Captive Power, Market Access and Macroeconomic Performance: Reforming the Bangladesh Electricity Sector

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Abstract

Integrating the captive capacity with the on-grid supply has been advocated as a way to improve resource utilisation in the electricity market in developing and emerging countries. Despite many countries granting Captive Power Plants (CPPs) access to the grid, integration may still be hindered by other barriers to entry. In Bangladesh, CPPs are required to sell their electricity surplus, but there is no evidence of trading with the national grid, mostly due to high connectivity costs. In this paper we develop and estimate a fit-for purpose Dynamic Stochastic General Equilibrium (DSGE) model to examine the effects of the Bangladeshi CPPs connecting to the national grid and selling their surplus at regulated prices. The model parameters are set through a combination of calibration and Bayesian estimation. We find that if CPPs are connected to the national grid, steady-state industrial output, GDP, and household consumption decrease due to pre-existing energy price distortions. These results support the second-best theory, which implies that merely connecting the CPPs to the national grid without firstly removing market distortions can lead to economically inefficient outcomes. Instead, government should first consider alternative reforms such as phasing out subsidised tariffs and enabling a competitive market environment.

Keywords: Bangladesh; CPPs; DSGE model; electricity generation.

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1. Introduction

Captive Power Plants (CPPs) generate in-house electricity for privately owned industries and are widespread in many developing and transition economies (Amin et al., 2019). They have a crucial function in providing privately sourced electricity to the industrial sector as a back-up against national grid power blackouts**.** The Bangladesh government started issuing licenses to industrial users to set up their CPPs in the mid-1990s to enable private industries to play a vital role for the country's development. Since 2010, the CPPs have generated around 10-15 percent of total electricity produced in Bangladesh and lessened the dependency on the national grid (Amin et al, 2020). According to the Bangladesh Energy Regulatory Commission (BERC), there are currently 799 captive power plants of more than 1 megawatts hour (MWh) production capacity and their cumulative generation capacity is 3,184 megawatts (MW).[1] Moreover, 2,502 smaller CPPs of up to 1 MWh production capacity are in operation and their accumulated power generation capacity is 1,302 MW (Bangladesh Energy Regulatory Commission, 2020).

Despite the government requiring the CPPs to sell their surplus to the national grid, in practice there is no evidence of any trading happening with the national grid, the main reason being the high connectivity costs to access the grid.[2] An important research question is therefore whether effectively integrating CPPs into the national grid (private-public integration) can improve resource utilization and benefit the Bangladesh economy. Previous literature mostly focuses on the reasons for the proliferation of the CPPs in developing countries, mainly through case studies, particularly on India (Shukla et al., 2004; Hansen, 2008; Nag, 2010 and Joseph, 2010; Jamasb and Sen, 2012).[3] The overall consensus from these studies is that governments should promote integration. To our knowledge, only one paper, Amin et al. (2019), is concerned with the macroeconomic effects of government policies towards CPPs, namely the impact of the closure of CPPs in Bangladesh, which is currently considered by the government. The authors find that due

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[1] For more details, see: http://www.berc.org.bd/sites/default/files/files/berc.portal.gov.bd/annual_reports/b02cf4c0_f55b_4a9a_8f58_eff25be80ce4/2021-04-26-04-40-7b86ad6519b8d2fe61987c6e30bc1589.pdf

[2] See: https://berc.portal.gov.bd/sites/default/files/files/berc.portal.gov.bd/page/d0035b95_d2f1_4dd8_bf09_d88e82759c31/Order%20No.%202%20of%202019.pdf

[3] Typically firms facing higher grid prices and blackouts quit the grid and establish their own CPPs.

to pre-existing price distortions, closing down the CPPs can reduce long-run industrial output and GDP, while oil price shocks would be more damaging to the economy.

This paper uses the fit-for-purpose DSGE model of CPPs developed by Amin et al. (2019) to focus on the macroeconomic effects of integrating CPPs into the national grid in Bangladesh. Our approach builds on the literature on energy augmented DSGE models, deployed since the early 1990s (e.g., Kim and Loungani, 1992; Rotemberg and Woodford, 1996; Finn, 2000; De Miguel et al., 2003 and 2005; Dhawan and Jeske, 2008; Millard, 2011; Tan, 2012; Aminu 2018 and 2019, Aminu et al., 2018, Balke and Brown, 2018, among others). Our model is able to capture the main features of the Bangladesh economy. We strike a balance on having a tractable and transparent model and enough disaggregation for policy analysis. We allow for three economic sectors, namely service, industry, and electricity producers,[4] and, in turn, for four types of electricity producers, namely public power generators, independent power producers (IPPs), quick rental power plants (QRs), and captive power plants (CPPs). In addition, we include a regulated electricity price schedule consistent with the BERC's tariff structure. We seek to model the situation where connection to the grid by CPPs is prohibitively costly (at firm level), in order to address the evidence that despite being licensed to do so, CPPs in Bangladesh do not trade their surplus with the national grid.[5] We do this by modelling the CPPs as not being grid-connected in the benchmark model. We then perform a policy experiment where the CPPs are grid connected and compare the steady states of the two model economies.

In order to fit the model to Bangladesh data, we calibrate and estimate the model parameters and report their priors and posterior distributions. Taking the calibrated and estimated parameters of the model, we next explore what the equilibrium would be if CPPs were grid connected. If large enough productivity gains arise from connecting the CPPs to the grid, then the government could subsidize the (sunk lump-sum cost) of connecting the CPPs. Since our findings show that productivity gains are negative, it is clear that it would not be desirable to subsidize a grid connection. The reason is that the regulated price schedule causes inefficiencies, and helping the CPPs to connect to the grid would exacerbate the existing distortions (the CPPs would trade at distorted prices).

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[4] As we wish to focus on Bangladesh electricity policy, we model sectors that are intensive in using electricity.

[5] On this, see Section 2 in this paper.

We finally investigate the economic responses to technology shocks and oil price shocks for the two economies (grid and non-grid connected CPPs). We investigate the cases of stationary-oil price shocks, with autocorrelation of 0.95, and near-non stationary shocks, with autocorrelation of 0.999. The estimated parameters in the two cases are nearly identical. We run simulations (allowing for all shocks simultaneously) for both cases and compare the moments of the model to the moments of the data. We find that the stochastic properties of the model fit the data well. We also produce a variance decomposition, showing that most variation comes from the productivity shocks.

