Combining Private and Public Resources: Using Captive Power Plants and Electricity Sector Development in Bangladesh

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Abstract

Developing economies need to efficiently utilise both public and private resources to develop their energy sectors. The opportunity cost of failing to do so is high. This paper uses a Dynamic Stochastic General Equilibrium (DSGE) approach to examine integration of the Captive Power Plants (CPPs) in the power sector of Bangladesh. We find that if Bangladesh shut down the CPPs, the long-run industrial output and GDP would fall by 1.5% and 1.2%, respectively. The Impulse Response Functions (IRFs) show that the Bangladesh economy would be more vulnerable to oil price shocks without CPPs. In order to minimise distortion in the energy markets, the government could instead consider reforms such as promoting the use of efficient production technologies or the replacement of fossil fuels with renewable energy sources.

Keywords: Captive power plants; electricity generation; DSGE model; natural gas; Bangladesh.

JEL Codes: D58; L94; Q43; Q48.

1. Introduction

Reliable electricity is essential to the functioning of developed, developing and emerging countries while frequent power outages constrain their economic development (Abdisa, 2018). In many countries, uninterrupted supply of electricity is regarded as a luxury (Menash, 2016). According to Abdisa (2018), worldwide, around 25% of large firms and 12% of medium firms face electricity constraints. Wijayatunga and Jayalath (2004) estimate that the cost of power outages for industries in Sri Lanka at 0.9 % of the GDP. Cole *et al*. (2018) estimate the cost of power outages across sub-Saharan Africa (SSA) at 2.1% of the total GDP, and industrial sales fell by 4.9%.

Empirical evidence finds a negative relationship between power outages and firms' productivity in China or India. (Allcott *et al*., 2016; Fisher-Vanden *et al*., 2015; Mensah, 2016). An inadequate supply of electricity affects firms' productivity and competitiveness by lowering product volume and quality, delaying order delivery, increasing production cost, switching technological choice away from energy-intensive technology, and changing investment decisions.[1]

Given the economic cost associated with power outages, industries attempt to respond in several ways. The most common strategy is investing in self-generation (Adenikinju, 2003; Oseni and Pollitt, 2015; Steinbuks and Foster, 2010). The decision to invest in self-generation depends on the degree of vulnerability, as some firms are more vulnerable to outages than others. For example, Ghosh and Kathuria (2014) treat electricity access as a transaction and show that there is a corresponding transaction cost when firms face a power outage. They find that a firm facing high transaction costs has more incentives to invest in self-generation of electricity.

The installation of self-generation depends on the size of the firm and the price of the inputs used in electricity generation. For small firms, reliance on self-generation may have a long-run negative impact on firm productivity as the high marginal cost of self-generation constrains firms' ability to invest in other productive factors and forces them to operate below their capacity. Larger firms enjoying economies of scale tend to have large investments and can minimise the negative consequences of relying on self-generation. In many countries, the

[1] The degree of impact varies across firm size and the type of economic activity in which firms are engaged. Moyo (2012) finds that electricity shortages are particularly harmful to small firms as they are unable to invest in backup energy. On the other hand, Oseni and Pollitt (2015) discuss that larger firms use more machine-dependent production processes than small firms.

availability of low cost fuel can outweigh the cost of establishing the self-generation infrastructure and make it a feasible alternative to tackle the power outages (Ghosh and Kathuria, 2014).

Historically, the state-owned electricity companies of Asia and Africa are in financial hardship (Amin, 2015). The inability of governments from developing economies to mobilise sufficient investment for the electricity sector development limits the role of the state in closing the electricity demand-supply gap. The energy sector has failed to attract adequate private investments due to poor pricing policies along with other bottlenecks such as inefficiency in the decision-making process or political instability among others. A combination of these factors along with the energy crisis of the 1970s resulted in the proliferation of industrial self-generation of electricity. This has materialised through backup units known as Captive Power Plants (CPPs)[2] and especially in the form of cogeneration technologies (Rose and McDonald, 1991).

When the economic development of Bangladesh was constrained by the limited generation capacity and poor supply quality in the 1990s, the government decided to open up the energy market and issued the Private Sector Power Generation Policy (PSPGP) in 1996.[3] A primary goal of this policy was to reduce the deficit between electricity supply and demand and to meet future electricity demand through better use of energy resources. The new private power generation policy allowed industrial users to build CPPs in order to generate electricity for own consumption and to sell the surplus electricity to consumers in the neighbouring areas.[4]

The literature on the causes of the growth of self-generation in the developing countries context is somewhat limited (Abdul-Majeed *et al.,* 2013; Joseph, 2010; Nag, 2010). Ghosh and Kathuria

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[2] A Captive Power Plant is a plant set up by industries to generate electricity mainly for their own use.
[3] For more details, see http://lib.pmo.gov.bd/legalms/pdf/power-policy-2004.pdf
[4] See the guidelines for CPPs at https://berc.portal.gov.bd/sites/default/files/files/berc.portal.gov.bd/policies/37a75205_8c94_434e_b8e8_0dd643b2a00d/Policy%20Guidelines%20for%20Power%20Purchase%20from%20Captive%20Power%20Plant,%202007.pdf

(2014) argue that industries that face high priced cross-subsidising power and shortages, can exit the grid and set up their own CPPs, and eventually feed the power back to the grid. It also gives politicians the option where they can continue to cross-subsidise the key political constituencies (like agriculture and household sectors) without depressing the growth of private power.

Thus, the CPPs play a key role in many countries as an alternative source of private supply of power (Hansen, 2008; Joseph, 2010; Nag, 2010; Shukla *et al*., 2004). The most striking benefits of the CPPs are to protect industrial companies from blackouts, which can damage the machinery, inventories, and increase the overhead expenses. Captive power plants can also increase productivity in off-grid regions and reduce the need for distribution companies to make expensive investments to extend the grid to remote locations.

