frac{v^m}{r} \text{ implies}$$

$$\frac{K_I}{m_I} = \frac{r\,K^I/P^I.I}{P^I.I/v^m.m}.\frac{v^m}{r};$$

Given the value of $\frac{rK^I}{P^I.I}$, $\frac{P^I.I}{v^m.m}$, v^m, r, α_I, and $\nu^{m,I}, \acute{\upsilon}^{m,II}$ we can calculate Ψ_I equals to 0.309381. Similarly we can also find Ψ_H=0.596484.

Finally, given the value of different ratios and using the following two first order conditions, we can estimate Ψ_G equals to 0.302053 and α_G equals to 0.042063.

$$v^m.\alpha_G[(1-\Psi_G)k_{G,t}^{-\nu^m} + \Psi_G.m_{G,t}^{-\nu^m}] = (\vartheta^G \frac{\nu^{m,G}}{\acute{\upsilon}^{m,GG}}).\Psi_G.m_{G,t}^{-\nu^m-1}.l_G.w$$

$$r.\Psi_G..m_{G,t}^{-\nu^m-1} = (1-\Psi_G)k_{G,t}^{-\nu^m-1}.v^m$$

Depreciation rate is usually very low in the developing countries. Thus, depreciation rate, δ has been set at 0.025 implying that the overall depreciation rate in Bangladesh is 2.5% annually. This value is equally realistic from the perspective of the developing countries. Prescott (1986) and Kydland and Prescott (1991) also measure the value of δ to be 0.025.

Now, we discuss parameters related to household utility. Given the value of q^e, ρ, and the ratio of $\frac{e}{c}$ calculated from data, we can obtain θ (equals to 0.911090), the share of non-electricity consumption in household aggregator using the following Euler equation:

$$\frac{e_t}{c_t} = (q_t^e.\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}$$

Given the ratio $\frac{nX}{c}$, q^e, ρ and θ, the share of service aggregator γ (equals to 0.811011), can be calculated using the following Euler equation:

$$\frac{c_t}{nX_t} = \frac{1-\gamma}{\gamma}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}}$$

φ reflects the share of electricity consumption and non-electricity consumption goods in the household's utility function and its value is calculated 0.607675 as follows:

The intra-temporal efficiency condition (the labour-leisure) trade off implies that the marginal rate of substitution between labour and consumption must equal the marginal product of labour. That means,

$$\frac{U_l}{U_c} = F_l$$

$$\frac{c_t}{1-l_t} = \frac{\varphi(1-\gamma)}{(1-\varphi)}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}}.w(1-\tau^l)$$

$$\geqslant \frac{(1-\varphi)}{\varphi} = \frac{(1-\gamma).\theta.(1-l_t).\frac{wl}{Y}.\frac{(1-\tau^l)}{l}.\frac{Y}{c}}{\theta+(1-\theta)(\frac{e_t}{c_t})^p}$$

Certain standard parameters are calibrated following standard literature. To begin with, since the length of a period in the model is taken to be one year, β, the discount factor, is set to 0.96 which is quite standard in DSGE literature (Heer and Mausser, 2009). We repeat the sensitivity analysis along three different discount parameters (β=0.88, β=0.96 and β=0.99) and confirm that our results are robust to a wide range of possible β values (**See Table 5.4**). This implies a real interest rate of 7.6%. The capital and labour income tax rates $\tau^k$and τ^l are set as 0.15 and 0.10 as mentioned in Bangladesh Tax Handbook 2012. Next, the household consumer price of electricity, q^e, the industry consumer price of electricity, q^g and the service consumer price of electricity, q^s are taken as 4.93 Taka/Kwh, 6.95 Taka/Kwh and 9.00 Taka/Kwh respectively from Bangladesh Power Development Board (BPDB) for the year 2012. The selling price of electricity by QR (P^H), and IPP (P^I) are set as 7.79 Taka/Kwh and 3.20 Taka/Kwh respectively, which is taken from Dutch Bangla Power and Associates and Summit Power Limited Company. However, the selling price of electricity by PDB (P^G) is calibrated using the country data which is equal to the value of 2.307534.

Finally, the world market price of oil, v^e and domestic market price of oil, v^h are calculated as 8.19 Taka/Kwh and 5.72 Taka/Kwh respectively from Bangladesh Petroleum Corporation (BPC) which is also consistent with the data obtained from Dutch Bangla Power and Associates. The market price of natural gas (v^m) is considered to be as 0.7755 Taka/Kwh, taken from Summit Power Limited Company. The extraction cost of gas, δ^c is set to be equal to the world gas price which is 1.1 Taka/Kwh.

Due to unavailability of the data of working hours, we set l=0.33 with an assumption that people work about one-third of their time endowment which is a widely accepted value for RBC/DSGE analysis. For example, l is set equal to 0.30, consistent with the time-allocation measurements of Ghez and Becker (1975) for the US economy. In this chapter, the household's utility function follows a general CES form, meaning that it cannot be used to model an elasticity of substitution of exactly 1. Following Tan (2012) here, it is set at 0.9 for the main analyses, and the CES parameter of the household's utility function, ρ, is therefore -0.11(1-(1/0.90)), which is negative and indicates that electricity and non-electricity consumption are somewhat complementary.

Owing to the unavailability of data, following King, Plosser and Rebelo (1988), we set the persistence of our exogenous shocks to 0.95 and standard deviation of the shocks to 0.01. Using different series, empirical literature get a range of estimates for persistence 0.85-0.95 and standard deviation 0.0095-0.01. We assume that productivity and oil shocks follows a mean zero AR (1) process in its natural log, with an i.i.d disturbance which is standard in DSGE literature (Tan, 2012).

5.5 Solution Algorithm

Solving DSGE models remain a wide area of research (Flotho, 2009). Both theoretical and computational issues are explored when setting up a DSGE model and applying it for macroeconomic analysis for analysing various questions in macroeconomics. In general, solving DSGE models follow the same solution procedure no matter what kind of model is analysed. After having identified the model's assumptions, the first-order equilibrium conditions have to be derived. The idea is that together with the structural equations, the non-linear system of optimality conditions and resource constraints are converted to a linear system of equations via a linear approximation of all equations in the neighbourhood of the non-stochastic steady state. Then a solution to the linear system is derived, which is an approximation to the solution of the underlying problem in the near of the stationary point. Finally, in order to analyse the performance of the model, impulse response functions or second moments are computed. The core of solving DSGE models consists of finding the solution of these linear systems of equations.

We use the stochastic perturbation method (log linearisation around the deterministic steady state) put forward by Collard and Julliard (2001) in order to approximate the dynamics of our model economy. In a nutshell, the main idea of perturbation methods is to replace the original difficult problem with a simpler one which is much easier to handle and solve. Then the solution of the simpler model is used to approximate the solution of the problem of interest. To be more precise, in practice this method refers to finding Taylor expansion of the policy function describing the dynamics of the variables of the model around the deterministic steady state. Judd (1998) refers to solution methods including the calculation of smooth Taylor series approximation to the solution of the equations as "perturbation methods".

From the Euler equations and the other relevant model equations in **Table 5.1** and the first order conditions in **Table 5.5**, we derive twenty eight equations guiding the dynamic behaviour of twenty eight endogenous variables plus five equations for the shocks. Since DSGE literature calibrates not only the parameter values but also the fundamental steady state variables (which Dynare consider as initial values), we follow the same procedure. The calculated steady state values are listed in **Table 5.6** along with the Dynare generated results. However, Dynare can solve models without setting up the steady state and by guessing initial values for the endogenous variables. In the same fashion, the RBC/DSGE model can be solved recursively by using initial value and given the Steady State (SS) results (Levine and Yang, 2012). In order to solve the models to generate a first order approximation for the policy function (See Adjemian et al., 2011 and Collard and Julliard, 2011 for the methodological details) and to conduct stochastic simulations, we run the program Dynare version 4.4.3-a pre-processor and a collection of Matlab routines. These routines linearise the system around its deterministic steady state and perform a second order Taylor approximation as argued by Schimitt and Uribe (2004). The Dynare codes are given in **Table 5.7**.

5.6 Results

In order to evaluate the performance of our model, i) we will compare steady state ratios from the models with their empirical counterpart and ii) analyse the impulse response function of different shocks.

Our model shows that most of the relevant variable ratios in steady states are fairly close to the actual data (**Table 5.8**). The model does a good job at matching the model generated ratios to the actual variable ratios in the industrial sector, service sector, IPP sector and government sector as showed in data. However, our model undershoots the ratio values in the QR sector by a small extent.

After considering the steady state ratios for our model with their empirical counterparts, finally we take a brief look at the Impulse Response Functions (IRF) generated in response to the productivity and oil price shocks. It is worth noticing that, IRF shows the expected future path of the endogenous variables conditional on a shock in period 1 of one standard deviation.

The model introduces five exogenous shocks, namely, oil price shock, productivity shocks in industry, BPDB, IPP and QR power plants. In this section, we analyse the impacts of the five shocks on the model variables through the impulse response functions. The impulse responses show deviations of key model variables from their steady state upon the positive exogenous shocks of one standard deviation. All the vertical axes are multiplied by 100, indicating the percentage deviation of the endogenous variables from their steady state values (Jian et al., 2010).

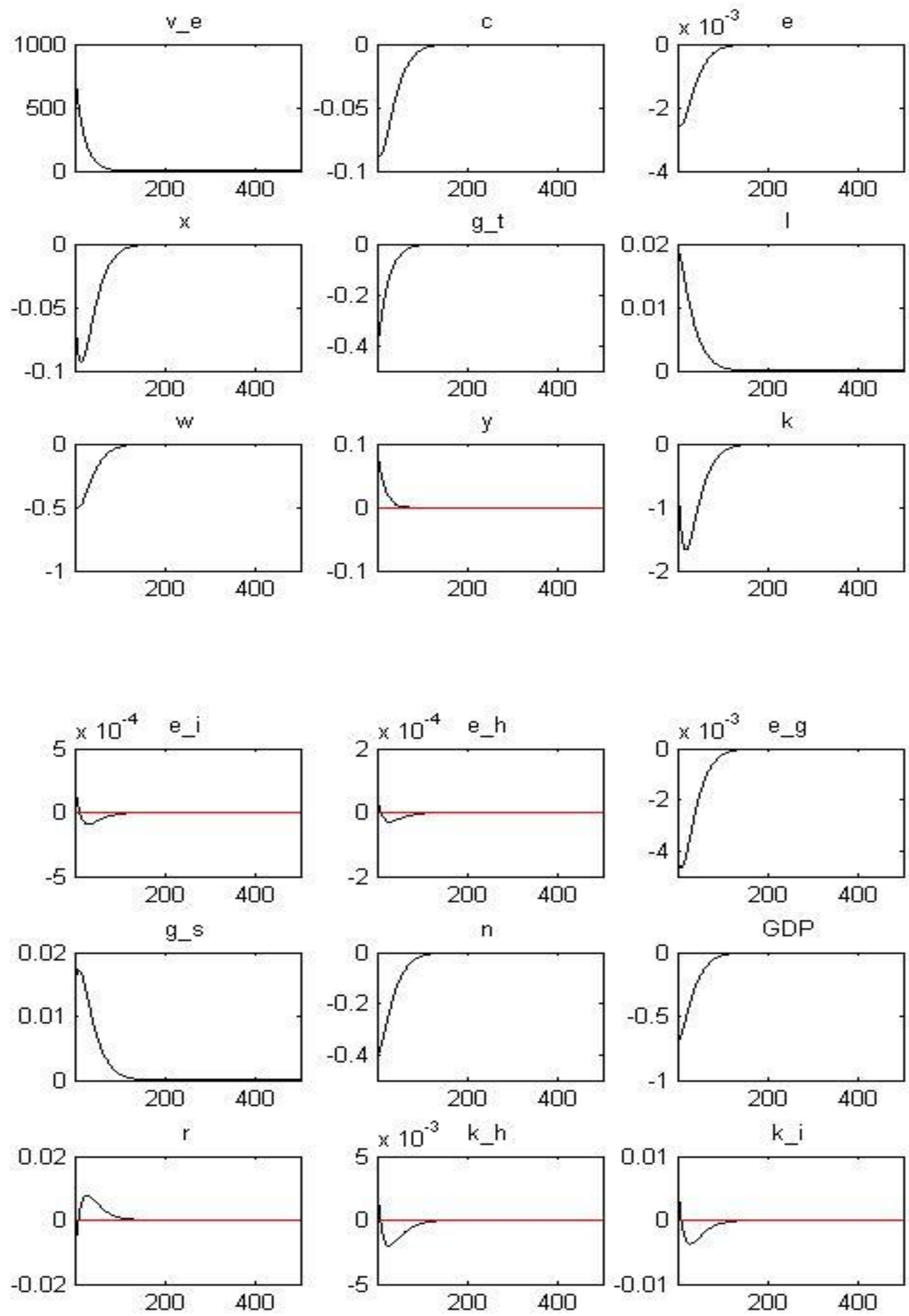
5.6.1 Transmission Mechanisms of Oil Price Shocks

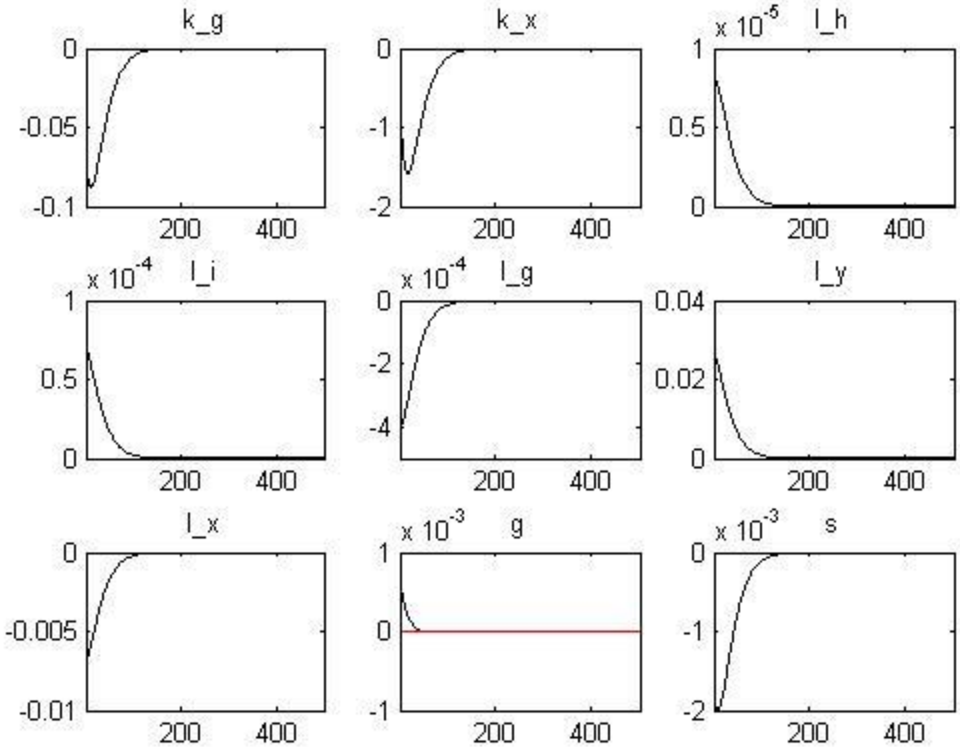
In this section, we describe the dynamic mechanism in which oil price shock is propagated. Changes in oil prices have a direct impact on the price level of the economy, they affect intra/intertemporal consumption decisions, and also influence the cost structure of firms and through this channel have a second round effect on domestic prices. The shock is equal in size to the standard deviation of the actual price. **Figure 5.1** plots the impulse responses to an oil price shock. A rise in world oil price (v_e) implies higher import price which makes the country worse off with respect to Terms of Trade (TOT). So, higher oil price makes consumption more expensive and thus reduces consumption (c), electricity consumption (e) and service consumption (x) through income effect. This is equivalent to a reduction of the Total Factor Productivity (TFP) in production. Changing oil prices may create uncertainty about the future path of the price of oil; causing consumers to postpone irreversible purchases of consumer durables (Bernanke, 2004 and 2006). Even when purchase decisions are reversible, consumption may fall in response to oil price shocks, as consumers increase their precautionary savings. Since taxes and other prices are fixed, higher world oil price makes the government worse off and reduces government transfer (g_t). Lower government transfer (g_t) increases labour supply (l) through income effect which in turn lowers the household wages (w). Industrial production (y) increases because oil imports are now more expensive and industrial sector needs to produce more exportable goods to keep the trade balance unchanged. In fact, lower household wage and capital interest rate allow industrial sector to employ more labour and capital which in turn increases the industrial production. Trade balance is also unchanged as we assume Ricardian equivalence which works through lump sum transfer in our model. The basic idea behind Ricardian equivalence is that no matter how a government chooses to increase spending, the outcome would be the same and demand would remain unchanged. For every level of oil import, the country needs to produce more goods for export. Higher oil price also acts as a negative technological shock which causes aggregate capital (k) to reduce initially to prevent household consumption to fall by a large extent. Lower wages coupled with fixed domestic prices allow the private electricity generating firms to produce at a cheaper cost. As a result, more resources are devoted towards IPP (e_i) and QR (e_h) sectors through factor markets which expands both IPP (e_i) and QR (e_h) electricity production. Since QR power plants are facing domestic oil price (v_h) which is fixed and controlled by government, QR sector is not affected by the negative consequences of higher oil price. The cost of oil becomes high and the other prices are not adjusted. Thereby, government intervention is required and accordingly government subsidy increases (g_s). Additionally, private sectors tend to expand with wrong prices and the government ends up paying for the differences. Since the industrial sector expands, higher currency inflows make the other sectors, especially the service sector, less competitive and the relative price between industry and service sector also declines (n). Apparently, this can be referred to the "Dutch Disease" in the economy as the service sector becomes less competitive.[8] Finally, government electricity supply (e_g) needs to be reduced to equate total supply and

[8] **Dutch disease** is the negative impact on an economy of anything that gives rise to a sharp inflow of foreign currency, such as the discovery of large oil reserves. The currency inflows lead to currency appreciation, making the country's other products less price competitive on the export market.

demand of electricity since electricity prices are fixed. Higher oil price in the world market also reduces GDP.

Figure 5.1: Impulse Responses to an Oil Price Shock




k_g
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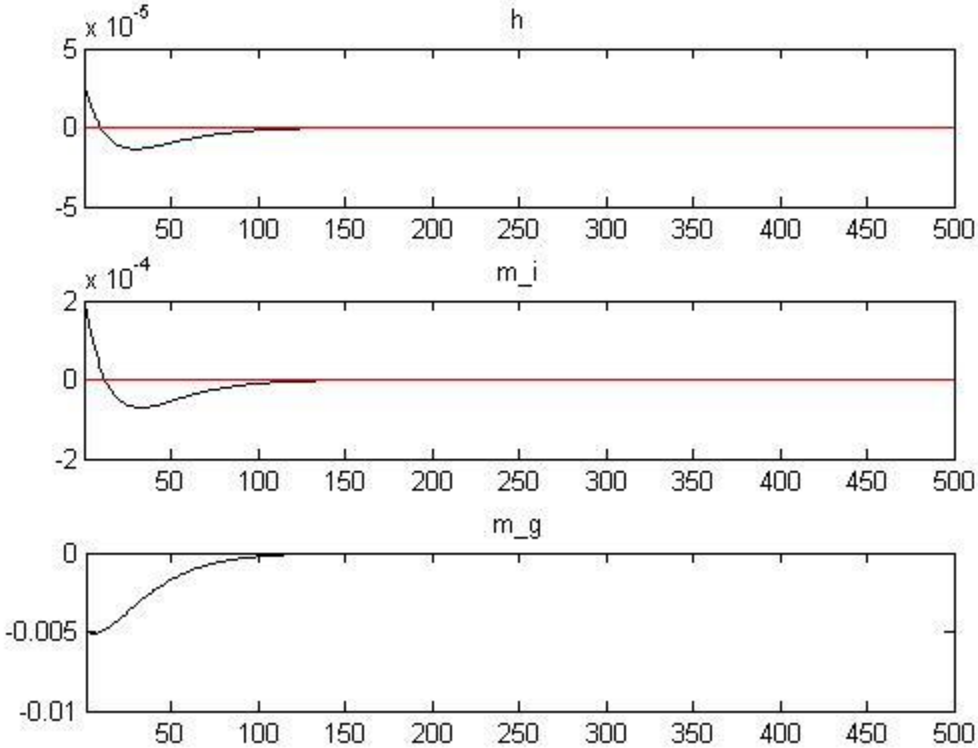
-0.05
-0.1
200
400
k_x
0
-1
-2
200
400
x 10^-5 l_h
1
0.5
0
200
400
x 10^-4 l_i
1
0.5
0
200
400
x 10^-4 l_g
0
-2
-4
200
400
l_y
0.04
0.02
0
200
400
l_x
0
-0.005
-0.01
200
400
x 10^-3 g
1
0
-1
200
400
x 10^-3 s
0
-1
-2
200
400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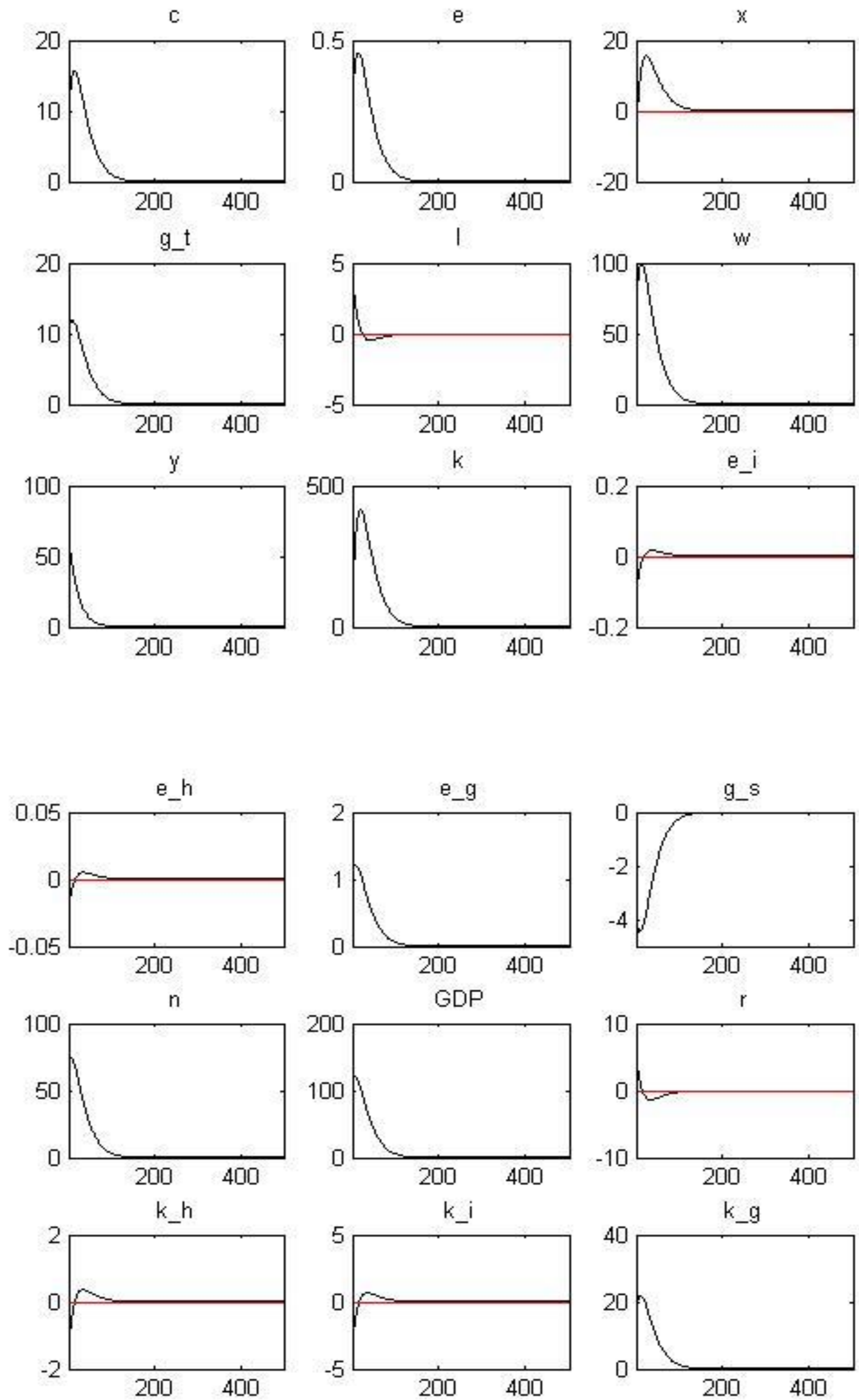
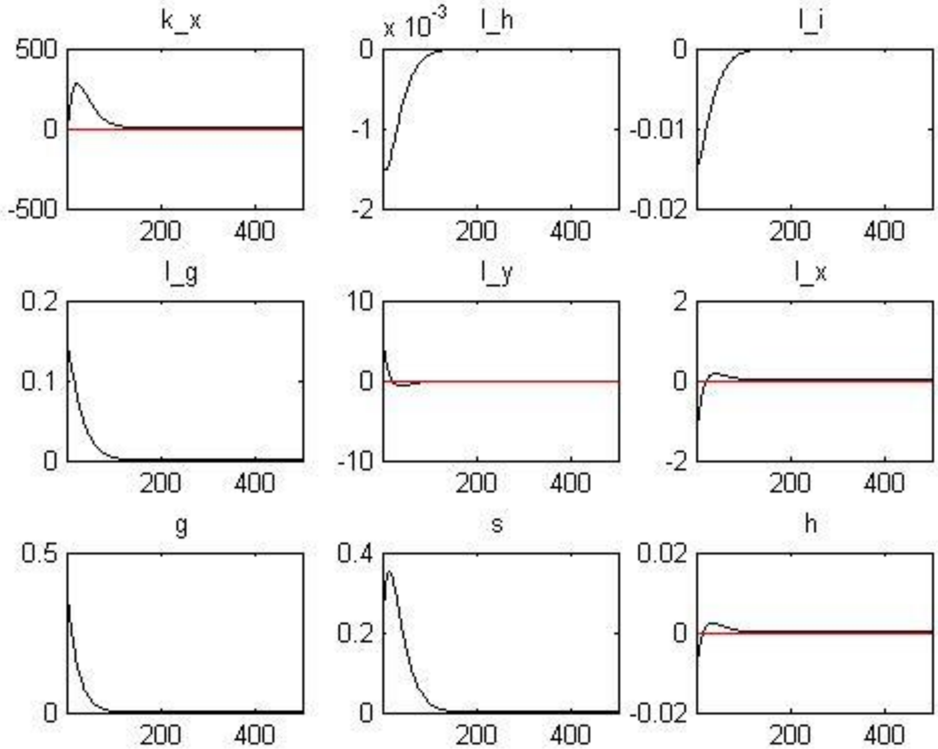
5
0
-5
50 100 150 200 250 300 350 400 450 500
x 10^-4 m_i
2
0
-2
50 100 150 200 250 300 350 400 450 500
m_g
0
-0.005
-0.01
50 100 150 200 250 300 350 400 450 500

5.6.2 Transmission Mechanisms of Productivity Shocks

Here, we describe the dynamic mechanism in which productivity shock is propagated in different sector. **Figure 5.2** displays the impulse response to a positive productivity shock in industrial sector (y). Positive productivity shock makes the factors of production more productive and accordingly labour wages increase (w). Higher wages also increase the labour supply (l) in the industrial sector. This is the substitution effect of the positive productivity shock in industrial sector towards the economy. Additionally, consumers would have gained positive welfare because of higher productivity and higher production and non-electricity consumption (c) and electricity consumption (e) increases due to income effect. Since substitution effect dominates over income effect, overall labour supply (l_y) increases in the industrial sector. Industrial output (y) increases as the sector enjoys productive efficiency. However, positive productivity shock makes industrial capital and labour more productive and accordingly wages (w) and capital interest rate (r) increase. Since the private electricity generating firms are now facing higher factor prices, labour and capital decreases in private electricity firms and electricity production in IPP (e_i) and QR (e_h) firms also decreases. Higher wage (w) and capital (k) also implies higher tax revenue for the government which increases government transfer (g_t). Industry now uses more electricity (g) as the sector expands and government intervenes in the electricity market to supply more electricity. Additionally, service sector uses more electricity (s) as electricity becomes relatively cheaper. However, overall service production (X) reduces as resources are being diverted to industrial sector and the sector faces higher wage and capital interest rate. Household also needs to cut off their leisure consumption and increases labour supply (l) to compensate the contraction of the service sector.

