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Sakib Amin
Tooraj Jamasb
Manuel Llorca
Laura Marsiliani
Thomas Renström

Department of Economics – Porcelænshaven 16A, 1. DK-2000 Frederiksberg

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Sakib Amin[*], *Tooraj Jamasb*[†], *Manuel Llorca*[‡], *Laura Marsiliani*[§], *Thomas Renström*[**]

Abstract

Electricity sectors in many emerging and developing countries are characterised by significant captive industrial generation capacity. This is mainly due to unreliable electricity supplies from state-owned utilities. Integrating the captive capacity with the on-grid supply can improve resource utilisation in the electricity market. We use a Dynamic Stochastic General Equilibrium (DSGE) model to examine the effects of allowing the Bangladeshi Captive Power Plants (CPPs) to sell their excess output to the national grid at regulated prices. We find that opening the grid to CPPs would reduce the industrial output and GDP due to energy price distortions. We also show that the Bangladeshi economy would become more vulnerable to oil price shocks when CPPs are connected to the national grid. These results support the second-best theory, which implies that granting grid access without removing other price distortions can lead to economically inefficient outcomes. We propose that the government should not open the grid to CPPs to minimise energy market distortions yet. Instead, it should first consider alternative reform measures such as taking steps to reduce price distortions and enabling a competitive market environment.

Keywords: Bangladesh, CPPs; DSGE model; Electricity generation.

JEL Classification: D58; L94; Q43; Q48.

[*] North South University, Dhaka-1229, Bangladesh; Email: sakib.amin@northsouth.edu

[†] Corresponding Author, Copenhagen School of Energy Infrastructure (CSEI), Department of Economics, Copenhagen Business School, Denmark; Email: tj.eco@cbs.dk

[‡] Copenhagen School of Energy Infrastructure (CSEI), Department of Economics, Copenhagen Business School, Denmark; Email: mll.eco@cbs.dk

[§] Durham University Business School, Mill Hill Lane, Durham DH1 3LB, United Kingdom; Email: laura.marsiliani@durham.ac.uk

[**] Durham University Business School, Mill Hill Lane, Durham DH1 3LB, United Kingdom; Email: t.i.renstrom@durham.ac.uk

1. Introduction

Captive Power Plants (CPPs) have a crucial function in many developing and transition countries as an alternative source of private electricity supply to the industrial sector (Hansen, 2008; Joseph, 2010; Nag, 2010; Shukla *et al*., 2004).[1] The relevance of the CPPs mainly arises from protecting the industries from electricity supply interruptions that can harm machineries, inventories, and boost overhead expenses. The Government of Bangladesh started issuing licenses to industrial users to set-up their CPPs in the mid-1990's due to the poor and intermittent power supply in the country. One of the primary goals of this policy was to allow the industries to generate electricity for their own uses and to sell the surplus of electricity to other consumers in the neighbouring places.[2]

CPPs quickly became a success for the Bangladesh industry and economy as the rapid industrialisation in the 1990s required expansions of the electricity supply. The national grid was deficient at the time with high transmission and distribution losses.[3] Moreover, the abundance of domestic natural gas implied that CPPs, which primarily use this fossil fuel to produce electricity, could obtain a reliable and economical energy source. Since then, the CPPs have generated approximately 10-15% of the electricity in Bangladesh throughout the last 30 years and contributed to the development of the country.[4]

In 2007 Bangladesh Ministry of Power, Energy and Mineral Resources issued policy guidelines to allow CPPs to sell their excess electricity to on-grid electricity distribution companies.[5] Nevertheless, the share of on-grid CPPs in electricity supply in Bangladesh is still very limited.

[1] A Captive Power Plant is a generation plant set up by industrial users to produce electricity mainly for own utilisation.
[2] Policy guidelines for CPPs:
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.
[3] For more details see:
https://powerdivision.portal.gov.bd/sites/default/files/files/powerdivision.portal.gov.bd/page/f6d0e100_e2d8_47e7_b7cd_e292ea6395d3/4.%20VSPSPSectorReform.pdf.
[4] There has been no recent investment in the search of natural gas reserves and hence the existing stock is predicted to become insufficient to sustain the economic growth of Bangladesh (Amin, 2015).
[5] Policy Guidelines for Power Purchase from Captive Power Plants (2007), Policy Guideline for Small Power Plant in Private Sector (1998) and Private Sector Power Generation Policy of Bangladesh (1996).

While India is strengthening the public-private network in the energy markets and encouraging third-party access to the grid including sale of excess electricity by CPPs [6], Bangladesh is yet to fully capitalise on the national policy for CPPs. Jamasb and Sen (2012) study the case of providing open access to transmission and distribution networks for third-party use in India and conclude that the implementation of the third-party access to the grid was a successful reform step in terms of enhancing electricity generation in the country.

Under the current policies, CPPs in Bangladesh do not have incentives to sell their excess electricity to the national grid for several reasons. First, the CPPs need to bear all the distribution and transmission-related charges. For example, the cost of connection to the grid (including switchgear, metering, protection, etc.) is borne by the CPPs. In the case of using the existing transmission and distribution network, the CPPs need to pay the wheeling charges fixed by the Bangladesh Energy Regulatory Commission (BERC). Second, the captive generators are subjected to customs duty, VAT, a supplementary duty at clearance stage and not receiving tax holidays or exemptions for importing electricity generation equipment. Finally, the government-regulated selling prices are not sufficiently high to ensure a profit for the CPPs.[7]

This paper aims to study the macroeconomic and welfare implications of public-private integration in the energy market in Bangladesh. Namely we use a Dynamic Stochastic General Equilibrium (DSGE) model to examine the effects of allowing the Bangladesh Captive Power Plants (CPPs) to sell their excess output to the national grid at regulated market prices.

