World Review of Business Research
Vol. 6. No. 3. October 2016 Special Issue. Pp. 1 – 13

Calibrating an Energy Augmented Real Business Cycle: The Case of Bangladesh

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We simulate an energy augmented RBC model for Bangladesh, characterised by shocks to the Solow residual as well as energy price. The model in this paper is calibrated using annual data of 1980-2010 to examine the model's ability to describe the dynamic structure of the Bangladesh economy. To the best of our knowledge, this is the first study to incorporate energy price shocks in the Real Business Cycle (RBC) model in the context of Bangladesh. Through the use of Impulse Response Functions (IRFs) this paper reveals that while the impact of an upward shock to factor productivity on all key endogenous variables is in the right direction, an upward shock in energy prices has an adverse impact on the key endogenous variables for the case of Bangladesh.

Field of Research: Calibration, Real Business Cycle Model, Energy, Bangladesh Economy

1. Introduction

Economic theory has long struggled in attempting to explain the energy-macroeconomic relationship. Researchers investigated the theoretical relationship between the use of energy and economic growth through different possible channels. In the neoclassical growth models, energy is simply considered as an intermediate input of production (Tsani, 2010). 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 hypotheses'. These hypotheses imply that energy would not have any negative effect on economic growth. Thus, the government can simultaneously adopt the energy conservation and economic growth policies (Bartleet and Gounder, 2010). In contrast, the ecological economic theory states that energy consumption is a limiting factor to economic growth (Stern, 2000, 2004, 2011). They 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 price will ultimately have an inverse effect on economic growth. Consequently, they stand against the energy conservation policies.

Another branch of the existing literature analyses the energy price shocks on economic variables by using Real Business Cycle (RBC) models. The case for incorporating energy

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shocks into the RBC models has been made credible by McCallum (1989). One of the identifiable sources of shocks that have claimed the attention of many economists are the energy price shocks. Some researchers suggest that such shock in energy prices are equivalent to adverse technology shocks and thus creates significant contractions in economic activity. Furthermore, Hall (1988, 1990) uses US data from 1953-1984 to show that a standard measure of technology, the Solow residual, systematically tends to fall whenever energy price increases.

The common features in all of the models in the existing literature are that energy prices are taken as an exogenous stochastic process and that energy is considered in the production functions only. However, the importance of energy in the household's utility function and thus the welfare of the households have remained unattended. In addition, very few of the studies have considered a decentralised economy where the household's income comprises of labour income, capital income, interest income and profits which it can utilize in consumption, accumulation of more capital or accumulation of more savings. To the best of our knowledge, no researcher has calibrated an RBC model with energy prices for the Bangladesh economy to investigate the interactions between energy prices, the performance of the economy and the welfare of the households under a decentralised economic structure.

In light of these limitations, this paper 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 price shocks and electricity policy related analysis. The basic building blocks of the model are standard in the literature. The main goals of this paper is to examine how the fluctuations of key economic variables such as investment, consumption and output are explained by the exogenous shocks, namely, energy price shock and productivity shock. 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 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. The paper is organised as follows. Section 2 consists of the review of relevant literature. The model, model calibration and estimation of the parameters are discussed in section 3. The results are analysed in the section 4 and finally, in the last section, we present the conclusions.

2. Literature Review

In addition to the extensive empirical literature examining the energy-economic activity nexus, 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 criticized (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 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, and 2009) 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.

However, De Miguel et al. (2003, 2005) shows 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 utilization.

The common features in most of the aforementioned models are that energy prices are taken as exogenous stochastic process and energy 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 to date, 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. Moreover, the empirical and theoretical results yield inconclusive results regarding the hypothesis that energy price fluctuations have effects on economic growth of the countries. It is also worth noting that the policymakers of the developing countries should know it beforehand the actual linkage between energy prices and economic movements.

3. The Model, Model Calibration and Estimation of Parameters

3.1 The Model

This paper attempts to construct a simple Real Business Cycle (RBC) model by extending Kydland and Prescott's (1982) analysis of a RBC model to understand the change in key economic variables caused by energy price shocks in addition to productivity shocks in a decentralised economic framework. It is worth noting that, energy is not considered in the Kydland and Prescott's (1982) paper. Therefore, energy is explicitly modeled in the household's utility function where the representative household derives utility from the consumption of energy oriented goods (e_t), non-energy oriented goods (c_t) and from their leisure (l_t). It is very important to consider energy in the utility function as the role of energy is important on the consumer's side since many types of household products; especially durables are completely energy dependent. Each household's endowment of time is normalised to 1 so that leisure is equal to ($1-l_t$) where l_t represents the number of working hours.