Figure 5.2: Impulse Responses to a Productivity Shock in Industry

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0
-500
200
400
x 10^-3
l_h
0
-1
-2
200
400
l_i
0
-0.01
-0.02
200
400
l_g
0.2
0.1
0
200
400
l_y
10
0
-10
200
400
l_x
2
0
-2
200
400
g
0.5
0
200
400
s
0.4
0.2
0
200
400
h
0.02
0
-0.02
200
400

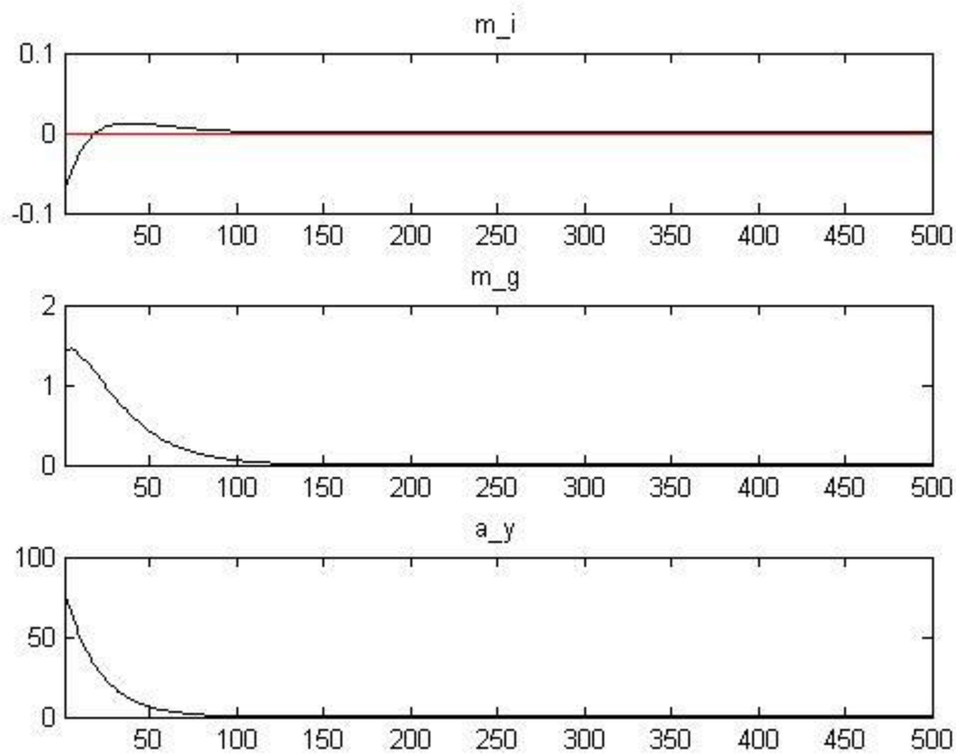
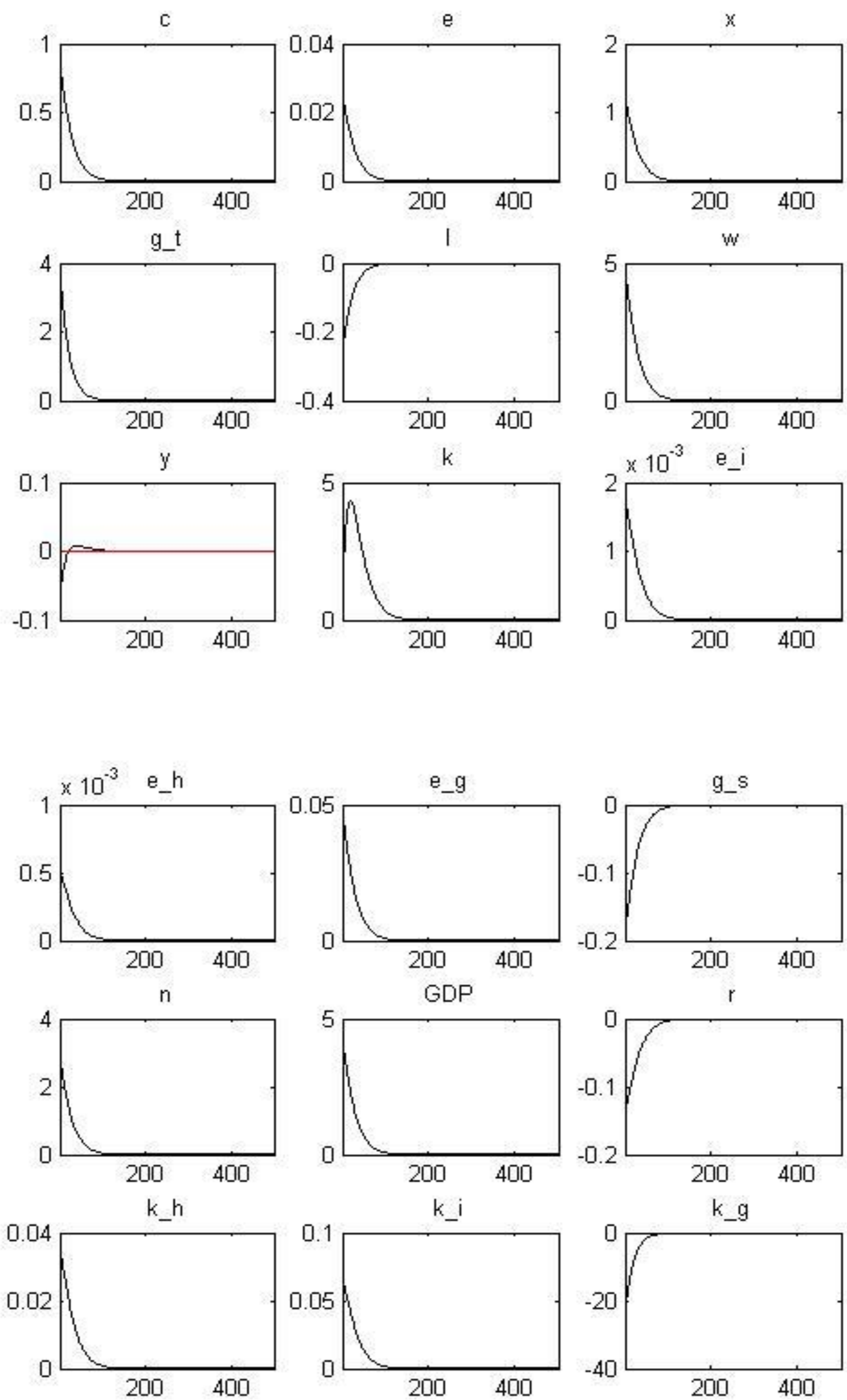
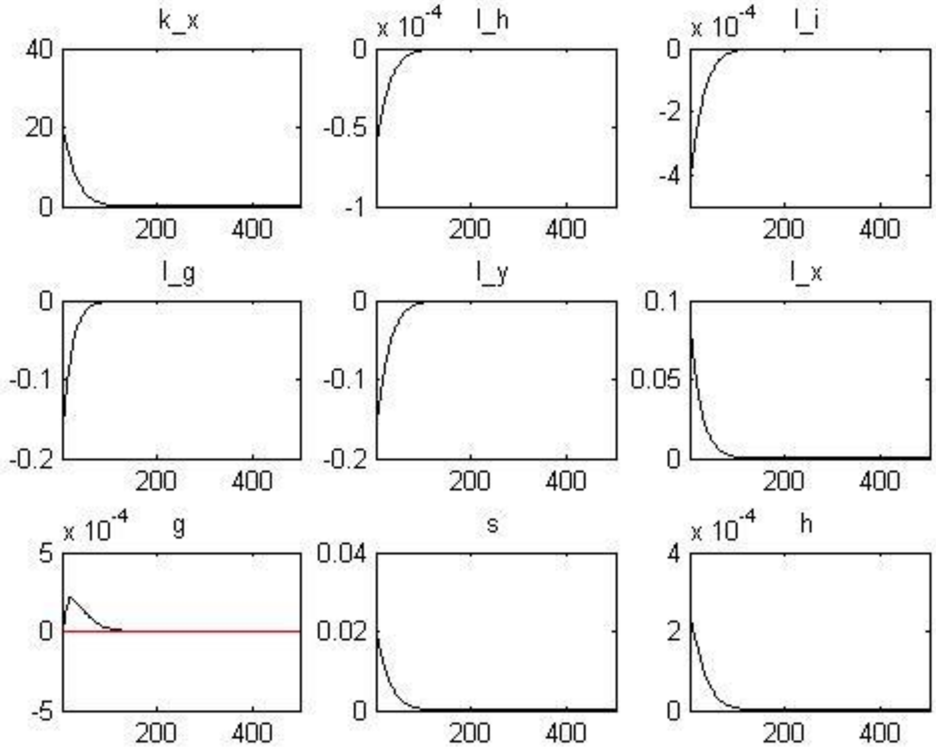

m_i
0.1
0
-0.1
50 100 150 200 250 300 350 400 450 500
m_g
2
1
0
50 100 150 200 250 300 350 400 450 500
a_y
100
50
0
50 100 150 200 250 300 350 400 450 500

Figure 5.3 presents the impulse response of a positive productivity shock in government electricity generating firm, BPDB. Higher productivity in BPDB implies that government becomes more efficient regardless of the prices and fewer resources are now needed. As a result, electricity generation (e_g) has increased in government sector and government transfer (g_t) also increases. Additionally, these free resources are diverted to private sectors and using these resources, IPP (e_i) and QR (e_h) expand their electricity supply. Higher government transfer also increases household leisure consumption and decreases labour supply (l) which causes labour wage to rise (w). The economy has experienced positive welfare gain because of higher productivity and household electricity consumption (e) and non-electricity consumption (c) increases. Positive productivity shock in BPDB causes a very small increase in consumption. Furthermore, domestic resources are now more productive and as a result, the volume of import and export also decreases. This can also be referred to the "Dutch Disease" as deindustrialisation is taken place in the economy. However, these changes are completely outweighed by the rest of the variables in the economy wide resource constraint, mainly the dominancy of the extraction cost. This is purely a quantitative issue where the household sector faces small changes and the gas sector has bigger effects on the economy. In fact, extraction cost creates few odd results as observed out of the positive productivity shock in BPDB.

Figure 5.3: Impulse Responses to a Productivity Shock in PDB




k_x
40
20
0
200
400
x 10^-4
l_h
0
-0.5
-1
200
400
x 10^-4
l_i
0
-2
-4
200
400
l_g
0
-0.1
-0.2
200
400
l_y
0
-0.1
-0.2
200
400
l_x
0.1
0.05
0
200
400
x 10^-4
g
5
0
-5
200
400
s
0.04
0.02
0
200
400
x 10^-4
h
4
2
0
200
400

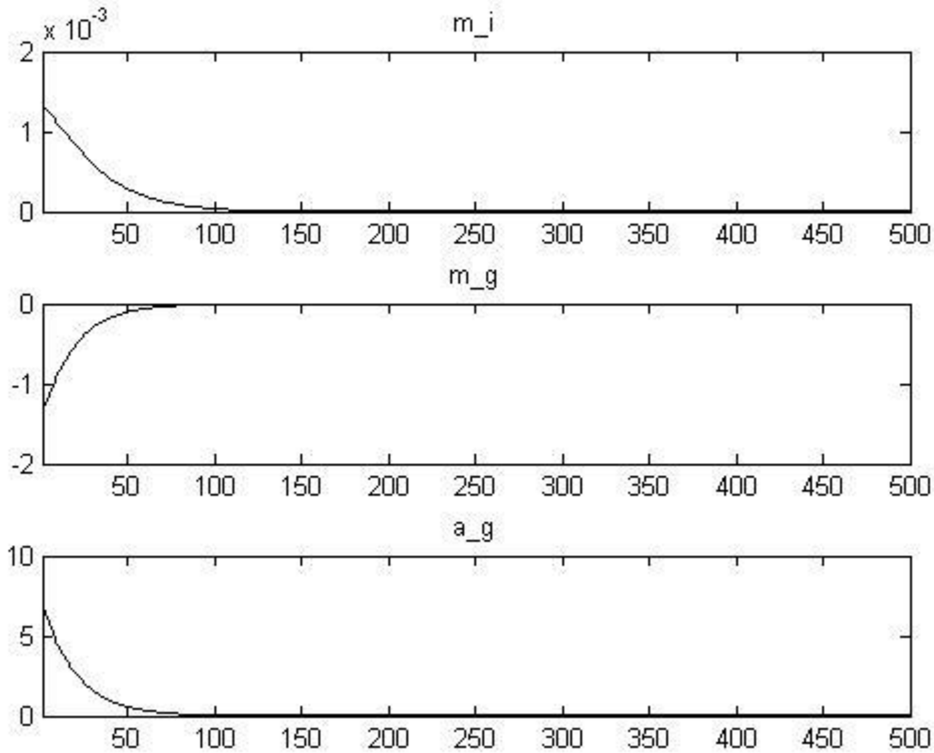
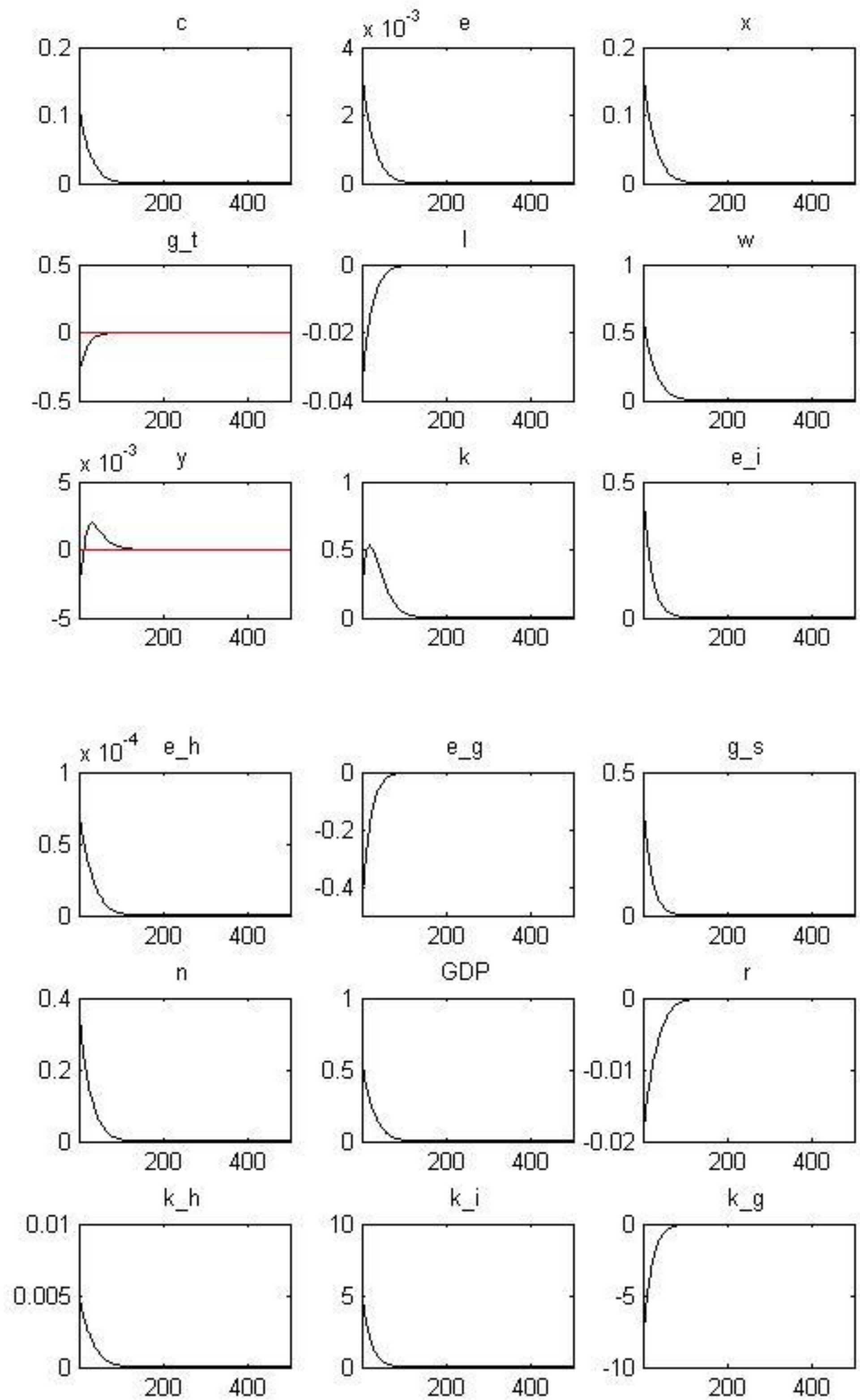
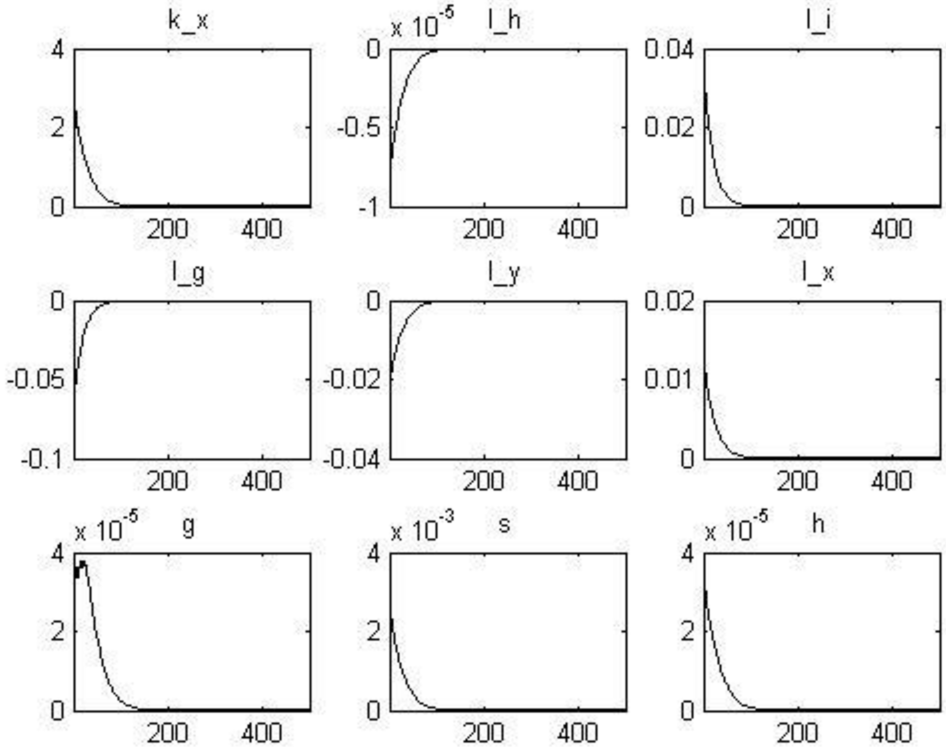

x 10^-3
m_i
2
1
0
50
100
150
200
250
300
350
400
450
500
m_g
0
-1
-2
50
100
150
200
250
300
350
400
450
500
a_g
10
5
0
50
100
150
200
250
300
350
400
450
500

Figure 5.4 shows the impulse response of a positive productivity shock in IPP electricity generating firms. Higher productivity makes household better off as their consumption increases (c, e and x). Household further increases their leisure consumption and reduce labour supply (l) for which overall wage (w) increases. IPP electricity supply (e_i) increases because of productivity efficiency achieved in this sector through positive productivity shock. In general, if both wage (w) and capital interest rate (r) increases, then relative factor prices are higher considering other prices being fixed. This is in turn should decrease the production of any sector. However, in our model, the results show that wage (w) increases and capital interest rate (r) decreases. So, the overall effect of the production side depends on the factor intensity in the production process. Since QR power plants are capital intensive, it could now produce more electricity as capital is increasing (for the same logic explained in previous shock). This result is sensitive with the type of production function and the degree of substitutability among the factors of production. Government is forced to reduce its electricity supply to hold equilibrium condition as both IPP and QR increases electricity production. Oil import is increasing and government also needs to increase its subsidy (g_s). Since government reduces electricity supply, it is also cutting back its transfer (g_t) to household from its budget.

Figure 5.4: Impulse Responses to a Productivity Shock in IPP




k_x
x 10^-5 l_h
l_i
l_g
l_y
l_x
x 10^-5 g
x 10^-3 s
x 10^-5 h
200
400

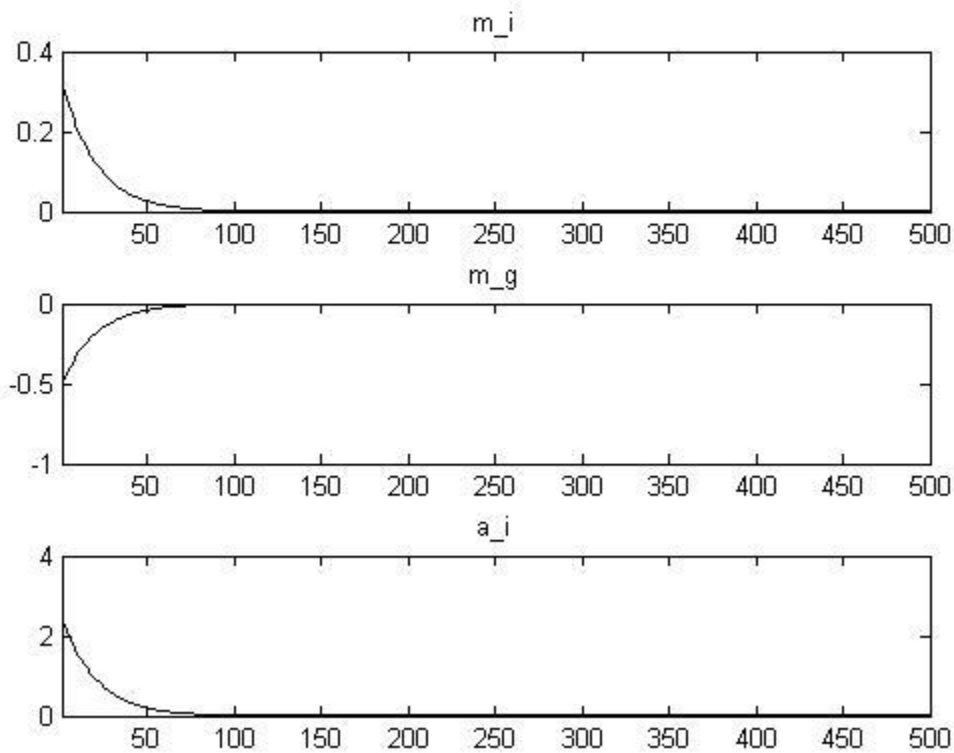
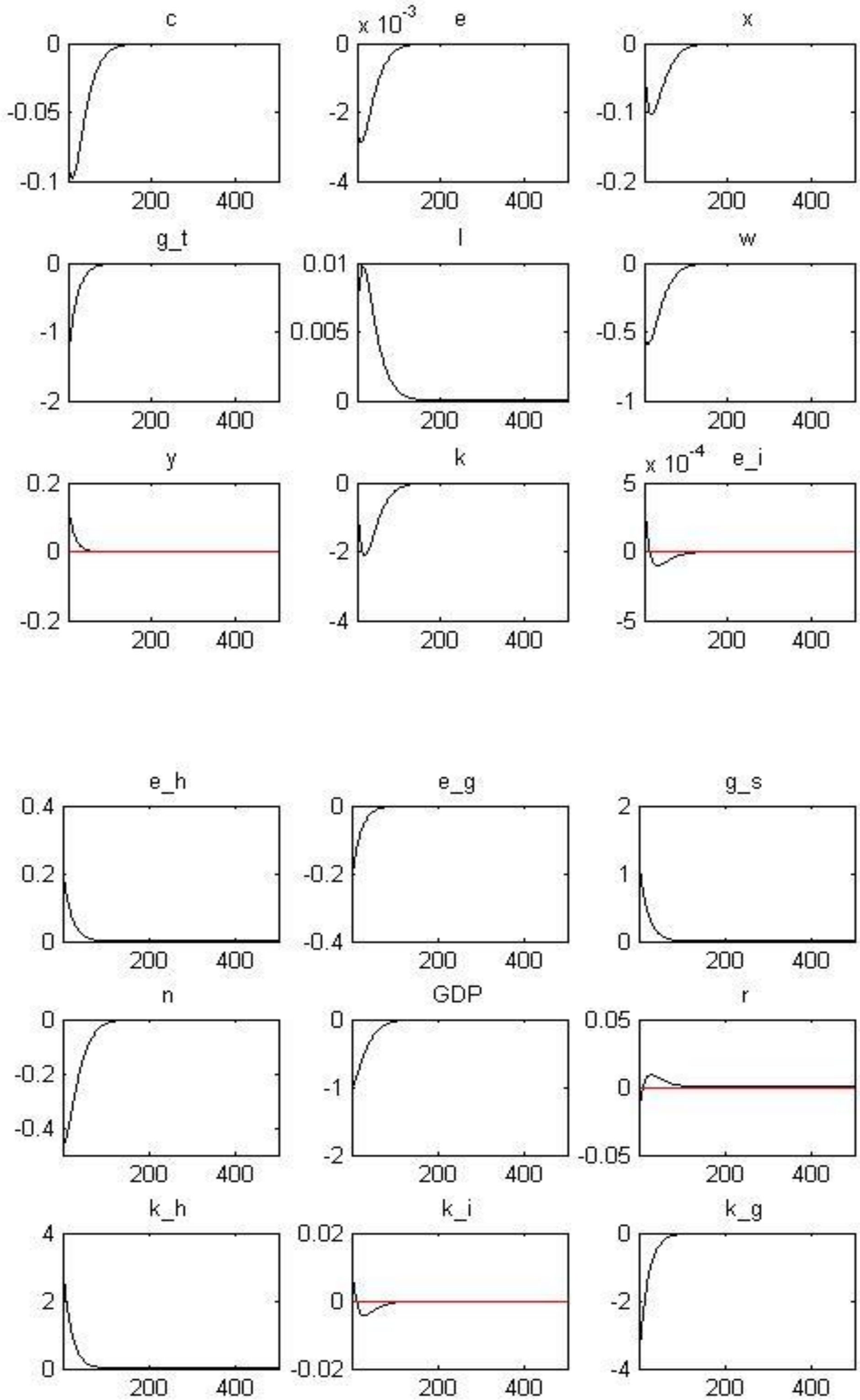
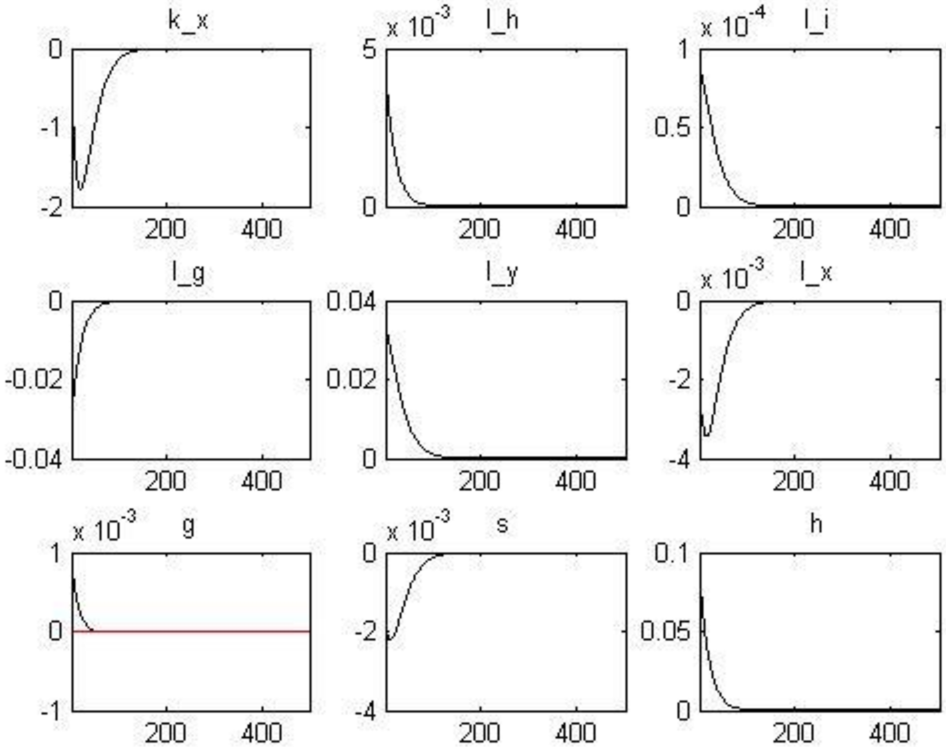
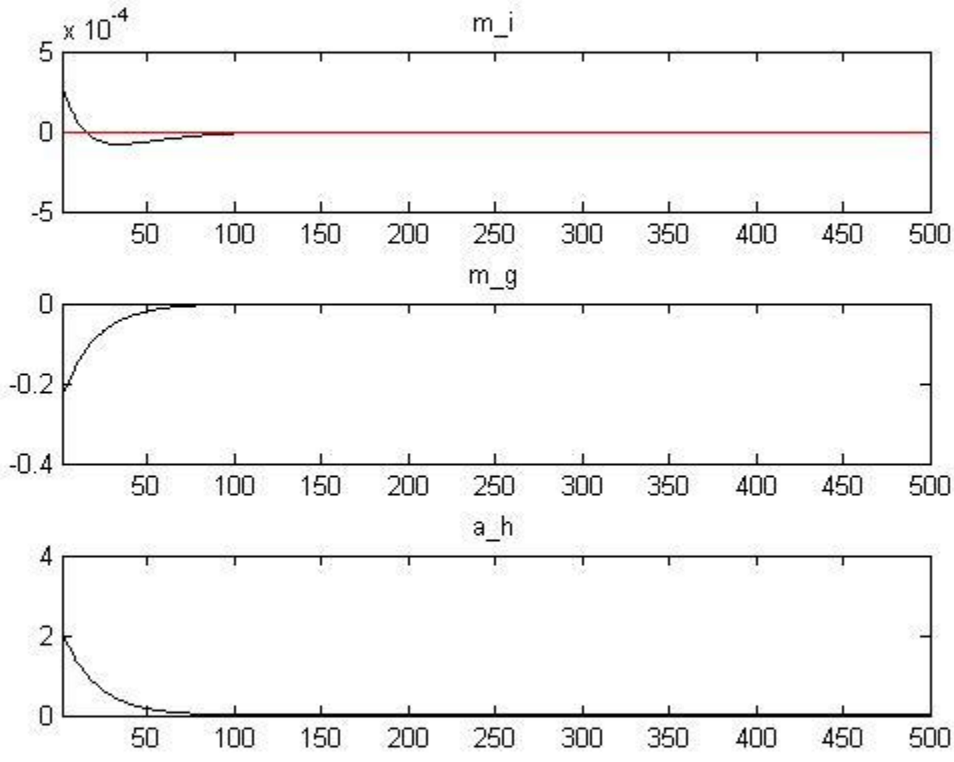