Our results reveal that connecting the CPPs to the grid will reduce the household electricity consumption by 1.74 percent, industrial output by 1 percent and GDP by 1.2 percent at the steady state due to the distorted energy prices and the associated inefficiency. The Impulse Response Functions (IRFs) show that Bangladesh economy does not respond differently to stationary oil price shocks in the non-grid connected model. However, for near non-stationary oil prices, there is ~~more~~ persistence in the economic response in the grid connected model (the effects of the shock last longer).

The main conclusions of our paper are twofold. Firstly, we show that existing market distortions need to be rigorously incorporated when assessing energy market policies in developing and emerging economies. In the case of our policy experiment, integrating CPPs into the national grid in Bangladesh has a detrimental impact on the economy due to pre-existing price distortions, despite anecdotal evidence pointing to the contrary. This leads us to our second major conclusive point, that governments and regulators in those countries, should first solve the underlining market distortions before implementing any structural policy. In the particular case of the CPPs in Bangladesh, the government should not enforce CPPs to integrate to the grid before introducing market mechanisms in the electricity sector.

The remaining of the paper is structured as follows. In Section 2 we present some stylized facts on the role of CPPs on the Bangladesh economy. Section 3 describes the DSGE model and Section 4 is concerned with the estimation process. The model results are discussed in Section 5. Finally, Section 6 concludes the paper.

2. The role of CPPs in the Bangladesh Economy: Opportunities and Challenges

The emerging of CPPs in the Bangladesh electricity sector was due to a significant structural change beginning in the mid-1990s. Until then, Bangladesh was mainly an agrarian economy. In the 1970s and 1980s the agricultural sector accounted for 55.30 percent and 32.20 percent of GDP respectively, decreasing to 26.57 percent in the 1990s and 17.34 percent in the 2000s. Since 1998, the GDP share of the industrial sector has exceeded the agriculture sector's share. At the same time Bangladesh has exhibited a dramatic shift in its export composition. The GDP share of the so-called traditional exports (such as raw jute and jute goods, tea, leather, frozen fish) has fallen from more than 75 percent to about 10 percent. In 2018-19 exports were worth 40.5 billion USD with the apparel industry being the leading contributor. In the period 1990-2019, the export earnings from apparels expanded from less than one billion to 34.1 billion USD, with an annual average growth rate of over 15 percent, against 6.5 percent growth rates for non-apparels. In the process, apparels, popularly known as readymade garments (RMGs), emerged as the flagship export product of Bangladesh, and singlehandedly shaped its structural transformation.

As the importance of the industrial sector increased, so was the role of the CPPs in the Bangladesh economy as, throughout this structural transformation, access to adequate electricity has been one of the major constraints faced by industries. The national grid was and still is prone to transmission and distribution (T&D) losses and blackouts.[6] Moreover, the then abundance of domestic natural gas implied that CPPs, which primarily use this fossil fuel, could get a reliable and economical domestic source of energy.[7] Many industries therefore viewed CPPs as an attractive off-grid option to generate their own electricity and increase their competitiveness. Accordingly, CPPs quickly became a success story for the Bangladesh industry. Other potential benefits of CPPs are that they can increase productivity in the off-grid region and reduce the need for distribution companies to make expensive investments to extend the grid to remote locations.[8] Despite recent improvements, electrification in rural areas remains a challenge in Bangladesh due to the high costs of providing grid connections and to infrastructural bottlenecks. In 2018, 78

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[6] 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

[7] 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

[8] For more details, see: http://www.berc.org.bd/site/view/policies/Policies.

percent of the rural population had access to electricity under grid coverage compared with 87.59 percent in the overall South Asia Region and 80.60 percent in lower middle-income countries. Therefore, there is scope for the CPPs to play a major role in overcoming the problem of access to electricity in remote areas and in doing so mitigating the issues resulted from the government's massive investments in power generation during the last decade at the expense of upgrading the power distribution system.[9]

Currently CPPs are regulated by BERC. Table 1 below reports the current regulatory requirements for CPPs (Bangladesh CPPs Policy Criteria). One interesting feature is that the government requires the CPPs to trade their surplus electricity at current tariffs with the distribution companies under the BERC Act 24 (1) and 24 (2)[10] to reduce the gap between demand and supply of electricity, especially in peak periods,[11] as well as to utilize energy resources optimally.[12] Despite this provision, according to the BERC (2019), only a few big companies sell their CPPs' surplus electricity to the Bangladesh Rural Electrification Board (BERB)[13] and there is no evidence of companies selling to the Bangladesh Power Development Board (the national grid).[14]

Table 1: Overview of the Bangladesh CPPs Policy Criteria

Criterion	Description
1	CPPs have to sell their excess electricity in accordance with the BERC tariff criteria
2	CPPs need to obey all the laws of Bangladesh, including environmental standards
3	CPPs' owners have to obtain statutory clearance of their own accord
4	CPPs' owners need to obtain synchronization permission beforehand
5	The purchase tariff should not exceed that at which the Bangladesh Power Development Board (BPDB) sells electricity (excluding wheeling charges)
6	The BERC may change the purchase tariff in the event of fuel price changes
7	Electricity purchasers have the option to buy electricity from CPPs either in peak or in off-peak hours. The BERC permits the period of supply
8	CPPs should bear the costs of interconnection (synchronization) networks and equipment

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[9] For more details, see: https://tbsnews.net/bangladesh/energy/low-quality-surplus-power-makes-industries-rely-captive-power.

[10] For more details, see: https://berc.portal.gov.bd/site/view/policies/Policies.

[11] The peak period refers to 17:00 to 23:00 every day according to Bangladesh's CPP policy of 2007.

[12] To sell electricity, CPPs need to purchase a license from the BERC.

[13] Established in 1977 under a government ordinance, the Rural Electrification Board is responsible for electrification of rural areas in Bangladesh. For more details, see: https://mpemr.gov.bd/power/details/33;

[14] For more details, see: https://sari-energy.org/oldsite/PageFiles/What_We_Do/activities/sariei_conference_website_october-2013/5th_October_2013/Session-IV/MRMANZ-2.pdf.