Previous literature focuses on the reasons for proliferation of the CPPs in developing countries, mainly through case-studies on India (Hansen, 2008; Joseph, 2010; Nag, 2010; Shukla *et al*., 2004).[8] To our knowledge only one paper, Amin *et al*. (2019), is concerned with the macroeconomic and welfare effects of government policies in relato to the CPPs, namely the

[6] On India policies on CPPs see Ghosh and Kathuria (2014), Joseph (2010), Hansen (2008), Nag (2010) and Shukla et al. (2004).
[7] CPPs cannot sell their excess electricity at a price higher than the regulated price sold by the Bangladesh Power Development Board.
[8] A common story is that firms facing higher on the grid prices and blackouts, quit the grid and establish their own CPPs.

impact of the closure of CPPs in Bangladesh which is currently considered by the government.[9] The authors find that shutting down CPPs in Bangladesh can reduce the long-run industrial output and GDP, while oil price shocks would be more damaging to the economy.

The methodological framework of this paper draws extensively on Amin (2015) and Amin *et al*. (2019), who developed a DSGE model for the Bangladesh economy. This model is flexible enough to allow for both public and private electricity generation. The assumptions made, in particular the functional forms for household preferences and technology, follow those of Dhawan and Jeske (2008) and Kim and Loungani (1992) respectively. The assumptions for the specific context of Bangladesh follow those of Amin and Marsiliani (2015). The model is calibrated for the Bangladesh economy, which is as an oil importing country with CPPs as major players in electricity generation. We then simulate the policy of allowing the CPPs to be grid connected and derive results in terms of steady-state GDP, standard consumption, electricity consumption, and welfare. Our results can inform policy makers on future policies on CPPs.

The paper is organised as follows. The DSGE model is presented in Section 2. The calibration of parameters and their derivation are then described in Section 3. Section 4 shows and discusses the results of model simulations. Finally, the conclusions and some policy implications are discussed in Section 5.

2. The Benchmark DSGE Model

We present an energy-augmented Dynamic Stochastic General Equilibrium (DSGE) model for a small open economy (in the sense that world market prices are not affected), which is an extension of the model developed by Amin *et al* (2019). Below we describe the household and general production sectors, the electricity generation sector (which uses two different fuels: oil and natural gas) and the public sector.

[9] For more detail, see: https://www.dhakatribune.com/bangladesh/power-energy/2017/11/16/govt-planning-reduce-gas-supply-captive-power-plants.

2.1 The Household Sector

Households' utility is a function of aggregate consumption (C) and made up of four consumption goods: electricity (*e*), general consumption goods (*c*), service goods (*x*) and of leisure (1-l). As in Kim and Loungani (1992), the utility function for each period can be defined as:

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

where C^A is the consumption aggreagator (as in Dawhan and Jeske, 2007):

$$C_t^A = x_t^\gamma \left(\theta c_t^\rho + (1-\theta) e_t^\rho\right)^{\frac{1-\gamma}{\rho}} \qquad (2)$$

The parameters φ, θ and γ represent the relative share of c, *e*, *1-l*, and x. The utility function in Equation 1 is also used by Amin (2015) and Amin *et al*. (2019) and allows for a substitution elasticity between general consumption and electricity consumption that is smaller than one.

The household income derives from capital income ($r. k_t$), labour income ($w. l_t$), a lump sum transfer, ъ, received from the government, and dividends π. Capital and labour income are taxed at the rates $\tau^k and\ \tau^l$ respectively. Income are subjected to capital and labour taxes at the rates at the rates $\tau^k and\ \tau^l$, respectively and capital depreciate overtime at a rate δ. The price of service goods and household electricity are *n* and q^e respectively, while the price of general consumption is normalised to 1. So, the intertemporal household budget constraint is:

$$k_{t+1} + c_t + n. X_t + q_t^e. e_t = (1-\tau^l) w. l_t + ъ + (1-\tau^k) r. k_t + (1-\delta) k_t + \pi \qquad (3)$$

The Lagrangian for the household is:

$$L = \sum_{t=0}^{\infty} \beta^t [(\varphi\, log \left[X_t^\gamma \left(\theta c_t^\rho + (1-\theta) e_t^\rho\right)^{\frac{1-\gamma}{\rho}}\right]) + (1-\varphi)\, log(1-l_t)] - \lambda_t [k_{t+1} + c_t + n. X_t + q_t^e. e_t - (1-\tau^l) w. l_t - ъ - (1-\tau^k) r. k_t - (1-\delta) k_t] \qquad (4)$$

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. For all calculations see Amin (2015).

2.2 The Industrial and Service Production Sectors

Final producers are distinguished into on-grid and off-grid producers, with the off-grid producers in the benchmark model operating their own CPPs. In the benchmark model, it is assumed that the total electricity produced by the CPPs is consumed by the industry. This means that there is no excess supply of electricity to feed into the national grid.