In 1996, the time was ripe for the introduction of CPPs in the Bangladesh energy market. Bangladesh's rapid industrialisation in the 1990s called for an increasing supply of electricity not only from the national grid but also from private providers such as CPPs. The national grid supply was also poor at the time with high transmission and distribution losses.[5] Besides, the electricity provided by the national grid was too costly for the industrial sector, reducing the international competitiveness of Bangladesh industries (Halim *et al.*, 2013). Finally, the abundance of natural gas in Bangladesh meant that CPPs that predominantly use natural gas to produce electricity could obtain consistent and low-cost fuel input. Since then, the CPPs generate nearly 10-15% of the total electricity generation in Bangladesh throughout the last three decades and contribute to the development process of Bangladesh.[6]

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[5] For more detail, see https://powerdivision.portal.gov.bd/sites/default/files/files/powerdivision.portal.gov.bd/page/f6d0e100_e2d8_47e7_b7cd_e292ea6395d3/4.%20VSPSPSectorReform.pdf.

[6] Since there has not been further investment in the exploration of natural gas reserves, the existing stock of natural gas is predicted not to be able to sustain Bangladesh's economic growth (Amin, 2015).

Despite the significance of the CPPs for the Bangladesh industry, the government has recently planned to gradually reduce the supply of natural gas to the CPPs and eventually shut them down mainly for two reasons. Firstly, CPPs use Open Cycle Gas Turbine (OCGT) systems, which can only offer a maximum efficiency of 25-30% compared to 52-60% efficiency of the Combined Cycle Gas Turbine (CCGT) power plants. Therefore, the power generation efficiency of these CPPs is generally less than the efficiency of supplies from the national grid (Power System Master Plan 2016).[7] Secondly, the CPPs are mainly use natural gas, and around 17% of the total natural gas is consumed by captive power plants. The gas consumption of these CPPs has increased from 37.9 Billion Cubic Feet in 2005 to 160.5 Billion Cubic Feet in 2017.[8] However, Bangladesh is at risk of exhausting her limited natural gas reserves due to the lack of technical expertise, which acts as a constraint in discovering large new gas fields.

Over the past 10 years, the government has succeeded in meeting the country's growing electricity demand to a great extent through public-private partnerships.[9] There are 138 power plants in 2018 as compared to just 27 in 2009. The net installed electricity generation capacity increased from 5,272 megawatts (MW) in 2009 to 16,892 MW in 2018 (Amin and Rahman, 2019). Accessibility of electricity has risen from 47% in 2009 to 90% in 2018. Large new investments are in the pipeline for setting up large power plants (Bangladesh Power Development Board, 2017). This success in electricity generation has instigated the government to close down the CPPs. However, the CPPs remain important to meet the peak load demand. Before shutting down the CPPs, a thorough economic analysis is needed. This paper provides an

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[7] For more details, see:
https://powerdivision.portal.gov.bd/sites/default/files/files/powerdivision.portal.gov.bd/page/4f81bf4d_1180_4c53_b27c_8fa0eb11e2c1/(E)_FR_PSMP2016_Summary_revised.pdf.

[8] Source: 2017 Statistical Yearbook of Bangladesh; page 223.

[9] For more details, see:
http://www.bpdb.gov.bd/download/annual_report/Annual%20Report%202016-17%20(2).pdf.

analysis to assess how the Bangladesh economy will behave in the long run if the CPPs are shut down.

We use a Dynamic Stochastic General Equilibrium (DSGE) framework.[10] To our knowledge, there are no other studies applying this type of approach to evaluate the effects of public-private integration in the electricity sector on macroeconomic variables and household welfare. The methodology of this paper is based on Amin (2015), who develops a DSGE model for the Bangladesh economy. Our model allows the flexibility of considering both public and private electricity generation using two fuels: natural gas and oil.[11] The basic assumptions, and in particular the functional forms of household preferences and technology, follow the seminal work of Kim and Loungani (1992) and have been used by Amin and Marsiliani (2015).

We calibrate and simulate the model for Bangladesh's economy as an example of an oil-importing country where CPP plays a major role in electricity generation. We further compare the steady-state results of the benchmark model with a model economy without the CPPs. These results can be taken into account to produce policy advice for the Bangladesh government policy with respect to CPPs.

The paper is organised as follows. Section 2 presents the DSGE model, which is followed by a discussion on the calibration of the parameters in Section 3. Section 4 discusses the results. Finally, conclusions and policy implications are presented in Section 5.

2. The Benchmark DSGE Model

[10] DSGE models are becoming popular among energy researchers as they can facilitate the forecast of changes in the degree of welfare that would be caused by a change in market conditions.

[11] Natural gas and oil represent nearly 90% of the total fuel used in electricity generation in Bangladesh (Bangladesh Power Development Board, 2017).

We develop a DSGE model,[12] which is an extension of the model developed by Amin and Marsiliani (2015). There are four main sectors in the model economy: the industrial and service production sector (which both use electricity as an input), the electricity generation sector, the household consumption sector, and the public sector. The economy is open and small in the sense that its behaviour does not affect the rest of the world. The energy sources in this model include oil and natural gas, which in turn are used to produce electricity for consumption in the household, industrial, and service sectors.

2.1 The Industrial and Service Production Sectors

The final output in the industrial and service sector is presented by a Constant Elasticity of Substitution (CES) technology, exhibiting Decreasing Returns to Scale (DRS) in the inputs: labour (*l*), capital (*k*), and electricity (*j*). The production function with DRS assumption, as defined in Equation 1, has been used in some standard DSGE literature (see, e.g., Rotemberg and Woodford, 1996; Jaaskela and Nimral, 2011).

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

where, A_t^i is the stochastic productivity shock, the index i represents the respective industrial (Y) or service (X) sectors, and j denotes electricity used by the respective sectors. α_i is the labour share; Ψ_i is the share of electricity in the production function. $\acute{\upsilon}^{jj}$ implies the degree of homogeneity in the CES production function and $\frac{1}{1+\nu^j}$ is the Elasticity of Substitution (EOS) between capital and electricity, which determines the degree of substitutability between these two inputs. In order to hold the DRS assumption, the following condition needs to be met:

1. $\frac{\nu^j}{\acute{\upsilon}^{jj}}<1$

[12] Our DSGE model incorporates the government's price-setting mechanism and the associated implicit subsidies which are overlooked in all the previous DSGE literature.