9	CPPs' owners have to pay the transmission wheeling charges, which the BERC pre-fixes
10	CPPs must maintain the voltage condition all the time. They must be able to handle abnormal fluctuations that can hamper the grid lines
11	There are no tax/VAT incentives for purchasing CPP-related machinery
12	CPPs have to take the necessary measures to control inadvertent power flow
13	No banking of energy is permissible
14	CPPs' owners should carry out metering arrangements
15	CPPs' owners have to install all the protection measures at the delivery point
16	The BERC will provide all types of assistance. The BERC will also have the regulatory power to resolve any disputes

Source: Ministry of Power, Energy and Mineral Resources (2007).[15]

The existing policy framework, however, contains no incentives for CPPs' owners to sell their excess electricity, effectively discouraging this sale. Indeed, CPPs need to bear all the T&D-related costs and the CPPs' owners must carry out the grid synchronization as well as being responsible for any damage to the grid system. Besides, there is no scope for the banking of energy in Bangladesh and CPPs can only supply electricity during peak hours, (unless they obtain a special permission to supply in the off-peak period if necessary). Finally, the government-regulated electricity prices prevent CPPs' sales to be profitable. [16,17]

Several countries, such as India, Uganda, Nigeria, and Saudi Arabia support the integration of CPPs with the national grid by providing incentives for CPPs to sell their surplus to the grid. India, one of the neighbouring countries of Bangladesh, has been successful in reforming the CPPs system (Jamasb and Sen, 2012). It has introduced a transparent regulation on the fixed and variable charges borne by the CPPs owners, reduced the wheeling charges, facilitated the banking of industry,[18] and lowered cross-subsidies surcharges to induce more CPPs to sell their surplus electricity to the bulk electricity purchasers (IEA, 2020). The CPPs producers' association of India plays a crucial role in developing the industry by liaising with the government to formulate CPPs

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[15] For more details, see: http://www.berc.org.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

[16] Although the CPP guidelines highlight the concept of a market-driven mechanism according to which the fuel's market price influences the electricity tariff, in practice, the government still heavily regulates and controls the electricity market in Bangladesh.

[17] For more details, see: https://berc.portal.gov.bd/site/view/policies/Policies.

[18] Suppose a power plant generates and sells electricity during daily peak hours but also wants to sell to a consumer that needs electricity at night peak hours. In this case, banking of electricity allows the generator to use banked grid-supplied electricity to serve the customer's needs at night.

related policies.[19, 20] Furthermore the Indian government is open to developments in the CPPs system. One example is the Group Captive Power Plants (GCPPs) which have been very popular in India since the late 1990's. Those are power plants set up by a group of consumers for their own consumption in remote areas. GCPPs cross subsidy[21] and surcharges[22] are waived as per the Indian Electricity Act 2003. This helps reduce the government fiscal burden and ease the process of setting up CPPs for industrial consumers. The Indian government has also supported the renewable-based CPPs (powered by solar, wind, bagasse, and biomass).[23]

On the contrary, Bangladesh is yet to capitalise on the national policy for CPPs integration into the grid. Recently a proposal of shutting down the CPPs has been put forward in some policy circles (see Amin et al. 2019) mainly on the ground that the national grid is currently generating electricity in excess of overall demand.[24] A throughout economic analysis is therefore needed to shed light on the current debate on the fate of CPPs in Bangladesh. In Amin et al. 2019, we have examined the impact of closing down the CPPs; in this paper we explore the consequences of integrating the CPPs with the national grid.

3. The DSGE Model

The CPPs-augmented DSGE model for Bangladesh firstly developed by Amin *et al.* (2019) will be used for our policy experiments. 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. We model Bangladesh as a small opening economy, importing oil at market prices.

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[19] For more details, see: https://energy.economictimes.indiatimes.com/news/power/new-norms-may-lead-to-group-captive-plants-equity-shareholding-rejig/64288620.

[20] For more details, see: https://economictimes.indiatimes.com/industry/energy/power/rules-for-captive-power-plants-to-be-amended/articleshow/70121180.cms?fbclid=IwAR0RLUAUMVFJe_zcogu1-tJ0K7CGQt8WdCCxNhkrUAgu2V6dQT6NhfRlOgs

[21] It is a type of subsidy, where a group of consumers pay more than the overall cost of supply, with the additional amount being utilised by the government to provide subsidy to another group.

[22] It refers to extra charge, tax, or payment that is added to the existing cost of a good or service.

[23] For instance, rooftop solar photovoltaic-based CPPs are given net metering benefits. For details, see Indian Electricity Act (2003).

[24] For more details, see: Amin et al (2021)

3.1 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 leisure (*1-l*). As in Kim and Loungani (1992), each period's utility function can be defined as:

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

where C^A is the consumption aggregator (as in Dhawan and Jeske, 2008):

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

The parameters φ, θ and γ represent the relative share of *c*, *e*, *1-l*, and *x*. A similar form of the utility function is also used by Amin *et al*. (2019), which considers the substitution possibility between general consumption and electricity consumption that is smaller than one.

The household income derives from capital income ($r_t . k_t$), labor income ($w_t . l_t$), a lump sum transfer, *g_t*, received from the government, and dividends π_t. Taxes are imposed on the capital and labor income at the rates $\tau^k and\ \tau^l$ respectively and capital depreciates overtime at a rate δ. The price of service goods and household electricity are n_t and q^e, respectively, while the price of general consumption is normalised to 1. So, the intertemporal household budget constraint is:

$$k_{t+1} + c_t + n_t . X_t + q_t^e . e_t = (1-\tau^l) w_t . l_t + g\_t + (1-\tau^k) r_t . k_t + (1-\delta) k_t + \pi_t \tag{3}$$

The Lagrangean for the household is:

$$L = \sum_{t=0}^{\infty} \beta^t [(\varphi \, log \left[X_t^{\gamma}\left(\theta c_t^{\rho} + (1-\theta) e_t^{\rho}\right)^{\frac{1-\gamma}{\rho}}\right]) + (1-\varphi) \, log(1-l_t)] - \lambda_t [k_{t+1} + c_t + n_t . X_t + q^e . e_t - (1-\tau^l) w_t . l_t - g\_t - (1-\tau^k) r_t . k_t - (1-\delta) k_t] \tag{4}$$

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.[25]

3.2 The Industrial and Service Sectors

Final producers in industry are distinguished into two sectors. Industry 1 producers purchase electricity from the grid and produce Y_1. Industry 2 producers operate their own CPPs, generating their own electricity, used in their production of Y_2. In the benchmark model, sector 2 producers are off the grid. When we conduct our policy experiment in Section 5, sector 2 producers can sell electricity to the grid.

Following Kim and Loungani (1992) and 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: labor (*l*), capital (*k*), and electricity (*g/s*).[26] The production functions for the sectors can be defined as:

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

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

$$X_{t}=l_{X,t}^{\alpha_X}[(1-\Psi_{X})k_{X,t}^{-\nu^{s}}+\Psi_{X}s_{t}^{-\nu^{s}}]^{-\frac{1-\alpha_{X}}{\acute{\upsilon}^{ss}}} \tag{7}$$

where $\mathrm{A}_\mathrm{t}^\mathrm{i}$ represents the stochastic productivity shock, the index i stands for the respective industrial (Y_1 and Y_2)[27] or service (*X*) sectors, α_i represents the labor share and Ψ_i is the share of electricity in the production function. It should be noted that $\acute{\upsilon}^{\mathrm{jj}}$ determines the degree of homogeneity in the CES production function.