The utility function is assumed to be perfect separable among the components. The utility function is represented by the following equation:

$$U_t = \ln c_t + \theta\,(1 - l_t) + \omega \ln e_t \qquad (1)$$

Utility function exhibits the commonly assumed properties like $V_c>0$, $V_{cc}<0$, $\lim_{c\to 0} = \infty$ and$\lim_{c\to\infty} = 0$. That means, additional consumption and leisure increases utility but does so at a diminishing rate. In addition, households earn a wage rate, w_t, which they take as given. They hold bonds, b_t, which pay interest rate r_t. $b_t>0$ means the household has a positive stock of savings whereas $b_t<0$ means the household has a stock of debt. Since savings is considered to be a stock, it is a flow. The households also take the interest rate as given. Moreover, they also own capital stock (k_t) and earn a rental rate (R_t) for renting out these capital stock to firms each period. Finally, they have profit distributions in the form of dividends, π_t. The household income thus comprises of labor income, capital income, interest income and profits, which it can utilize to consume, accumulate more capital or accumulate more savings. Their budget constraint states that for each period, total expenditure must be equal to their total income. Hence we can write the constraint as

$$c_t + k_{t+1} - (1-\delta)k_t + b_{t+1} - b_t = w_t l_t + R_t k_t + r_t b_t + \pi_t$$

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

$$y_t = A k_t^{\propto} l_t^{\gamma} g_t^{1-\alpha-\gamma} \qquad (2)$$

The firm produces output y_t. It hires labour and issues debt. Additionally, the firm chooses capital today given the rental rate R_t. It is worth noting that the firm can vary capital today even though the household cannot, given that capital is predetermined. The debt is denoted as d_t and the interest the firm pays on this debt is denoted as r_t. Its revenue each period is equal to the output. The costs incurred each period are the wage bill, investment in new capital and services costs on its debt. Since the amount of debt will eventually end up being indeterminate, it is common to simply assume that firms do not issue/hold debt and therefore solve a static problem. It is thus evident that 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.

The law of motion of the stochastic productivity shock A is assumed to be: $A_t = \rho A_{t-1} + u_t$ u_t ~ (0, σ2) as like Tan (2012).

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:

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

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

$$P_t = \varphi P_{t-1} + v_t$$

Where v_t is i.i.d 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:

$$y_t = c_t + i_t + P_t(e_t + g_t) \qquad (4)$$

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

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln c_t + \theta\,(1 - l_t) + w \ln e_t\right] + \lambda_t \left[w_t l_t + R_t k_t + (1+r)b_t + \pi_t - c_t - k_{t+1} + (1-\delta)k_t - b_{t+1} - P_t\,(e_t + g_t)\right] \qquad (5)$$

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:

$$\frac{1}{c_t} = \beta \,[\frac{1}{c_{t+1}} \,(A\alpha k_{t+1}^{\alpha-1} l_{t+1}^{\gamma} g_{t+1}^{1-\alpha-\gamma} + (1-\delta)] \qquad (6)$$

$$\frac{\theta}{1-l_t} = \frac{1}{c_t} \left[A k_t^{\alpha} \gamma l_t^{\gamma-1} g_t^{1-\alpha-\gamma}\right] \qquad (7)$$

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 difference equations that fully characterises the cyclical properties of the model economies.

$$\frac{c_t}{e_t} = \frac{P_t}{w} \tag{8}$$

$$P_t = Ak_t^{\alpha} l_t^{\gamma} (1 - \alpha - \gamma) g_t^{-(\alpha+\gamma)} \tag{9}$$

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

$$y_t = Ak_t^{\alpha} l_t^{\gamma} g_t^{1-\alpha-\gamma} \tag{11}$$

$$A_t = \rho A_{t-1} + u_t \tag{12}$$

$$P_t = \varphi P_{t-1} + v_t \tag{13}$$

3.2 Model Calibration and Estimation of Parameters

In this section, we discuss the calibration of different parameters of the model. There are 11 parameters in total with 7 structural and 4 shock 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 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 1:

Table 1: Model Parameters

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
ω, share of energy in household utility	2.01
θ, the share of leisure in household utility	0.33
σ, the CES parameter of household's utility function	-0.11
ρ, persistence coefficient in 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

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). To examine the credibility of the model in describing the Bangladesh economy's dynamic structure, we calibrate the model using annual data from 1980 to 2010. Due to unavailability of data, the study considers data from 1980 to 2010.