There are two industries in our model economy. One group of industries consumes electricity from the national grid to produce their output (Equation 2). The second group of industries operates the CPPs to produce their electricity and does not take electricity from the national grid (Equation 3). In the benchmark model, we assume that the entire electricity produced by the CPPs is consumed by the industry, and there is no excess supply of electricity to feed into the national grid. Following Amin (2015) and Kim and Loungani (1992), we specify the production function in industry and service sectors as follows:

$$Y_{1,t}=A_{1,t}^{Y} l_{Y1,t}^{\alpha,1}[(1-\Psi_{Y1})k_{Y1,t}^{-\nu^{g,1}}+\Psi_{Y1}g_{1,t}^{-\nu^{g,1}}]^{-\frac{1-\alpha_{Y1}}{\acute{\upsilon}^{gg,1}}} \quad (2)$$

$$Y_{2,t}=A_{2,t}^{Y} l_{Y2,t}^{\alpha,2}[(1-\Psi_{Y2})k_{Y2,t}^{-\nu^{g,2}}+\Psi_{Y2}g_{2,t}^{-\nu^{g,2}}]^{-\frac{1-\alpha_{Y2}}{\acute{\upsilon}^{gg,2}}} \quad (3)$$

$$X_{t}=A_{t}^{X} l_{X,t}^{\alpha_X}[(1-\Psi_{X})k_{X,t}^{-\nu^{s}}+\Psi_{X}s_{t}^{-\nu^{s}}]^{-\frac{1-\alpha_{X}}{\acute{\upsilon}^{ss}}} \quad (4)$$

All the firms operate under perfect competition and maximise profits as follows:

$$Max\ \pi_{i,t}=P^{i}.A_{t}^{i}.l_{i,t}^{\alpha_i}[(1-\Psi_{i})k_{i,t}^{-\nu^{j}}+\Psi_{i}j_{i,t}^{-\nu^{j}}]^{-\frac{(1-\alpha_{i})}{\acute{\upsilon}^{jj}}}-r.k_{i,t}-w.l_{i,t}-q^{j}.j_{i,t} \quad (5)$$

where w is the wage rate, r is capital interest rate, and q is the (market) price of electricity. Wage and interest rate are assumed to be equal across all the sectors. The electricity consumption (j) of industries and service sectors is denoted by g_1, g_2, and s, respectively. The price of the final good is normalised to 1 in our model, and, ν^{j} is considered as the relative price of electricity.

2.2 The Energy Sector

We consider four types of electricity-generating firms in our model: the public power producers (G), the independent power producers (I), the captive power producers (g_2) and the rental power producers (R). Except for public power producers, the remaining three power producers are privately owned and behave as profit maximiser in our model.

Similar to the production function used by Amin (2015), we employ a CES production function for different electricity generating firms. Each electricity generating firm transforms the three-factor inputs, namely, labour, capital and energy (natural gas, *m*, or oil, *h*) into electricity according to the following specification:

$$G_t = A_t^G l_{G,t}^{\alpha_G} [(1-\Psi_G) k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\nu^{m,GG}}} \tag{6}$$

$$I_t = A_t^I l_{I,t}^{\alpha_I} [(1-\Psi_I) k_{I,t}^{-\nu^{m,I}} + \Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\nu^{m,II}}} \tag{7}$$

$$g_{2,t} = A_t^C l_{C,t}^{\alpha_C} [(1-\Psi_C) k_{C,t}^{-\nu^{m,C}} + \Psi_C m_{C,t}^{-\nu^{m,C}}]^{-\frac{\vartheta^C}{\nu^{m,CC}}} \tag{8}$$

$$R_t = A_t^R l_{R,t}^{\alpha_R} [(1-\Psi_R) k_{R,t}^{-\nu^R} + \Psi_R h_t^{-\nu^R}]^{-\frac{\vartheta^R}{\nu^{H,RR}}} \tag{9}$$

Sectors *G*, *I*, and g_2 face the same natural gas price υ^m and sector *R* faces the oil price υ^h. Sector *G*, *I* and R sell electricity at government regulated prices P^G, P^I, and P^R, whereas, g_2 is sold at internal price q^{g_2} and any difference between P^j and q^j implies implicit subsidy.

The parameter ν depends on the EOS between capital and energy. Labour's share in production is given by the parameter α and Ψ is the share of energy in production where $\Psi \in (0, 1)$.

2.3 The Household Sector

The households receive utility from consuming four types of consumption goods: electricity (*e*), standard consumption goods (*c*), service goods (*x*) and leisure (1-l). We assume the per-period utility function is:

$$U(c_t^A, l_t) = \varphi \log c_t^A + (1-\varphi) \log(1-l_t) \tag{10}$$

where:

$$c_t^A = X_t^\gamma \left(\theta c_t^\rho + (1-\theta) e_t^\rho\right)^{\frac{1-\gamma}{\rho}} \tag{11}$$

The log-utility specification in Equation (10) is similar to that in Amin (2015). Each household's endowment of time is normalised to 1, implying that leisure is equal to (1-*l*) where *l* denotes the number of working hours. The formulation in Equation (11) allows for a less than unity substitution elasticity between ordinary consumption and electricity consumption. In particular, the EOS between c and e is 1/(1-ρ). Following Amin and Marsiliani (2015), we set ρ to -0.11 in the computations implying EOS smaller than one. Equation (11) is similar to the aggregator function in Dhawan and Jeske (2007), where they include consumption of nondurables and services excluding energy, flow of services from the stock of durable goods and energy goods. The parameters $\varphi, \theta,$ and γ represent the relative share of c, e, 1-*l*, and X, and will be calibrated for the computation.

The households have four primary sources of income: i) capital income $(r.k_t)$, ii) labour income $(w.l_t)$, iii) lump-sum transfer payment, ъ, from the government, and iv) dividend, π. Capital and labour income are taxed at the rates $\tau^k and\, \tau^l$, respectively. The price of service goods and household electricity is n and q^e, respectively. The household budget constraint is as follows:

$$k_{t+1} + c_t + n.X_t + q_t^e.e_t = (1-\tau^l)w.l_t + ъ + (1-\tau^k)r.k_t + (1-\delta)k_t + \pi \qquad (12)$$

where δ is the depreciation rate.

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

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

$$n.X_t + q_t^e.e_t - (1-\tau^l)w.l_t - ъ - (1-\tau^k)r.k_t - (1-\delta)k_t] \qquad (13)$$

where β is the discount factor, 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.