Following Kim and Loungani (1992) and the work developed by Amin (2015), the production function of the industry and service sectors is a Constant Elasticity of Substitution (CES) technology, which exhibits Decreasing Returns to Scale (DRS) in the three inputs: labour (*l*), capital (*k*), and electricity (*g/s*).[10] The production functions for the sectors can be defined as:

$$Y_{1,t}=A_{1,t}^{Y} l_{Y1,t}^{\alpha_{,1}}[(1-\Psi_{Y1})k_{Y1,t}^{-\nu^{g,1}}+\Psi_{Y1}g_{1,t}^{-\nu^{g,1}}]^{-\frac{1-\alpha_{Y1}}{ύ^{gg,1}}} \quad (5)$$

$$Y_{2,t}=A_{2,t}^{Y} l_{Y2,t}^{\alpha_{,2}}[(1-\Psi_{Y2})k_{Y2,t}^{-\nu^{g,2}}+\Psi_{Y2}g_{2,t}^{-\nu^{g,2}}]^{-\frac{1-\alpha_{Y2}}{ύ^{gg,2}}} \quad (6)$$

$$X_{t}=A_{t}^{X} l_{X,t}^{\alpha_{X}}[(1-\Psi_{X})k_{X,t}^{-\nu^{s}}+\Psi_{X}s_{t}^{-\nu^{s}}]^{-\frac{1-\alpha_{X}}{ύ^{ss}}} \quad (7)$$

where A_t^i represents the stochastic productivity shock, the index i stands for the respective industrial (Y) or service (X) sectors, α_i represents the labour share and Ψ_i is the share of electricity in the production function. It should be noted that $ύ^{jj}$ determines the degree of homogeneity in the CES production function. We assume perfect competition and that all firms maximise profits as follows:

$$Max\ \pi_{i,t}=P^{i}.A_{t}^{i}.l_{i,t}^{\alpha_i}[(1-\Psi_i)k_{i,t}^{-\nu^j}+\Psi_i j_{i,t}^{-\nu^j}]^{-\frac{(1-\alpha_i)}{ύ^{jj}}}-r.k_{i,t}-w.l_{i,t}-\nu^{j}.j_{i,t} \quad (8)$$

[10] The DRS assumption is standard in some DSGE literature (see, e.g., Rotemberg and Woodford, 1996; Jaaskela and Nimral, 2011).

where w is the wage rate, r stands for the capital interest rate, and v represents the market price of electricity. Wage and interest rate are assumed to converge to the same value across all the sectors. The electricity consumption (*j*) of the two industrial sectors and the service sectors is denoted by g_1, g_2, and *s*, respectively. The price of the final good is normalised to 1, and, v^j is considered as the relative price of electricity.

2.3 The Energy Sector

In our model, there are four types of firms that can generate electricity: public power producers (G), independent power producers (I), captive power producers (g2) and rental power producers (R).[11] In a similar way to Amin (2015), we employ a CES production function for the electricity generators:

$$G_t = A_t^G l_{G,t}^{\alpha_G}[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}]^{-\frac{\vartheta^G}{\nu^{m,GG}}} \quad (9)$$

$$I_t = A_t^I l_{I,t}^{\alpha_I}[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}} + \Psi_I m_{I,t}^{-\nu^{m,I}}]^{-\frac{\vartheta^I}{\nu^{m,II}}} \quad (10)$$

$$g_{2,t} = A_t^C l_{C,t}^{\alpha_C}[(1-\Psi_C)k_{C,t}^{-\nu^{m,C}} + \Psi_C m_{C,t}^{-\nu^{m,C}}]^{-\frac{\vartheta^C}{\nu^{m,CC}}} \quad (11)$$

$$R_t = A_t^R l_{R,t}^{\alpha_R}[(1-\Psi_R)k_{R,t}^{-\nu^R} + \Psi_R h_t^{-\nu^R}]^{-\frac{\vartheta^R}{\nu^{H,RR}}} \quad (12)$$

The parameter ν depends on the Elasticity of Substitution (EOS) between capital and energy. Labour's share in production is given by the parameter α, and Ψ is the share of energy (natural gas, *m*, or oil, *h*) in production where $\Psi \in (0, 1)$. Accordingly, (1- Ψ) represents the share of capital in the production function.

[11] Since the mid-1990s, the government of Bangladesh fostered the entry into the electricity generation market of several Independent Power Producers (I) that were mostly using natural gas. On the other hand, in 2009-2010, the government introduced the Rental (R) power plants as a short term solution to mitigate the decade-long energy crisis associated with shortage of electricity supply. Apart from these rentals and independent power producers, we also consider the public power producer (G) and the CPPs (g). These 4 types of electricity generating firms produce nearly 100% electricity in Bangladesh.

Additionally, we are also interested in analysing whether connecting the CPPs to the grid affects the vulnerability of the Bangladesh economy from oil price shocks.[12] As in Amin and Marsiliani (20015), the stochastic oil price shock is assumed to be:

$$\text{Oil Price Shock: } ln\, v_t^e = {}'\Omega^v + \omega ln v_{t-1}^e + \eta_t^O \tag{13}$$

where $'\Omega^v$ represents the coefficients in the shock equation. The residual (η_t^O) are normally distributed with a standard deviation of one and zero mean.