m_i
m_g
a_i
50
100
150
200
250
300
350
400
450
500

Figure 5.5 describes the impulse response to a positive productivity shock in QR electricity generating firms. Impulse response function shows production inefficiency as a result of higher productivity because of the prevalence of the distorted prices in the economy. Any change in QR firms without price changes make the sector more expensive. Inefficient allocation of resources will have negative impact on household welfare and household consumption (c) decreases. Households reduce their leisure consumption and accordingly wage (w) decreases. Oil imports have increased to meet the higher demand coming from the QR firms which causes industrial production (y) to rise and government subsidy (g_s) also increases. Lower wage (w) and capital interest rate (r) makes labour and capital cheaper which expands the IPP (e_i) electricity production. Since both IPP and QR (e_h) production increases, government needs to cut back its electricity supply (e_g).

Figure 5.5: Impulse Responses to a Productivity Shock in QR




k_x
x 10^-3 l_h
x 10^-4 l_i
l_g
l_y
x 10^-3 l_x
x 10^-3 g
x 10^-3 s
h


x 10^-4 m_i
m_g
a_h

5.7 Conclusions

The measure of economic performances in the developing countries like Bangladesh is synonymous with the level of electricity used in the economy as it is required in some form almost in every activity. Ferguson (2000) analysed the correlations between electricity use and economic development in over 100 countries and found strong correlation between these concerned variables throughout the globe. Since, generating and supplying electricity remains an unsolved challenge for Bangladesh persistently, the government has allowed the private generating firms to produce electricity and some of the private firms rely on imported oil. Oil price shocks are often identified as a source of macroeconomic fluctuations in the developing countries and Bangladesh economy is also vulnerable to the world oil price as the country needs to import oil to generate electricity. Historically, oil price increases appear to cause substantial and persistent recessions in economic activity (Finn, 2000).

Despite the wide literature on DSGE models, there is no model for Bangladesh economy to ask the question of how the oil price shocks and other disturbances related to oil industry would affect macroeconomic variables and what impacts do they have on a small, oil-importing developing country like Bangladesh. In order to answer these questions, this chapter constructs an energy augmented DSGE Model for the Bangladesh economy. Therefore, this chapter would fill this gap, which ultimately can positively influence the effectiveness of policy management in Bangladesh and other countries with similar economic structures.

Our model includes household consumption of electricity along with non-electricity oriented consumption and service consumption in the utility function in addition to electricity use at the firm level in industry and service sector. Our model further includes price setting mechanism, three electricity generating firms where electricity is produced both publicly and privately with multi fuel generating capacity. These firms combine capital, labour and energy (gas or oil) in a CES production functions to generate electricity. As far as we have been concerned this is the first study that considers government price setting mechanism in energy sector in the model economy. One of the main assumptions of this model is that all the economic agents rely on electricity either for household electricity consumption or for production of various goods. Any electricity production is allowed to freely respond to demands.

The model is solved and quantitatively simulated, so that the dynamic impacts of various shocks can be computed. Our simulation results highlight several important dimensions to the relationship between oil prices and economic performances in Bangladesh. First, oil price shocks have a negative welfare effect on the economy through reducing electricity consumption, non-electricity consumption and service consumption and reducing economic activities. Second, relative factor prices play a substantial role in shaping the energy (electricity) sector as more resources are devoted towards IPP sector through factor market which expands IPP electricity production. Several authors [Davis (1987), Loungani (1986) and Mork (1989)] have emphasised the “re-allocative” effects of energy (oil) price shocks. In a multi-sector economy with specialised inputs, oil price shocks can require costly reallocations of capital and labour across sectors, and this may be an important channel through which oil price can affect the economy. Third, higher oil price also acts as a negative technological shock which causes aggregate capital to reduce initially to prevent household consumption to fall by a large extent. Finally, industrial production increases because oil imports are now more expensive and industrial sector needs to produce more exportable goods to keep the trade balance unchanged.

Given our results, it is advisable that policymakers carefully assess the overall welfare effect of oil price shocks and when appropriate take measures to redistribute welfare from industrial sector to the household sector. This is left for future research. Additionally, it would be interesting to see how electricity tariff liberalisation could affect the household welfare, electricity sector and overall economy in Bangladesh. Another avenue of future research would be to see the welfare effect of subsidies removal and privatisation policy in Bangladesh.

Appendix 5A

Table 5.1: The Dynamic Stochastic General Equilibrium Model: The Model Structure

Household Utility Function:

$$\varphi \log\left[X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta)e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right] + (1-\varphi)\log(1-l_t)$$

Household Resource Constraint:

$$k_{t+1} + c_t + n.X_t + q_t^{e}.e_t = (1-\tau^{l})wl_t + \text{ъ} + (1-\tau^{k})rk_t + (1-\delta)k_t + \pi$$

Government Resource Constraint:

$$\tau^{l}.w.l + \tau^{k}.r.k + (v^{m} - \delta^{C})(m^{I} + m^{G}) + (v^{h} - v^{e})h$$

$$+ P^{G}A_t^{G}[l_t^{\alpha_G}(1-\Psi_G)k_{G,t}^{-v^{m,G}} + \Psi_G m_{G,t}^{-v^{m,G}}]^{-\frac{\vartheta^{G}}{\acute{\upsilon}^{m.GG}}} - rk_G - wl_G - v^{m}.m^{G} - \text{ъ} = b$$

Economy wide Resource Constraint:

$$k_{t+1} = A_t^{Y}l_{Y,t}^{\alpha_Y}[(1-\Psi_Y)k_{Y,t}^{-v^{g}} + \Psi_Y g_t^{-v^{g}}]^{-\frac{\vartheta^{Y}}{\acute{\upsilon}^{gg}}} - c_t - v^{e}.h + (1-\delta)k_t - \delta^{C}(m^{I} + m^{G})$$

Negative of Total Subsidy:

$$-b = q^{e}.e + q^{s}.s + q^{g}.g - P^{H}.A_t^{H}l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-v^{h}} + \Psi_H h_t^{-v^{h}}]^{-\frac{\vartheta^{H}}{\acute{\upsilon}^{hh}}}$$

$$- P^{I}.A_t^{I}l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-v^{m,I}} + \Psi_I m_{I,t}^{-v^{m,I}}]^{-\frac{\vartheta^{I}}{\acute{\upsilon}^{m,II}}}$$

$$- P^{G}A_t^{G}[l_t^{\alpha_G}(1-\Psi_G)k_{G,t}^{-v^{m,G}} + \Psi_G m_{G,t}^{-v^{m,G}}]^{-\frac{\vartheta^{G}}{\acute{\upsilon}^{m,GG}}}$$

Production Functions:

H= $A_t^{H}l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-v^{h}} + \Psi_H h_t^{-v^{h}}]^{-\frac{\vartheta^{H}}{\acute{\upsilon}^{hh}}}$ [QR]

I=$A_t^{I}l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-v^{m,I}} + \Psi_I m_{I,t}^{-v^{m,I}}]^{-\frac{\vartheta^{I}}{\acute{\upsilon}^{m,II}}}$[IPP]

G=$A_t^{G}l_t^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-v^{m,G}} + \Psi_G m_{G,t}^{-v^{m,G}}]^{-\frac{\vartheta^{G}}{\acute{\upsilon}^{m,GG}}}$ [PDB]

Y=$A_t^{Y}l_{Y,t}^{\alpha_Y}[(1-\Psi_Y)k_{Y,t}^{-v^{g}} + \Psi_Y g_t^{-v^{g}}]^{-\frac{\vartheta^{Y}}{\acute{\upsilon}^{gg}}}$ [Industrial Sector]

X=$l_{X,t}^{\alpha_X}[(1-\Psi_X)k_{X,t}^{-v^{s}} + \Psi_X s_t^{-v^{s}}]^{-\frac{\vartheta^{X}}{\acute{\upsilon}^{ss}}}$ [Service Sector]

Equilibrium in Electricity Markets:
$e + s + g = A_t^G l_{G,t}^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\acute{\upsilon}^{m,GG}}} + A_t^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}} + \Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\acute{\upsilon}^{m,II}}} + A_t^H l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-\nu^h} + \Psi_H h_t^{-\nu^h}]^{-\frac{\vartheta^H}{\acute{\upsilon}^{hh}}} - x(H+I+G)$
Equilibrium in Labour Markets:
$l = l_H + l_I + l_G + l_Y + l_X$
Equilibrium in Capital Markets:
$k = k_H + k_I + k_G + k_Y + k_X$
Firms Profit Maximisation Problem:
$\pi_H = P^H . A_t^H l_{H,t}^{\alpha_H}[(1-\Psi_H)k_{H,t}^{-\nu^h} + \Psi_H h_t^{-\nu^h}]^{-\frac{\vartheta^H}{\acute{\upsilon}^{hh}}} - rk_H - wl_H - v^h . h$ [QR]
$\pi_I = P^I . A_t^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}} + \Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\acute{\upsilon}^{m,II}}} - rk_I - wl_I - v^m . m_{I,t}$ [IPP]
$\pi_Y = P^Y . A_t^Y l_{Y,t}^{\alpha_Y}[(1-\Psi_Y)k_{Y,t}^{-\nu^g} + \Psi_Y g_t^{-\nu^g}]^{-\frac{\vartheta^Y}{\acute{\upsilon}^{gg}}} - rk_Y - wl_Y - q^g . g$ [Industrial Sector]
$\pi_X = n . l_{X,t}^{\alpha_X}[(1-\Psi_X)k_{X,t}^{-\nu^s} + \Psi_X s_t^{-\nu^s}]^{-\frac{\vartheta^X}{\acute{\upsilon}^{ss}}} - rk_X - wl_X - q^s . s$ [Service Sector]
Government cost minimisation problem:
$c_G = wl_G + rk_G + v^m . m_{G,t} - P^G . A_t^G l_t^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\acute{\upsilon}^{m,GG}}}$
Exogenous Shocks:
$ln\, v_t^e = {}'\Omega^v + \omega ln v_{t-1}^e + \kappa_t$ (Oil Price Shocks in Quick Rentals)
$ln\, A_t^Y = {}'\Omega^Y + \mu^Y ln A_{t-1}^Y + \eta_t^y$ (Productivity Shocks in Industrial Sector)
$ln\, A_t^G = {}'\Omega^G + \mu^G ln A_{t-1}^G + \eta_t^G$ (Productivity Shocks in Government Sector)
$ln\, A_t^I = {}'\Omega^I + \mu^I ln A_{t-1}^I + \eta_t^I$ (Productivity Shocks in IPP)
$ln\, A_t^H = {}'\Omega^H + \mu^H ln A_{t-1}^G + \eta_t^H$ (Productivity Shocks in QR)

Table 5.2: The Dynamic Stochastic General Equilibrium Model: The Basic Data Set		
c, Consumption by Household	As percentage of GDP	0.806
q^e.e, electricity consumption by household	Sectoral Share of GDP (%)	1.45
Y, Industry, value added	(% of GDP)	29.81%
GDP	Value	9,147,840,000,000 Taka
Y	Value	2,726,971,104,000 Taka
V^h.h	Value	30,803,363,910 Taka
V^h.h/ GDP	Ratio	0.003367
c/Y	Ratio	0.337915
nX, Service, value added	(% of GDP)	49.45%
nX/Y	Ratio	1.658839
c/nX	Ratio	0.203706
e/GDP	Ratio	0.002941
e/Y	Ratio	0.009866
e/c	Ratio	0.029197
e, Domestic Electricity Consumption	Million Kilowatt Hours(Mkwh)	11627
g, Industrial Electricity Consumption	Million Kilowatt Hours(Mkwh)	6719
s, Service Electricity Consumption	Mkwh	5612
l^Y, Labour Share of Industry	In Percentage	27.668593%
l^X, Labour Share of Service	In Percentage	71.946050%
l^e, Labour Share of Electricity	In Percentage	0.385356%
q^e, consumer price of electricity faced by residential household	Taka/Kwh	4.93
q^S, consumer price of electricity faced by commercial/service sector	Taka/Kwh	9.00

q^{Z}, consumer price of electricity faced by industry	Taka/Kwh	6.95
p^{H}, selling price of electricity produced by Quick Rentals	Taka/Kwh	7.79
P^{I}, selling price of electricity produced by IPP	Taka/Kwh	3.20
V^{m}, market price of gas	Taka/Kwh	0.7755
V^{h}, market price of Oil (Domestic)	Taka/Kwh	5.72
V^{e}, market price of gas(World)	Taka/Kwh	8.19
δ^{C},extraction Cost of Gas	Taka/Kwh	1.1
Sources: BBS (2012), BER (2012), BPDB (2012), BPC (2015), Annual Report of Summit Power Limited 2012, Annual Report of Dutch Bangla Power and Associates Limited 2012 and Bangladesh Tax Handbook (2012).		

Table 5.3: The Dynamic Stochastic General Equilibrium Model: The Structural Parameters	
1. β, discount factor	0.96(Borrowed)
2. φ, the share of electricity and non-electricity consumption in the household's utility	0.607623 (Calculated)
3. θ, the share of non-electricity consumption in household aggregator	0.091109 (Calculated)
4. σ, the CES parameter of household's utility function	ρ=0.11(Borrowed)
5. γ, the share of service in the household consumption aggregator	0.811011 (Calculated)
6. α_H, labour distributive share in QR	0.004125 (Calculated)
7. α_I, labour distributive share in IPP	0.036183 (Calculated)
8. α_G, labour distributive share in BPDB	0.058408(Calculated)
9. $\alpha_{Y,}$ labour distributive share in industrial sector	0.2(Calculated)
10. $\alpha_{X,}$ labour distributive share in service/commercial sector	0.313410 (Calculated)
11. Ψ_H, share of capital used in electricity production by QR	0.596484(Calculated)
12. Ψ_I, share of gas used in electricity production by IPP	0.309381 (Calculated)
13. Ψ_G, share of gas used in electricity production by BPDB	0.302053(Calculated)
14. Ψ_Y, share of electricity used in industrial production	0.073398(Calculated)
15. Ψ_X, share of electricity used in commercial production	0.079017(Calculated)
16. ϑ_H, share of non-labour input used by QR	0.895874(Calculated)
17. ϑ_I, share of non-labour input used by IPP	0.863816(Calculated)
18. ϑ_G, share of non-labour input by BPDB	0.857936(Calculated)

19. ϑ_Y, share of non-labour input used in industrial production	0.7(Calculated)
20. ϑ_X, share of non-labour input used in service production	0.586494(Calculated)
21. v^h, Domestic Price of Oil	5.72 (Data)
22. δ^c, Extraction Cost of Gas	1.1(Data)
23. κ, fraction of system loss	0.10(Data)
24. ω, persistence coefficient of oil price shock	0.95(Borrowed)
25. μ^Y, persistent coefficient of productivity in industry	0.95(Borrowed)
26. μ^G, persistent coefficient of productivity shock in BPDB	0.95(Borrowed)
27. μ^I, persistent coefficient of productivity shock in IPP	0.95(Borrowed)
28. μ^H, persistent coefficient of productivity shock in QR	0.95(Borrowed)
29. ζ, standard error of oil price shock	0.01(Borrowed)
30. ε^Y, standard error of productivity shock in industry	0.01(Borrowed)
31. ε^G, standard error of productivity shock in BPDB	0.01(Borrowed)
32. ε^I, standard error of productivity shock in IPP	0.01(Borrowed)
33. ε^H, standard error of productivity shock in QR	0.01(Borrowed)
34. δ, depreciation rate	0.025(Borrowed)
35. τ^K, tax on capital	0.15(Data)
36. τ^l, tax on labour	0.10(Data)
37. q^e, consumer price of electricity faced by household	4.93(Data)
38. q^S, consumer price of electricity faced by service sector	9.00(Data)
39. q^g, consumer price of electricity faced by industry	6.95(Data)
40. p^H, selling price of electricity produced by Quick Rentals	7.79(Data)

41. P^I, selling price of electricity produced by IPP	3.20(Data)
42. V^m, market price of gas	0.7755(Data)
43. P^G, selling price of electricity produced by BPDB	2.307534(Calculated)
44. $\nu^{m,g}$, depends on the elasticity of substitution between capital and gas used by BPDB in generating electricity	0.1 (Calculated)
45. $\nu^{m,i}$, depends on the elasticity of substitution between capital and gas used by IPP in generating electricity	0.1 (Calculated)
46. ν^g, depends on elasticity of substitution between capital and electricity used in industry	0.1 (Calculated)
47. ν^s, depends on elasticity of substitution between capital and electricity used by commercial (service) production	0.1 (Calculated)
48. ν^h, depends on elasticity of substitution between capital and oil used by Quick Rentals in generating electricity	0.1 (Calculated)
49. $\nu^{m,g}$, degree of homogeneity in CES function in PDB	0.2(Assumed)
50. $\nu^{m,i}$, degree of homogeneity in CES function in IPP	0.2(Assumed)
51. ν^g, degree of homogeneity in CES function in Industry	0.2(Assumed)
52. ν^s, degree of homogeneity in CES function in Service	0.2(Assumed)
53. ν^h, degree of homogeneity in CES function in QR	0.2(Assumed)
54. $'\Omega^v$, coefficient in the oil Price shock equation	0.105145(Calculated)
55. $'\Omega^I$, coefficient in the productivity shock equation in IPP	-0.184991(Calculated)
56. $'\Omega^Y$, coefficient in the productivity shock equation in Industry	-0.011859(Calculated)

57. $'\Omega^{G}$, coefficient in the productivity shock equation in PDB	-0.132152(Calculated)
58. $'\Omega^{H}$, coefficient in the productivity shock equation in QR	-0.192480(Calculated)

Table 5.4: Sensitivity Analysis for β (Main Model)			
Endogenous Variables	**β=0.88**	**β=0.96**	**β=0.88**
1. c, non-electricity oriented goods by household	0.1990	0.2548	0.2736
2. e, electricity consumption by household	0.005810	0.007439	0.007988
3. X, Total production in Service Sector	0.589014	0.789328	0.940821
4. Y, Total production in industry	0.253645	0.412446	0.412446
5. G, electricity produced by government sector (BPDB)	0.010249	0.013914	0.015847
6. I, electricity produced by private sector(IPP)	0.001662	0.002580	0.003543
7. H, electricity produced by private sector(QR)	0.000944	0.001197	0.001411
8. K, total capital($K=K^H+K^I+K^G+K^Y+K^X$)	1.77588	5.7749	12.8867
9. K^H, capital used in Quick Rental firms	0.005897	0.017145	0.036895
10. K^I, capital used by IPP	0.007820	0.028532	0.072787
11. K^G, capital used by BPDB (Government sector)	0.041787	0.114601	0.196097
12. K^X, capital used in commercial/service sector	1.30958	4.01408	8.11753
13. l, total labour($l=l^H+l^I+l^G+l^Y+l^X$)	0.293132	0.300926	0.314385
14. l^H, labour used in Quick Rental firms	0.000024	0.000024	0.000026
15.l^I, labour used by IPP	0.000157	0.000188	0.000236
16. l^G, labour used by BPDB (Government sector)	0.000973	0.000877	0.000737
17. l^Y, labour used in industrial sector	0.041489	0.052110	0.070429
18. l^X, labour used in service sector	0.250487	0.247725	0.242955
19. g, electricity consumption by industry	0.001552	0.002708	0.004215

20. s, electricity consumption by service sector	0.004207	0.005774	0.006517
21. h, oil used by Quick Rental in electricity production	0.000380	0.000495	0.000594
22. m^I, gas used by IPP in electricity production	0.001048	0.001712	0.002438
23. m^G, gas used by BPDB in electricity production	0.005429	0.006666	0.006366
24. n, price of service products	1.65858	1.58467	1.42764
25. w, price of labour	1.22271	1.58297	1.73318
26. r, price of capital	0.18984	0.0784314	0.0412953
27. b, subsidy	-0.040977	-0.057779	-0.068437
28. ъ, government transfer	0.134663	0.185974	0.220678
29. V^e, World market price of oil	8.19	8.19	8.19
30. A_t^Y, productivity shock in industrial sector	0.788846	0.788846	0.788846
31. A_t^G, productivity shock in government electricity generating firms(BPDB)	0.0711435	0.071143	0.0711435
32. A_t^I, productivity shock in private electricity generating firms(IPP)	0.024727	0.024727	0.024727
33. A_t^H, productivity shock in private electricity generating firms(Quick Rentals)	0.021287	0.021287	0.021287
34. GDP	1.66142	2.10122	2.39332

Table 5.5: Euler Equations and First Order Conditions
1. $\frac{c_{t+1}}{c_t} = \beta^t[(1-\tau^k)r_{t+1} + (1-\delta)]\frac{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.q_t^{e\frac{\rho}{\rho-1}}}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}.q_{t+1}^{e\frac{\rho}{\rho-1}}}$
2. $\frac{c_t}{1-l_t} = \frac{\varphi(1-\gamma)}{(1-\varphi)}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}}.w(1-\tau^l)$
3. $\frac{c_t}{nX_t} = \frac{1-\gamma}{\gamma}.\frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}}$
4. $\frac{e_t}{c_t} = (q_t^e.\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}$
5. $w = \alpha_H.p^H.\frac{H}{l_{H,t}}$
6. $r = (\vartheta^H\frac{\nu^h}{ύ^{hh}})\frac{p^H(1-\Psi_H)k_{H,t}^{-\nu^h-1}.H}{(1-\Psi_H)k_{H,t}^{-\nu^h}+\Psi_H.h_t^{-\nu^h}}$
7. $v^h = (\vartheta^H\frac{\nu^h}{ύ^{hh}})\frac{p^H\Psi_H h_t^{-\nu^h-1}.H}{(1-\Psi_H)k_{H,t}^{-\nu^h}+\Psi_H.h_t^{-\nu^h}}$
8. $w = \alpha_I.p^I.\frac{I}{l_{I,t}}$
9. $r = (\vartheta^I\frac{\nu^{m,I}}{ύ^{m,II}})\frac{p^I(1-\Psi_I)k_{I,t}^{-\nu^{m,I}-1}.I}{(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I.m_{I,t}^{-\nu^{m,I}}}$
10. $v^m = (\vartheta^I\frac{\nu^{m,I}}{ύ^{m,II}})\frac{p^I\,\Psi_I m_{I,t}^{-\nu^{m,I}-1}.I}{(1-\Psi_I)k_{I,t}^{-\nu^{m,I}}+\Psi_I.m_{I,t}^{-\nu^{m,I}}}$
11. $w = \alpha_Y.\frac{Y}{l_{Y,t}}$
12. $r = (\vartheta^Y\frac{\nu^g}{ύ^{gg}})\frac{(1-\Psi_Y)k_{Y,t}^{-\nu^g-1}.Y_t}{(1-\Psi_Y)k_{Y,t}^{-\nu^g}+\Psi_Y.g_t^{-\nu^g}}$
13. $q^g = (\vartheta^Y\frac{\nu^g}{ύ^{gg}})\frac{\Psi_Y g_t^{-\nu^g-1}.Y_t}{(1-\Psi_Y)k_{Y,t}^{-\nu^g}+\Psi_Y.g_t^{-\nu^g}}$

14. $w = \alpha_x . \frac{nX_t}{l_{x,t}}$
15. $r = (\vartheta^X \frac{\nu^s}{ύ^{ss}}) \frac{(1-\Psi_x) k_{x,t}^{-\nu^s-1} . nX_t}{(1-\Psi_x) k_{x,t}^{-\nu^s} + \Psi_x . s_t^{-\nu^s}}$
16. $q^s = (\vartheta^X \frac{\nu^s}{ύ^{ss}}) \frac{\Psi_x s_t^{-\nu^s-1} . nX_t}{(1-\Psi_x) k_{x,t}^{-\nu^s} + \Psi_x . s_t^{-\nu^s}}$
17. $v^m . \alpha_G [(1-\Psi_G) k_{G,t}^{-\nu^m} + \Psi_G . m_{G,t}^{-\nu^m}] = (\vartheta^G \frac{\nu^{m,G}}{ύ^{m,GG}}) . \Psi_G . m_{G,t}^{-\nu^m-1} . l_G . w$
18. $r . \Psi_G . . m_{G,t}^{-\nu^m-1} = (1-\Psi_G) k_{G,t}^{-\nu^m-1} . v^m$