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[25] For all calculations see Amin (2015).

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

[27] $Y_{A,t} = Y_{1,t} + Y_{2,t}$; where $Y_{A,t}$ is the aggregate industrial output.

3.3 The Energy Sector

In our model, there are four types of firms that can generate electricity: public power producers (*G*), independent power producers or IPPs (*I*), captive power producers or CPPs (g_2) and quick rental power producers or QRs (*R*).[28] In a similar way to Amin (2015), we employ a CES production function for the electricity generators:

$$\mathrm{G_t} = A_t^G l_{G,t}^{\alpha_G}\left[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}\right]^{-\frac{\vartheta^G}{\nu^{m,GG}}} \tag{8}$$

$$\mathrm{I_t} = A_t^I l_{I,t}^{\alpha_I}\left[(1-\Psi_I)k_{I,t}^{-\nu^{m,I}} + \Psi_I m_{I,t}^{-\nu^{m,I}}\right]^{-\frac{\vartheta^I}{\nu^{m,II}}} \tag{9}$$

$$\mathrm{g_{2,t}} = A_t^C l_{C,t}^{\alpha_C}\left[(1-\Psi_C)k_{C,t}^{-\nu^{m,C}} + \Psi_C m_{C,t}^{-\nu^{m,C}}\right]^{-\frac{\vartheta^C}{\nu^{m,CC}}} \tag{10}$$

$$\mathrm{R_t} = A_t^R l_{R,t}^{\alpha_R}\left[(1-\Psi_R)k_{R,t}^{-\nu^R} + \Psi_R h_t^{-\nu^R}\right]^{-\frac{\vartheta^R}{\nu^{R,RR}}} \tag{11}$$

The parameter ν depends on the Elasticity of Substitution (EOS) between capital and energy. The parameter α gives labor's share in production, 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. In Bangladesh, the most widespread fuel for electricity generation is natural gas which is domestically sourced and supplied by the government (71.8 percent of total fuel use in 2019-20 according to the latest BPDB Annual Report).[29] Until recently, imported oil was typically used in emergency situations when a high amount of electricity needs to be rapidly produced. More recently, the use of oil has expanded considerably and now it accounts for 13.25 percent of total fuel usage in 2019-20 according to the latest BPDB Annual Report).[29] Since 2015 the use of oil in the private generation sector has also increased. For modelling purposes, in our

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[28] 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 Quick Rental (*R*) power plants as a short term solution to mitigate the decade-long energy crisis associated with a shortage of electricity supply. Apart from these rentals and independent power producers, we also consider the public power producers (*G*) and the CPPs (*g*). These 4 types of electricity-generating firms produce nearly 100% of the electricity in Bangladesh.

[29] https://www.bpdb.gov.bd/bpdb_new/resourcefile/annualreports/annualreport_1605772936_AnnualReport2019-20.pdf

framework only the QRs are modelled as using oil. Indeed, more than 80 percent of QR plants use imported oil to generate electricity.[30]

Additionally, we are also interested in analysing whether connecting the CPPs to the grid affects the Bangladesh economy's vulnerability from oil price and productivity shocks. As in Amin et al. (2019), the stochastic oil price shock is assumed to be:

$$ln\, v_t^e = {}'\Omega^v + \omega ln v_{t-1}^e + \eta_t^O \tag{12}$$

The residual (η_t^O) are normally distributed with a standard deviation of one and a zero mean. However, since the data reveals that oil price follows an I (1) process, following Chang et al. (2007) we also check the robustness of the findings incorporating a nearly nonstationary shock setting $\omega = 0.999$. Like many DSGE models, all the remaining productivity shocks in our model are also assumed to be autoregressive processes rather than being serially independent. 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.

Productivity shocks in industry 1: $ln\, A_t^{Y,1} = {}'\Omega^{Y,1} + \mu^{Y,1} lnA_{t-1}^{Y,1} + \eta_t^{y,1}$ (13)

Productivity shocks in industry 2: $ln\, A_t^{Y,2} = {}'\Omega^{Y,2} + \mu^{Y,2} lnA_{t-1}^{Y,2} + \eta_t^{y,2}$ (14)

Productivity shocks in govt. electricity generating firms: $ln\, A_t^G = {}'\Omega^G + \mu^G lnA_{t-1}^G + \eta_t^G$ (15)

Productivity shocks in IPP electricity generating firms: $ln\, A_t^I = {}'\Omega^I + \mu^I lnA_{t-1}^I + \eta_t^I$ (16)

Productivity shocks in QR electricity generating firms: $ln\, A_t^R = {}'\Omega^R + \mu^R lnA_{t-1}^R + \eta_t^R$ (17)

Productivity shocks in CPP electricity generating firms: $ln\, A_t^C = {}'\Omega^C + \mu^C lnA_{t-1}^C + \eta_t^C$ (18)

3.4 The Public Sector

In the model, the government produces electricity and provide lump-sum benefits to the households. Government revenue derives from taxing labor income ($\tau^l . w_t . l_t$), capital income ($\tau^k . r_t . k_t$), selling natural gas to firms that generate electricity $\left((v^m - \delta^C)(m_{I,t} + m_{G,t})\right)$, and

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[30] For more details, see: https://bd.bpdb.gov.bd/bpdb_new/d3pbs_uploads/files/Generation%20Capacity%2012_11_2020.pdf

also selling electricity to the national grid ($P^G.G_t$).[31] The government uses its revenue to pay for labor ($w_t.l_{G,t}$), capital ($r_t.k_{G,t}$) and natural gas ($v^m.m_{G,t}$) used for its electricity production and provides a lump sum transfer to households (g_t). The government fixes the natural gas price at v^m, which is below the cost of its extraction (shadow price) (δ^C). In the absence of this extraction cost, there will be the overconsumption of natural gas due to the under-pricing of this scarce natural resource.