2.4 The Public Sector

In the model, the government produces electricity and provide lump-sum benefits to the households. Government revenue derives from taxing labour income ($\tau^l. w. l_t$), capital income ($\tau^k. r. k_t$), selling natural gas to firms that generate electricity$\left((v^m - \delta^C)(m_{I,t} + m_{G,t})\right)$, and also selling electricity to the national grid ($P^G. G_t$). The government uses its revenue to pay for labour ($w. l_{G,t}$), capital ($r. k_{G,t}$) and natural gas ($v^m. m_{G,t}$) used for its electricity production and provides a lump sum transfer to households (ъ). The government fixes natural gas price at v^m which is below the cost of its extraction (shadow price) (δ^C). In absence of this extraction cost, there will be overconsumption of the natural gas due to under-pricing of this scarce natural resource.

The government's objective is to minimise its cost:

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

The government, in effect, provides a subsidy as it purchases electricity from electricity producers at a high price and then sells it at a lower price to the consumers. The total subsidy can be computed as follows:

[12] A common practice in DSGE models is to consider the random shocks (such as technological change or fluctuations in oil prices) that can affect the economy (Amin, 2015).

$$b = P^G.G_t + P^I.I_t + P^R.R_t - q^e.e_t - q^s.s_t - q^{g_1}.g_t \tag{15}$$

where q^S and q^{g_1} are the electricity prices for service and industrial sectors, and p^G is the price at which the government sells the electricity. It is worth noting that q^{g_2} is the efficient price from the point of view of industry 2, ensuring production efficiency in CPPs. Moreover, since these prices are regulated (and hence not market prices), the market may not clear. Therefore, the government is the residual producer and supply electricity to clear the market.

The government budget constraint can be described as:

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

Finally, combining both household and government budget constraints, along with the subsidy equation, the economy-wide resource constraint can be derived.[13]

$$k_{t+1} = Y_{A,t} - c_t + (1-\delta)k_t - \delta^C\left(m_{I,t} + m_{G,t} + m_{C,t}\right) \tag{17}$$

2.5 Equilibrium Conditions

The equilibrium in the labour, capital, and electricity markets can be expressed as follows:

$$l = l_H + l_I + l_G + l_Y + l_X + l_2 + l_C \tag{18}$$
$$k = k_H + k_I + k_G + k_Y + k_X + k_2 + k_C \tag{19}$$
$$e_t + s_t + g_t + g_{2,t} = \left(G_t + I_t + g_{2,t} + R_t\right) \tag{20}$$

2.6. The Captive-Grid Augmented DSGE Model

In this section, we relax the assumption that electricity generated by CPPs is entirely consumed by the owner of the CPPs (sector 2 in our model), and allow the captive power producers to sell

[13] $Y_{A,t} = Y_{1,t} + Y_{2,t}$

surplus electricity (g_g) to the national grid. Therefore, the industrial sector 2 own consumption of electricity is ($g_2 - g_g$) and its production function (Equation 6) is augmented as follows:

$$Y_{2,t} = A^{Y}_{2,t} l^{\alpha,2}_{Y2,t} [(1 - \Psi_{Y2}) k^{-\nu^{g,2}}_{Y2,t} + \Psi_{Y2} (g_2 - g_g)^{\nu^{g,2}}]^{-\frac{1-\alpha_{Y2}}{\vartheta^{g,2}}} \tag{21}$$

The new profit function for industry 2 and the new equilibrium in the electricity market are as follows:

$$\pi_Y = P^Y . A^Y_t l^{\alpha_Y}_{2,t} \left[(1 - \Psi_Y) k^{-\nu^g}_{2,t} + \Psi_Y g_2^{-\nu^g}\right]^{-\frac{\vartheta^Y}{\vartheta^{g}g}} - r\left(k_c + k_{2)} - w(l_c + l_2\right)$$

$$-v^m . m_{C,t} + q^g . g_g \tag{22}$$

$$e_t + s_t + g_t + g_{2,t} = \left(G_t + I_t + +R_t + g_g\right) \tag{23}$$

This framework will allow us to examine the impact on economic welfare of integrating the CPPs into the national grid in the Bangladesh energy sector. Therefore, welfare changes can be computed as $\frac{\hat{c} - c_1}{c_1}$, where:

$$\hat{c} = (c_2^{\rho} + \frac{1-\theta}{\theta} e_2^{\rho})(\frac{X_2}{X_1})^{\gamma \frac{\rho}{1-\gamma}} . (\frac{1-l_2}{1-l_1})^{\frac{1-\varphi}{\varphi} . \frac{\rho}{1-\gamma}} - \frac{1-\theta}{\theta} e_1^{\rho} \tag{24}$$

$\hat{c}$represents the changes of household standard consumption when the CPPs are grid-connected. See Appendix B for more details.

3. Parameter Specification, Calibration and Data

Our calibration follows Amin and Marsiliani (2015) and Amin *et al*. (2019)**.**[14] To determine our parameters we use the standard DSGE literature, the steady state conditions of the model and the available data sources[15]. For the variables of interest, we use values for the years 2012-2013, the latest data available for most of the variables included in the model. Due to data restrictions, all

[14] Calibration has become a standard tool in dynamic modelling as it can serve as the basis for further methodological development (Cooley, 1997; Kydland and Prescott, 1982).
[15] For more detail about the data set, see: Amin, 2015. The macroeconomics of energy price shocks and electricity market reforms: the case of Bangladesh. Ph.D. thesis. Durham University.

the parameters in our model are calibrated for annual frequency. Overall, our numerical model includes 74 of which 42 are structural parameters, 21 shock-related parameters, and 11 policy-related parameters. Below we describe our derivations for all parameters.