2.4 The Public Sector

The government earns revenue from taxing labour income ($\tau^l . w . l_t$), capital income ($\tau^k . r . k_t$), selling natural gas to other electricity-generating firms ($(v^m - \delta^C)(m_{I,t} + m_{G,t})$) and selling electricity to the national grid ($P^G . G_t$). On the expenditure side, the government purchases labour ($w . l_{G,t}$), capital ($r . k_{G,t}$), and natural gas ($v^m . m_{G,t}$) for own electricity production and makes a lump sum transfer to households (ъ). The price of natural gas in the local market is v^m. Additionally, the extraction cost of natural gas (δ^C) is the actual cost of a true gas price to control the use of the free resource. The government faces the following cost minimisation function:

$$c_{G,t} = w . l_{G,t} + r . k_{G,t} + v^m . m_{G,t} - P^G . A_t^G l_t^{\alpha_G} \left[(1 - \Psi_G) k_{G,t}^{-v^{m,G}} + \Psi_G m_{G,t}^{-v^{m,G}}\right]^{-\frac{\vartheta^G}{v^{m,GG}}} \qquad (14)$$

The government provides a subsidy as it purchases electricity from electricity producers at a high price and sells it at a low price to consumers. The total subsidy is calculated from (15):[13]

$$b = P^G . G_t + P^I . I_t + P^R . R_t - q^e . e_t - q^s . s_t - q^{g_1} . g_t$$

(*15*)

The government budget constraint is as follows:

$$\tau^l . w . l_t + \tau^k . r . k_t + (v^m - \delta^C)(m_{I,t} + m_{G,t} + m_{C,t}) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G . G_t - r . k_{G,t} - w . l_{G,t} - v^m . m_{G,t} - ъ = b \qquad (16)$$

Finally, combining household budget constraint, government budget constraint, and the subsidy equation, the economy-wide resource constraint can also be derived.

$$k_{t+1} = Y_{A,t} - c_t + (1 - \delta) k_t - \delta^C (m_{I,t} + m_{G,t} + m_{C,t}) - v^h . h$$

(*17*)

[13] q^s and q^{g_1} are the electricity prices for service and industrial sectors whereas $\mathrm{P^G}$ is the selling price of electricity by the government. It is worth noting that $q^{g_2}$is the efficient price from the viewpoint of industry 2, ensuring production efficiency in CPPs. Moreover, since these prices are not market prices (but regulated prices), the market may not clear. Therefore, the government is the residual producer and supply electricity to clear the market.

2.5 Equilibrium Conditions

The equilibrium in the labour market, capital market, and the electricity markets is represented by the following equations:

$$l = l_H + l_I + l_G + l_Y + l_X + l_2 + l_C \tag{18}$$

$$k = k_H + k_I + k_G + k_Y + k_X + k_2 + k_C \tag{19}$$

$$e_t + s_t + g_t + g_{2,t} = \left(G_t + I_t + g_{2,t} + R_t\right) \tag{20}$$

2.6 Model Shocks

We model 6 different productivity shocks and an oil price shock in our benchmark model.[14] Following Cooley and Prescott (1995), the stochastic productivity shock A^i across sectors is assumed to be:

Productivity shocks in industry 1: $ln\, A_t^{Y,1} = A^{Y,1} + \mu^{Y,1} lnA_{t-1}^{Y,1} + \eta_t^{y,1}$ (21)

Productivity shocks in industry 2: $ln\, A_t^{Y,2} = A^{Y,2} + \mu^{Y,2} lnA_{t-1}^{Y,2} + \eta_t^{y,2}$ (22)

Productivity shocks in service sector: $ln\, A_t^{X} = A^{X} + \mu^{X} lnA_{t-1}^{X} + \eta_t^{X}$ (23)

Productivity shocks in the government: $ln\, A_t^{G} = A^{G} + \mu^{G} lnA_{t-1}^{G} + \eta_t^{G}$ (24)

Productivity shocks in the independent producers: $ln\, A_t^{I} = A^{I} + \mu^{I} lnA_{t-1}^{I} + \eta_t^{I}$ (25)

Productivity shocks in the CPP: $ln\, A_t^{C} = A^{C} + \mu^{C} lnA_{t-1}^{C} + \eta_t^{C}$ (26)

Productivity shocks in the rentals: $ln\, A_t^{R} = A^{R} + \mu^{R} lnA_{t-1}^{R} + \eta_t^{R}$ (27)

Oil Price Shock: $ln\, v_t^{e} = '\Omega^{v} + \omega ln v_{t-1}^{e} + \eta_t^{O}$ (28)

Here, μ^i represents the persistent coefficient of the shocks. and $'\Omega^i$ represents the coefficients in the shock equations. In all the cases, the residuals (η_t^i) are normally distributed with a standard deviation of one and zero mean.

2.7 The Welfare Equation

[14] A common practice in DSGE models is to consider random shocks (such as technological change, fluctuation in the price of oil) that can affect the economy (Amin, 2015).

Rather than comparing changes in utility numbers, we compare the equivalent required changes in ordinary consumption. Let c_1, e_1, X_1, and l_1 be the steady-state values in the benchmark scenario with associated utility:

$$U_B = X_1^{\gamma}\left(\theta c_1^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi} \tag{29}$$

Similarly, let c_2, e_2, X_2, and l_2 be the new steady-state values for an alternative equilibrium (shutting down the CPPs), then the utility of consumers is:

$$U_A = X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi} \tag{30}$$

We now find the level of ordinary consumption, $\hat{c}$, which gives the same utility in the benchmark equilibrium as with the alternative equilibrium.

$$X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi} = X_1^{\gamma}\left(\theta \hat{c}^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

$$\Rightarrow \left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}} = \left(\theta \hat{c}^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}} \left(\frac{X_2}{X_1}\right)^{\gamma} \left(\frac{1-l_2}{1-l_1}\right)^{\frac{1-\gamma}{\gamma}}$$

$$\text{So, } \hat{c} = (c_2^{\rho} + \frac{1-\theta}{\theta} e_2^{\rho})(\frac{X_2}{X_1})^{\gamma \frac{\rho}{1-\gamma}} (\frac{1-l_2}{1-l_1})^{\frac{1-\varphi}{\varphi} \cdot \frac{\rho}{1-\gamma}} - \frac{1-\theta}{\theta} e_1^{\rho} \tag{31}$$

Welfare gains can then translate into equivalent percentage changes in consumption, computed as $\frac{\hat{c}-c_1}{c_1}$.