The government's objective is to minimise its cost:

$$c_{G,t} = w_t.l_{G,t} + r_t.k_{G,t} + v^m.m_{G,t} - P^G.A_t^G l_t^{\alpha_G}\left[(1-\Psi_G)k_{G,t}^{-\nu^{m,G}} + \Psi_G m_{G,t}^{-\nu^{m,G}}\right]^{-\frac{\vartheta^G}{\nu^{m,GG}}} \qquad (19)$$

In effect, the government 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:

$$g\_s = P^G.G_t + P^I.I_t + P^R.R_t - q^e.e_t - q^s.s_t - q^{g_1}.g_{1,t} \qquad (20)$$

where q^S and q^{g_1} are the electricity prices for service and industrial sectors, P^I, and P^R are the selling price of electricity by the IPPs and QRs. 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:

$$\tau^l.w_t.l_t + \tau^k.r_t.k_t + (v^m - \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e}).\mathrm{h} + P^G.G_t - r_t.k_{G,t} - w_t.l_{G,t} - v^m.m_{G,t} - g\_t = g\_s \qquad (21)$$

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[31] P^G is the price at which the government sells the electricity.

Finally, the economy-wide resource constraint [32] is as follows.[33]

$$k_{t+1} = Y_{A,t} - c_t - \mathrm{v}^{\mathrm{e}}.\mathrm{h}_t + (1-\delta).k_t - \delta^C\left(m_{I,t} + m_{G,t} + m_{C,t}\right) \tag{22}$$

3.5 Equilibrium Conditions

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

$$l_t = l_{R,t} + l_{I,t} + l_{G,t} + l_{Y1,t} + l_{X,t} + l_{Y2,t} + l_{C,t} \tag{23}$$

$$k_t = k_{R,t} + k_{I,t} + k_{G,t} + k_{Y1,t} + k_{X,t} + k_{Y2,t} + k_{C,t} \tag{24}$$

$$e_t + s_t + g_{1,t} + g_{2,t} = \left(G_t + I_t + g_{2,t} + R_t\right) \tag{25}$$

3.6. 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 model the captive power producers as selling the excess electricity $(g_{g,t})$ to the national grid. Therefore, the own consumption of electricity in the industrial sector 2 is $(g_{2,t} - g_{g,t})$, and its production function (Equation 6) is augmented as follows:

$$Y_{2,t} = A^Y_{2,t} l^{\alpha,2}_{Y2,t}\left[(1-\Psi_{Y2})k^{-\nu^{g,2}}_{Y2,t} + \Psi_{Y2}(g_{2,t} - g_{g,t})^{\nu^{g,2}}\right]^{-\frac{1-\alpha_{Y2}}{\acute{\upsilon}^{g g,2}}} \tag{26}$$

It is worth noting that q^{g_1} is the government regulated buying price of electricity by industry and CPPs have to sell electricity at this price. The profit function for industry 2 and the new equilibrium in the electricity market are as follows, where $g_{2,t}$ is given by equation (10):

$$\pi_{Y,t} = P^Y.A^Y_t l^{\alpha_Y}_{Y2,t}\left[\Psi_{Y2}(g_{2,t} - g_{g,t})^{\nu^{g,2}}(1-\Psi_Y)k^{-\nu^g}_{Y2,t} + \Psi_Y g^{-\nu^g}_{2,t}\right]^{-\frac{\vartheta^Y}{\acute{\upsilon}^{gg}}} - r_t\left(k_c + k_{Y2}\right) -$$
$$w_t\left(l_{c,t} + l_{Y2,t}\right) - v^m.m_{C,t} + q^{g_1}.g_{g,t} \tag{27}$$

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[32] See the Technical Appendix for the derivation.

[33] As the policy focus of the model is on assessing the economic consequences of connecting the CPPs to the national grid, we simplify the international dimension by assuming international trade balance that is equating the value of the imported oil with the value of the exported industrial output (the only exported good).

$$e_t + s_t + g_{1,t} + g_{2,t} = \left(G_t + I_t + R_t + g_{g,t} + g_{2,t}\right) \qquad (28)$$

4. Calibration and Estimation

In this section we seek numerical values for the parameters of the model. Data on international oil price was taken from the BP Statistical Review of World Energy[34] and all the remaining data used in the estimation were collected from the World Development Indicators.[35] The amount and frequency of data have been dictated by current data availability. Following Millard (2011), we divide our parameters into two groups: calibrated parameters and estimated parameters (posteriors).

For the calibrated parameters we follow Amin and Marsiliani (2015) and Amin *et al*. (2019). We take the preference parameters from Amin et al. (2019) as they make the model replicate consumption ratios in the data. The value of ρ is to be estimated. For the production parameters, we set $\Psi_{Y,1} = \Psi_{Y,2}$ and $\alpha_{Y,1} = \alpha_{Y,2}$ (as the two industry sectors are assumed to use the same production technology to produce the good), and estimate $\Psi_{Y,2}$ and $\alpha_{Y,2}$. We also estimate Ψ_C and α_C (the parameters in the CPP electricity generation). Regarding the priors, for the estimation we use the parameter values from the calibration in Amin et al. (2019). For the rest of the production parameters, we use the calibrated values in Amin et al. (2019), as they replicate the relevant ratios from the data. Regarding the total factor productivity, we choose the autoregressive parameter, μ, to equal 0.95, as in Amin and Marsiliani (2015). We can then compute the steady state levels of total factor productivity given Ω^j. We calibrate Ωj to reflect the relative sizes of the sectors, *j*. In particular, we set $\Omega_{Y,1}$ and $\Omega_{Y,2}$ so that the industry with CPPs (industry 2) accounts for 27% of total industrial production. For the oil price shock, we allow two possibilities, either the autoregressive parameter is 0.95 as in Amin and Marsiliani (2015), or it is 0.999 giving us a close to non-stationary process. Finally, the standard deviations of the shocks are chosen so that

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[34] https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

[35] https://databank.worldbank.org/source/world-development-indicators

when the model is simulated it replicates the standard deviations of the key data. The values for the calibrated parameters, and the energy prices data are shown in Table 2a.

Table 2a: Calibrated Parameters

Parameter	Description	Values
θ	Share of non-electricity consumption in household aggregator	0.91
γ	Share of service in the household consumption aggregator	0.81
φ	Share of electricity and non-electricity consumption in the household's utility	0.60
α_X	Labor share in service sector	0.313
α_G	Labor share in government electricity generating firms	0.042
α_I	Labor share in IPP electricity generating firms	0.036
α_R	Labor share in QR electricity generating firms	0.004
Ψ_X	Capital share in service sector	0.079
Ψ_G	Capital share in government electricity generating firms	0.302
Ψ_I	Capital share in IPP electricity generating firms	0.309
Ψ_R	Capital share in QR electricity generating firms	0.596
$\nu^{g,1}$	EOS between capital and electricity used in industry 1	0.1
$\nu^{g,2}$	EOS between capital and electricity used in industry 2	0.1
ν^{s}	EOS between capital and electricity used in service sector	0.1
$\nu^{m,G}$	EOS between capital and gas used in govt. electricity generating firms	0.1
$\nu^{m,I}$	EOS between capital and gas used in IPP electricity generating firms	0.1
$\nu^{m,R}$	EOS between capital and oil used in QR electricity generating firms	0.1
$\nu^{m,C}$	EOS between capital and gas used in CPP electricity generating firms	0.1
$\acute{\upsilon}^{gg,1}$	Degree of homogeneity in industry 1 production function	0.2
$\acute{\upsilon}^{gg,2}$	Degree of homogeneity in industry 2 production function	0.2
$\acute{\upsilon}^{ss}$	Degree of homogeneity in service production function	0.2
$\nu^{m,GG}$	Degree of homogeneity in government electricity production function	0.2
$\nu^{m,II}$	Degree of homogeneity in IPP electricity production function	0.2