Due to data constraints, all parameters in our model are calibrated for annual frequency. 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 (BBS). First of all, we discuss parameters related to production. Following Rahman and Yusuf (2010), we set alpha (α) equals to 0.31 which implies capital's share of national income in Bangladesh is slightly less than a third. 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.

Depreciation rate, δ, is usually very low in the developing countries. So, depreciation rate delta has been set at 0.025 implying that the overall depreciation rate in Bangladesh is 2.5 percent annually. This value is fairly realistic form the perspective of the developing countries. The capital output ratio in Bangladesh is borrowed from Rahman and Rahman (2002) who estimated that the trends in capital output ration in Bangladesh over the period of 1980/81 to 2000/01 is equal to 2.

Now, we discuss parameters related to household utility. Given, alpha, delta and Capital-output ratio, the values of discount factor beta (β) is obtained from equations 6 and 11 calculated in steady state

$$\beta=1/\alpha(y/k) +1-\delta$$

Our estimated value 0.88 is compatible with the other existing literature considered the value of discount factor, beta for annual frequency for developing countries. 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 widely accepted value for RBC/DSGE analysis. Omega (ω) reflects household's preference for leisure and its value is chosen from equations 7 and 8 once again calculated in the steady state which yields b=2.01. The value of 2.01 falls within the range as estimated in other existing literature reported by DiCecio and Nelson (2007).

$$\omega=\gamma\ (1-l)\ y/c.l$$

Similarly, the household's preference for energy consumption, Zeta, is also calculated from equation 8 which yields a value 0.33.

$$\zeta= p.e/c$$

Finally, following King, Plosser and Rebelo (1988), we set the persistence of our two exogenous shocks equals to 0.95 and standard deviation of the shocks equals to 0.01.