3. Parameter Specification, Data and Calibration

For the calibration of our model,[15] some of the parameters are selected from the existing 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 and the rest of the parameter values are taken from the available data sources. The dataset reflects the variable

[15] Calibration has become a standard tool in dynamic modelling as it can serve as building blocks for further methodological development (Cooley, 1997; Macera and Divino, 2015; Gomme and Rupert, 2007).

values for 2012-2013, the latest data available for the different variables. Due to data constraints, all parameters in our model are calibrated for annual frequency.

There are 74 parameters in total, which include 42 structural parameters, 21 shock-related parameters, and 11 policy-related parameters. Structural parameters can be categorised into production and utility function related parameters α, ψ, ν, and δ are the main parameters related to production. Since the model has two different sectors, namely industry and service sector, and three different types of electricity-generating firms, we need to calculate the values of different alpha (α), for each sector.

Following Roberts and Fagernas (2004), we set the labour share in the industrial sectors, $\alpha_{Y,1}$ and $\alpha_{Y,2}$ equal to 0.2. The labour shares in the service sector, α_X can be calculated as 0.3135 using the first-order conditions and the subsequent ratios: $\frac{wl_X}{wl} = 0.7194$; $\frac{nX}{Y} = 1.6588$ and $\frac{wl}{Y} = 0.7228$. Given the value of total labour cost $(w.l_{i,})$ and total revenue $(p^i.i)$ in respective sectors; the labour share of different electricity generating sectors can be calculated as $\alpha_I = 0.0361$, $\alpha_C = 0.0361$, and $\alpha_R = 0.0041$.

Calculation of psi (ψ) involves two different approaches to sectoral production sectors and the energy sector where electricity is generated. The main dissimilarity between the approaches is due to the differences in the data and calculation process. For example, the share of electricity consumed in industrial production, $\psi_{Y,1}$ and $\psi_{Y,2}$ can be calculated by employing the first-order conditions and DRS assumptions as follows. Given the values of q^g,r,$\frac{rk^Y}{Y}$, $\frac{Y}{q^g.g}$, $\alpha_{Y,}$ ν^g and $\acute{\upsilon}^{gg}$, we can calculate the value of $\psi_{Y,1}$ and $\psi_{Y,2}$ equals to 0.0733. Similarly, we can also find the value of $\Psi_X = 0.0790$.

In order to calculate the share of energy used in three different electricity generating firms, we require the value of total revenue $(p^{i}.i)$, total labour cost $(w.l_{i,})$ and total cost of sales $(v^{m}.m_{i})$ to estimate Ψ_{I}, Ψ_{C}, Ψ_{H}, and Ψ_{G}. Using the first-order condition and holding DRS assumptions, we calculate Ψ_{I} and Ψ_{C} equal to 0.3093. Similarly, we can also find $\Psi_{H} = 0.5964$.

Following the first-order conditions and given the values of the concerned variables and parameters in the equations, we can calculate Ψ_{G} equal to 0.302, and α_{G} equal to 0.042.

$$v^{m}.\alpha_{G}\left[(1-\Psi_{G})k_{G,t}^{-\nu^{m}}+\Psi_{G}.m_{G,t}^{-\nu^{m}}\right]=\left(\vartheta^{G}\frac{\nu^{m,G}}{\acute{\upsilon}^{m,GG}}\right).\Psi_{G}.m_{G,t}^{-\nu^{m}-1}.l_{G}.w \tag{32}$$

$$r.\Psi_{G}.m_{G,t}^{-\nu^{m}-1}=(1-\Psi_{G})k_{G,t}^{-\nu^{m}-1}.v^{m} \tag{33}$$

We set ν^{h}, $\nu^{m.i}$, $\nu^{m,g}$, ν^{Y}, and ν^{X} equal to 0.1 from Thompson and Taylor (1995). Here, ν^{i}= (1-1/η), where η is the EOS 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 $\acute{\upsilon}^{XX}$ equal to 0.2 to fulfill DRS assumptions. Since $\acute{\upsilon}^{jj}$ is the degree of homogeneity in the CES production function, $\acute{\upsilon}^{jj}<1$ implies DRS in the production functions.

The depreciation rate is usually very low in developing countries. So, depreciation rate delta (δ) has been set at 0.025, implying that the overall depreciation rate in Bangladesh is 2.5% annually. This rate is consistent with recent studies on developing economies by Tanzi and Zee (2001) and Yisheng (2006).

As regards the utility function, we use several approaches to derive relevant parameters. Given the value of q^{e}, ρ, and the ratio of $\frac{e}{c}$ calculated from data, we can obtain θ (equals to 0.9110), the share of non-electricity consumption in household aggregator using the first-order conditions. It is worth noting that since the household's utility function follows a general CES form, it cannot be used to model an EOS exactly equal to 1. Following Tan (2012) we set the EOS at 0.9 for the analyses, and the CES parameter of the household's utility function, ρ, is, therefore, -0.11, which is negative and indicates that standard consumption and electricity consumption are somewhat complementary.

Given the ratio $\frac{nX}{c}$, q^e, ρ, and θ, the share of service aggregator γ (equals to 0.8110) can be calculated using the following equation:

$$\frac{c_t}{nX_t} = \frac{1-\gamma}{\gamma} \cdot \frac{1}{1+(\frac{\theta}{1-\theta})^{\frac{1}{\rho-1}}(q_t^e)^{\frac{\rho}{\rho-1}}} \tag{34}$$

φ reflects the share of electricity consumption and standard consumption goods in the household's utility function, and its value is calculated 0.6076 as follows:

$$\frac{(1-\varphi)}{\varphi} = \frac{(1-\gamma).\theta.(1-l_t).\frac{wl}{Y}.\frac{(1-\tau^l)}{l}.\frac{Y}{c}}{\theta+(1-\theta)\left(\frac{e_t}{c_t}\right)^p} \tag{35}$$

Due to the 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 DSGE analysis.