$\nu^{R,RR}$	Degree of homogeneity in QR electricity production function	0.2
$\nu^{m,CC}$	Degree of homogeneity in CPP electricity production function	0.2
ω	Persistence coefficient of oil price shock	0.95
$\mu^{Y,1}$	Persistent coefficient of productivity shock in industry 1	0.95
$\mu^{Y,2}$	Persistent coefficient of productivity shock in industry 2	0.95
μ^{G}	Persistent coefficient of productivity shock in government generators	0.95
μ^{I}	Persistent coefficient of productivity shock in IPP	0.95
μ^{R}	Persistent coefficient of productivity shock in QR	0.95
μ^{C}	Persistent coefficient of productivity shock in CPP	0.95
$'\Omega^{v}$	Coefficient in the oil price shock	0.105
$'\Omega^{Y,1}$	Coefficient in the productivity shock equation in Industry 1	-0.007
$'\Omega^{Y,2}$	Coefficient in the productivity shock equation in Industry 2	-0.04
$'\Omega^{G}$	Coefficient in the productivity shock equation in government generators	-0.132
$'\Omega^{I}$	Coefficient in the productivity shock equation in IPP	-0.184
$'\Omega^{R}$	Coefficient in the productivity shock equation in QR	-0.192
$'\Omega^{C}$	Coefficient in the productivity shock equation in CPP	-0.184
$\zeta,$	Standard deviation of oil price shock	0.002
$\varepsilon^{Y.1}$	Standard deviation of productivity shock in industry 1	0.006
$\varepsilon^{Y.2}$	Standard deviation of productivity shock in industry 2	0.006
ε^{G}	Standard deviation of productivity shock in government generators	0.06
ε^{I}	Standard deviation of productivity shock in IPP	0.06
ε^{R}	Standard deviation of productivity shock in QR	0.06
ε^{G}	Standard deviation of productivity shock in CPP	0.06

Table 2b present the parametric prices of electricity and fuels. Those are the same as in Amin et al (2019).

Table 2b: Electricity and Fuel Prices (Taka/kWh)

Parametric prices	Description	Values

q^e	Buying price of electricity by household	4.93
q^{g_1}	Buying price of electricity by industrial sector	6.95
q^s	Buying price of electricity by service sector	9.00
P^I	Selling price of electricity by the independent power producer	3.20
P^R	Selling price of electricity by the rental power producers	7.79
P^G	Selling price of electricity by the government	2.30
v^e	International price of imported oil	8.19
v^h	Selling price of imported oil to the rental power producers	5.72
v^m	Selling price of domestically produced natural gas	0.77

For the second group of parameters, the prior information about the estimated parameters is gathered from the values (calibrated values) obtained in Amin et al. (2019). We use the Bayesian technique provided in Dynare [36] to estimate our DSGE model on de-trended data for 2009 (the earliest year for which data on quick rental electricity generation were available) to 2019.[37] In Table 3 we report our prior means and the estimated posterior means and modes, as well as their 90 percent confidence intervals. We see that all of our estimated parameter means fall within the confidence intervals. Our acceptance rate of 0.59 is also large for models of this kind (see Millard, 2011).

Table 3a shows the results for the autoregressive parameter in the oil price of 0.95, while Table 3b shows results for the near non-stationary oil price (the autoregressive parameter at 0.999). We see that quantitatively the posterior mode and means of Table 3a and 3b are very close. We therefore take the posterior means from Table 4a when we simulate the model (both for ω =0.95 and ω =0.999) to evaluate the stochastic properties of our model and for our policy experiment in section 5. The discount factor, β, is estimated as 0.947, which is standard in the DSGE literature. The CES parameter of the household's utility function, ρ, is estimated as -0.11 which is negative and indicates that energy and general consumption are somewhat complementary. The posterior mean further estimates the depreciation rate δ as 0.0326, which also seems to be realistic for a

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[36] See: https://www.dynare.org/

[37] Before the estimation, all data were de-trended using the Hodrick-Prescott (HP) filter with the smoothing parameter, λ, set to 100.

developing country (Yisheng, 2006). The industrial labor share is estimated to be around 0.20, supporting the findings of Roberts and Fagernas (2004). The other estimated parameters are also consistent with the calibrated values as found in Amin et al. (2019).

Table 3a: Prior and Posterior Distributions of the Estimated Parameters (with stationary oil price shock)

Parameters	Description of the Parameters	Prior Mean	Posterior Mean	Posterior Mode	Confidence Interval	
β	Discount factor	0.960	0.9470	0.9512	0.9293	0.9633
ρ	Consumption substitution parameter	-0.110	-0.1121	-0.1101	-0.1284	-0.0962
δ	Depreciation rate	0.025	0.0326	0.0271	0.0137	0.0504
$\alpha_{Y,1}$	Labor share used in production by 1st group of industry	0.200	0.2023	0.2031	0.1884	0.2158
$\alpha_{Y,2}$	Labor share used in production by 2nd group of industry	0.200	0.2012	0.2001	0.1847	0.2175
α_C	Labor share used in production by the CPPs	0.030	0.0311	0.0267	0.0167	0.0488
$\Psi_{Y,2}$	Electricity share used in production by 2nd group of industry	0.070	0.0701	0.0687	0.0531	0.0865
Ψ_C	Natural gas share used in production by the CPPs	0.300	0.2989	0.2998	0.2837	0.3134
τ^k	Capital Income Tax Rate	0.150	0.1495	0.1503	0.1344	0.1656
τ^l	Labor Income Tax Rate	0.100	0.0990	0.0994	0.0841	0.1146

Table 3b: Prior and Posterior Distributions of the Estimated Parameters (with nearly non-stationary oil price chock)