Table 5.6: The Dynamic Stochastic General Equilibrium Model: The Steady State(SS) Values		
Endogenous Variables	Initial SS Values	Dynare SS Values
1. c, non-electricity oriented goods by household	0.3379	0.2548
2. e, electricity consumption by household	0.009866	0.007439
3. X, Total production in service Sector	1.010007	0.789328
4. Y, Total production in industry	1	0.412446
5. G, electricity produced by government sector(BPDB)	0.017323	0.013914
6. I, electricity produced by private sector(IPP)	0.003364	0.002580
7. H, electricity produced by private sector(QR)	0.001901	0.001197
8. K, Total capital($K=K^H+K^I+K^G+K^Y+K^X$)	9.3645	5.7749
9. K^H, capital used in Quick Rental firms	0.028670	0.017145
10. K^I, capital used by IPP	0.038420	0.028532
11. K^G, capital used by BPDB(Government sector)	0.184667	0.114601
12. K^X, capital used in commercial/service sector	5.28755	4.01408
13. l, total labour($l=l^H+l^I+l^G+l^Y+l^X$)	0.33	0.300926
14. l^H, labour used in Quick Rental firms	0.000027	0.000024
15.l^I, labour used by IPP	0.000177	0.000188
16. l^G, labour used by BPDB(Government sector)	0.001065	0.000877
17. l^Y, labour used in industrial sector	0.091306	0.052110
18. l^X, labour used in commercial/service sector	0.237421	0.247725
19. g, electricity consumption by industry	0.005701	0.002708
20. s, electricity consumption by service sector	0.004762	0.005774

21. h, oil used by Quick Rental in electricity production	0.001792	0.000495
22. m^I, gas used by IPP in electricity production	0.005608	0.001712
23. m^G, gas used by BPDB in electricity production	0.011182	0.006666
24. n, price of service products	0.49170	1.58467
25. w, price of labour	2.19042	1.58297
26. r, price of capital	0.078431	0.0784314
27. b, subsidy	-0.065575	-0.057779
28. ъ, government transfer	0.275536	0.185974
29. V^e, World market price of oil	8.19	8.19
30. A_t^Y, productivity shock in industrial sector	1.267680	0.788846
31. A_t^G, productivity shock in government electricity generating firms(BPDB)	0.071143	0.071143
32. A_t^I, productivity shock in private electricity generating firms(IPP)	0.024727	0.024727
33. A_t^H, productivity shock in private electricity generating firms(Quick Rentals)	0.021287	0.021287
34. GDP	2.10121	2.10122

Table 5.7: The Dynamic Stochastic General Equilibrium Model: Dynare Code

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renstrom, Durham University Business School

var v_e c e x g_t l w y k e_i e_h e_g g_s n GDP r k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g a_y a_g a_i a_h ;

varexo kappa eta_yeta_geta_ieta_h;

parameters v_hdelta_cdelta_gnu_m_ggdelta_inu_m_iidelta_xnu_ssdelta_ynu_ggdelta_hnu_hh  betaphithetarho
gama alpha_ialpha_halpha_galpha_yalpha_xpsi_hpsi_ipsi_gpsi_ypsi_xnu_m_gnu_m_inu_hnu_gnu_s chi omega
mu_ymu_gmu_imu_hzetaepsilon_yepsilon_gepsilon_iepsilon_h delta
tau_ktau_lq_eq_sq_gp_hp_iv_mp_gcapomega_vcapomega_gcapomega_icapomega_hcapomega_y;

v_h=5.72;
delta_c=1.1;
delta_g=0.857936486;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.042063514;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.302053239;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
zeta=0.01;
epsilon_y=0.01;
```

```
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
q_e=4.93;
q_s=9.0;
q_g=6.95;
p_h=7.79;
p_i=3.20;
p_g=2.307534701;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.132152826;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_g*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;

w * l_x = alpha_x * n*x;

r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;
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```
q_s*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;

v_m*alpha_g*((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g))=((delta_g*nu_m_g)/nu_m_gg)* psi_g* m_g
^ (-nu_m_g -1)* l_g*w;

r* psi_g* m_g ^ (-nu_m_g -1)= (1- psi_g)* k_g^ (-nu_m_g -1)* v_m;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g-r*k_g-w *l_g -v_m
*m_g- g_t+ p_g * e_g=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_s *s-q_g *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;
end;

initval;
c=0.337915857;
e=0.009866408825;
x=1.010007997;
l=0.33;
y=1;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
k=9.364512596;
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
k_x=5.287550443;
l_h=0.00002789761551;
```

```
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182969;
n=0.491705834;
w=2.190427966;
r=0.078431372;
g_s=-0.065575779;
g_t=0.275536049;
v_e=8.19;
a_y=1.267680833;
a_g=0.071143485;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

end;

steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul (hp_filter=100, order=2, irf=500, relative_irf );
```

Table 5.8: Ratios of Economic Variables of Bangladesh Data and Models in the Steady State		
Economic Ratios	Data	Model
$\frac{c}{Y}$	0.337915857	0.366179146
$\frac{e}{Y}$	0.009866408825	0.010691614
$\frac{wl}{Y}$	0.722841226	0.766714885
$\frac{wl^Y}{Y}$	0.2	0.20000066
$\frac{g}{e}$	0.577879074	0.533274284
$\frac{s}{e}$	0.482669648	0.482664841
$\frac{l^Y}{l}$	0.2766859345	0.26085402
$\frac{l^X}{l}$	0.719460501	0.735026207
$\frac{v^m m^G}{wl^G}$	3.71428727	3.714323001
$\frac{rk^G}{v^m m^G}$	3.340192542	3.340275433
$\frac{wl^H}{P^H H}$	0.004125745272	0.003639919117
$\frac{rk^H}{P^H H}$	0.303638701	0.282791109
$\frac{v^H h}{P^H H}$	0.692235553	0.690616997
$\frac{wl^I}{P^I I}$	0.036183313	0.036181998
$\frac{rk^I}{P^I I}$	0.559816252	0.559814098
$\frac{v^m m^I}{P^I I}$	0.40400036	0.403998855
$\frac{wl^X}{nX}$	0.313505778	0.313505084
$\frac{rk^X}{nX}$	0.660656913	0.660660048
$\frac{q^s s}{nX}$	0.025837309	0.025836835
$\frac{q^g g}{Y}$	0.039626058	0.039625861

Appendix 5B

Technical Appendix

1. **Derivation of Euler Equation:**

$L = \sum_{t=0}^{\infty} \beta^t (\varphi \log\left[X_t^\gamma \left(\theta c_t^\rho + (1-\theta) e_t^\rho\right)^{\frac{1-\gamma}{\rho}}\right]) + (1-\varphi)\log(1-l_t) - \lambda_t [k_{t+1} + C_t + nX_t +$

$q_t^e . e_t - (1-\tau^l) w l_t + ъ + (1-\tau^k) r k_t + (1-\delta) k_t]$

First Order Conditions:

$\frac{\delta L}{\delta ct} = \beta^t . \varphi . \frac{1}{X_t^\gamma (\theta c_t^\rho + (1-\theta) e_t^\rho)^{\frac{1-\gamma}{\rho}}} . X_t^\gamma . \frac{1-\gamma}{\gamma} (\theta c_t^\rho + (1\text{-}\theta) e_t^\rho)^{\frac{1-\gamma}{\rho} - 1} . \theta . \rho c_t^{p-1} - \lambda_t = 0$

$=> \beta^t . \varphi . \frac{1}{X_t^\gamma (\theta c_t^\rho + (1-\theta) e_t^\rho)^{\frac{1-\gamma}{\rho}}} . X_t^\gamma . \frac{1-\gamma}{\rho} (\theta c_t^\rho + (1\text{-}\theta) e_t^\rho)^{\frac{1-\gamma}{p} - 1} . \theta . \rho c_t^{\rho-1} = \lambda_t$

$=> \lambda_t = \beta^t . \varphi . (1-\gamma) . \theta . c_t^{\rho-1} . (\theta c_t^\rho + + (1\text{-}\theta) e_t^\rho)^{-1}$

$\lambda_t = \frac{\beta t . \varphi . (1-\gamma) . \theta . c_t^{p-1}}{\theta c_t^p + (1-\theta) e_t^p}$ **(1)**

$\frac{\delta l}{\delta et} = \beta^t . \varphi . \frac{1}{X_t^\gamma . (\theta c_t^\rho + (1-\theta) e_t^\rho)^{\frac{1-\gamma}{\rho}}} . X_t^\gamma . \frac{1-\gamma}{\rho} (\theta c_t^\rho + (1\text{-}\theta) e_t^\rho)^{\frac{1-\gamma}{\rho} - 1} . (1\text{-}\theta) . e_t^{\rho-1} - \lambda_t q^{z=0}$

$=> \frac{\beta t . \varphi (1-\theta)(1-\gamma) . e_t^{\rho-1}}{\theta c_t^\rho + (1-\theta) e_t^\rho} = q^e . \frac{\beta^t . \varphi . \theta . (1-\gamma) c_t^{\rho-1}}{\theta c_t^\rho + (1-\theta) e_t^\rho}$

$=> (\frac{e_t}{c_t})^{\rho-1} = q^e \frac{\theta}{1-\theta}$

$\frac{e_t}{c_t} = (q^e . \frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}$ **(2)**

$\frac{\delta l}{\delta X_t} = \beta^t . \varphi . \frac{1}{X_t^\gamma . (\theta c_t^\rho + (1-\theta) e_t^\rho)^{\frac{1-\gamma}{\rho}}} . [\theta c_t^\rho + (1\text{-}\theta) e_t^\rho]^{\frac{1-\gamma}{p}} . \gamma . X_t^{\gamma-1} - ŋ \lambda t = 0$

$=> \beta^t . \varphi . \frac{1}{X_t^\gamma . (\theta c_t^\rho + (1-\theta) e_t^\rho)^{\frac{1-\gamma}{\rho}}} . [\theta c_t^\rho + (1\text{-}\theta) e_t^\rho]^{\frac{1-\gamma}{\rho}} . \gamma . X_t^{\gamma-1} = ŋ . \frac{\beta t . \varphi . \theta (1-\gamma) . c_t^{\rho-1}}{\theta c_t^\rho + (1-\theta) e_t^\rho}$

$\frac{1}{X_t} . \gamma = ŋ . \frac{\theta . c_t^{\rho-1} . (1-\gamma)}{\theta c_t^\rho + (1-\theta) e_t^\rho}$

$\frac{1}{X_t} = n . \frac{1-\gamma}{\gamma} . \frac{\theta . c_t^{\rho-1}}{\theta c_t^\rho + (1-\theta) e_t^\rho}$ **(3)**

$\frac{\delta L}{\delta \varphi}=\beta^t.(1\text{-}\varphi).\frac{1}{1-l_t}(-1)+\lambda_{t.}.w\,(1\text{-}\tau^l)=0$

$=>\beta^t.(1\text{-}\varphi).\frac{1}{1-l_t}=\frac{\beta^t.\varphi(1-\gamma)\theta.c_t^{\rho-1}}{\theta c_t^{\rho}+(1-\theta)e_t^{\rho}}.w(1\text{-}\tau^l)$

$=>\frac{1}{1-l_t}=\frac{\varphi\theta.(1-\gamma)}{1-\varphi}.\frac{c_t^{\rho-1}}{\theta c_t^{\rho}+(1-\theta)e_t^{\rho}}.w(1\text{-}\tau^l)$ **(4)**

$\frac{\delta L}{\delta k_{t+1}}= -\lambda_t+\lambda_{t+1}[(1\text{-}\ \tau^k)r_{t+1}+(1-\delta]=0$ **(5)**

Assuming $M_{t+1}=[(1\text{-}\tau^k)\,r_{t+1}+(1-\delta]$ from **(5)**

$\lambda_{t+1}=\frac{\lambda_t}{M_{t+1}}$ **(6)**

Multiplying equation 1 with c_t, we have:

$C_t\lambda_t=\beta^t.\frac{\varphi(1-\gamma)\theta C_t^p}{\theta C_t^p+(1-\theta)e_t^p}$

$=\ \beta^t.\frac{\varphi(1-\gamma)\theta}{\theta+(1-\theta)(\frac{e_t}{c_t})^p}$

$=\beta^t.\frac{\varphi(1-\gamma)\theta}{\theta+(1-\theta)(q^{z^e}.\frac{\theta}{1-\theta})^{\frac{p}{p-1}}}$ [From 2]

$C_t\lambda_t=\beta^t.\frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}}$ (7)

Similarly, we can write:

$C_{t+1}\lambda_{t+1}=\beta^{t+1}.\frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}.(q_{t+1}^e)^{\frac{p}{p-1}}}$ **(8)**

From (7), we get

$\lambda_t=\frac{\beta^t}{C_t}.\frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}}$ **(9)**

Combining equation (8) and (6)

$C_{t+1}.\frac{\lambda_t}{M_{t+1}}=\beta^{t+1}.\frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}.(q_{t+1}^e)^{\frac{p}{p-1}}}$

$$=> \frac{C_{t+1}}{M_{t+1}} \{ \frac{\beta^t}{C_t} . \frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}} \} = \beta^{t+1} . \frac{\varphi(1-\gamma)}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}} \quad \text{[From 7]}$$

$$=> \frac{C_{t+1}}{C_t} = \beta^t .M_{t+1} . \frac{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_{t+1}^e)^{\frac{p}{p-1}}}$$

$$\therefore \frac{C_{t+1}}{C_t} = \beta^t .[(1-\tau^k)r_{t+1} + (1-\delta)] \frac{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_{t+1}^e)^{\frac{p}{p-1}}}$$

Multiplying equation (4) with c_t , we obtain:

$$\frac{C_t}{1-l_t} = \frac{\varphi.\theta.(1-\gamma)}{1-\varphi} . \frac{c_t^p}{\theta c_t^p + (1-\theta)e_t^p} . \text{w} \ (1\text{-}\tau^l)$$

$$= \frac{\varphi.\theta.(1-\gamma)}{1-\varphi} . \frac{1}{\theta + (1+\theta)(\frac{e_t}{C_t})^p} . \text{w} \ (1\text{-}\tau^l)$$

$$= \frac{\varphi.(1-\gamma)}{1-\varphi} . \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}} . \text{w} \ (1\text{-}\tau^l)$$

$$\therefore \frac{C_t}{1-l_t} = \frac{\varphi.(1-\gamma)}{1-\varphi} . \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{p-1}}(q_t^e)^{\frac{p}{p-1}}} . w(1-\tau^l)$$

Multiplying equation (8) with C_t

$$\frac{C_t}{X_t} = n. \frac{\theta C_t^p}{\theta c_t^p + (1-\theta)e_t^p} . \frac{1-\gamma}{\gamma}$$

$$= n. \frac{\theta}{\theta + (1-\theta)\left(q_t^e . \frac{\theta}{1-\theta}\right)^{\frac{p}{p-1}}} . \frac{1-\gamma}{\gamma}$$

$$= \eta . \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{e-1}}(q_t^z)^{\frac{p}{p-1}}} . \frac{1-\gamma}{\gamma}$$

$$\therefore \frac{C_t}{X_t} = \eta. \frac{1-\gamma}{\gamma} . \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{e-1}}(q_t^z)^{\frac{p}{p-1}}}$$

2. Derivation of Decreasing Returns to Scale (DRS) condition

Assuming DRS implies, the following equation holds in each sector in the model (except the government sector, since they are cost minimiser). Let us focus on the industry sector to derive the necessary conditions for the model.

$$Y-\frac{\partial Y}{\partial l_Y}.l_Y-\frac{\partial Y}{\partial k_Y}.k_Y-\frac{\partial Y}{\partial g}.g>0$$

$$\geqslant\ Y-\ \alpha^Y.Y-\left(\delta^Y.\frac{v^1}{v^2}\right)(1-\psi_Y)\frac{k_Y^{-v^1-1}.Y}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}.k_y$$

$$-\left(\delta^Y.\frac{v^1}{v^2}\right)(\psi_Y)\frac{g^{-v^1-1}.Y}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}.g>0$$

$$\geqslant\ Y-\ \alpha^Y.Y-\left(\delta^Y.\frac{v^1}{v^2}\right)Y[(1-\psi_Y)\frac{k_Y^{-v^1-1}}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}.k_y$$

$$-\left(\delta^Y.\frac{v^1}{v^2}\right)(\psi_Y)\frac{g^{-v^1-1}}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}.g]>0$$

$$\geqslant\ Y-\ \alpha^Y.Y-\left(\delta^Y.\frac{v^1}{v^2}\right)Y\ [(1-\psi_Y)\frac{k_Y^{-v^1}}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}$$

$$-\left(\delta^Y.\frac{v^1}{v^2}\right)(\psi_Y)\frac{g^{-v^1}}{\left[(1-\psi_Y)k_Y^{-v^1}+\psi_Y g^{-v^1}\right]}]>0$$

$\geqslant\ Y-\ \alpha^Y.Y-\left(\delta^Y.\frac{v^1}{v^2}\right)Y>0$ [Since the some of the bracketed term equals to 1]

$$\therefore\ Y(1-\ \alpha^Y-\delta^Y.\frac{v^1}{v^2})>0$$

This equation give use the following two conditions to hold DRS.

1. $\boldsymbol{\frac{v^1}{v^2}<1}$
2. $\boldsymbol{\delta<1-\alpha}$

3. Derivation of Economy Wide Resource Constraint

Household Resource Constraint:

$$k_{t+1} + c_t + n.X_t + q^e_t.e_t = (1-\tau^l)w.l_t + ъ + (1-\tau^k)r.k_t + (1-\delta)k_t + \pi \quad (1)$$

Government Resource Constraint:

$$\tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)(m^I_t + m^G_t) + (v^h - v^e)h_t + P^G.G_t - rk_G - wl_G - v^m.m^G_t - ъ = b \quad (2)$$

So, the negative of total subsidy is:

$$-b = q^e.e_t + q^s.s_t + q^g.g_t - P^H.H_t - P^I.I_t - P^G.G_t \quad (3)$$

Finally, combining household resource constraint, government resource constraint and the subsidy equation, the economy wide resource constraint can also be derived as follows.

$$\tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)(m^I_t + m^G_t) + (v^h - v^e)h_t + P^G.G_t - rk_G - wl_G - v^m.m^G_t - ъ$$
$$= P^H.H_t + P^I.I_t + P^G.G_t - q^e.e_t - q^s.s_t - q^g.g_t$$

Inserting the previous equation in the household resource constraint we find:

$$k_{t+1} + c_t + n.X_t + q^e_t.e_t = (1-\tau^l)w.l_t + ъ + (1-\tau^k)r.k_t + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)(m^I_t + m^G_t) + (v^h - v^e)h_t + P^G.G_t - rk_G - wl_G - v^m.m^G_t - P^H.H_t - P^I.I_t - P^G.G_t + q^e.e_t + q^s.s_t + q^g.g_t + \pi$$

$$\geqslant k_{t+1} + c_t + n.X_t = (1-\tau^l)w.l_t + ъ + (1-\tau^k)r.k_t + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)(m^I_t + m^G_t) + (v^h - v^e)h_t + P^G.G_t - rk_G - wl_G - v^m.m^G_t - P^H.H_t - P^I.I_t - P^G.G_t + q^s.s_t + q^g.g_t + \pi$$

$$\geqslant k_{t+1} + c_t + n.X_t = w.l_t - \tau^l.w.l_t + ъ + r.k_t - \tau^k.r.k_t + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)(m^I_t + m^G_t) + (v^h - v^e)h_t + P^G.G_t - rk_G - wl_G - v^m.m^G_t - P^H.H_t - P^I.I_t - P^G.G_t + q^s.s_t + q^g.g_t + \pi$$

$\geqslant \mathrm{k_{t+1}} + \mathrm{c_t} + \mathrm{n.X_t} = \mathrm{w.l_t} + \mathrm{r.k_t} + (1-\delta)\mathrm{k_t} + (\mathrm{v^m} - \delta^{\mathrm{C}})(m_t^I + m_t^G) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h}_t - \mathrm{rk_G} - \mathrm{wl_G} - \mathrm{v^m}.\mathrm{m}_t^G - P^H.H_t - P^I.I_t + q^s.s_t + q^g.g_t + \pi$

$\geqslant \mathrm{k_{t+1}} + \mathrm{c_t} + \mathrm{n.X_t} = \mathrm{w}(l^H + l^I + l^G + l^X + l^Y) + \mathrm{r}(k^H + k^I + k^G + k^X + k^Y) + (1-\delta)\mathrm{k_t} + (\mathrm{v^m} - \delta^{\mathrm{C}})(m_t^I + m_t^G) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h}_t - \mathrm{rk_G} - \mathrm{wl_G} - \mathrm{v^m}.\mathrm{m}_t^G - P^H.H_t - P^I.I_t + q^s.s_t + q^g.g_t + \pi$ **(4)**

Now, holding Decreasing Returns to Scale (DRS) we have:

$\pi = \pi^H + \pi^I + \pi^X + \pi^Y$

$\geqslant \pi = (P^H.H_t - w.l^H - r.k^H - \mathrm{v^h}.\mathrm{h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m}.\mathrm{m}_t^I) + (\mathrm{n.X_t} - w.l^X - r.k^X - q^s.s_t) + (Y - w.l^Y - r.k^Y - q^g.g_t)$

Now inserting the value of π in equation 4, we have:

$\geqslant \mathrm{k_{t+1}} + \mathrm{c_t} + \mathrm{n.X_t} = \mathrm{w}(l^H + l^I + l^G + l^X + l^Y) + \mathrm{r}(k^H + k^I + k^G + k^X + k^Y) + (1-\delta)\mathrm{k_t} + (\mathrm{v^m} - \delta^{\mathrm{C}})(m_t^I + m_t^G) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h_t} - \mathrm{rk_G} - \mathrm{wl_G} - \mathrm{v^m}.\mathrm{m}_t^G - P^H.H_t - P^I.I_t + q^s.s_t + q^g.g_t + (P^H.H_t - w.l^H - r.k^H - \mathrm{v^h}.\mathrm{h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m}.\mathrm{m}_t^I) + (\mathrm{n.X_t} - w.l^X - r.k^X - q^s.s_t) + (Y - w.l^Y - r.k^Y - q^g.g_t)$

$\geqslant \mathrm{k_{t+1}} + \mathrm{c_t} + \mathrm{n.X_t} = \mathrm{w}(l^H + l^I + l^G + l^X + l^Y) + \mathrm{r}(k^H + k^I + k^G + k^X + k^Y) + (1-\delta)\mathrm{k_t} + (\mathrm{v^m} - \delta^{\mathrm{C}})(m_t^I + m_t^G) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h_t} - \mathrm{rk_G} - \mathrm{wl_G} - \mathrm{v^m}.\mathrm{m}_t^G - P^H.H_t - P^I.I_t + q^s.s_t + q^g.g_t + (P^H.H_t - w.l^H - r.k^H - \mathrm{v^h}.\mathrm{h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m}.\mathrm{m}_t^I) + (\mathrm{n.X_t} - w.l^X - r.k^X - q^s.s_t) + (Y - w.l^Y - r.k^Y - q^g.g_t)$

$\geqslant \mathrm{k_{t+1}} + \mathrm{c_t} + \mathrm{n.X_t} = \mathrm{w}.l^X + \mathrm{w}.l^Y + \mathrm{r}.k^X + \mathrm{r}.k^Y + (1-\delta)\mathrm{k_t} + \mathrm{v^m}.m_t^I + \mathrm{v^m}m_t^G - \delta^{\mathrm{C}}m_t^I - \delta^{\mathrm{C}}m_t^G + \mathrm{v^h}.\mathrm{h}_t - \mathrm{v^e}.\mathrm{h}_t - \mathrm{rk_G} - \mathrm{wl_G} - \mathrm{v^m}.\mathrm{m}_t^G - P^H.H_t - P^I.I_t + q^s.s_t + q^g.g_t + (P^H.H_t - w.l^H - r.k^H - \mathrm{v^h}.\mathrm{h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m}.\mathrm{m}_t^I) + (\mathrm{n.X_t} - w.l^X - r.k^X - q^s.s_t) + (Y - w.l^Y - r.k^Y - q^g.g_t)$

$\geqslant \mathrm{k_{t+1} + c_t = (1-\delta)k_t - \delta^C} m_t^I - \delta^C m_t^G - \mathrm{v^e.h}_t + Y$

$\geqslant \mathrm{k_{t+1} = Y - c_t - v^e.h}_t + (1-\delta)\mathrm{k_t} - \delta^C m_t^I - \delta^C m_t^G$

$\therefore \mathrm{k_{t+1} = Y - c_t - v^e.h}_t + (1-\delta)\mathrm{k_t} - \delta^C(m^I + m^G)$ **(Economy wide Resource Constraint)**

4. GDP Calculation

We model GDP as follows.

$GDP = A + n.X + Y + q^e.e + v^h.h$

From Data, we know that, $\frac{A}{GDP} = 0.1929$

Let us assume that, $n.X + Y + q^e.e + v^h.h = B$. This implies that,

$GDP = 0.1929GDP + B$

$$\geqslant GDP = \frac{B}{1-0.1929}$$

$$\therefore A^{SS} = \frac{0.1929}{1-0.1929}B$$

Now given the steady state value of expression B and A^{SS}, we calculate

$\boldsymbol{GDP = 2.101215168}$

Chapter 6

A Dynamic Stochastic General Equilibrium Analysis of the Welfare Effects of Alternative Electricity Pricing Schemes: The Case of Bangladesh

6.1 Introduction

Energy (electricity) sector reforms are multidimensional with a variety of impacts on economy. One of the key forces of energy (electricity) sector reform is price reform in the form of setting subsidy-free and competitive prices. Energy (electricity) price and subsidy reform is considered as the pillar for any energy/electricity market restructuring. In most of the developing countries, electricity reform requires extensive restructuring of prices and subsidy arrangements (Jamasb, 2006). However, policymakers are very sensitive regarding the effect of energy (electricity) price changes on consumers and producers. In general, energy (electricity) demand and supply situation in any country depends on a subsidy and price fixing effect. Subsidising consumers of fuel products is a common phenomenon in many developing countries like Bangladesh.

The term subsidy is very common and widely used in economics. Energy (electricity, gas and petroleum) subsidies lower the prices paid by energy consumers, lower the cost of energy production or raise the revenues of energy producers (IEA, OECD and World Bank, 2010). However, economic theory suggests that subsidies are inefficient as consumers do not use resources optimally (Katz and Rosen, 1994). Economists further argue that income transfers are superior to subsidies and reduce inefficiencies, as the former do not create the deadweight loss associated with subsidies and maximise welfare. There have been studies on subsidies and economy and several researchers have directed the focus of their studies on subsidies and economic welfare in many developing countries (Moltke et al., 2004).

Some subsidy schemes are designed to be permanent in the developing countries like cross subsidies across different consumer categories. For example, in Bangladesh the electricity price structures differ across sectors and levels of consumption. Industrial and service sectors pay higher price compared to the domestic sectors. Thus, the domestic sectors are cross subsidised by the industrial and service sectors. According to World Bank (2010), cross-subsidies include a group of consumers paying more than the general cost of supply and the surplus is used to subsidise the provision to the other group at a price that is lower than the cost of supply to the subsidised group. It is also argued in the World Bank group energy sector background paper (2010) that this cross-subsidisation may be formulated with varying degrees of transparency. A variation on this theme is where the cost of supply is higher to the targeted group, but the price to both groups is set the same. This has the consequence that one group pays above cost and the other pays below cost.

Subsidies on energy (electricity, gas and petroleum) sector have also been an important issue for many developing countries because of the cost of providing them. For example, one IMF report (2013) shows that energy subsidies exceeded 3% of GDP in four countries (Bangladesh, Brunei, Indonesia, and Pakistan) where petroleum products and electricity accounts for nearly 90% of subsidies. They could also create distortions which would have negative impact on welfare. Another reason that energy subsidies have been an important policy issue is the difficulty in reducing or removing them, often due to the political turmoil their removal causes. Subsidies prevail in most of the developing countries due to equity consideration. In most of the developing countries, subsidies serve the purpose of legitimate social goals benefiting the marginalised consumers by lowering the cost of energy. However, there are controversies whether these subsidies actually benefit the poor people. Energy subsidies are mentioned as both inefficient and inequitable (IMF, 2013). They send false price signal that encourage overconsumption of fuel, delay the adoption of energy-efficient technologies, and crowd out high-priority public spending, including spending on physical infrastructure, education, health and social protection. Most of the benefits of fuel subsidies also go to higher income groups who tend to consume more fuel (Arze et al., 2012). Moreover, Moltke et al. (2004) discuss that cross subsidies could undermine the international competitiveness of industrial firms that are forced to pay above cost tariffs and impede economic development. Jamasb and Nepal (2015) also argue that cross subsidies from industrial to residential users are not economically desirable.

In fact, there are some differences in subsidy definition as several international players like the Organisation for Economic Co-operation and Development (OECD), the World Trade Organization (WTO), the European Union (EU), the International Energy Agency (IEA), the International Monetary Fund (IMF), the World Bank (WB) and the Global Subsidies Initiatives (GSI), have contributed to defining subsidy boundaries (OECD, 2013). In practice, how a country defines a subsidy depends on regional and political decision reflecting domestic political, economic settings and institutional frameworks and local traditions. Both at the domestic and international level, these definitions largely reflect the essential elements of a subsidy as accepted in economic theory. The original and simple definition of a subsidy is a direct budgetary payment made by a government to the producers and the consumers under the form of a grant or loan. The practice of providing direct subsidies to the recipients is known as explicit (cash) subsidies. Additionally, when government provides subsidy to protect the consumers through price mechanism is called Market Transfer. These transfers usually delivered as regulated prices for consumers set at below market prices and provided as a means to guarantee access to minimum volumes of consumption of a certain goods (OECD, 2013). This kind of subsidy is more widespread in the energy sector in the developing countries. This form of subsidy can also be defined as implicit subsidy. Consumer subsidies (such as electricity tariffs provided at a price lower than the full supply cost) are also known as on-budget subsidies which are easily identifiable. On the other hand, producer subsidies are often off-budget subsidies and less visible. One can also classify subsidy as indirect subsidies where subsidies are received indirectly by the recipient as a higher market price for output and/or a lower market price for input goods (For example, a reduced cost of oil fuel sold to electricity companies as a result of subsidies to electricity generators). Thus, governments can provide support directly or indirectly through market interventions and the overall impact of subsidies entirely depends on the underlying elements of the subsidies. Our model mainly includes implicit form of subsidy directed to both the consumers and energy producers. Furthermore, we pay attention to cross subsidies across sectors since industrial and service sectors cross subsidising domestic sector by 40.97% and 82.55% respectively (BPDB, 2015). We have also estimated that industrial and service customers have to pay 34.94% and 74.75% more than actual supply cost. On the other hand, prices to domestic consumers cover only 64.66% of the supply cost. Jamasb and Sen (2012) argue that reduction on cross-subsidies would in themselves lead to the release of previously constrained capital, thus improving efficiency. However, the representative agent assumption of the model would not allow us to consider the cross subsidies prevailing within domestic group of consumers.

Bangladesh has undergone fundamental changes in their electricity industry over the last few decades. The country has practiced some reforms in 1970s and 1980s since the demand for electricity was low during that time. However, intensive reform initiatives have been observed in the electricity sector in the 1990s and 2000s and is still continues. For example, the electricity industry has been functionally unbundled. The generation sector has been rearranged to encourage competition and increase electricity supply. This is also clearly observed that the industry is driving away from the public domain towards the private domain.

The energy policymakers would like to achieve a wide range of objectives like attracting foreign investments, providing electricity to all, ensuring price competitiveness, tackling fiscal burden from the removal of energy subsidy, encouraging privatisation to increase efficiency and economic development. However, to the best of our knowledge, existing literature has not paid any attention to examine the effect of electricity price reform on Bangladesh economy in a dynamic framework. This chapter addresses this concern and considers a DSGE model to study some alternative electricity pricing experiment for policy purposes in Bangladesh as an example of small developing country where energy (mainly electricity and fuels) subsidy is very high, energy prices are distorted and government controls energy prices. Since policy discussions were primarily focused in this chapter, we examine the effects of some proposed energy reforms particularly electricity pricing reform policies on household welfare and macroeconomy in Bangladesh in its endeavours to develop and enhance electricity systems. Although the analysis mainly focuses on

Bangladesh electricity sector, the results and policy implications are also relevant for the other developing countries undertaking reform in this sector.

The chapter is organised as follows. The literature review is discussed in section 6.2; policy experiments are explained in section 6.3. Section 6.4 focuses on welfare estimation formula; followed by a discussion on dataset, parameter specification and calibration in section 6.5. Section 6.6 portrays the analysis of the results obtained and finally, in the last section, we present the conclusions.

6.2 Literature Review

According to Jamasb et al. (2005), the reviewed literature on energy reforms can be broadly divided into two categories: i) the determinants of reform and the key steps taken and ii) the effects of various reform steps on performance indicators. Following Jamasb et al. (2004), Zhang et al. (2008), Jamasb and Nepal (2011), the primary driving forces behind energy reform movement can be distinguished between 'push' and 'pull' factors. The 'push factors' were twofold; the first was related to the adoption of structural adjustment programmes by developing countries, such as Bangladesh, in cooperation with multilateral lending agencies, such as the World Bank, the ADB and the IMF, as a condition of multilateral financial support following fiscal crises. The second 'push factor' was related to widespread problems within the electricity sectors of developing countries, and a genuine need for reform (Sen, 2014). For example, the push factor includes the poor performance of state-run electricity operators in terms of high costs, the inability of the state sector to meet the investment and maintenance costs of the electricity industry associated with the increasing demands for electricity resulting from economic development in other sectors of the economy and the need to remove electricity subsidies so as to release resources for other areas of public expenditure etc. The 'pull' factors included a demonstration effect following experiences in the Chile, England and Wales and Norway in the 1980s and early 1990s (Zhang et al., 2008).

The core reform elements so far adopted by different countries as mentioned by Jamasb (2006) have tended to include i) Restructuring and corporatisation or commercialisation of the core power utility, ii) Tariff and subsidy reform, iii) Development of an independent regulatory authority, iv) Enactment of an 'Energy Law' and v) Privatisation. These elements would aim to introduce competition by increasing the number of players in the market, ensuring cost-reflective tariffs, breaking up the incumbent monopoly utilities and shifting the regulatory mandate from the Ministry/Department of Energy to an "independent" regulatory agency to ensure a level playing field.

Researchers have also attempted to quantify the effect of energy (electricity) price and subsidy reform on economy. Several findings emanate from the empirical investigations on energy (electricity) price reform and petroleum products subsidy and its effect of removal on household welfare. For example, Hartley and Medlock (2008) studied the behaviour of National Oil Companies (NOC's) and showed that NOC's are inefficient compared to private companies and having the NOC's subsidise domestic customers increased this inefficiency. Using a small open-economy model, Plante (2014) showed that sizable subsidies could introduce significant distortions into the country that put them in place.

Andriamihaja and Vecchi (2007) employed Price Shifting Model to assess the distributional impact of higher energy price in Madagascar on households' real expenditure. They showed that a 17% rise in the price of energy products leads to a 1.75% average decrease in real expenditure. This percentage is higher for low-income households (2.1%) than for high-income households (1.5%). The study concludes that the benefit of introducing price subsidies would be progressive; that is, in percentage terms, subsidy would benefit poor households' more than rich household. However, subsidising would involve substantial leakage in favour of high income households and there is an issue of identifying more cost-effective policies to protect poorest households.

Adagunodo (2013) examined petroleum products pricing reform and welfare in Nigeria and concluded that if implemented correctly, the removal of subsidy would save largest amount from government budget and the subsidy funds could lead to major development gains for the country. Nwafor et al. (2006) investigated the impact of removal of petroleum products subsidies on poverty in Nigeria. The study concluded that subsidy removal, without spending of the associated savings, would increase the national poverty level. This is due to the consequent rise in inputs' costs which is higher than the rise in selling prices of most firms. The key sectors which experience increased nominal output are the refined petroleum products which provide income for an extremely low number of households. Freund and Wallach (1995) looked at the welfare effects of increasing energy prices in Poland and concluded that programmes that subsidising household energy prices in Poland as well as the other transition economies help the rich more than they help the poor. Not only do the wealthy consume more energy in absolute terms, but also spend a larger portion of their income on energy. Based on their results, they proposed that the first best policy would be to raise energy prices while targeting cash relied to the poor through a social assistance programme.

Oktaviani et al. (2007) used a CGE model to analyse the elimination of fuel subsidies in Indonesia, which occurred in three stages over the period 2000-2005 (prices were increased by 21% in 2000, 30% in 2001 and 29% in 2005). They concluded that the short to medium-term macroeconomic performance of the economy was adversely affected by the removal of the subsidies, due to reduction in household incomes and increase in domestic prices. Furthermore, the reduction of fuel subsidies increased overall impact of poverty in Indonesian economy from 8.9 to 12.9% of population, with rural areas are worst affected. However, Gibson and Olivia (2008) used the Marginal Social Cost approach to evaluate the equity and efficiency of subsidy reform in Indonesia and concluded that large subsidies on kerosene should be reduced.

Kpodar and Djiofack (2009) assessed the distributional effects of a rise in various petroleum product prices in Mali using a standard CGE model. Their results suggest that higher diesel prices primarily affect richer households, while the poorest ones tend to suffer more from higher kerosene and gasoline prices. Overall, the impact of fuel prices on household budgets shows a U-shaped relationship with expenditure per capita. Regardless of the oil product considered, high-income households benefit disproportionately from oil price subsidies. This suggests that petroleum price subsidies are ineffective in protecting the income of poor households compared with a targeted subsidy.

Coady et al. (2006) simulated both direct and indirect effects of fossil-fuel subsidy reform in Bolivia, Ghana, Jordan, Mali and Sri Lanka. They found that the direct effects of increased fossil fuel prices on aggregate real income ranged from 0.9% in Mali to 2.0% in Bolivia. However, in Ghana, Jordan and Sri Lanka they were regressive affecting the lowest income more than the highest. Indirect effect resulting from increases in the prices of other goods and services were higher, ranging from 1.1% to 6.7%, but tended to be equally distributed across income quintiles. This reflects the higher proportion of their budgets that lower income quintiles must devote to energy as opposed to other goods and services.

Angel-Urdinola et al. (2006) examined the extent to which the poor did benefit from past subsidies in Rwanda, and to discover whether they would benefit from alternative implicit or explicit cross-subsidies. Because access rates to network are very low among the poor, the share of the implicit subsidies that prevailed before the increase in tariff and that benefited the poor was also very low. They concluded that previous subsidies were badly targeted. Another important result of their analysis was the finding that it would probably be better for poverty reduction to give priority to a subsidy mechanism for new connections to the network rather than a subsidy for consumption for those households that are already connected.

6.3 Policy Experiments

In general, the electricity sector in developing countries performs poorly. Electricity access is scarce, transmission losses are high, blackouts are common, prevalence of high subsidy and distorted price and many state owned power utilities are in serious financial hardship. In order to bring the fiscal burden from subsidy under control, to remove the price distortions in electricity market and to ensure better service quality in electricity sector, we propose some electricity price reform policies in this section. Electricity price reform is considered as the foundation of long anticipated changes that are aimed at liberalising electricity sector. In almost all reforming countries, electricity reform has been a part of wider policies towards a liberal market economy. This liberalisation is generally set simultaneously through the pricing mechanism and through competition to provide incentives to consumers to use electricity productively. Some of the key elements of electricity market reforms in the developing countries which are widely discussed in the literature (For example, Williams and Ghanadan, 2004, Jamasb et al., 2005) include tariff reforms, privatisation, commercialisation etc. A tariff reform implies adjusting tariffs in order to remove subsidies to reflect cost efficiency. This process is also known as commercialisation.

Philip (2004) argues that liberalisation acts as the most effective means of fixing the many difficulties and challenges faced by energy (electricity) sectors across the world. Liberalisation, in its fullest sense, comprises four main reforms: i) A change in the structure of the energy (electricity) industry, ii) A change in the ownership of the energy (electricity) companies, iii) A change in the structure and function of government and iv) the development of energy (electricity) markets regulation.

A successful privatisation and liberalisation programme can improve the financial position of both the government and the company. In the short term, the government is relieved of the need to subsidise a loss-making entity and should raise money from the sale. The company gains from privatisation because, free from social objectives, it should find it easier to raise loans for financing capital projects. Moreover, other financial and economic benefits may accrue. The budget deficit should decline along with the need to subsidise loss-making enterprises, and thus the pressures on inflation are reduced. If the privatised company increases its profitability, the government's tax revenue will increase. Successful liberalisation should lead to increased level of investment in the energy sector from the newly privatised companies as well as new entrants. If foreign companies purchase part of or all of the state entity, the foreign exchange reserves are boosted. Finally, public flotation can help the domestic stock markets develop.

In Bangladesh, electricity is the most widely used form of energy. However, since independence from Pakistan in 1971, the country has struggled to generate adequate electricity to meet demand. Meanwhile, state-owned electricity utilities suffer from large deficits. The electricity sector has also failed to attract adequate private investments due to poor pricing policies and other bottlenecks. This lack of investment is a major contributing factor to Bangladesh's electricity crisis. In order to improve the situation, the government has adopted a comprehensive electricity development strategy to explore supply-side options along with demand management that conserves electricity and discourages inefficient use. The thrust of the government's policy is to treat electricity as a private good such that its price reflects the cost of production and a fair return is generated on investment. The policy maintains that "social objectives like reaching out to the poor and rural community could be achieved through cross-subsidisation as well as explicit budget subsidies" (Planning Commission 2011). As such, a key policy reform for the government is to ensure proper pricing of electricity based on international best practices. However, the rationality of subsidies needs to be economically justified.

In order to perform policy experiments, we proceed as follows. We first assume the economy is in an initial steady state condition consistent with our calibration, dataset, existing electricity prices, underlying subsidies, parameter values and the model's equations explained in chapter 5.

We then propose some alternative electricity pricing schemes and analyse what would happen in the economy in terms of welfare context if these policies are being implemented. More precisely, we intend to focus on the macroeconomic impact of these policy changes, i.e. we ask how the steady state of the model is affected. Technically, we conduct a comparative statics exercise. For each variable of interest we numerically calculate the percentage change of that variable across steady states. Introducing different policy experiments, we make an attempt to remove the price distortions which had led to sub optimal outcomes in the economy.

Our proposed policy experiments are as follows.

6.3.1 Equal Price Experiment

Like many other developing countries, Bangladesh has a complicated electricity pricing system that includes different approaches for households, industry and commercial users. The pricing of electricity is the most complex among all energy resources, perhaps because it is also politically sensitive. The pricing policy for energy (electricity) in Bangladesh is formulated and implemented by the Bangladesh Energy Regulatory Commission (BERC) with support from related agencies. It may be mentioned here that there are separate tariff rates in Bangladesh for different categories of consumers. Some of these tariffs are distorted. This experiment can be considered as the most common forms of government reform to phase out electricity price distortions. We would like to analyse how policy could work if we remove the differential electricity consumer prices and selling prices and introduce common electricity price respectively for all the consumers and the generators. Nevertheless, we eliminate price distortions; propose new electricity prices as a method of simple reform. This experiment involves partial liberalisation.

6.3.2 Flexible Price Experiment

This experiment suggests full electricity liberalisation policies to eliminate electricity and fuel price distortions all the way. Here, government abolishes all price controls and allow market to adjust prices. We intend to examine whether flexible price regime is better than the fixed price regime to protect the economy from adverse effects of oil price shocks. Therefore, we consider a weighted average electricity price for all the electricity consumers and producers. We also propose there is no difference in world and domestic fuel prices. Erdogdu (2011) mentions that in a situation where there is no cross subsidy across different group of consumers and ignoring disproportional transmission and distribution charges paid by different consumer groups, electricity prices across different consumer groups are expected to be almost the same. Jamasb and Pollitt (2005) also argue that the existence divergence of transmission and distribution network tariffs limits the convergence of end-user prices. However, for simplicity, we do not consider the differences in cost of electricity supplying households and industry in terms of transmission and distribution.

6.3.3 Efficient Electricity Price Experiment

This is the extension of the previous policy experiment (Flexible Price Experiment). In the previous experiment, there was no government intervention in price control at all. However, in this policy experiment we would like to consider the controlled price for oil and gas simply liberalising the electricity sector and study what electricity price is needed for government to operate at efficient level.

6.3.4 Privatisation Experiment

This experiment also advocates partial liberalisation reform steps. The electricity market in Bangladesh is mainly controlled by the public sector which does not necessarily allocate resources efficiently. In our benchmark model, government is a cost minimiser. However, in this policy experiment, we consider government as a profit maximising firm and then investigate the differences in steady state values of some selected economic indicators and household welfare under two scenarios. Being a profit maximiser, government is now not dictating electricity prices anymore. Given fixed factor prices, now consumers' electricity prices need to be adjusted to hold equilibrium condition in electricity market. Here we liberalise the government firm in order to get rid of government involvement in the production side and accordingly, budget constraint should be free from any kind of government intervention. It is widely believed that privatisation would improve not only the financial health of the sector, but would also increase revenue for government treasuries which help to reduce and restructuring public debt. Baumol (1982, 1996) argue that privately owned firms are more efficient than the state owned ones under perfect contestability theory. The contestability theory (the contestable market analysis) does offer the regulator guidance on the regulatory rules for the behaviour of privatised firms that would provide the economy with the benefits of effective competition. Jamasb et al. (2014) also mentions that the theoretical arguments for efficiency improvements dominated the motives for privatisation and adopting market-oriented reforms. It is also assumed that a blend of privatisation, regulatory reform and liberalisation improves economic efficiency and service standards in all energy sectors (Pollitt, 2002). However, Bonifaz and Jaramillo (2010) reveal that privatisation does not lead to an improvement in efficiency in distribution operators in Peruvian electricity market.

6.3.5 Subsidy Experiment

In this policy experiment, we would like to explore what would happen to the economy if government decides to change the subsidy. At present government provides 30% subsidy to the electricity generating firms for importing oil from the rest of the world. We propose a reduction of 10% subsidy as a step of reform instruments.

For the successful implementation of any policy experiment, it requires tremendous political will to take tough decision that results in adverse short term effect but positive impact on economy in the long run. If the country has a long history of subsidy, it would be very difficult to phase it out. Additionally, the consumers who get used to cheap energy (electricity and fuel) cannot be blamed when they react violently to major energy price increase.

The model considered in this chapter is the same DSGE model of a small economy as explained in chapter five[9]. The only observed difference is in the government resource constraint for the privatisation policy experiment as we have liberalised the government firm who now acts as a profit maximising firm. Additionally, there should not be any government intervention on the production side and government resource constraint should be free from the government electricity firm's monetary transactions.

So, in the privatisation experiment, the government should satisfy the following resource constraint:

$$\tau^{l}.w.l + \tau^{k}.r.k + (v^{m} - \delta^{C})(m^{I} + m^{G}) + (v^{h} - v^{e})h - ъ = b$$

However, in the previous chapter, we assume that, the government, like any other entity in the economy, must satisfy a resource constraint:

$$\tau^{l}.w.l + \tau^{k}.r.k + (v^{m} - \delta^{C})(m^{I} + m^{G}) + (v^{h} - v^{e})h + P^{G}G - rk_{G} - wl_{G} - v^{m}m^{G} - ъ = b$$

6.4 Welfare Estimation

In addition to asking how variables changed across steady states, we have also calculated how steady state welfare in the country was affected by the policy experiments.

[9] For More detail discussion please see section 5.2 of chapter 5.

The welfare gain of different policy experiments can be estimated comparing two different states of the economy: an economy where consumers and producers face differential tariffs (The benchmark case) and an economy where various groups of consumers and producers face the proposed electricity prices under the policy experiments. If c_1, e_1, X_1 and l_1 are the steady state values with differential electricity prices, one can estimate the value of the utility, U_1 for the first economy using the following equation:

$$U_1 = X_1^{\gamma}\left(\theta c_1^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

Similarly, U_2, the level of utility, can be obtained with a new set of steady state values (c_2, e_2, X_2 and l_2) from the proposed policy experiments. Then the utility changes under two different states of economy can be observed. However, this value is not meaningful as utility is an ordinal measure.

The actual gain in welfare can be calculated considering the percentage change of consumption which is required to reach the new level of utility, U_2, according to the following equation[10]:

$$\hat{c}^{\rho} = (c_2^{\rho} + \frac{1-\theta}{\theta} e_2^{\rho})(\frac{X_2}{X_1})^{\gamma\frac{\rho}{1-\gamma}} \ (\frac{1-l_2}{1-l_1})^{\frac{1-\varphi}{\varphi}\cdot\frac{\rho}{1-\gamma}} - \frac{1-\theta}{\theta} e_1^{\rho}$$

Here, we solve for how much non-electricity consumption would need to be increased in the benchmark steady state in order for utility to be the same as in the new steady state under different policies. We then convert these numbers into percentages which gives the welfare gain from the policy experiments.

[10] See Technical Appendix for the derivation of the Welfare Equation

6.5 Dataset, Parameter Specification and Calibration

The benchmark model is calibrated following Kydland and Prescott (1982). The model is implemented numerically using detailed data and parameter sets as discussed in chapter 5. The data needed to calibrate the model for Bangladesh economy comes from Bangladesh Bureau of Statistics (BBS), Bangladesh Economics Review (BER), World Development Indicator (WDI), Bangladesh Labour Force Survey (BLFS), Bangladesh Power Development Board (BPDB), Bangladesh Petroleum Corporation (BPC), Summit Power Limited, Dutch Bangla Power and Associates Limited and Bangladesh Tax Handbook. In this section, we present data used in the calibration to perform our proposed policy experiments to examine how sensitive Bangladesh economy are to these proposed electricity prices as policy alternatives. The data will be a key input into the theoretical models to quantify the importance of the policy experiments of different policy experiments.

For some of the experiments, we calculate the proposed electricity prices for the different policy experiments from the original data following Weighted Average Index. Weighted averages are used extensively in descriptive statistical analysis. We estimate an average (mean) electricity price in which electricity price of a particular group of consumer or producer in any sector being averaged is multiplied by quantity (weights) based on the respective sector's relative importance. The result is summed and the total is divided by the sum of the quantities. **Table 6.1** shows the experimental prices under different policy experimentation.

6.6 Results

Our results are presented in **Table 6.2 and 6.3**. At first, we analyse the percentage changes across steady state for the different variables and then calculate the household welfare under alternative policy experiments.

Under the **"Equal Price Experiment (EPE)"**, non-electricity consumption, service consumption increases by 0.45% and 1.45%. Since the QR firms now face only one third of the benchmark price under this experiment, they are reluctant to generate electricity with oil. So, oil usage has declined by 84.25% which in turn lowers the import volume and bills. This causes a reduction in industrial production by a small margin (-0.06%) as industrial sector now does not need to produce extra volume of exportable goods to counter the higher import bills. In the benchmark model with the given electricity price, household, industry and service represents 47%, 37% and 16% of total electricity consumption respectively as observed in the steady state. However, under this experiment with a higher electricity price faced by the household consumers and lower electricity price faced by the industry and service consumers, the previous ratio has been altered. Now, consumer share of total electricity consumption is only 35%. Nevertheless, service and industrial electricity consumption increased by 48% and 17% respectively. The overall electricity supply and demand increases by 0.51% under the equalisation of electricity prices among the different group of consumers. The increase in electricity supply mainly comes from the higher government electricity generation to equalise electricity demand and supply in the economy. Government now uses more gas to produce electricity and need 16.93% higher amount of gas than the benchmark scenario. Implicit subsidy also decreases, but this is a purely quantitative issue as modelled in the equation. The overall household welfare increases by 3.70% and GDP increases by 0.72% in this experiment.

The **"Flexible Price Experiment (FPE)"** leads to an increase of overall household consumption as the relative price of electricity faced by the household has declined. Industry enjoys lower input price since electricity prices go down under this experiment which expands the industrial production by 2.85%. There is a reallocation of the usage of fuel needed to generate electricity because of the changes of the relative prices faced by the producers. Quick rental firms have to sell their electricity at a price which is half of the benchmark price. Consequently, these firms are facing loses as there is no changes in subsidy compared to the benchmark cases. Thus, they reduced their electricity generation by 34.44% and accordingly use of oil has also declined by 61%. But a boom is observed in IPP sector as their production has increased by almost 40%. The overall demand and supply is also increased by 43.44% in this experiment. Government has no control over prices in this scenario and increased the electricity generation to match the overall electricity supply. Since all the price distortion has been removed in this experiment, this is the most welfare enhancing policy as observed in the results. There is a 20.87% increase in household welfare in this policy experiment. GDP has also increased by 2.15% here.

In the next policy experiment titled **"Efficient Electricity Price Experiment (EEEP)"**, we have calculated the most efficient price of electricity which helps to operate government electricity firm at an efficient level. This is the extension of the previous policy where we have not locked the fuel prices. The results revealed nearly comparable picture like the flexible price experiment in terms of qualitative and quantitative changes. The magnitude of quantitative changes is slightly different than the previous policy experiment. For example, now household non-electricity consumption increases by 1.94% compared to a 2.49% increment in the previous analysis. Industrial output increases at 3.08% rate as they can efficiently use the resources than before. The welfare and the GDP have increased by 18.9% and 1.86% respectively under this experiment. The results also show that the price faced by the government electricity firm should be kept at 3.22 Taka/kwh to make them operate at a most efficient level.

Unlike the other policy experiments, the **"Privatisation Experiment"** observes a reduction in total use of gas by 44% while total supply of electricity has increased by 8.17%. Although, we have observed a huge reduction in oil usage in the previous three experiments, here it has declined by a very small margin (-0.01%). This happens because now the quick rental producers are facing the exactly same price like the benchmark cases. There are no changes in producer prices in this experiment as consumers are now facing uniform electricity price which is needed to be adjusted to hold equilibrium. Since household consumers now face higher electricity price, they reduce their electricity consumption. However, industry and service sector enjoys the lower electricity price and increase their overall electricity consumption. Household welfare is increased by 7.61% and GDP increases nearly about 1%.

Our **"Subsidy Experiment"** with alternative subsidy policy shows that household welfare varies inversely with the level of producer subsidy. In the subsidy experiment, a 10% reduction of producer subsidy is experimented. As a result, overall household welfare increases by 0.36% and GDP increases by 0.10%. All the consumer and producer electricity prices remain unchanged from the benchmark scenario under this experiment. Since the producers are facing less subsidy than before they reduce their oil import by 19% which lowers QR electricity generation by 7.25%. The IPP generation has also reduced by 0.77% and government generation has increased by 0.74%. This implies that the private and public sectors react inversely to subsidy reductions. The government has now higher revenue, while the private sector has to buy electricity at higher prices. The total use of gas has increased by 1.59%. Although the electricity price reform is necessary, the removal of fuel subsidies creates a huge burden on electricity-intensive industries which led to disruption in production. As a result industrial production deceases by a small margin (-0.051%) in Bangladesh.

6.7 Conclusions

Electricity demand is rising rapidly in developing countries. The electricity pricing policies of those countries are therefore increasingly important for the efficient use of the overall electricity supply. However, electricity markets in most of the developing countries are highly distorted. Additionally, subsidising consumers of petroleum goods is a common phenomenon in many developing and emerging economies. Given their cost and persistence, it is likely that these price distorions and subsidies have important macroeconomic implications for the developing countries. For example, fuel subsidies affect wages, distort input choises in the production of goods and services, altering the demand for production factors. These efffects also lead to changes in the composition of sectoral and overall output. Thus, the energy sector is one of the most strategic ones from a development perspective. This chapter proposes some policy alternatives to remove electricity price distortions and phase out subsidies and evaluate how effective they are towards the economy of a small, oil importing developing country compared to the existing disorted fuel prices and subsidies.

Electricity price reform has been on the Bangladesh government's policy reform agenda over the past few years. A very few number of reports have been published analysing the approach to electricity pricing, the need for electricity price and fuel subsidy reforms and reform options in Bangladesh. The reform options need to be sorted very carefully evaluating the policy's overall performance in terms of achieving the goals as the demand and supply in Bangladesh are inelastic to some extent.

The purpose of this chapter is to propose some alternative electricity price mechanisms using a DSGE model assuming the country to be a small open developing economy where government controls electricity and fuel prices and to analyse the consequences of the energy price reforms (the removal of distorted electricity prices and electricity and fuel subsidies) on household welfare and macroeconomic condition in Bangladesh as an example of the developing countries. Our results show that electricity tariff and subsidy experiments have important effects on a number of macroeconomic variables and electricity market in Bangladesh economy.

Since all our proposed policies are welfare and GDP enhancing, decision makers can implement any of the policies considering the country's underlying macroeconomic condition, energy security, fuel options and political condition. Our results reveal that full liberalisation will ensure maximum welfare for Bangladesh. Moreover, the stochastic nature of our dynamic model also allow us to analyse the possible expected future path of different endogenous variables especially GDP on an oil price shock in period 1 of one standard deviation from the Impulse Response Functions. In fact, the transition path of the key endogenous variable of different policy experiments is very similar to their response to an oil price shock and the only difference observed is in the magnitude of the effect. The most feasible policy depends on government's objective as to whether it would maximise welfare or reduce the risk of oil price shocks. For example, impulse response function shows that equal price experiment should be the best option to be implemented at the risk of high oil price fluctuations as the deviation in GDP and the other key endogenous variables out of an oil price shock is lowest in this experiment. However, if government wants to maximise welfare, flexible price experiment should be the most feasible one (Figure 6.1-Figure 6.5).

We have found few common outcomes in all the policy experiments. For example, reduction in private activities and expansion of public sector, reallocation of fuel within electricity industry, higher welfare and higher GDP has been observed in our experiments. Firstly, all the policy experiments lead to a reallocation of fuel uses. Secondly, under every experiment, government electricity generating firm increases their generation because of following reasons mainly. First, the new prices faced by the private producers under some experiments are much lower than the price the firms faced in the benchmark case. This increases their relative input costs which reduce private supply of electricity. Thus, government need to intervene in the market and supply more electricity to equate the electricity demand. Second, the removal of subsidy reduces government expenditure which can be diverted to innovate in R&D sector, purchase new equipment etc. This would make government firm more efficient and allow generating more electricity. Finally, all the policy experiments are welfare and GDP enhancing.

Given our results, it is worthwhile that government could use the revenue earned from the subsidy removal and offer monetary and non-monetary incentives to producers who are affected. Uses of natural and renewable resources as alternative sources of fuel in electricity generation, innovation, application of R&D could play a key role to mitigate the current crisis in electricity market in Bangladesh. Hence, incentive could also be given to new electricity generators who would enter in the market planning to produce electricity with renewable energy or existing electricity generating companies intending to convert from using traditional fuel to renewable energy in producing electricity. For example, incentives could include tax rebates, long term subsidised loans for purchasing equipment, access to foreign exchange at preferred rates, etc. A limited amount of subsidy could also be reallocated to the electricity generators for the use of renewable inputs or the introduction of renewable technology. The policy implications of our results are clear and relevant not only for Bangladesh but also for many other developing countries sharing a similar electricity sector.

Appendix 6A

Table 6.1: Calibration & Parameter Values of Alternative Policy Experiments

Policy Experiments[11]	q^e	q^g	q^s	p^I	p^H	p^G
Benchmark Model	4.93	6.95	9.00	3.20	7.79	2.30
Equal Price Experiment	6.74	6.74	6.74	2.80	2.80	2.30
Flexible Price Experiment[12]	4.67	4.67	4.67	4.67	4.67	3.24
Efficient Electricity Price Experiment	4.67	4.67	4.67	4..67	4.67	3.22
Privatisation Impact	6.26	6.26	6.26	3.20	7.79	2.30
Subsidy Experiment	4.93	6.95	9.00	3.20	7.79	2.30

Source: BPDB and Authors' own calculation.

Table 6.2: Percentage Change in SS Values from Policy Experiments

Policy Experiments	c	x	y	H+I+G	GDP	h	$m^I + m^G$
Equal Price Experiment	0.45%	1.45%	-0.06%	0.51%	0.72%	-84.52%	8.95%
Flexible Price Experiment	2.49%	3.35%	2.85%	43.44%	2.15%	-60.66%	9.47%
Efficient Electricity Price Experiment	1.94%	3.17%	3.08%	42.86%	1.86%	-60.66%	9.45%
Privatisation Impact	1.06%	1.90%	0.44%	8.17%	1%	-0.01%	-44.25%
Subsidy Experiment	0.12%	0.03%	-0.05%	0.09%	0.1%	-18.68%	1.26%

Source: Authors' own calculation.

[11] Some of the electricity prices are calculated in Dynare software.

[12] The world and domestic price of oil and the domestic price of gas and extraction cost assumed to be same in the flexible price experiment.

Table 6.3: Welfare Changes of Alternative Policy Experiments	
Policy Experiments	Welfare Increases
Equal Price Experiment	3.70%
Flexible Price Experiment	20.87%
Efficient Electricity Price Experiment	18.9%
Privatisation Impact	7.61%
Subsidy Experiment	0.36%
Source: Authors' own calculation.	

Table 6.4: Dynare Code for Equal Price Experiment

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renström, Durham University Business School
var GDP v_e c e x l y e_g e_i e_h k k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g n w r g_s g_t  a_y a_g a_i a_h ;

varexo kappa eta_y eta_g eta_i eta_h;

parameters A v_h delta_c delta_g nu_m_gg delta_i nu_m_ii delta_x nu_ss delta_y nu_gg delta_h nu_hh  beta phi
theta rho gama alpha_i alpha_h alpha_g alpha_y alpha_x psi_h psi_i psi_g psi_y psi_x nu_m_g nu_m_i nu_h nu_g
nu_s chi omega mu_y mu_g mu_i mu_h zeta epsilon_y epsilon_g epsilon_i epsilon_h delta tau_k tau_l q_e q_s q_g
p_h p_i v_m p_g capomega_v capomega_g capomega_i capomega_h capomega_y;

v_h=5.72;
A=0.405324405;
delta_c=1.1;
delta_g=0.857936486;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.042063514;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.302053239;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
zeta=0.01;
epsilon_y=0.01;
```

```
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
q_e=6.749634418;
q_s=6.749634418;
q_g=6.749634418;
p_h= 2.802819511;
p_i= 2.802819511;
p_g= 2.802819511;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.132152826;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_g*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;
```

```
w * l_x = alpha_x * n*x;

r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;

q_s*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;

v_m*alpha_g*((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g))=((delta_g*nu_m_g)/nu_m_gg)* psi_g* m_g
^ (-nu_m_g -1)* l_g*w;

r* psi_g* m_g ^ (-nu_m_g -1)= (1- psi_g)* k_g^ (-nu_m_g -1)* v_m;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g-r*k_g-w *l_g -v_m
*m_g- g_t+ p_g * e_g=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_s *s-q_g *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;
GDP=A+n*x+y+q_e*e-v_e*h;

end;

initval;
c=0.337915857;
e=0.009866408825;
x=1.010007997;
l=0.33;
```

```
y=1;
GDP=2.101215168;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
k=9.364512596;
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
k_x=5.287550443;
l_h=0.00002789761551;
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182969;
n=0.491705834;
w=2.190427966;
r=0.078431372;
g_s=-0.065575779;
g_t=0.275536049;
v_e=8.19;
a_y=1.267680833;
a_g=0.071143485;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

end;

steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul (hp_filter=100, order=2, irf=500,relative_irf );
```