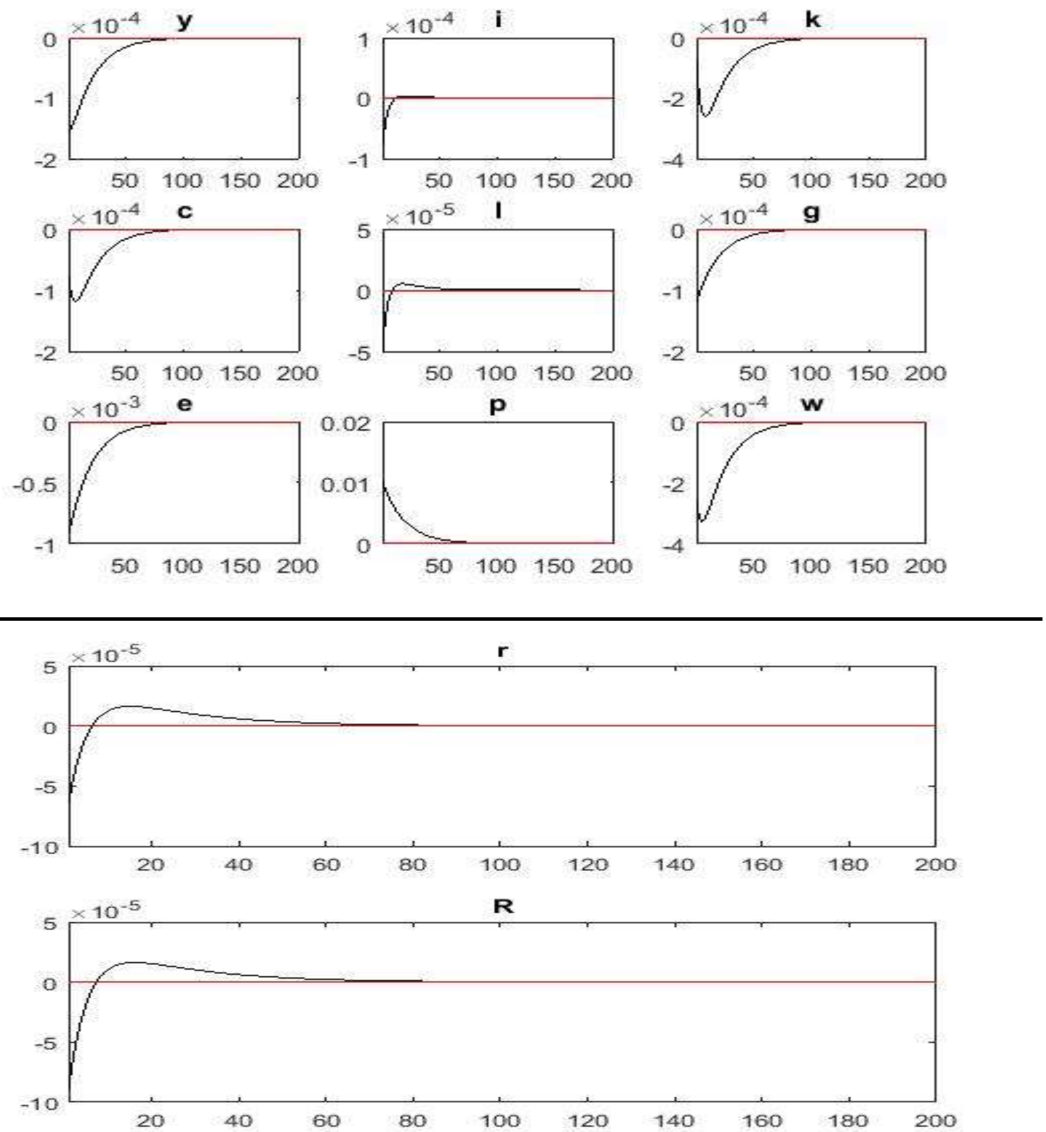
4. Results

4.1 Transmission Mechanisms of Energy Price Shocks

After calibration, we describe the dynamic mechanism in which energy price shock is propagated. To get simulation results we use the software Dynare 4.4.3 which is a preprocessor and collection of MATLAB routines that linearise the deterministic steady state around the system. The shock is equal in size to the standard deviation of the normalised price.

Figure 1 shows the response of the different endogenous variables of the model in presence of such shock. When there is an increase in relative energy price, both the amount of energy consumption and the amount of energy used in the production decreases by 1 percent approximately. Because of the complementarity effects, the reduction in the use of energy in production decreases the amount of capital as well as the amount of labour by 1 percent and 4 percent respectively. The decrease in the productive inputs is translated into an output decrease which would imply a negative correlation between output and energy prices. A rise in energy price also negatively affects the overall investment as expected. An inverse relationship is observed between high energy price and interest rate on capital and debt. In reality, many factors could affect the direction of both interest rates and energy prices. For example, higher energy price lower the investment and volume of capital. Therefore, a reduction in interest rate is required to stimulate the economic activities. Finally, consumption exhibits a similar response to the output. The results of this paper indicate that energy price shocks can lead to an adverse impact on the Bangladesh economy. Existing literature argues that energy is a strategic determinant of economic progress. Our results support the hypothesis that energy price can negatively affect the economy. Our finding also strengthens the existing literature about the importance of energy in the economic growth of Bangladesh.

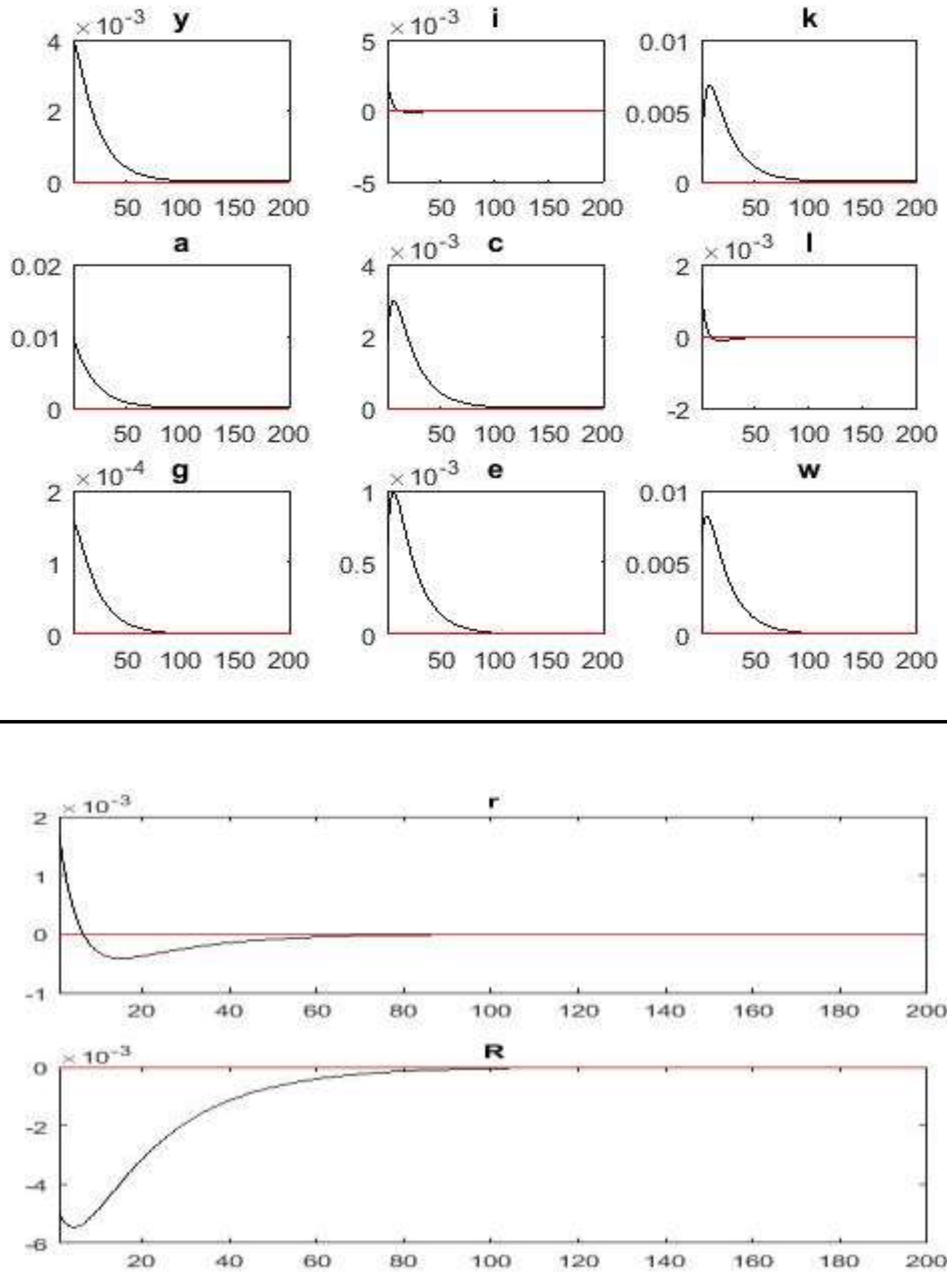
Figure 1: Relative Impulse Responses to an Energy Price Shock