Other parameters of interest are obtained from the standard literature or data. β, the discount factor, is set to 0.96 since the length of a period in the model is assumed to be one year, which is quite standard in DSGE literature (Heer and Mausser, 2009). The capital and labour income tax rates τ^k and τ^l are set as 0.15 and 0.10, as mentioned in Bangladesh Tax Hand Book 2012 All other energy prices are presented in **Table 1** and **Table 2** and are from the available data of the annual reports of BPDB, Summit Power International, and the Dutch Bangla Power Associates. The selling price of electricity by BPDB (P^G) is calibrated as 2.30 using country data.

Table 1: Electricity prices (Taka/kWh) by users and producers

Households (q^e)	Industry (q^{g_1})	Service (q^s)	IPP (P^I)	Quick Rentals (P^R)	Government (P^G)
4.93	6.95	9.00	3.20	7.79	2.3

Table 2: Fuel prices (Taka/kWh)

International Oil Price ($\mathbf{v^e}$)	Domestic Oil Price (v^h)	Domestic Natural Gas Price (v^m)
8.19	5.72	0.77

Following Amin and Marsiliani (2015), we set the persistence of our two exogenous shocks equal to 0.95 and the standard deviation of the shocks equal to 0.01, following the unavailability of data for the Bangladesh economy.

4. Results and Discussion

We calibrate and simulate the model for the Bangladesh economy and then compare the steady-state values of critical economic variables of the benchmark model with a policy experiment of shutting down the CPPs.

The steady-state results reveal that shutting down the CPPs in Bangladesh would hamper long-run economic development in the country. The results reveal that closing them down would lower the total electricity generation of 5.18% in the long run. The lower availability of electricity would affect the entire economy. The industrial output would be reduced by 1.54%, and the household standard consumption would fall by 1.47%. As a consequence, the GDP would decline by 1.24%. We also find that the share of the electricity generation by the public sector rises by nearly 4% as a result of shutting down the CPPs. Even though the use of natural gas in electricity production falls by 15.1%, this implies a household welfare decrease of 2.3% in the long run.

Since Bangladesh is a small oil-importing country, we also analyse the impacts of the oil price shocks on the model variables through the Impulse Response Functions (IRFs) under the different experiments (see **Figure A.1** in **Appendix A**). The IRFs show that a rise in the world oil price (*v_e*) makes consumption more expensive and thus reduces all types of consumption in the economy through the income effect. 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 the aggregate labour supply (*l*) through income effect, which in turn lowers the market wages (*w*). Lower market 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 to the private sector through factor markets, which expand the electricity production from the private sectors.

Moreover, since the rental power plants (*e_h*) are facing domestic oil price (*v_h*), which is fixed and controlled by the government, this sector is not affected by the adverse impact of higher oil prices. The cost of oil becomes high, and other prices are not adjusted. Thereby, government intervention is required, and accordingly, government subsidy (*g_s*) increases. Additionally, since private sector tends to expand with wrong prices, the government electricity supply (*e_g*) needs to be reduced to equate total supply and demand for electricity since electricity prices are fixed. A rise in industrial production (*y_a*) can be attributed to oil imports that have become more expensive because of the higher oil prices. Since the price of labour decreases, more resources would be diverted towards the industrial sector, which ultimately increases its size. As a result, the volume of exports must increase proportionately to keep the trade balance unchanged. For every level of oil import, the country needs to produce more goods for export.

When CPPs are shut down, the behaviour of the IRFs for the model variables is very similar after oil price shocks. However, the difference is that the magnitude of the changes is greater in the experiment, which implies that the country is prone to experience higher deviations from the steady-state situation when the captives are shut down.[16]

5. Conclusions and Policy Implications

Bangladesh is one of the fastest-growing economies of the world. Based on improved socio-economic indicators, the United Nations have recently declared Bangladesh as a lower middle-income country in 2018. One of the growth engines of the country is the Ready-Made Garments (RMG) industry. In 2018, the RMG industry exported 32 billion US dollars. This amount is 84 percent of total exports and equivalent 12 percent of year on year growth.

With an aspiration to become a high-income country by 2041, Bangladesh now looks forward to sustained economic growth. Since the industrial growth is a major engine for the government's economic development policies, CPPs can play a major role by providing uninterrupted electricity supply to industry and also increase productivity in the off-grid regions by reducing the need for distribution companies to make expensive investments for grid extensions. However, in Bangladesh, the electricity demand of many factories mainly relies on captive generation, whereas the power supply from the grid is used as a backup. This is due to the fact that the tariff of natural gas supply for captive power is set lower than the electricity tariff. Thus, the cost of captive power generation is less expensive than the cost of power purchase from the grid.

The government has achieved success in electricity generation, and the generation capacity in Bangladesh has significantly improved compared to the 1990s. Bangladesh is near self-sufficient in meeting the country's generation requirements. Large new investments are in the pipeline for

[16] Although we have considered productivity shocks in our model, we do not report the IRFs from the productivity shocks since our focus is on the steady-state results. The IRFs from productivity shocks in different model variables show the standard results out of productivity shocks. For example, positive productivity shock makes the factors of production more productive, and accordingly, output and household welfare increase due to income effect.

setting up large power plants. So, the Bangladesh government is now planning to shut down the CPPs. The government has already started reducing the supply of natural gas to the CPPs as reserves of natural gas in Bangladesh are currently at risk of depletion.[17]

Moreover, the gas supplied to the CPPs is underpriced, which causes distortion and anomaly in the comparative cost of their power against industries that use grid power. Hossain (2015) argues that the cost difference between grid electricity and captive power stood at an intolerable level. In a perfect energy market, industries using grid electricity would shift to gas-based captive power as an alternative to closure. The sound policy is to rationalise the price of natural gas for the CPPs for creating a level playing field between those with captive power and those that have to use grid electricity. However, since 2014, Bangladesh's gas price has gone up by almost USD 1/million Btu (British Thermal Unit) for the captive users (Gas Sector Master Plan Bangladesh 2017). There is also the issue regarding efficiency; therefore, the government is discouraging captive power plants by increasing the gas price and diverting to national power plants.

There is a growing concern that the reduced supply of natural gas to the CPPs will adversely affect the country's economy. The government also needs to be careful to revise any policy on CPPs as 80% of the RMG industries have their own captive power plants.[18] Since, RMG contributes major share to the country's total export earnings, shutting down the CPPs or restricting the supply of the natural gas to the CPPs can potentially affect the macroeconomic performance and household welfare of the country. Moreover, the reliability of the grid power supply to substitute the CPPs has not proven yet.