Table 6.5: Dynare Code for Flexible Price Experiment

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renström, Durham University Business School

var GDP c e x l y e_g e_i e_h k k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g n w r g_s g_t v_e a_y a_g a_i a_h p_g;

varexo kappa eta_y eta_g eta_i eta_h;

parameters A v_h delta_c delta_g nu_m_gg delta_i nu_m_ii delta_x nu_ss delta_y nu_gg delta_h nu_hh  beta phi
theta rho gama alpha_i alpha_h alpha_g alpha_y alpha_x psi_h psi_i psi_g psi_y psi_x nu_m_g nu_m_i nu_h nu_g
nu_s chi omega mu_y mu_g mu_i mu_h zeta epsilon_y epsilon_g epsilon_i epsilon_h delta tau_k tau_l q_e q_s q_g
p_h p_i v_m  capomega_v capomega_g capomega_i capomega_h capomega_y;

v_h=5.72;
A=0.405324405;
delta_c=0.7755;
delta_g=0.841591248;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.058408752;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.108672063;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
zeta=0.01;
```

```
epsilon_y=0.01;
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
q_e=4.67236292;
q_s=4.67236292;
q_g=4.67236292;
p_h=4.67236292;
p_i=4.67236292;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.139983299;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_g*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;

w * l_x = alpha_x * n*x;

r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;
```

```
q_s*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;

w * l_g = alpha_g* p_g* e_g;

r *((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*(1-psi_g)*k_g^ (-
nu_m_g -1)*e_g;

v_m *((1-psi_g)*k_g^ (-nu_m_g) +psi_g* m_g ^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*psi_g* m_g ^
(-nu_m_g -1)*e_g;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g-r*k_g-w *l_g -v_m
*m_g- g_t+ p_g * e_g=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_s *s-q_g *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;
GDP=A+n*x+y+q_e*e-v_e*h;
end;

initval;
c=0.337915857;
e=0.009866408825;
x=1.010007997;
l=0.33;
y=1;
GDP=2.101215168;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
k=9.364512596;
```

```
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
k_x=5.287550443;
l_h=0.00002789761551;
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182961;
n=0.491705834;
w=2.190427966;
r=0.078431372;
g_s=-0.065575779;
g_t=0.275536049;
p_g=4.67236292;
v_e=5.72;
a_y=1.267680833;
a_g=0.060830377;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

end;

steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul ( order=2, irf=500,relative_irf );
```

Table 6.6: Dynare Code for Efficient Electricity Price Experiment

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renström, Durham University Business School


var GDP v_e c e x l y e_g e_i e_h k k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g n w r g_s g_t  a_y a_g a_i a_h p_g;

varexo kappa eta_y eta_g eta_i eta_h;

parameters A v_h delta_c delta_g nu_m_gg delta_i nu_m_ii delta_x nu_ss delta_y nu_gg delta_h nu_hh  beta phi
theta rho gama alpha_i alpha_h alpha_g alpha_y alpha_x psi_h psi_i psi_g psi_y psi_x nu_m_g nu_m_i nu_h nu_g
nu_s chi omega mu_y mu_g mu_i mu_h zeta epsilon_y epsilon_g epsilon_i epsilon_h delta tau_k tau_l q_e q_s q_g
p_h p_i v_m  capomega_v capomega_g capomega_i capomega_h capomega_y;

v_h=5.72;
A=0.405324405;
delta_c=1.1;
delta_g=0.841591248;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.058408752;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.108672063;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
```

```
zeta=0.01;
epsilon_y=0.01;
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
q_e=4.67236292;
q_s=4.67236292;
q_g=4.67236292;
p_h=4.67236292;
p_i=4.67236292;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.139983299;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_g*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;

w * l_x = alpha_x * n*x;
```

```
r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;

q_s*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;

w * l_g = alpha_g* p_g* e_g;

r *((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*(1-psi_g)*k_g^ (-
nu_m_g -1)*e_g;

v_m *((1-psi_g)*k_g^ (-nu_m_g) +psi_g* m_g ^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*psi_g* m_g ^
(-nu_m_g -1)*e_g;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g-r*k_g-w *l_g -v_m
*m_g- g_t+ p_g * e_g=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_s *s-q_g *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;
GDP=A+n*x+y+q_e*e-v_e*h;
end;

initval;
c=0.337915857;
e=0.009866408825;
x=1.010007997;
l=0.33;
y=1;
GDP=2.101215168;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
```

```
k=9.364512596;
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
k_x=5.287550443;
l_h=0.00002789761551;
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182961;
n=0.491705834;
w=2.190427966;
r=0.078431372;
g_s=-0.065575779;
g_t=0.275536049;
p_g=4.67236292;
v_e=8.19;
a_y=1.267680833;
a_g=0.060830377;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

end;

steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul (hp_filter=100, order=2, irf=500,relative_irf );
```

Table 6.7: Dynare Code for Privatisation Experiment

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renström, Durham University Business School

var GDP v_e q_e c e x l y e_g e_i e_h k k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g n w r g_s g_t  a_y a_g a_i a_h ;

varexo kappa eta_y eta_g eta_i eta_h;

parameters A p_g v_h delta_c delta_g nu_m_gg delta_i nu_m_ii delta_x nu_ss delta_y nu_gg delta_h nu_hh  beta
phi theta rho gama alpha_i alpha_h alpha_g alpha_y alpha_x psi_h psi_i psi_g psi_y psi_x nu_m_g nu_m_i nu_h
nu_g nu_s chi omega mu_y mu_g mu_i mu_h zeta epsilon_y epsilon_g epsilon_i epsilon_h delta tau_k tau_l  p_h
p_i v_m  capomega_v capomega_g capomega_i capomega_h capomega_y;

v_h=5.72;
A=0.405324405;
delta_c=1.1;
delta_g=0.841591248;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.058408752;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.108672063;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
zeta=0.01;
```

```
epsilon_y=0.01;
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
p_g=2.307534701;
p_h=7.79;
p_i=3.20;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.139983299;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_e*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;

w * l_x = alpha_x * n*x;

r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;

q_e*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;
```

```
w * l_g = alpha_g* p_g* e_g;

r *((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*(1-psi_g)*k_g^ (-nu_m_g -1)*e_g;

v_m *((1-psi_g)*k_g^ (-nu_m_g) +psi_g* m_g ^ (-nu_m_g)) = p_g*((delta_g*nu_m_g)/nu_m_gg)*psi_g* m_g ^ (-nu_m_g -1)*e_g;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g- g_t=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_e *s-q_e *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;
GDP=A+n*x+y+q_e*e-v_e*h;
end;

initval;
c=0.337915857;
e=0.009866408825;
x=1.010007997;
l=0.33;
y=1;
GDP=2.101215168;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
k=9.364512596;
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
```

```
k_x=5.287550443;
l_h=0.00002789761551;
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182961;
n=0.491705834;
w=2.190427966;
r=0.078431372;
q_e=6.749634418;
g_s=-0.065575779;
g_t=0.275536049;
v_e=8.19;
a_y=1.267680833;
a_g=0.060830377;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

end;

steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul (hp_filter=100, order=2, irf=500,relative_irf );
```

Table 6.8: Dynare Code for Subsidy Experiment

```
% Dynare Code for Dynamic Modelling of Electricity Reforms in Bangladesh
% Sakib Amin, Dr. Laura Marsiliani and Dr. Thomas Renström, Durham University Business School

var  GDP c e x l y e_g e_i e_h k k_h k_i k_g k_x l_h l_i l_g l_y l_x g s h m_i m_g n w r g_s g_t v_e a_y a_g a_i a_h ;

varexo kappa eta_y eta_g eta_i eta_h;

parameters A v_h delta_c delta_g nu_m_gg delta_i nu_m_ii delta_x nu_ss delta_y nu_gg delta_h nu_hh  beta phi theta rho gama alpha_i alpha_h alpha_g alpha_y alpha_x psi_h psi_i psi_g psi_y psi_x nu_m_g nu_m_i nu_h nu_g nu_s chi omega mu_y mu_g mu_i mu_h zeta epsilon_y epsilon_g epsilon_i epsilon_h delta tau_k tau_l q_e q_s q_g p_h p_i v_m p_g capomega_v capomega_g capomega_i capomega_h capomega_y;

v_h=6.552;
A=0.405324405;
delta_c=1.1;
delta_g=0.857936486;
nu_m_gg=0.2;
delta_i=0.863816687;
nu_m_ii=0.2;
delta_x=0.586494222;
nu_ss=0.2;
delta_y=0.7;
nu_gg=0.2;
delta_h=0.895874254;
nu_hh=0.2;
beta=0.96;
phi=0.607623316;
theta=0.911090619;
rho=-0.11;
gama=0.811011098;
alpha_i=0.036183313;
alpha_h=0.004125745272;
alpha_g=0.042063514;
alpha_y=0.2;
alpha_x=0.313505778;
psi_h=0.5964848;
psi_i=0.309381618;
psi_g=0.302053239;
psi_y=0.073398567;
psi_x=0.079017608;
nu_m_g=0.1;
nu_m_i=0.1;
nu_h=0.1;
nu_g=0.1;
nu_s=0.1;
chi=0.10;
omega=0.95;
mu_y=0.95;
mu_g=0.95;
mu_i=0.95;
mu_h=0.95;
zeta=0.01;
```

```
epsilon_y=0.01;
epsilon_g=0.01;
epsilon_i=0.01;
epsilon_h=0.01;
delta=0.025;
tau_k=0.15;
tau_l=0.10;
q_e=4.93;
q_s=9.0;
q_g=6.95;
p_h=7.79;
p_i=3.20;
p_g=2.307534701;
v_m=0.7755;
capomega_v=0.105145694;
capomega_g=-0.132152826;
capomega_i=-0.184991735;
capomega_h=-0.192480869;
capomega_y=-0.011859455;

model;

1/c = beta*(1/c(+1))*((1- tau_k)*r(+1)+(1- delta)) * (1 +(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-
1)))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c = (1-l)*(1-gama)* w*(1-tau_l)* (phi/(1-phi))/(1+(theta/(1-theta))^(1/(rho-1))* q_e ^(rho/(rho-1)));

c=n*x*((1- gama)/ gama)/ (1+ (theta/ (1-theta)) ^ (1/ (rho-1))* q_e ^ (rho/ (rho-1)));

e = c*(q_e *theta/ (1-theta)) ^ (1/ (rho-1));

w * l_h = alpha_h* p_h* e_h;

r *((1- psi_h)*k_h^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*(1-psi_h)*k_h^ (-nu_h-1)*e_h;

v_h*((1-psi_h)*k_h ^ (-nu_h) +psi_h*h^ (-nu_h)) = p_h*((delta_h*nu_h)/nu_hh)*psi_h*h^ (-nu_h-1)*e_h;

w * l_i = alpha_i* p_i* e_i;

r *((1- psi_i)*k_i^ (-nu_m_i) +psi_i*m_i^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*(1-psi_i)*k_i^ (-nu_m_i
-1)*e_i;

v_m *((1-psi_i)*k_i^ (-nu_m_i) +psi_i* m_i ^ (-nu_m_i)) = p_i*((delta_i*nu_m_i)/nu_m_ii)*psi_i* m_i ^ (-
nu_m_i -1)*e_i;

w * l_y = alpha_y * y;

r *((1- psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*(1-psi_y)* (k(-
1)-k_g-k_x-k_h-k_i)^ (-nu_g-1)*y;

q_g*((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i) ^ (-nu_g) +psi_y*g^ (-nu_g)) = ((delta_y*nu_g)/nu_gg)*psi_y*g^ (-
nu_g-1)*y;
```

```
w * l_x = alpha_x * n*x;

r *((1- psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*(1-psi_x)*k_x^ (-nu_s-1)*n*x;

q_s*((1-psi_x)*k_x^ (-nu_s) +psi_x*s^ (-nu_s)) = ((delta_x*nu_s)/nu_ss)*psi_x*s^ (-nu_s-1)*n*x;

v_m*alpha_g*((1- psi_g)*k_g^ (-nu_m_g) +psi_g*m_g^ (-nu_m_g))=((delta_g*nu_m_g)/nu_m_gg)* psi_g* m_g
^ (-nu_m_g -1)* l_g*w;

r* psi_g* m_g ^ (-nu_m_g -1)= (1- psi_g)* k_g^ (-nu_m_g -1)* v_m;

e_h = a_h * l_h ^alpha_h * ((1-psi_h)* k_h ^ (-nu_h) + psi_h * h^(-nu_h))^-(delta_h/nu_hh);

e_i = a_i * l_i ^alpha_i * ((1-psi_i)* k_i ^ (-nu_m_i) + psi_i * m_i^(- nu_m_i))^-(delta_i/nu_m_ii);

e_g = a_g * l_g ^alpha_g * ((1-psi_g)* k_g ^ (-nu_m_g) + psi_g * m_g^(- nu_m_g))^-(delta_g/nu_m_gg);

y = a_y * l_y ^alpha_y * ((1-psi_y)* (k(-1)-k_g-k_x-k_h-k_i)^ (-nu_g) + psi_y * g^ (-nu_g)) ^-(delta_y/nu_gg);

x = l_x ^alpha_x * ((1-psi_x)* k_x ^ (-nu_s) + psi_x * s^(-nu_s))^-(delta_x/nu_ss);

v_e = (exp(capomega_v))*(v_e(-1)^(omega))*exp(kappa);

a_y = (exp(capomega_y))*(a_y (-1) ^(mu_y))*exp (eta_y);

a_g = (exp(capomega_g))*(a_g (-1) ^(mu_g))*exp (eta_g);

a_i = (exp(capomega_i))*(a_i (-1) ^(mu_i))*exp (eta_i);

a_h = (exp(capomega_h))*(a_h (-1) ^(mu_h))*exp (eta_h);

l = l_h+ l_i + l_g +l_y + l_x;

tau_l * w *l + tau_k * r *k(-1) +v_h*h -v_e*h+ v_m*m_i + v_m*m_g-delta_c*m_i-delta_c*m_g-r*k_g-w *l_g -v_m
*m_g- g_t+ p_g * e_g=g_s;

g_s = p_g *e_g +p_i * e_i + p_h * e_h-q_e*e-q_s *s-q_g *g;

e + s + g = (1-chi)*(e_h +e_i +e_g);

k= y-c-v_e * h + (1-delta)*k(-1)-delta_c*m_i-delta_c*m_g;

GDP=A+n*x+y+q_e*e-v_e*h;

end;

initval;
c=0.337915857;
e=0.009866408825;
```

```
x=1.010007997;
l=0.33;
y=1;
GDP=2.101215168;
e_g=0.017323554;
e_i=0.00336425;
e_h=0.001901324262;
k=9.364512596;
k_h=0.028670212;
k_i=0.038420574;
k_g=0.184667446;
k_x=5.287550443;
l_h=0.00002789761551;
l_i=0.0001778351454;
l_g=0.001065944239;
l_y=0.091306358;
l_x=0.237421965;
g=0.005701591201;
s=0.004762216077;
h=0.001792468442;
m_i=0.005608390837;
m_g=0.011182969;
n=0.491705834;
w=2.190427966;
r=0.078431372;
g_s=-0.065575779;
g_t=0.275536049;
v_e=8.19;
a_y=1.267680833;
a_g=0.071143485;
a_i=0.024727613;
a_h=0.021287879;

end;
shocks;
var kappa = zeta ^2;
var eta_y = epsilon_y ^2;
var eta_g = epsilon_g ^2;
var eta_i = epsilon_i ^2;
var eta_h = epsilon_h ^2;

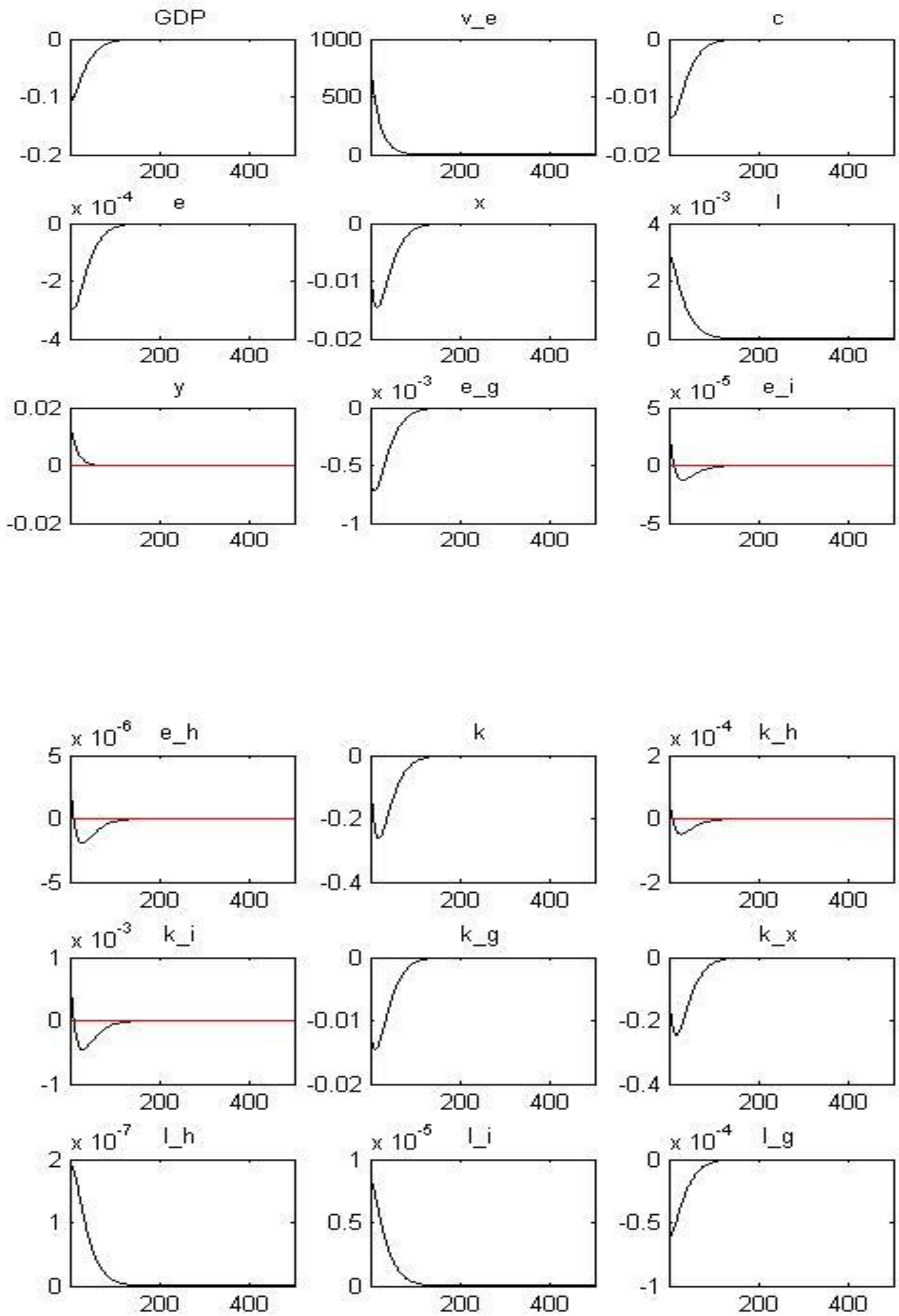
end;