3.1 Preference Parameters

Following the standard DSGE literature (see, e.g., Heer and Mausser, 2009) the discount factor, β, is set to 0.96. Regarding the utility function, we use several approaches to derive relevant parameters. Given the value of q^e, ρ, and the ratio $\frac{e}{c}$ calculated from data and using the first order conditions from the households problem, we compute θ equals to 0.91. Following Amin (2015), we set the EOS at 0.9, and therefore the CES parameter of the household's utility function, ρ, is equal to -0.11, indicating complementary of general consumption and electricity consumption. Due to the absence of good quality data for working hours for Bangladesh, we set l = 0.33, which implies that people work about one-third of their time endowment (Ghez and Becker, 1975).

Given the ratio $\frac{nX}{c}$, q^e, ρ and θ, the share of services consumption in the consumption aggregator, γ is computed as 0.81 using equation 32:

$$\frac{c_t}{nX_t} = \frac{1-\gamma}{\gamma} \cdot \frac{1}{1+\left(\frac{\theta}{1-\theta}\right)^{\frac{1}{\rho-1}} (q_t^e)^{\frac{\rho}{\rho-1}}} \qquad (25)$$

Similarly, the share of electricity consumption and general consumption in the household's utility function φ is calculated 0.60 from the following equation:

$$\frac{(1-\varphi)}{\varphi} = \frac{(1-\gamma).\theta.(1-l_t).\frac{wl}{Y}.\frac{\left(1-\tau^l\right)}{l}.\frac{Y}{c}}{\theta+(1-\theta)\left(\frac{e_t}{c_t}\right)^p} \qquad (26)$$

3.2 Production Parameters

As in Roberts and Fagernas (2004) and Amin *et al.* (2019) we set the labour shares in the industrial sectors, $\alpha_{Y,1}$ and $\alpha_{Y,2}$, equal to 0.2. The labour shares in the service sector, α_X, is equal to 0.313

and is computed using the first-order conditions and the subsequent ratios: $\frac{wl_X}{wl}$; $\frac{nX}{Y}$ and $\frac{\omega 1}{y}$. Given the value of total labour cost ($w.l_{i,}$) and total revenue ($p^i.i$) for each sector, the labour share of the three distinct electricity generating sectors are: α_I = 0.036, α_C = 0.036 and $\alpha_R = 0.004$.

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 obtain that the value of $\psi_{Y,1}$ and $\psi_{Y,2}$ is equal to 0.0733. In a similar way, we also find that Ψ_X = 0.0790. Finally we find Ψ_I and Ψ_C equal to 0.3093 and Ψ_H = 0.5964, using the value of total revenue ($p^i.i$), total labour cost ($w.l_i$) and total cost of sales ($v^m.m_i$) in each sector.

Using the first-order conditions and the values of the appropriate parameters and variables, we find that Ψ_G is equal to 0.3020 and α_G is equal to 0.0420 for the governmental electricity generating sector.

$$v^m.\alpha_G\left[(1-\Psi_G)k_{G,t}^{-\nu^m} + \Psi_G.m_{G,t}^{-\nu^m}\right] = \left(\vartheta^G \frac{\nu^{m,G}}{\acute{\upsilon}^{m,GG}}\right).\Psi_G.m_{G,t}^{-\nu^m-1}.l_G.w \qquad (27)$$

$$r.\Psi_G.m_{G,t}^{-\nu^m-1} = (1-\Psi_G)k_{G,t}^{-\nu^m-1}.v^m \qquad (28)$$

We assume $\nu^h, \nu^{m.i}, \nu^{m,g}, \nu^Y$, and ν^X *to be* equal to 0.1 and $\acute{\upsilon}^{hh}, \acute{\upsilon}^{m.ii}, \acute{\upsilon}^{m,gg}, \acute{\upsilon}^{YY}$, and $\acute{\upsilon}^{XX}$ to be equal to 0.2. following Amin (2015) and Amin *et al*. (2019). Finally, the depreciation rate (δ) has been set at 0.025, which implies that the overall depreciation rate in Bangladesh is 2.5% annually. This value is consistent with other analyses on developing economies (Tanzi and Zee, 2001; Yisheng, 2006).

3.3 Remaining Parameters

The remaining parameters of the model are either taken from Bangladesh data or the specialised literature. Capital and labour income tax rates τ^k and τ^l are set as 0.15 and 0.10 as from Amin (2015). The selling price of electricity by the Bangladesh Power Development Board (BPDB) (p^G) is calibrated as 2.30 to clear the electricity market.

All other energy prices are presented in Table 1 and Table 2. These have been collected from the annual reports of BPDB, Summit Power International, and the Dutch Bangla Power Associates. The selling price of electricity by BPDB (P^G) is equal to 2.30 using data from the country.

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

Due to lack of data for the Bangladesh economy, the persistence of oil price shock is set equal to 0.95 and the standard deviation of the shock equal to 0.01 (Amin and Marsiliani, 2015).