[17] Now 19 gas fields are in production with 110 producing wells. The power sector has been the biggest consumer of natural gas, accounting for 41% of total gas consumption in 2015. This is followed by captive power 17%, industry sector 17%, domestic sector 13%, fertilizer sector 6%, Compressed Natural Gas (CNG) sector 5%, and the commercial sector 1%. Unless the proven gas reserves increase, the current reserve will be finished by 2028-2041 (Moazzem and Ali, 2019).

[18] There are also many manufacturers who require captive power generation to guarantee a high-quality power supply for their production process.

In this paper, we develop a DSGE model to analyse the significance of CPPs for the Bangladesh economy. We calibrate the model for the Bangladesh economy and run a policy option which is based on shutting down the CPPs. The steady-state results show that the country's long-run economic development would be hindered without the CPPs as the GDP would fall by 1.24%. The industrial output would also decrease by 1.54% without the presence of CPPs. On the contrary, the share of the public sector in the total electricity generation would expand by 4% when the CPPs shut down. However, household welfare decreases by 2.35% without captive power plants. The IRFs further show that the Bangladesh economy would be more vulnerable to oil price shocks when the CPPs are shut down.

Given our results, we argue that the government should not shut down the CPPs, as they are closely associated with the household welfare and the economic benefits. We also propose alternative reforms to mitigate the adverse effects of existing CPPs and energy market distortions. First, the majority of the CPPs are not efficient (Power System Master Plan, 2016) as they use inefficient production technology and there is scope for efficiency in energy use in these plants. Since Combined Cycle Gas Turbine (CCGT) generators offer efficiencies of 52-60%, all CPPs should be encouraged to use CCGT technologies which can produce electricity at average heat rate of 6,600 Btu per kWh, wherein these CPPs electricity is produced at heat rate always above 10,000 Btu/kWh. Moreover, Combined Heat and Power (CHP) systems (also called cogeneration) can be encouraged to increase the energy conversion efficiency in the industries. This system helps in cost-saving and allows CPPs to be encouraged indirectly.[19]

Second, the CPPs are overly reliant on natural gas in generating electricity. Since the reserves of natural gas in Bangladesh are at risk of depletion, the government can encourage the CPPs to

[19] CHP is the simultaneous production of electricity and heat using a single fuel, e.g., natural gas, or a variety of fuels, e.g., biogases, coal, waste gas or liquid fuels.

replace the current fuel with renewable energies (like solar or wind) or liquefied gas instead of using natural gas. Finally, a competitive market environment needs to be ensured to minimise price distortions and rationalise and rebalance gas prices for the captive generation to bring parity in power prices with grid power users.

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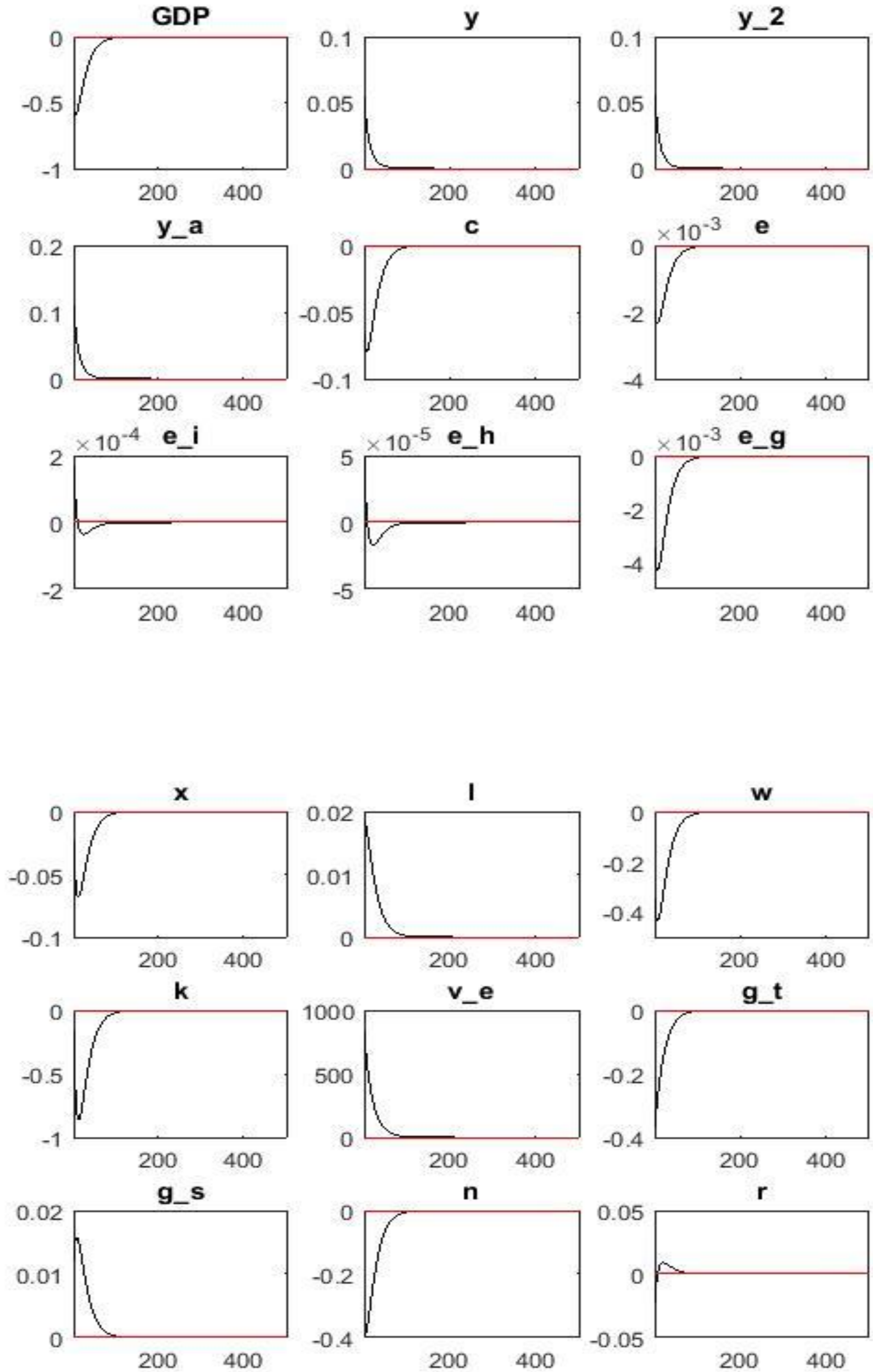
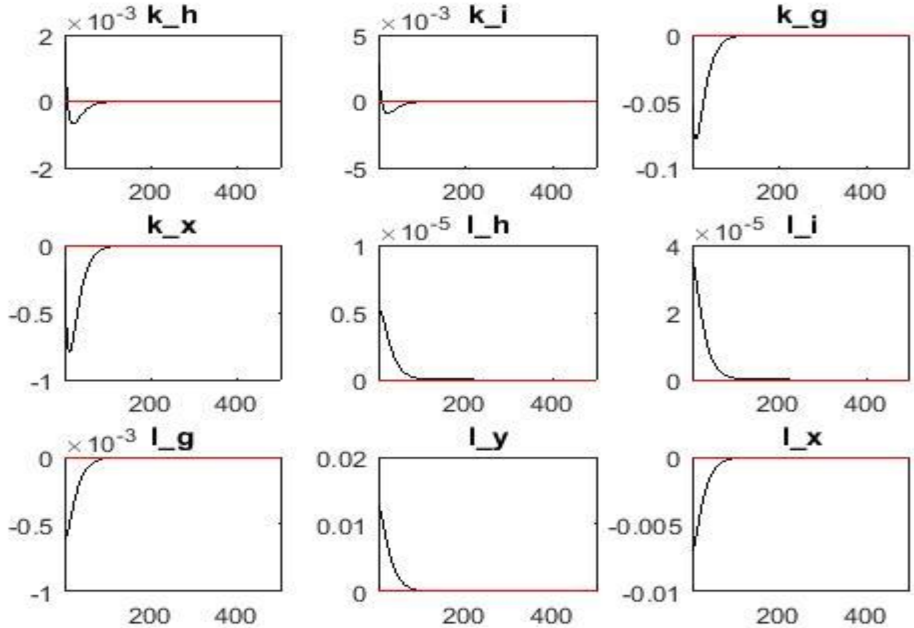
Appendix A