4.2 Transmission Mechanisms of Productivity Shocks:

Figure 2 displays the impulse response to a positive productivity shock towards economy. 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 economy. This is the substitution effect of the positive productivity shock 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. An increase in productivity makes capital more productive in the future, since future productivity is expected to be higher (as rho is close to 1), the social planner responds optimally by immediately building up the capital stock. As a result of a positive technology shock, investment rises the most followed by output. Investment reverts back to original pre-shock levels just after a few periods compared to other endogenous variables.

Figure 2: Relative Impulse Responses to Productivity Shocks



5. Conclusions

In the introduction to this paper we referred to McCallum's suggestion that RBC theory should explicitly model exogenous energy price changes. Furthermore, the significance of energy in the household's utility function, and therefore, on their overall welfare, has remained widely unattended. In addition, very few studies have considered a decentralized economy in which the household's income is comprised of labour income, capital income, interest income and profits which it can utilize in consumption, accumulation of more capital or accumulation of more savings. To the best of our knowledge, no researcher has endeavored to calibrate an RBC model with energy prices in the context of the Bangladesh economy in an effort to investigate the interactions among energy prices, economic performance and impact on the welfare of households under a decentralised economic structure. This model 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.

We made an attempt to implement this suggestion in the simplest possible way where energy is included both in the utility and production function. Energy price shock is explicitly introduced in our model in addition to the productivity shocks. The model used in this paper is based on the standard Dynamic Stochastic General Equilibrium (DSGE) analysis which is a small first step in modelling energy price shocks in a RBC framework for Bangladesh economy.

Our main finding from this paper is the existence of an inverse relationship between different economic variables such as energy usage, productive inputs, consumption and output and energy prices in the Bangladesh economy. Moreover, an adverse shock in energy prices causes consumption of both energy oriented goods and non-energy oriented goods to fall, hence inducing a negative impact on the welfare of households. Our results are consistent with the other studies done in different developing countries supporting the hypothesis that energy price has an adverse effect towards economy.

However, the model is still rather stylised. It abstracts from many of the channels through which energy prices may affect the macro economy. Firstly, 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. Secondly, it abstracts from the presence of fiscal and monetary authorities as well as market competitiveness. For further research, it would be interesting to include pollution on our baseline model to do some comparative static to evaluate the dynamic effects of specific emission policy choices. We would also like to consider externality where it is assumed to enter household utility additively separable and furthermore assess the overall welfare effect of a reform. Finally, we would also intend to extend the model by explicitly modelling the energy market so that energy policy reforms and their impact on the overall economy can be accurately analysed.

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