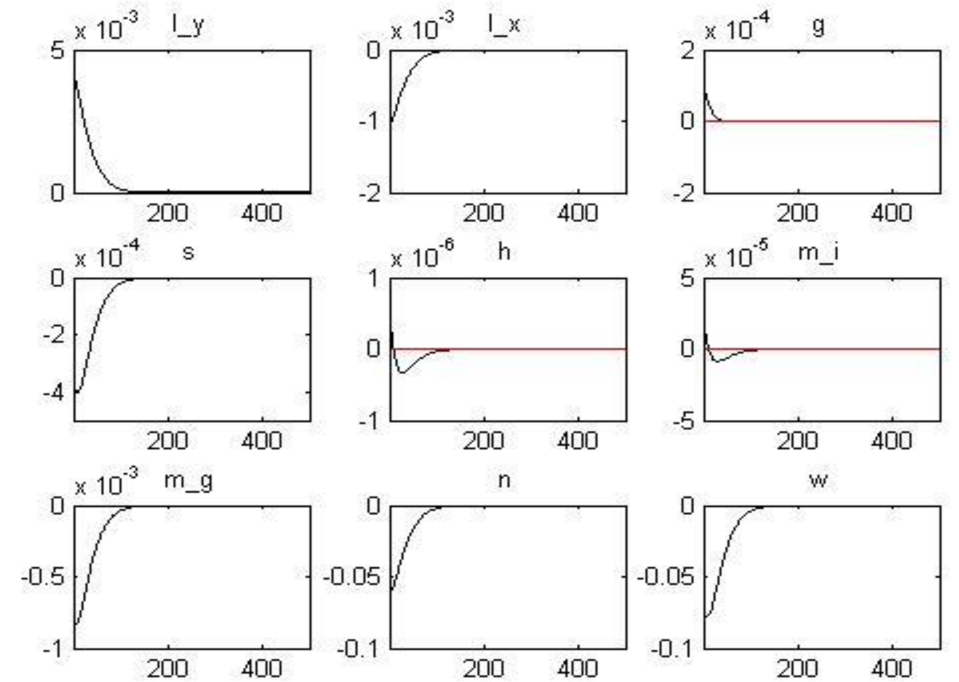
steady(maxit=2000);
check(qz_zero_threshold=1e-10);
model_diagnostics;