4. Results and Discussion

The steady state results show that when CPPs are connected to the grid, the overall electricity consumption is scaled back due to the prevailing inefficiency in the electricity market. This inefficiency arises from the distorted energy prices in the market due to government-regulated prices. The CPPs have potential to supply 3.3% of the total electricity generated to the national grid. However, due to the inefficiency, opening up the grid would reduce the steady state consumption by 1%, aggregate industrial output by 1.4% and the GDP by 1%.[16]

We also find that when the CPPs sell electricity to the grid, the captive-operated industries produce more efficiently than the industries that consume electricity from the national grid. Since the CPPs-operated industries are getting the electricity at efficient prices compared to the non-captive operated industries, more resources are allocated to those industries. Consumption of natural gas also increase by 1.7% under this experiment. Therefore, under distorted prices, connecting the CPPs to the grid would not provide economic benefits to the country.

Since Bangladesh is a small oil importing country, it is relevant to analyse the impacts of oil price shocks on the economy. This is studied by looking at how the model variables are affected through the Impulse Response Functions (IRFs) after an international oil price increase. This experiment reveals that a rise in the world oil price (v_e) implies higher import price, which makes the country worse off with regard to Terms of Trade (TOT). Higher oil price also makes consumption costlier and thus reduces standard consumption (c), electricity consumption (e), and service consumption (X) through the income effect. Furthermore, since taxes and other prices are constant, higher oil price makes the government worse off and reduces government transfer (g_t). Lower government transfer (g_t) increases labour supply (l) through the income effect, which in turn lowers the household wages (w).

Industrial production (y_a) increases because oil imports now more expensive, and the sector needs to produce more exportable goods to keep the trade balance unchanged. Government subsidy increases as the cost of energy become high, and the other prices are not adjusted. Since all types of consumption and capital decrease, economic output also falls (Figure A.1 in the Appendix).

When the CPPs are connected to the gird, the behaviour of the IRFs for the variables affected by an oil price shock is very similar. However, the difference is that the magnitude of the changes is

[16] Although the CPPs need to sell the excess electricity to the national grid at a lower price, the end tariff of the industrial consumers is higher reducing their competitiveness compared to the industries who own CPPs. The CPP owned industries can internalise their shadow prices from the revenues of exporting RMGs.

greater in the experiment, which implies that the country is prone to experience higher deviations from the steady-state situation when the captives are grid-connected.

5. Conclusions and Policy Discussion

In 2018, the World Bank defined Bangladesh (a country heavily based on industry, and mainly on the garment products especially for export) as a lower middle-income country (Amin and Rahman, 2019). Currently, Bangladesh looks forward to a sustained economic growth to become a high-income country by 2041. Until now, captive power plants have played an important role for the country's development by providing uninterrupted electricity supply to industry. Captive power plants can increase productivity in the off-grid regions and reduce the need for distribution companies to make expensive investments to extend the grid to remote locations. To attain energy security and to lessen the pressure of the public generators, one of the future possible options for Bangladesh is to encourage the already installed CPPs to sell their electricity to the national grid, following the experience of neighbouring countries like India.

This paper presents a fit-for-purpose Dynamic Stochastic General Equilibrium framework to simulate the policy of connecting the CPPs to the national grid. The model is calibrated for the Bangladeshi economy and derive results in terms of GDP, household consumptions, electricity consumptions and welfare. The steady state results of our model show that the country's long run economic development would be hampered when the CPPs are grid-connected.

Since the regulated prices on the grid do not reflect the true cost, opening up the grid for the CPPs will imply that their electricity production decision is distorted. The overall effect is a reduction household electricity consumption by 1.1%, industrial output by 1.4% and GDP by 1%, at the steady state, though the CPPs increase their electricity supply by 3.3%.

The IRFs further show that the Bangladesh economy would be more affected by oil price shocks when the CPPs are connected to the grid. As the prices of the grid are sub optimal, a distortion is created when CPPs are producing at those prices. The economic variables will be more sensitive under a greater distortion to exogenous fluctuations.

Our results find support for the theory of second best in regulation and government policy. The importance of this theory is widely recognised, but very few realise the importance of applying the concept to the rationale for regulation and government involvement in the development of the energy sector. Morriss (1998) argues that second best policies can make a sub-optimal situation worse. We stress the fact that although many economists argue in favour of designing government policy leading to welfare improvement, in practice, the incidence of second best theorem requires attention to the interaction between inefficiencies in the sector and the economy.

Given our results, we recommend that to maximise Bangladesh macroeconomic performance and household welfare, the government should not be opening up the grid to the CPPs without correcting the existing energy price distortions first. We suggest alternative reforms to alleviate the negative impacts of connecting the existing CPPs to the grid and reduce the distortions in the energy market. For instance, a competitive market environment can be guaranteed to minimise the price distortions and to strengthening the public-private network.