Parameters	Description of the Parameters	Prior Mean	Posterior Mean	Posterior Mode	Confidence Interval	
β	Discount factor	0.960	0.9481	0.9512	0.9321	0.9657
ρ	Consumption substitution parameter	-0.110	-0.1112	-0.1101	-0.1263	-0.0943
δ	Depreciation rate	0.025	0.0329	-0.0271	0.0148	0.0509
$\alpha_{Y,1}$	Labor share used in production by 1st group of industry	0.200	0.2028	0.2031	0.1893	0.2158
$\alpha_{Y,2}$	Labor share used in production by 2nd group of industry	0.200	0.2017	0.2001	0.1851	0.2189
α_C	Labor share used in production by the CPPs	0.030	0.0307	0.0267	0.0138	0.0471
$\Psi_{Y,2}$	Electricity share used in production by 2nd group of industry	0.070	0.0698	0.0687	0.0539	0.0841
Ψ_C	Electricity share used in production by the CPPs	0.300	0.2995	0.2998	0.2858	0.3167
τ^k	Capital Income Tax Rate	0.150	0.1495	0.1503	0.1346	0.1675
τ^l	Labor Income Tax Rate	0.100	0.0995	0.0994	0.0827	0.1138

In the next section we simulate the model to obtain second order moments and evaluate their fit with the actual data. We also report the variance decomposition.

5. Simulation and Stochastic Properties

We simulate the model for 120 time periods and compute the second moments. Table 4 shows that most generated moments are consistent with those of the data, apart from the correlation between industrial output and services. We also see that the moments for the model with the near non-stationary oil price produces moments close to those of the model with stationary oil prices.

Table 4. Actual and Predicted Moments

Statistics	Data	DSGE Model (with stationary shock)	DSGE Model (with nearly non-stationary shock)
Standard Deviation			
GDP, Aggregate Economic Output	0.0051	0.0059	0.0059
Y_a, Aggregate Industrial Output	0.0027	0.0030	0.0030
c, General Consumption	0.0007	0.0006	0.0006
e, Electricity Consumption	0.0002	0.0000	0.0000
X, Service Production	0.0011	0.0007	0.0007
g_2, CPP Electricity Generation	0.0004	0.0004	0.0004
K, Aggregate Capital	0.0064	0.0047	0.0047
G, Public Electricity Generation	0.0001	0.0005	0.0005
v_e, International Oil Price	0.0142	0.0152	0.0148
Autocorrelation			
GDP, Aggregate Economic Output	0.5321	0.5110	0.5110
Y_a, Aggregate Industrial Output	0.4740	0.4788	0.4788
c, General Consumption	0.56	0.5417	0.5417
e, Electricity Consumption	0.56	0.5417	0.5417
X, Service Production	0.8516	0.5368	0.5368
CPP Electricity Generation	0.17	0.4738	0.4738
K, Aggregate Capital	0.7947	0.8484	0.8484
G, Public Electricity Generation	0.28320	0.4743	0.4743
v_e, International Oil Price	0.01540	0.4738	0.4773
Correlation with Output			
Y_a, Aggregate Industrial Output	0.76630	0.9255	0.9255
c, General Consumption	0.80590	0.9409	0.9409
e, Electricity Consumption	0.20410	0.9409	0.9409
X, Service Production	0.80590	-0.7056	-0.7056
CPP Electricity Generation	-.4181	-0.2191	-0.2191
K, Aggregate Capital	0.7120	0.5726	0.5726

G, Public Electricity Generation	0.9580	0.9277	0.3121
v_e, International Oil Price	0.0016	-0.0019	-0.0021

Table 5 shows the variance decomposition of the aggregate variables to the model shocks. The productivity shock in industrial sector 1 is clearly the most important in explaining the output volatility in our model. The changes in industrial productivity explain around two thirds of the variation in key macroeconomic variables. This is not surprising given the significance of the industrial sector for the Bangladesh's economy (see Section 1). Apart from the industrial productivity shocks, the variance decomposition also shows that the productivity shocks in the public electricity generating firm and in CPPs explain most of variation in electricity production.

However, overall, productivity shocks in the energy sectors (Table 5) are a less important source of aggregate fluctuations in Bangladesh's economy. The reason is that there are several different electricity producing sectors, helping to mitigate a shock in one individual sector. We also see that for near non-stationary oil prices, the oil price shock accounts for some variation in consumption, household electricity consumption, and the government lump-sum transfer.

Table 5a: Variance Decomposition of Different Exogenous Shocks on Key Model Variables (with Stationary Shocks)

Criteria	Oil price shock	Productivity shock in industry 1	Productivity shock in industry 2	Productivity shock in IPPs	Productivity shock in QRs	Productivity shock in government electricity generators	Productivity shock in CPPs
GDP	0.00	82.63	4.60	0.06	0.86	4.82	4.03
Industry 1 Output (y_1)	0.00	98.97	0.97	0.00	0.05	0.01	0.00
Industry 2 Output (y_2)	0.00	9.37	90.18	0.00	0.03	0.01	0.43
Aggregate Industry Output (y_a)	0.00	94.69	5.12	0.00	0.09	0.03	0.08
General Consumption (c)	0.00	63.23	3.37	0.20	0.80	17.00	15.41
Electricity Consumption (e)	0.00	63.23	3.37	0.20	0.80	17.00	15.41
IPP Electricity Production (I)	0.00	0.04	0..00	99.95	0.00	0.00	0.00
QR Electricity Production (R)	0.00	0.01	0..00	0.00	99.99	0.00	0.00
Govt. Electricity Production (G)	0.00	1.39	0.07	13.00	4.50	0.07	80.97
Service Production (X)	0.00	39.34	2.18	0.28	0.31	29.88	27.93
Labor (l)	0.00	67.02	3.65	0.28	0.30	18.64	10.11
Wages (w)	0.00	71.13	3.85	0.13	0.63	11.81	11.45
Capital (k)	0.00	94.59	5.14	0.00	0.00	0.00	0.02
Government Transfer (g_t)	0.00	11.06	0.26	1.45	19.36	40.04	27.83
Energy Subsidies (g_s)	0.00	2.35	0.01	1.88	25.38	0.25	70.13

Table 5b: Variance Decomposition of Different Exogenous Shocks on Key Model Variables

(with Near Non Stationary Shocks)