stoch_simul (hp_filter=100,order=2, irf=500, relative_irf );
```

Appendix 6B

Figure 6.1: Impulse Responses to an Oil Price Shock in EPE Experiment




x 10^-3 l_y
x 10^-3 l_x
x 10^-4 g
x 10^-4 s
x 10^-6 h
x 10^-5 m_i
x 10^-3 m_g
n
w
200
400

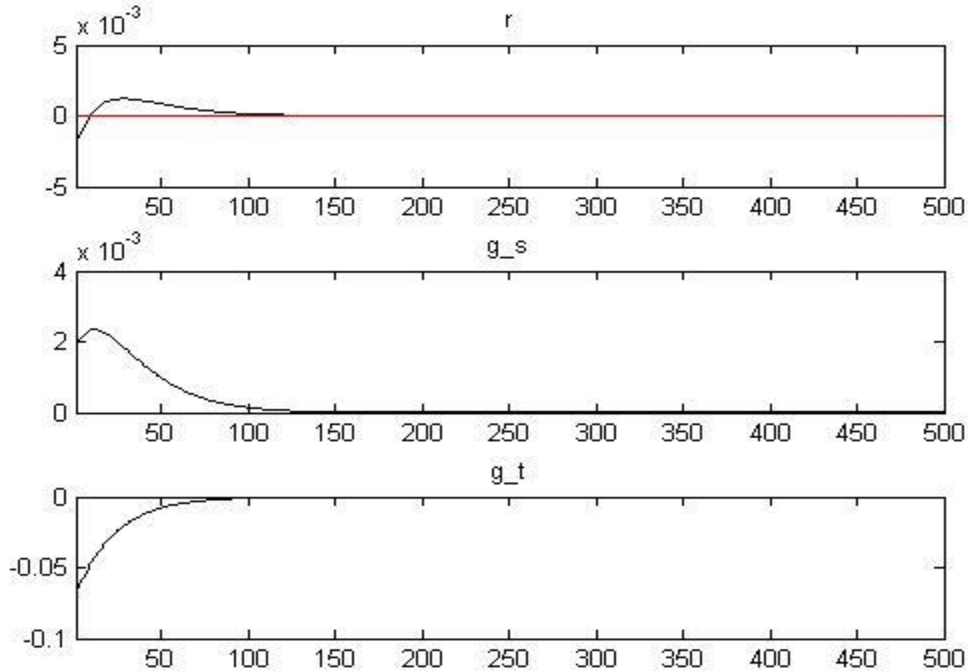
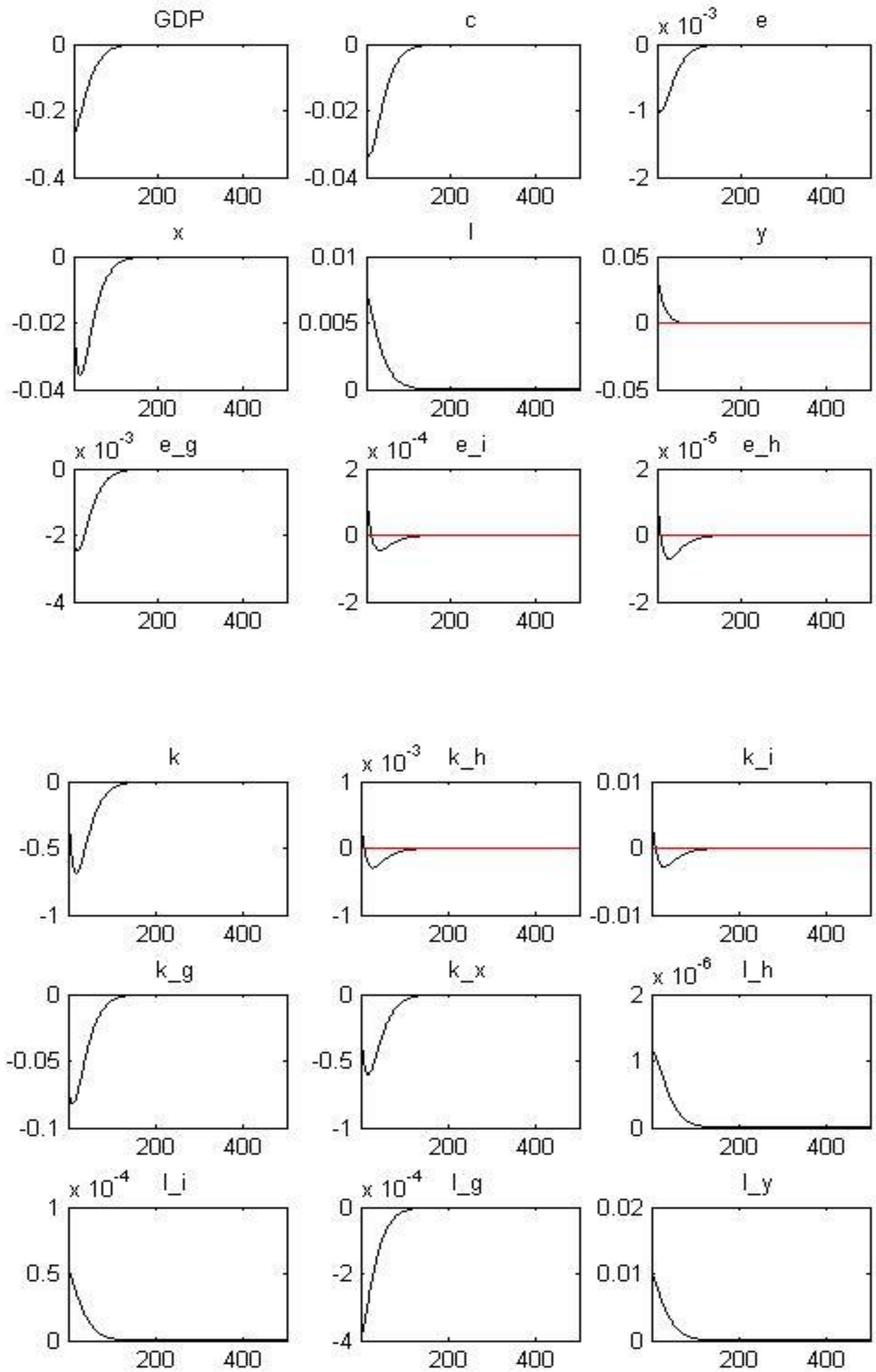
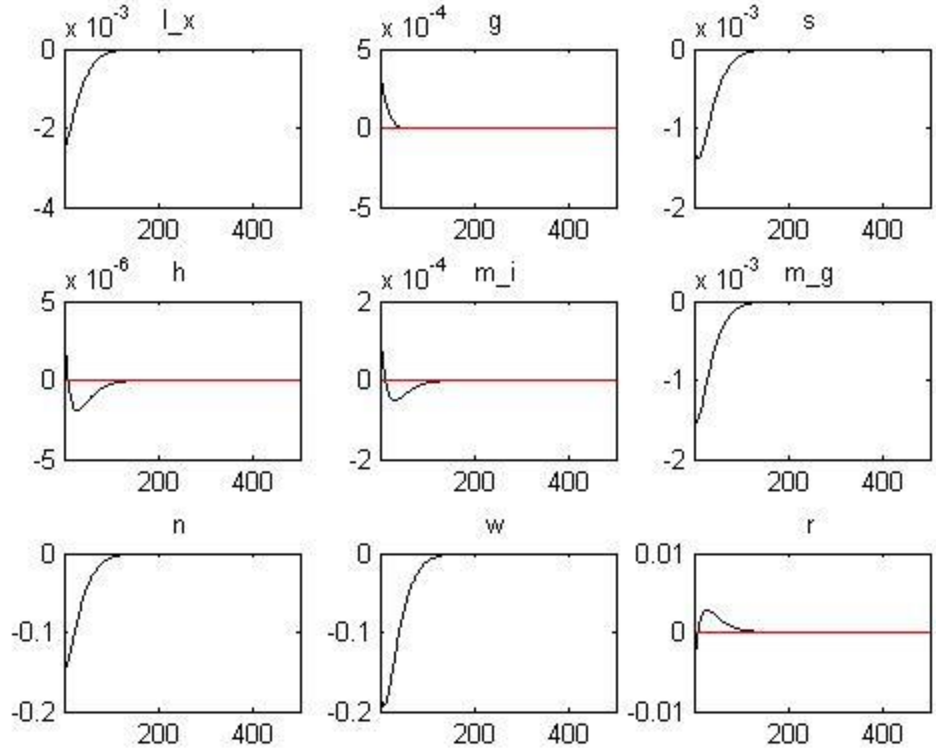

x 10^-3 r
x 10^-3 g_s
g_t
50
100
150
200
250
300
350
400
450
500

Figure 6.2: Impulse Responses to an Oil Price Shock in FPE Experiment




l_x
g
s
h
m_i
m_g
n
w
r

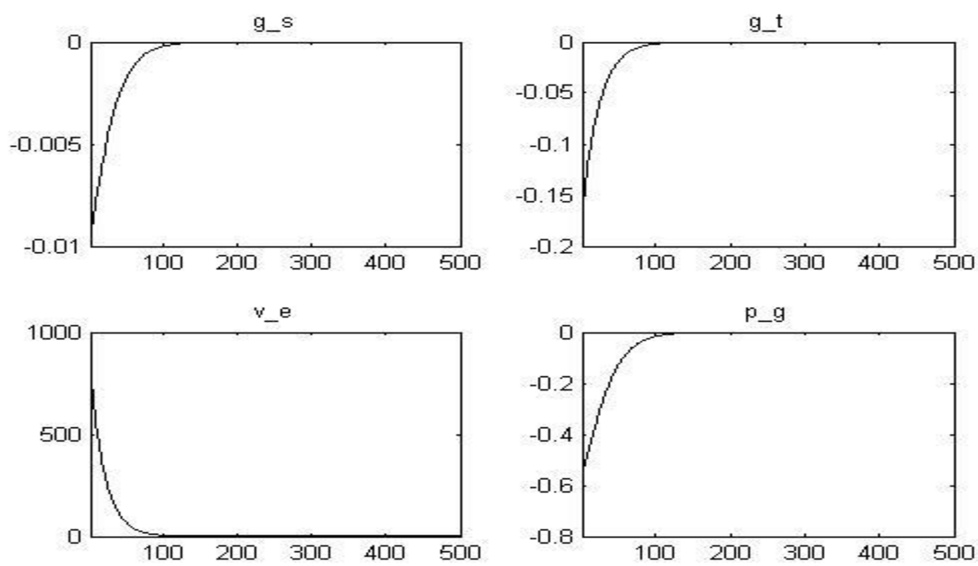
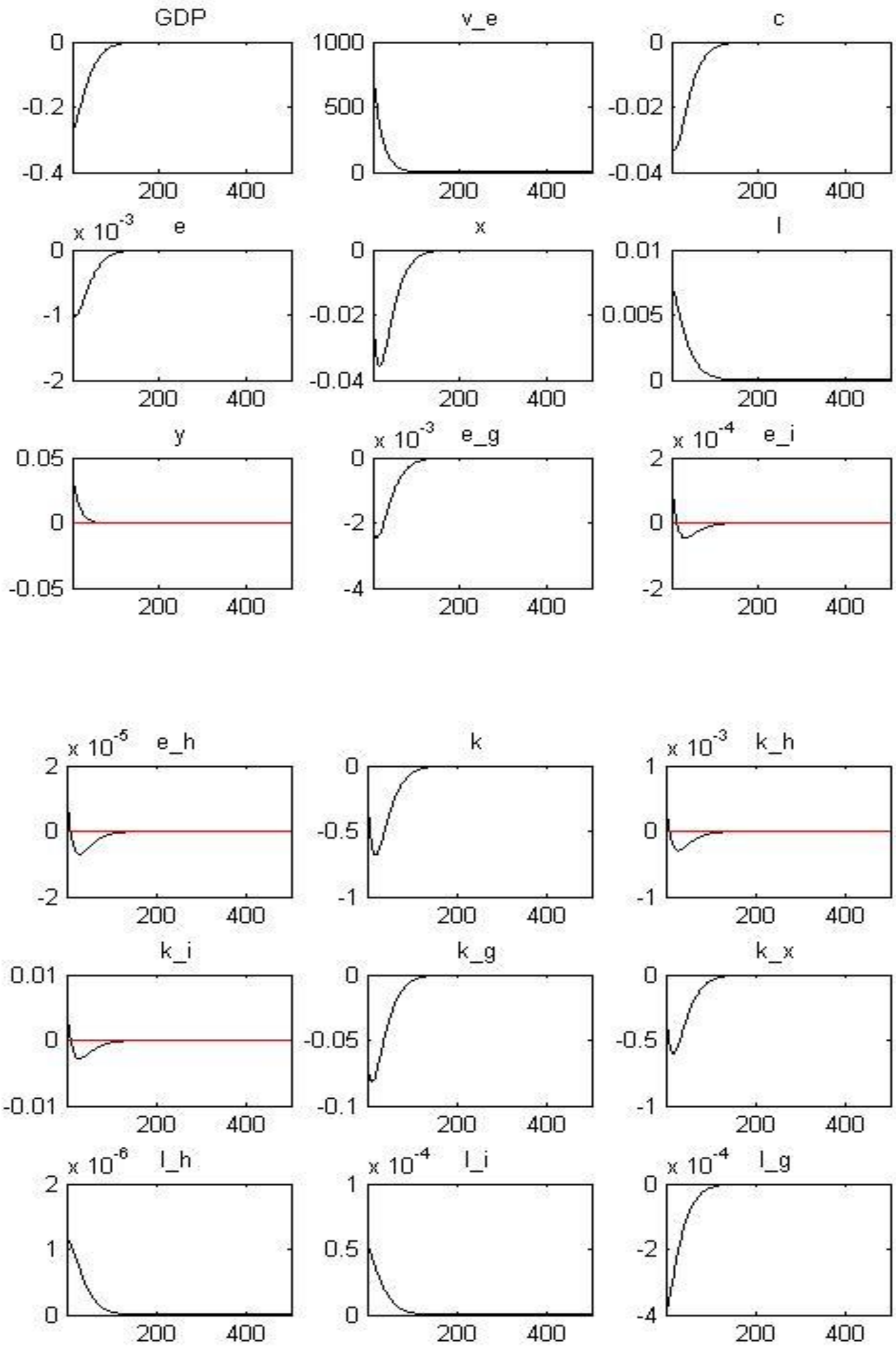
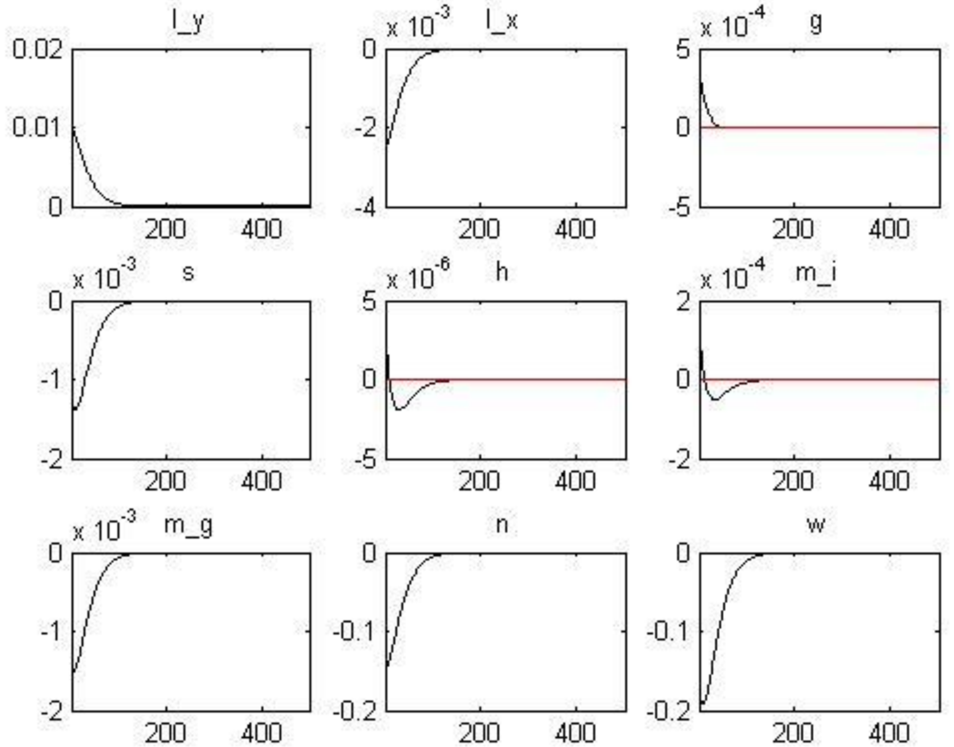

g_s
g_t
v_e
p_g

Figure 6.3: Impulse Responses to an Oil Price Shock in EEEP Experiment




l_y
x 10^-3 l_x
x 10^-4 g
x 10^-3 s
x 10^-6 h
x 10^-4 m_i
x 10^-3 m_g
n
w

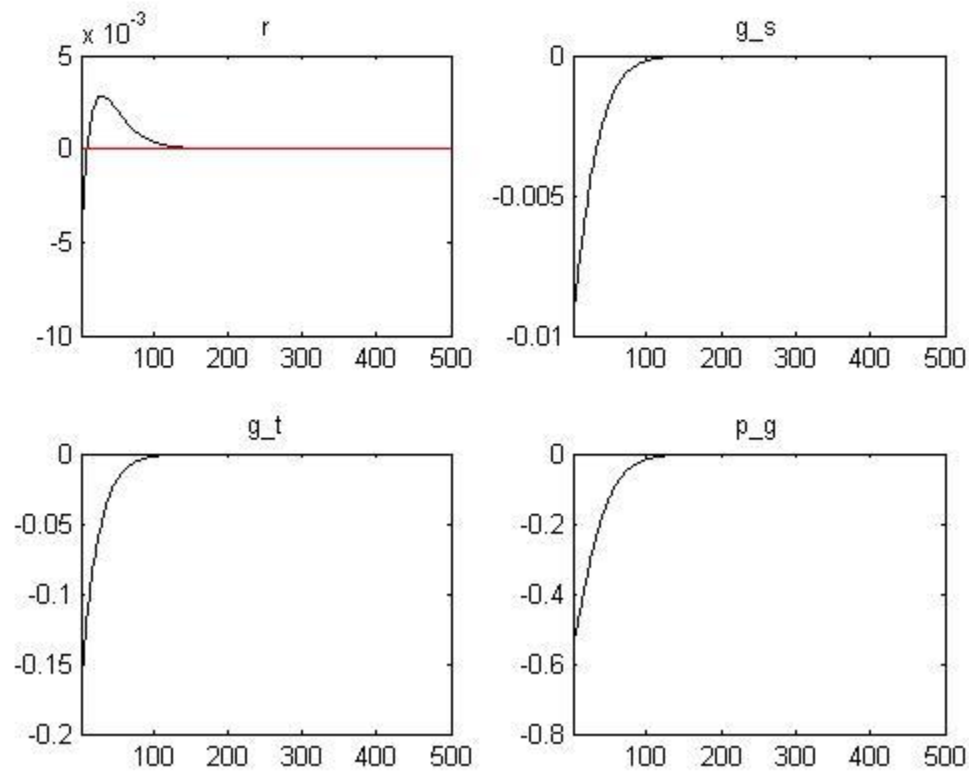
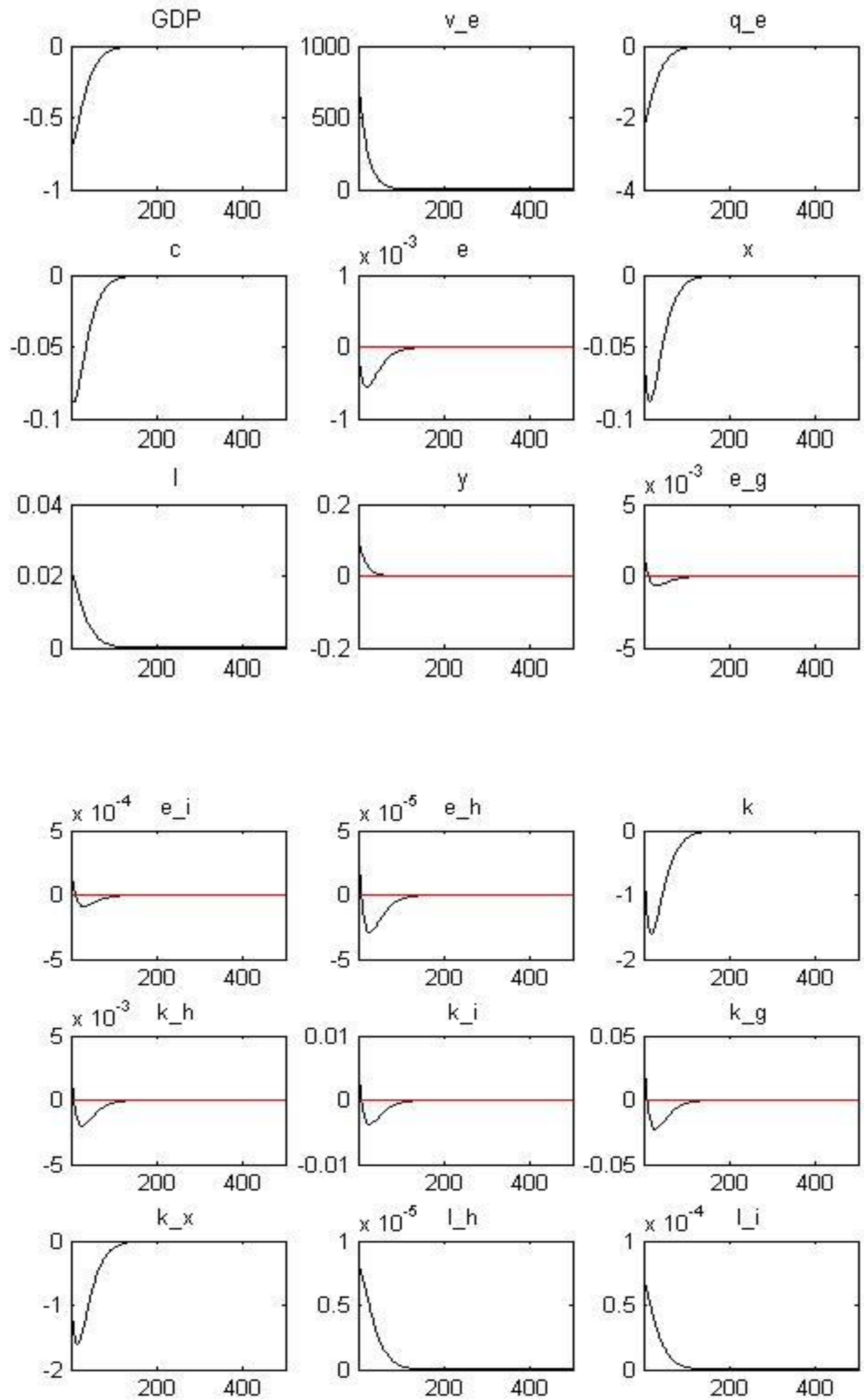
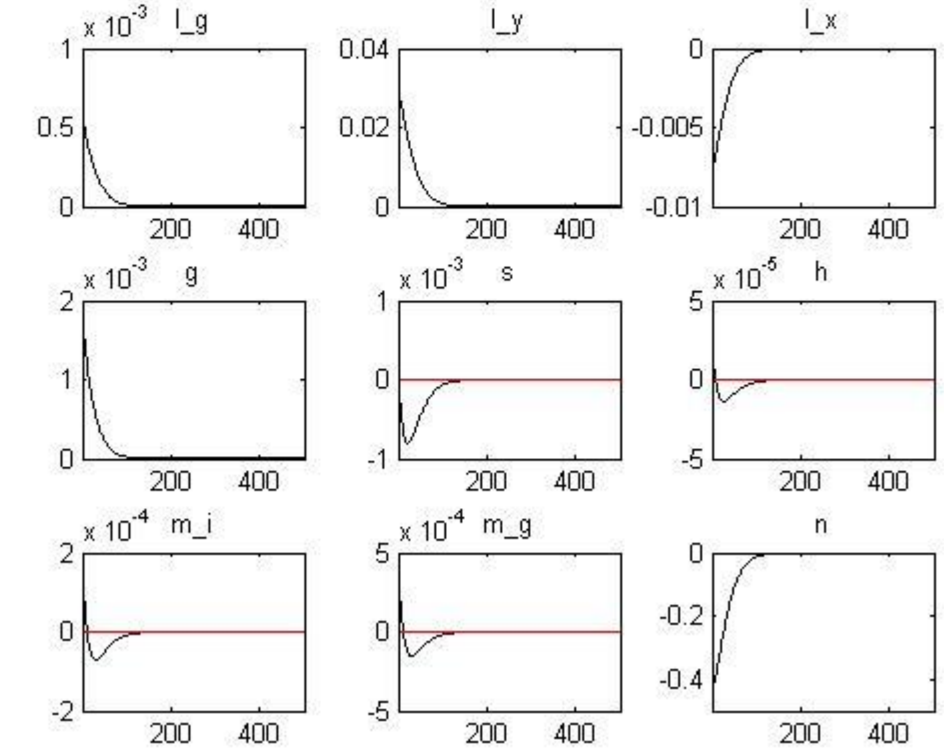

x 10^-3 r
g_s
g_t
p_g

Figure 6.4: Impulse Responses to an Oil Price Shock in Privatisation Experiment




x 10^-3 l_g
l_y
l_x
x 10^-3 g
x 10^-3 s
x 10^-5 h
x 10^-4 m_i
x 10^-4 m_g
n

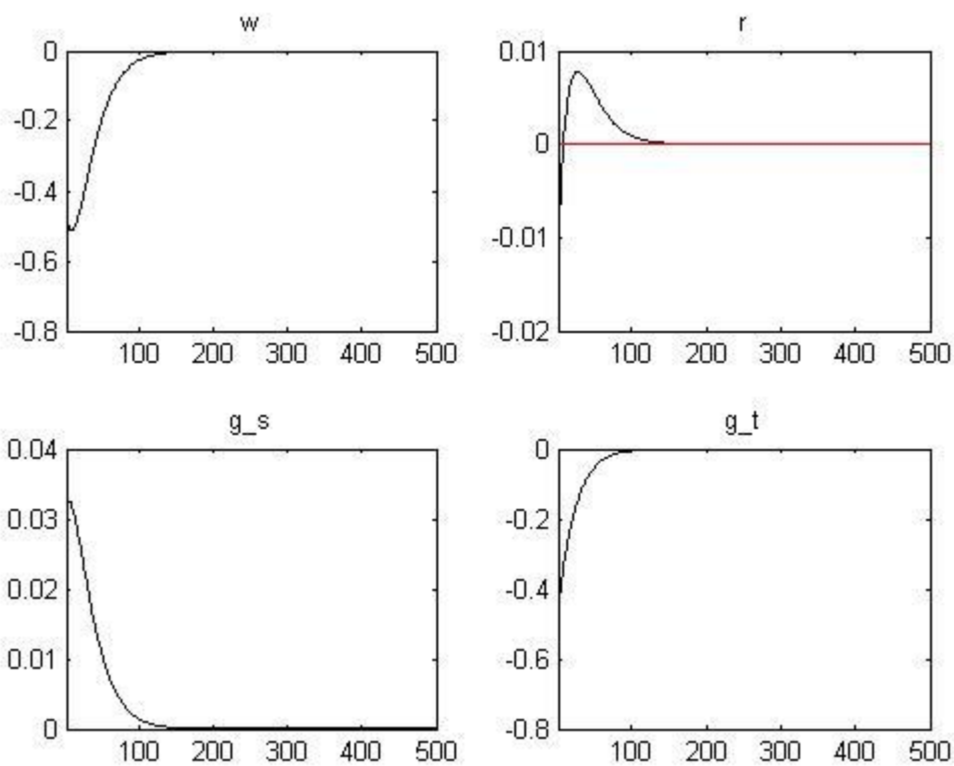
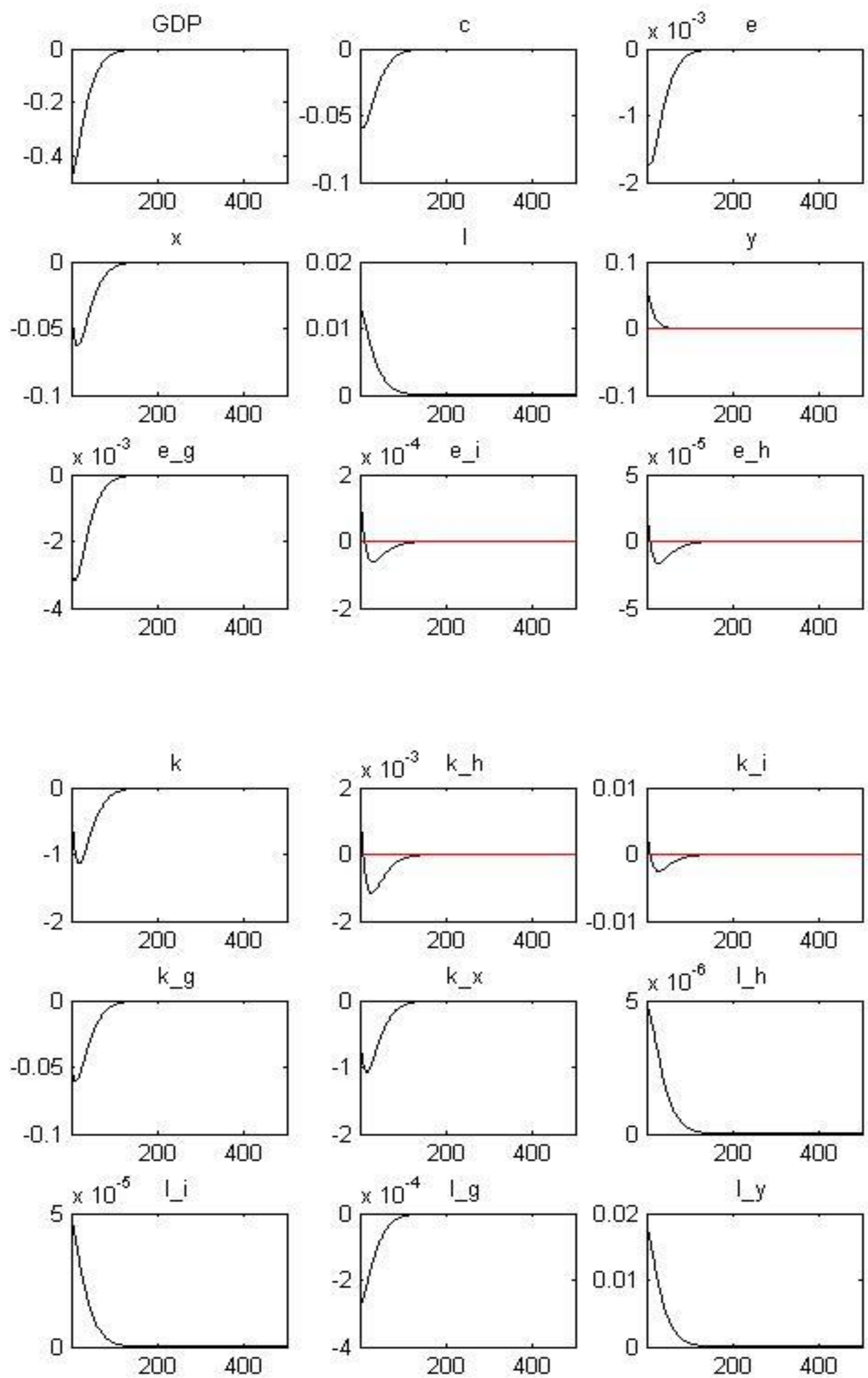
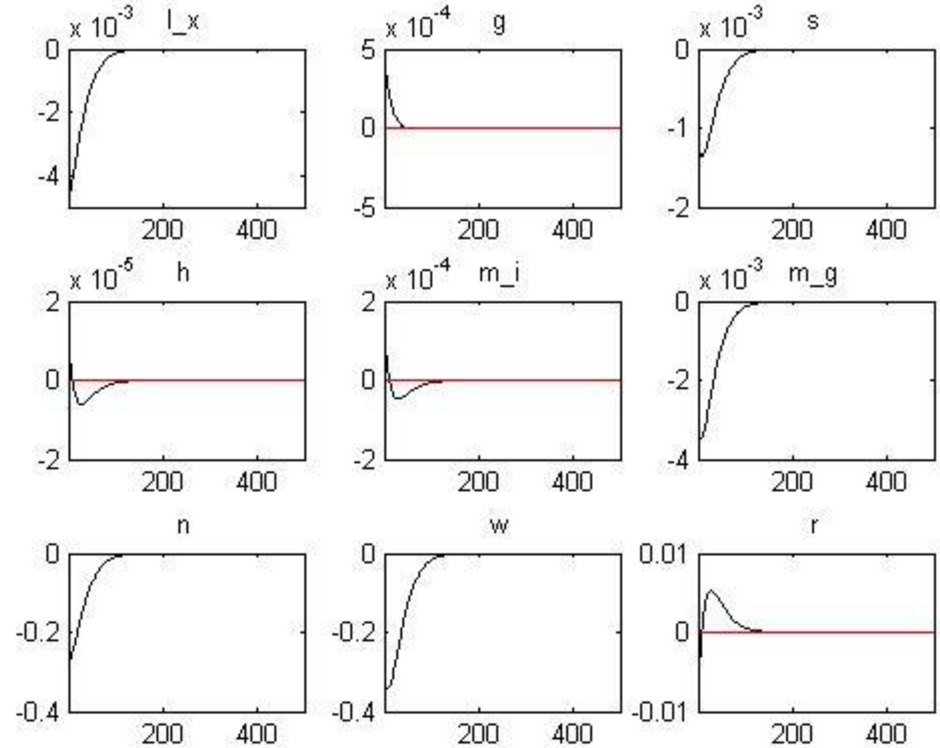
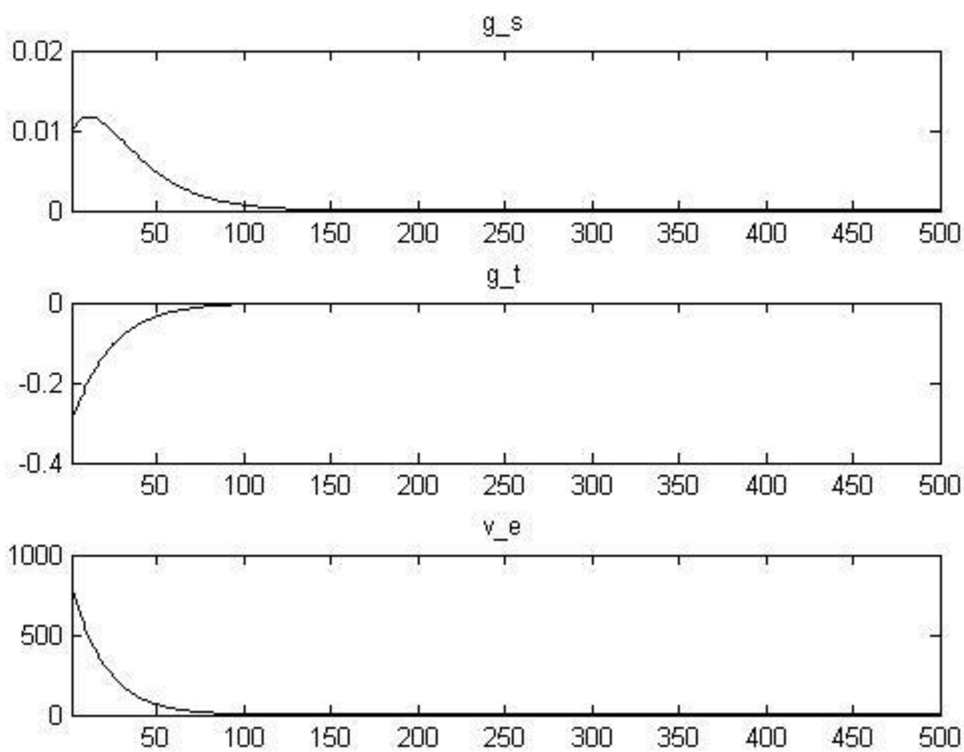

w
r
g_s
g_t

Figure 6.5: Impulse Responses to an Oil Price Shock in Subsidy Experiment




x 10^-3 l_x
x 10^-4 g
x 10^-3 s
x 10^-5 h
x 10^-4 m_i
x 10^-3 m_g
n
w
r


g_s
g_t
v_e

Appendix 6C

Technical Appendix

Derivation of Welfare Equation

The formula of welfare equation is derived by using the utility function as follows. If c_1, e_1, X_1 and l_1 are the steady state values in benchmark scenario, one can estimate the value of the utility, U_1 for the economy using the following utility equation:

$$U_1 = X_1^{\gamma}\left(\theta c_1^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

Similarly, if c_2, e_2, X_2 and l_2 reprents a new steady state values for an alternative scenario, the utility of consumers can be estimated as follows:

$$U_2 = X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi}$$

In principal, to get the actual change of consumption out of a policy option, we need to equate the value of the new utility function considering the new set of values of steady state variables and old set of steady state variables except the value of consumption. That implies,

$$U_2 = X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi} = X_1^{\gamma}\left(\theta c^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

$$\Rightarrow X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi} = X_1^{\gamma}\left(\theta c^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

$$\Rightarrow \left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}} = \left(\theta c^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}} \left(\frac{X_2}{X_1}\right)^{\gamma} \left(\frac{1-l_2}{1-l_1}\right)^{\frac{1-\gamma}{\gamma}}$$

So, $\hat{c}^{\rho} = (c_2^{\rho} + \frac{1-\theta}{\theta} e_2^{\rho})(\frac{X_2}{X_1})^{\gamma\frac{\rho}{1-\gamma}} (\frac{1-l_2}{1-l_1})^{\frac{1-\varphi}{\varphi}\cdot\frac{\rho}{1-\gamma}} - \frac{1-\theta}{\theta} e_1^{\rho}$

Chapter 7

Conclusions

Energy plays a very key role for the economic development of human societies. Energy goods are also important both as intermediate inputs for production and as final outputs that are often necessary for basic human welfare. According to Global Energy Assessment (2012), energy is crucial for the necessary transition to a more equitable and sustainable world and one where all have access to the energy services required for comfort and for a secure and healthy livelihood. Electricity is the mostly used form of energy and its central role in achieving economic progress is broadly accepted throughout the world. Oil is also one of the most important energy and known as “the blood of industry” in any economy (Ftiti et al., 2014). Therefore, ensuring affordable supplies of energy in various forms is central to the socio-economic development of a country.

There are various channels exists through which energy (oil) price may have an impact on economic activity. A great number of studies have analysed why rising energy (oil) prices appear to hinder macroeconomic activities since the seminal paper by Hamilton (1983). Existing literature mostly focuses on oil or aggregate energy in investigating energy price and macroeconomic relationship. Some studies have also examined the possibility of a weakening relationship between energy price fluctuations and aggregate economic activity (Brown and Yücel, 2002). One common feature in almost most of the studies (mainly, the theoretical studies) is a focus on developed countries such as US or European countries and relatively less attention has been paid to developing economies despite the fact that energy (oil) can have serious adverse effect on their economy.

Dependency on oil-derived fuels in electricity generation has left the economy of many developing countries vulnerable to several adverse macroeconomic consequences. These electricity generation fuels are either available as indigenous resources or as traded commodities in the international market. Price volatility is inherent in good market, but has been advancing at a faster rate in oil market in comparison to other commodities over the past decade. An oil price shock is an indicator of extreme volatility. Oil price shocks represent a fundamental barrier to economic growth, due to its damaging and destabilising effects on macroeconomy.

Therefore, in order to ensure macroeconomic stability and energy security, many governments in the developing countries provide subsidies to the energy markets. Following the internationally accepted definition of subsidy, one can identify two major types of subsidies that are provided by government: subsidies designed to reduce the cost of consuming energy (electricity) and fuel subsidies aimed at supporting domestic production (Ellis, 2000). Given their cost and persistence, it is obvious that these subsidies have important macroeconomic implications. Said et al. (2006) show that for a sample of countries in 2005, the average cost of expenditures on fuel subsidies was almost 2.5% of GDP. One IMF (2013) report shows that electricity and fuel subsidies exceeded 3% of GDP in four countries (Bangladesh, Brunei, Indonesia, and Pakistan). Since government controls electricity prices, cost reflective tariffs in electricity tariff are also absent in many developing countries. For example, electricity prices in Nepal have been historically low to cover the costs and electricity is supplied to consumers at highly subsidised rates creating distortions on demand and adverse impact on fiscal balance (Jamasb and Nepal, 2011).

Thus, energy (mainly fuel and electricity) subsidies are large, wide and diverse (OECD, 2013). These subsidies can be justified if overall social welfare is increased. However, in many countries in the world, the net effects of subsidies are negative and overall social welfare would be higher without subsidies (Moltke et al., 2004). They can place a heavy burden on government finances, weaken the foreign trade balance and stunt the potential of economies. This may be the case if the rationale of subsidy is invalid and inefficient. Electricity subsidies in India, for example, by undermining the financial health of the state electricity boards, undermine investment and the quality of electricity service (Moltke et al., 2004). Thus, electricity sector reforms became a global trend during the 1990s. The need for electricity sector reform arose from two primary concerns: firstly, the dissatisfaction over the poor technical, financial and managerial performance of the state owned electricity utilities. Secondly, the inability of government to mobilise sufficient investment capital for the electricity subsector's development and expansion. According to Jamasb et al. (2014), the main driver of energy sector reforms in the developing countries are: burden of energy subsidies, low service quality, high energy losses, poor service coverage, capacity shortage and energy sector investment constraints.

The underlying principle of energy reform policy is to take into account the overall well-being of both individuals and society as a whole (Moltke et al., 2004). There are different types of reform policies those can be applied by considering their merits and demerits compatible with the economic conditions of the developing countries. A number of countries around the world have embarked on programmes of reform in order to promote investment, to improve technical performance and the productive efficiency of energy companies, and to enhance end-use energy efficiency. These reforms programmes have initiated in Latin American countries and included variously the restructuring and privatisation of state energy companies, the introduction of competition, the promotion of foreign investment, and the price setting mechanism in energy markets.

Moreover, unlike the developed countries, energy industries in many developing countries are still mostly or completely controlled by government and energy prices are set by government. The government in many developing countries also provide high subsidy on energy products to reduce the cost of consuming energy and to support domestic production. Although the motivations for changing the electricity industry structure vary from country to country, but in general, in almost all reforming countries, electricity reform has been a part of wider policies towards a liberal market economy and it is expected that successful reforms can improve the efficiency of the sector and provide better quality of service. Cost-reflective tariffs and proper subsidy schemes are also decisive for the sustainability of reforms.

It is evident that reforming electricity market in developing small countries across the world is a complicated issue especially under the twin conditions of growing political instability and rapidly increasing electricity demand (Jamasb and Nepal, 2011). In principle, in order for the electricity prices to send the correct and efficient signals, they need to reflect the true cost of providing the service. Economic theory also suggests that cost reflective prices are desirable as it leads to net social welfare gain. This implies that the welfare gains by those who benefit from lower prices will exceed the welfare losses incurred by who stand to lose price increases. Therefore, Jamasb (2006) recommends that in most developing countries electricity reform requires extensive restructuring of pries and subsidy arrangements since the tariff can contain government subsidies to specific users, cross subsidies from industrial and commercial users to residential consumers and cross subsidies among residential customer groups.

While the economy wide implications of aggregate energy and oil price shocks have been broadly studied, the literature examining the macroeconomics of aggregate energy and oil price shocks in a mixed economy with government price setting mechanism remains relatively underdeveloped. So, electricity market liberalisation and price reforms and the linkage between aggregate energy and oil price shocks and macroeconomy in the developing countries are still an area which requires extensive research to develop appropriate models for policy experiments.

The link between energy (both at aggregate and disaggregate level) and economy in Bangladesh is strong and any disruption in energy supplies is bound to have a negative impact on the economy. Hence, it becomes important to protect Bangladesh's economy from any kind of energy (oil) price shocks and maintain a cushion against such shocks. Like many other developing countries, Bangladesh is also carrying out electricity reform programmes. However, several initiatives still need to be undertaken by the Bangladesh government in the energy sector apart from just allowing the entry of the private sector, reducing government regulation and unbundling energy utilities to bring about reforms in the power sector. It also becomes important that market forces are allowed to play a role and induce further competition, which will ultimately provide better services to the end-users at a competitive price. The market forces will also ensure that during times of crisis, demand and supply are balanced, as in such a situation the prices will indicate relative shortage and surplus in the sector. All the initiatives in various energy sub-sectors will boost the country's energy security in the long run.

Energy and environmental problems are often complex and detailed modelling are necessary to analyse the interactions of the energy sector and the overall economy for policy references. Therefore, the complex dynamics between energy and economy have increasingly attracted modelling studies over the past decade. Analysing the interaction of the macroeconomy and the energy sector is also essential for gaining understandings into the mid to long term development of each of them (Bauer et al., 2010). The development of energy statistics made it possible to develop dynamic models with a rigorous description of energy market, and the inter linkages between economic activity, energy production and energy use. Dynamic Stochastic General Equilibrium (DSGE) models are relatively new, but increasingly popular, additions to the tool kits of practical macroeconomic modellers (Jaaskela and Nimark, 2011). The main motivation for developing DSGE models reflects the appetite for frameworks that place emphasis on sound micro foundations and theoretical consistency. DSGE models can also play an important role in support of their forecasts and policy analysis in energy sector.

My thesis investigated the qualitative and quantitative analysis of the consequences of energy (oil) price shocks and electricity market reforms towards the Bangladesh economy. In particular, within a Real Business Cycle (RBC) model and a Dynamic Stochastic General Equilibrium (DSGE) model, the latter including a detailed model of the electricity sector, we have tried to show i) how important aggregate energy price shocks are to explain business cycle fluctuations in Bangladesh economy (**Chapter 4**) since no such study is done for Bangladesh economy and RBC is the first step of developing a DSGE model, ii) how would oil price shocks affect the macroeconomy of Bangladesh economy in the presence of government price controlling mechanism (**Chapter 5**) and iii) the outcomes of liberal electricity price reforms policies at macro level as a move towards the free market economy (**Chapter 6**). The main contribution of this thesis is twofold. At first, we develop a Dynamic Stochastic General Equilibrium (DSGE) model with a detailed disaggregation of the electricity sector which focuses on a mixed economy where government still controls some electricity prices when electricity and fuels enter both production and consumption functions (Methodological Contribution). Then, we propose some alternative electricity pricing schemes for Bangladesh as part of liberalisation towards free market economy and analyse the consequences of the electricity price reforms on household welfare, electricity market condition and macroeconomy in Bangladesh (Policy Contribution). Our model assumes that electricity supply comes both from public and private sectors. The model also allows the flexibility of multi-fuel option in the electricity generating sectors. Both these features are very important for developing country's perspective. The summaries of different chapter are described as follows.

Chapter 2 reviews the theoretical and empirical literature on macroeconomic effects of energy (oil) price shocks and energy (electricity) market reforms and highlights their special features, findings and evolution through time as well as their limitation.

Over the last three decades, the demand for energy (electricity) in Bangladesh has grown, as it has pursued policies geared towards greater economic growth and social development. However, the mounting debt burden from high subsidy coupled with distorted price of electricity has large economic and financial implications for the country's capacity to achieve its goal in both the near and long terms. The **3rd chapter** attempts to address current energy scenario in Bangladesh, examines the current fuel options in Bangladesh with their availability and impacts on environment, illustrates a comprehensive review of electricity sector in Bangladesh and reviews energy and electricity sector reforms in Bangladesh.

Chapter 4 made an attempt to explore to what extent movements in aggregate energy prices can help to explain business cycle fluctuations in Bangladesh. The main goals of this chapter is about the examination and validation of the basic RBC model with regard to its performance in terms of the common RBC properties and to see how important productivity shocks are to the basic RBC model, once the model is extended to allow for aggregate energy price shocks. Many macroeconomic researchers pay attention to the RBC model because it constitutes a useful benchmark framework as a vehicle for developing DSGE model to address the source fluctuations and the behaviour of different macroeconomic variables for policy analysis. One of the novelties of the RBC approach is that it takes a model that is (a) designed to explain the long run; (b) picked parameters designed to explain the long run but then, (c) used that model and those parameters to explain the short run (Sims, 2012).

We attempt to calibrate the RBC model to explain the quantitative business cycle properties of macroeconomic variables in Bangladesh economy. Then, we examine how the fluctuations of key economic variables such as investment, consumption and output are explained by the exogenous shocks. The model's ability to describe the dynamic structure of the Bangladesh economy is analysed by means of Impulse Response Functions (IRFs) which yield useful qualitative and quantitative information. Our result shows that the basic RBC model does a modest job of replicating some of the broad features of annual data of 1990-2010 in Bangladesh. Our results also show that exogenous shock's impact on endogenous variables are in the right direction. We also reveal that aggregate energy price shocks have a negative impact on macroeconomic variables in Bangladesh economy. Finally, we show that aggregate energy price shock does not explain the business cycle fluctuations in Bangladesh.

In **chapter 5**, we have developed a DSGE model for a mixed economy with detailed disaggregation of electricity sector to examine the macroeconomic impacts of an international oil price shock and higher productivity shocks in Bangladesh economy. The contribution of this chapter is central to the thesis, as it develops an entirely new macroeconomic framework to address the impact of oil price shocks on economy. In order to obtain quantitative results the usual practice is to calibrate models to a particular economy and we simulate the model for Bangladesh economy to analyse the impulse response functions to productivity and oil price shocks pertinent in Bangladesh economy. The key difference of this model and the other energy models is the presence of government price setting mechanism, three different electricity generating sectors in addition to two production sectors which have not been experimented in energy literature till now. Our model further allows for fuel diversification which is highly realistic for a developing country's perspective and somehow overlooked in the literature. The model is solved and quantitatively simulated, so that the dynamic impacts of various shocks can be computed. Our simulation results highlight several important dimensions to the relationship between oil prices and economic performances in Bangladesh. Firstly, oil price shocks have a negative welfare effect on the economy through reducing electricity consumption, non-electricity consumption and service consumption. Secondly, relative factor prices play a substantial role in shaping the energy sector as more resources are devoted towards IPP sector (private electricity generating company) through factor market which expands IPP electricity production. Thirdly, higher oil price also acts as a negative technological shock which causes aggregate capital to reduce initially to prevent household consumption to fall by a large extent. Finally, industrial production increases because oil imports are now more expensive and industrial sector needs to produce more exportable goods to keep the trade balance unchanged.

Chapter 6 examines some price reform experiments in electricity market in Bangladesh as a drive from mixed economy towards free market economy to improve the electricity sector and to remove electricity subsidy and price distortions. Thus, we consider the same energy augmented DSGE model developed in the previous chapter. The model is calibrated for Bangladesh economy to compute steady state values for different macroeconomic variables in the model and household's welfare in the presence of existing electricity pricing schemes in Bangladesh. Then we compute the changes of the steady state values and household's welfare from the proposed alternative electricity price reform schemes to draw policy implications. Our results show that electricity tariff and fuel subsidies have important effects on a number of macroeconomic variables and electricity market. For example, household consumption increases in all the different experiments ranging from 0.03 to 2.49%. Our results also reveal that all the reform experiments are welfare and GDP enhancing.

To conclude, it should be noted that the results in the thesis are directly relevant for policy making in Bangladesh. Since concerns over macroeconomic stability and fiscal sustainability are at the forefront of policy discussion in many developing countries, many of the lessons presented in this thesis are not only applicable to Bangladesh but also can easily be used to inform policy making in other developing countries as well.

The study, undertaken in this thesis, opens up several promising avenues for future research. First, a shortcoming of this thesis is that our models consider the representative agent approach for mathematical convenience. Although this representative agent method is widely used by the macro modellers, Boland (2013, 2014) argues that there are serious logical and methodological problems with the idea of a representative agent given the diversity of any real economy. Kirman (1992) also criticises the representative agent model and argues that the reduction of the behaviour of a group of heterogeneous agents even if they are all utility maximisers is both unjustified and leads to conclusions which are usually unreliable and often wrong. He highlights that the reaction of the representative to some changes in a parameter of the benchmark model (for example, a change in government policy) may not be the same as the aggregator reaction of the individuals. Thus, using representative agent models to analyse the consequences of policy changes may not be valid and policy recommendations to improve the welfare of the representative agent would be misleading in this case. Since the representative agent assumption is not necessary for building of DSGE models and it is used just for convenience, the model developed in this thesis can be extended with heterogeneous household agents for policy purposes.

Another limitation of this thesis is that it is essentially silent on distributional issues. Chang (1997) argues that measuring distributional impacts of tariff adjustments is an inherently complex task. The electricity tariff structures in Bangladesh like many other developing countries are cross subsidised and the residential households pay lower subsidised tariffs than the industrial and service sector electricity consumers. Consequently, restructuring of electricity tariffs can result in considerable price increases for residential consumers while industry and service sectors are usually the first group to benefit from cost reflecting pricing reforms (Jamasb, 2006).

Given our results both from the impact of oil price shocks on macroeconomy and from the policy experiments, it is advisable that policymakers carefully assess the overall welfare effect of oil price shocks and when appropriate take some measures to redistribute welfare from industrial sector to the household sector. Since household heterogeneity is a crucial element in the determination of how the electricity market reform and energy (oil) price shocks affects the household's behaviour and welfare more precisely, our DSGE model can also be extended with heterogeneous households in their income to examine the distributional effects of government intervention that means which types of household are mainly benefitted from the welfare retribution with their overall impact for accurate welfare comparisons and ensuring equity. Moreover, the heterogeneity nature of the extended model would also be useful to examine the results of reforms in cross subsidies which are common in many developing countries.

A further possible future research is to extend the model with endogenous technology and environmental constraints in order to coordinate the energy policy debates and to investigate the behaviour of oil market price when oil in the ground is considered as an asset. It is also worth noting that any changes in local gas extraction would have some effect on longer term gas reserves. However, the model in its present form could not apprehend this effect and accordingly our model has not paid any attention regarding this issue. Thus, a further probable extension of the model is to impose a physical constraint on natural gas stock level where gas extraction must be less than or equal to the stock. This would certainly give more realistic picture from the different policy experiments.

Since Bangladesh is a disaster-prone country, we would also like to extend our DSGE model introducing a small time-varying disaster risk to analyse the dynamic behaviour of macroeconomic variables for policy analysis. For example, Gourio (2012) and Isore and Szczerbowicz (2013) argue that an increase in disaster risk leads to a decline of output, investment, interest rate etc. One could also use our model to compare the differences in welfare from price control and quantity control as reform instruments for policy alternatives. Another avenue of future research would to include pollution on our model to do some comparative static to evaluate the dynamic effects of specific emission policy choices. It would also be very thought-provoking to examine how a revenue neutral subsidy removal with equal cash payment to households would affect Bangladesh economy. Finally, we would also plan to extend the model by explicitly modelling the renewable technology since renewable resources as an alternative source of fuel will play a significant role in mitigating energy crisis in the developing countries. These are left for future research.

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