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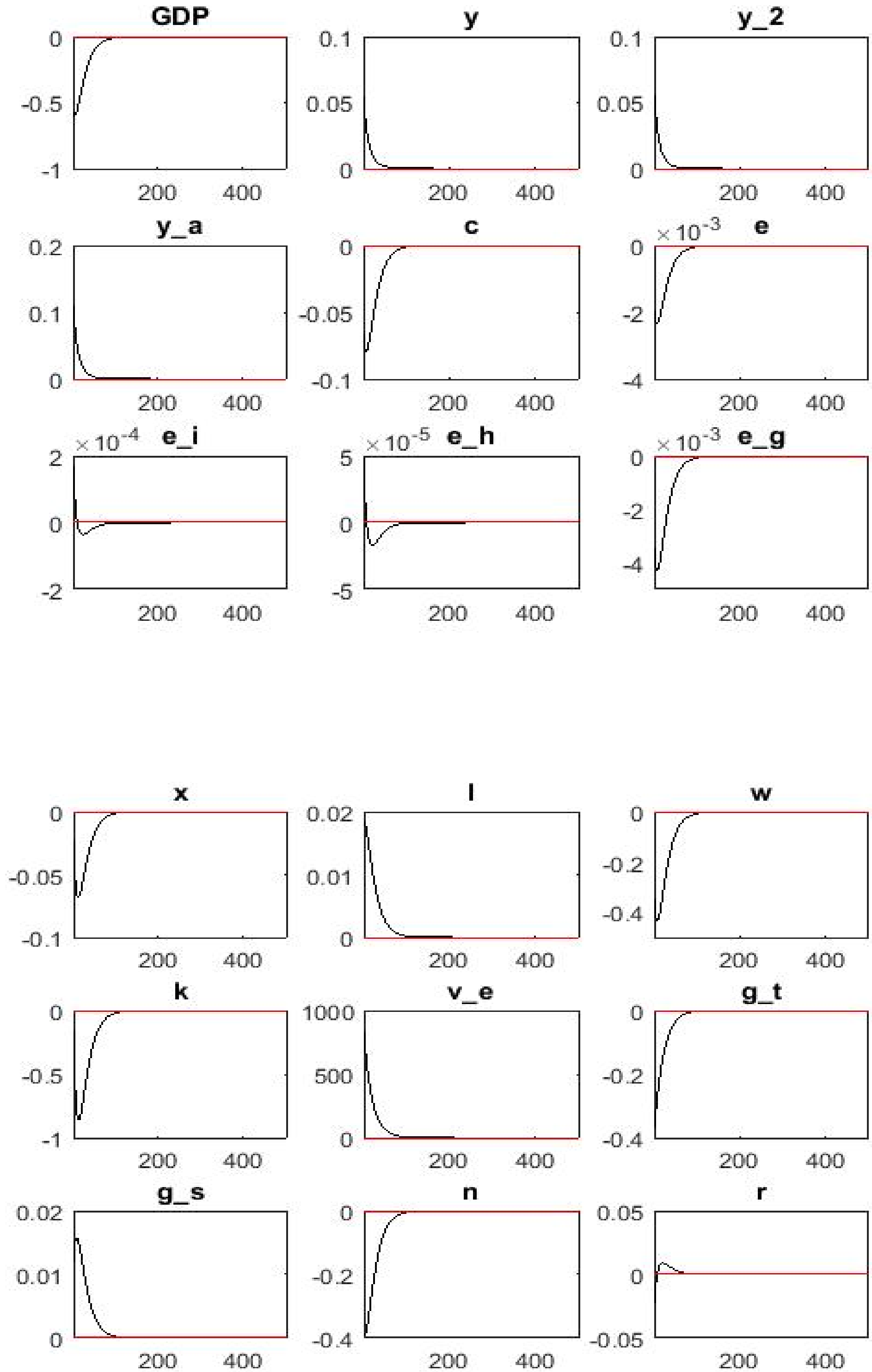
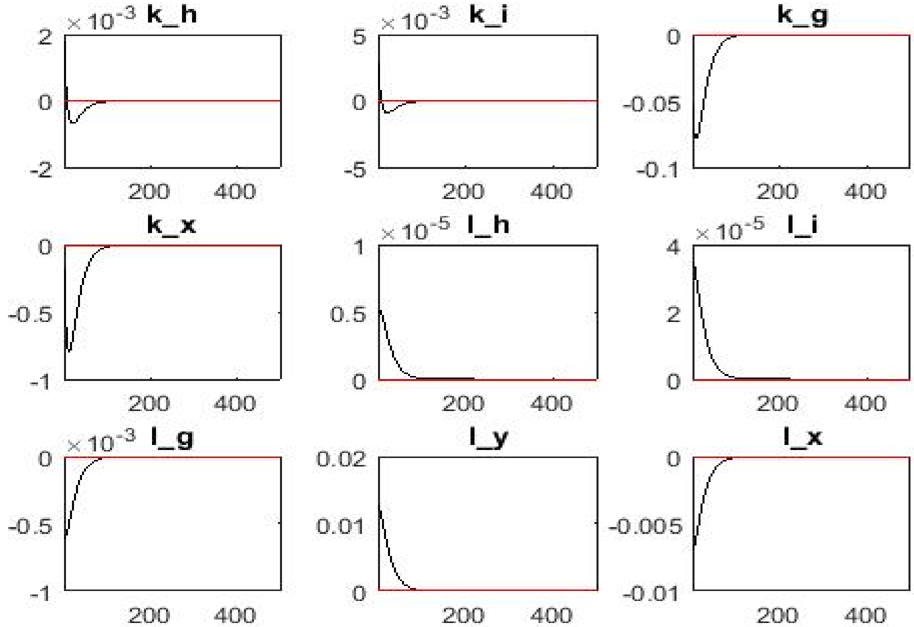
Appendix A