Figure A.1: Impulse Responses to Oil Price Shocks

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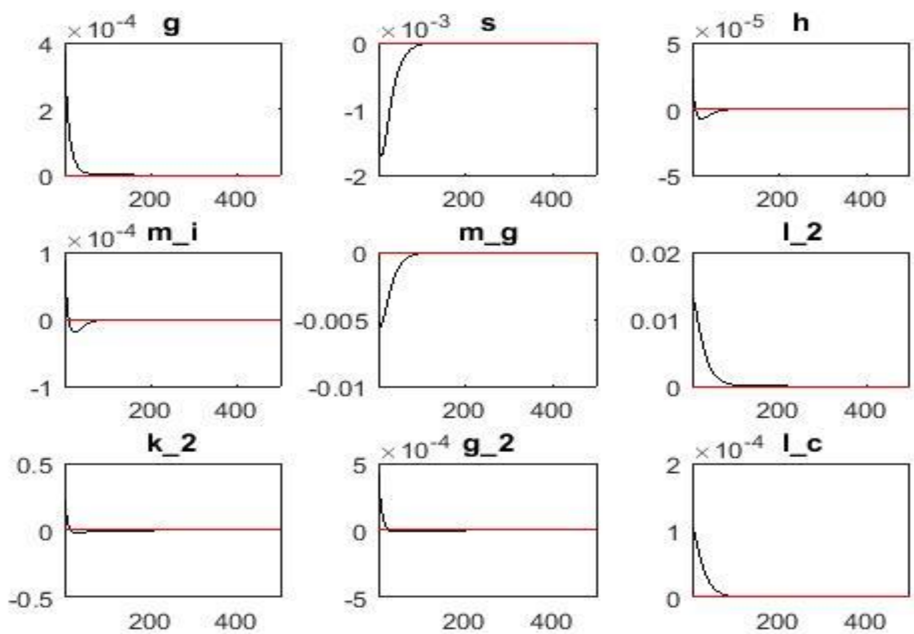
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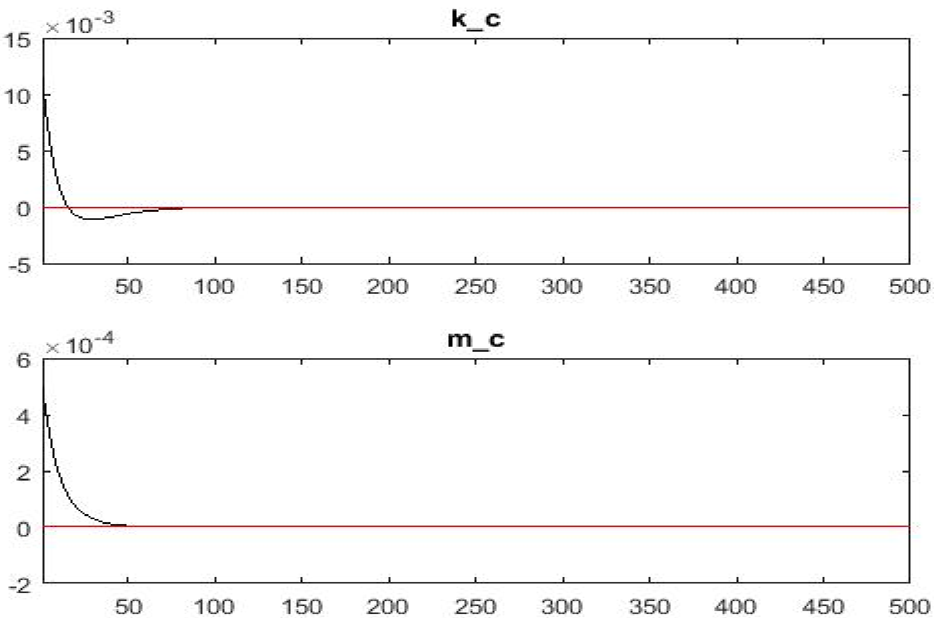
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m_c
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