Figure A. 1: Impulse Responses to Oil Price Shocks





k_h
k_i
k_g
k_x
l_h
l_i
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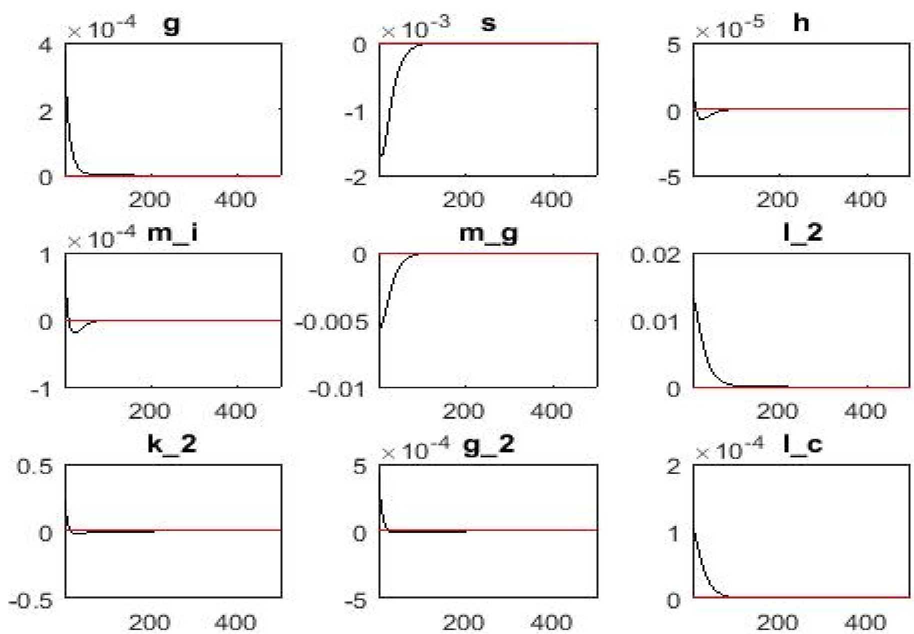
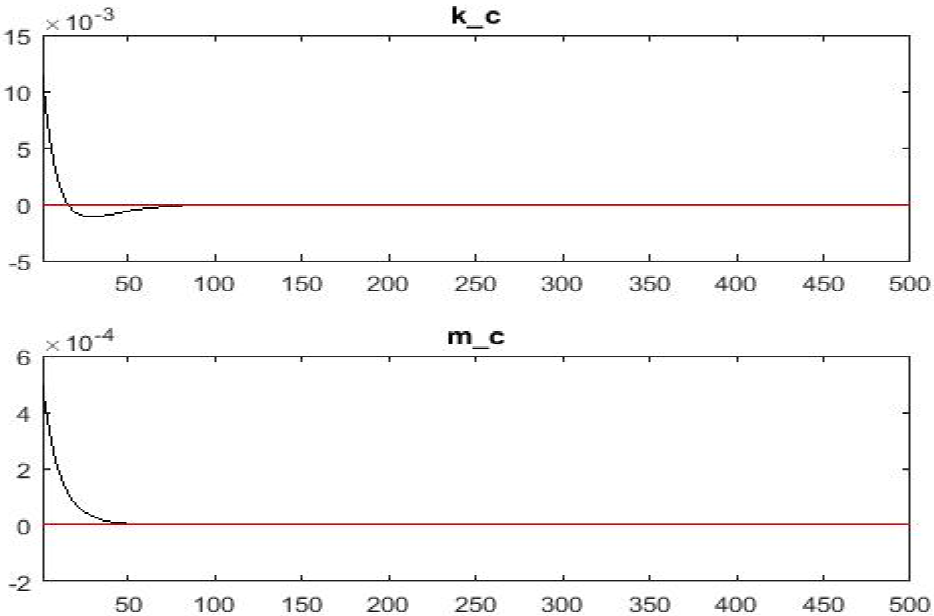
l_y
l_x



g
s
h
m_i
m_g
l_2
k_2
g_2
l_c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×10^-3
15
10
5
0
-5
50 100 150 200 250 300 350 400 450 500
m_c
×10^-4
6
4
2
0
-2
50 100 150 200 250 300 350 400 450 500

Appendix B

The formula of welfare equation is derived from the utility function as follows. If c_1, e_1, X_1 and l_1 are the steady state values in the benchmark model, the value of the utility for the economy, U_1, can be obtained as follows:

$$U_1 = X_1^{\gamma}\left(\theta c_1^{\rho} + (1-\theta)e_1^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_1]^{1-\varphi}$$

Similarly, if c_2, e_2, X_2 and l_2 represent new steady state values for an alternative experiment, the utility of consumers, U_2, can be computed as:

$$U_2 = X_2^{\gamma}\left(\theta c_2^{\rho} + (1-\theta)e_2^{\rho}\right)^{\frac{1-\gamma}{\rho}}]^{\varphi}[1-l_2]^{1-\varphi}$$

In principle, 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 the previous set of steady state variables except for the value of consumption, which 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, $\hat{c}=(c_2^{\rho}+\frac{1-\theta}{\theta}e_2^{\rho})(\frac{X_2}{X_1})^{\gamma\frac{\rho}{1-\gamma}}(\frac{1-l_2}{1-l_1})^{\frac{1-\varphi}{\varphi}\cdot\frac{\rho}{1-\gamma}} - \frac{1-\theta}{\theta}e_1^{\rho}$