Criteria	Oil price shock	Productivity shock in industry 1	Productivity shock in industry 2	Productivity shock in IPPs	Productivity shock in QRs	Productivity shock in government electricity generators	Productivity shock in CPPs
GDP	0.00	85.63	4.60	0.06	086	4.82	4.03
Industry 1 Output (y_1)	0.00	98.97	0.97	0.00	0.05	0.01	0.00
Industry 2 Output (y_2)	0.00	9.37	90.18	0.00	0.03	0.01	0.43
Aggregate Industry Output (y_a)	0.00	94.69	5.12	0.00	0.09	0.02	0.08
General Consumption (c)	0.01	63.23	3.37	0.20	0.80	17.00	15.41
Electricity Consumption (e)	0.01	63.23	3.37	0.20	0.80	17.00	15.41
IPP Electricity Production (I)	0.00	0.04	0..00	99.95	0.00	0.00	0.00

QR Electricity Production (R)	0.00	0.01	0..00	0.00	99.99	0.00	0.00
Govt. Electricity Production (G)	0.00	1.39	0.07	13.00	4.50	0.07	80.97
Service Production (X)	0.00	39.34	2.18	0.36	0.31	29.88	27.93
Labor (l)	0.00	67.02	3.65	0.28	0.30	18.64	10.11
Wages (w)	0.00	72.13	3.85	0.13	0.63	11.81	11.45
Capital (k)	0.00	94.59	5.14	0.00	0.00	0.00	0.02
Government Transfer (g_t)	0.04	11.06	0.26	1.45	19.36	40.04	27.83
Energy Subsidies (g_s)	0.00	2.35	0.01	1.88	25.38	0.25	70.13

5. Connecting CPPs to the Grid

In this section we model the CPPs as grid-connected. Industrial Sector 2 can then sell surplus electricity to the grid at the government set price. We compute the steady state of this economy and compare it to the case when they are not grid connected. If there are gains from grid connection, then there would be a case for the government to provide a lump-sum subsidy to enable it.

Table 6 reports the results of having the CPPs connected to the grid. We find that when the CPPs are grid-connected, the steady-state value of the overall electricity consumption is reduced due to the pre-existing inefficiency in the electricity market. This inefficiency arises from the distorted energy prices in the market due to government-regulated prices. Opening up the grid would reduce the steady-state consumption by 1.73 percent, aggregate industrial output by 1 percent and GDP by 1.2 percent.

We also find that when the CPPs sell electricity to the grid, they expand their own production set. However, under distorted prices, connecting the CPPs to the grid would not provide economic benefits to Bangladesh, due to resource misallocation.

Table 6: Steady State Values

Variables	**With Stationary Shocks**	**With Non-Stationary Shocks**

	Benchmark Model	Grid-Connected Model	Benchmark Model	Grid-Connected Model
GDP, Aggregate Economic Output	2.0001	1.97611	2.00117	1.97611
Y_1, Industrial 1 Output	0.3773	0.379934	0.3769	0.379934
Y_2, Industrial 2 Output	0.0963	0.0890442	0.0961659	0.0890442
Y_a, Aggregate Industrial Output	0.4736	0.468978	0.473066	0.468978
c, General Consumption	0.2226	0.218733	0.222822	0.218733
e, Electricity Consumption	0.0065	0.00638652	0.00650766	0.00665615
I, IPP Electricity Generation	0.0019	0.00176771	0.00176554	0.00176771
R, QR Electricity Generation	0.0011	0.00103263	0.00103249	0.00103263
G, Government Electricity Generation	0.0122	0.00852403	0.012436	0.00852403
g_2, CPP Electricity Generation	0.0017	0.00425667	0.00163773	0.00425667
X, Service Production	0.6650	0.661474	0.665285	0.661474
l, Aggregate Labor	0.3272	0.327559	0.327054	0.327559
w, Wages	1.3429	1.32033	1.34436	1.32033
K, Aggregate Capital	3.1970	3.16947	3.19286	3.16947
g_t, Government Transfer	0.1663	0.176061	0.1682	0.176061
g_s, Energy Subsidies	-0.0492	-0.0574102	-0.0496661	-0.0574102

We next examine the effects of individual shocks (productivity and oil price) by reporting the Impulse Response Functions, in Tables A.1-A.7 in Appendix A.

Figure A.1a and A.1b show that for a stationary oil price, whether or not the CPPs are grid connected makes no differences to the impulse response functions for an oil price shock. An oil price shock worsens the trade balance, and due to fixed regulated prices QRs are not reducing their production of electricity. This causes the implied electricity subsidy to increase. As a consequence, the government transfer (*g_t*) to the households is reduced. The income effect makes households to increase the labor supply and reduce consumption of *c* and *X*. The industrial sector expands (to clear the trade balance) making the service sector to shrink. The overall effect is a reduction in GDP. Figure A.1c and A.1d, show the impulse response functions for near non-stationary oil prices, and their responses are qualitatively in line with those for stationary oil prices.

However, comparing no grid connection (Figure A.1c) with grid connection (A.1d) for near non-stationary shocks we see that a shock causes more persistence in the response of the endogenous variables for the grid connection case. The effects here only phase out after 250 periods, while for the non-grid economy it did so after 120 periods.

The IRFs for shocks to technology in industries 1 and 2 show similar results, also when grid connected (Figures A.2a, A.2b, A.3a, and A.3b). The IRFs are in line with previous macroeconomic studies. Positive productivity shocks make the factors of production more productive, and accordingly, the wage and the capital interest rate increase. Higher wages also increase labor supply. Additionally, general consumption and electricity consumption increase because of the income effect due to the expansion in the production possibilities set. The industrial sector with the positive shock expands and the other contracts, with the overall industrial output increasing. Since the private electricity generating firms are now facing higher factor prices, labor and capital decreases in private electricity firms, and private firms' electricity production also decreases. Higher wages and capital also imply higher tax revenue for the government, which increases government transfer. Industries now use more electricity as the sector expands, and the government intervenes in the electricity market to supply more electricity.

Figure A.4a and A.4b show the IRFs for a technology shock to government production of electricity. Higher productivity in the public generating firms (G) implies that production becomes more efficient regardless of the prices, and fewer resources are now needed. As a result, electricity generation increases in the government sector, and government transfer also increases. Higher government transfer also increases household leisure consumption and decreases labor supply which causes labor wage to rise. Household electricity consumption, general consumption, and service consumption increase. Grid connection makes a difference, as it smoothens the magnitude of the responses due to the shocks.

A positive shock to technology in IPP produces similar IRFs (Figure A.5a and A.5b) as for the government electricity production shock, in the sense that the service sector increases, the industry sector shrinks, and overall GDP increases, as well as consumption. Also here, when CPPs are connected to the grid, the responses are of smaller magnitudes.

Figure A.6a and A.6b show the IRFs for a positive shock to technology in QRs. It produces the opposite result to IPP and government production shocks. Furthermore, for the case when CPPs are grid connected, the magnitude of the responses is larger, thus exacerbating the shock. The difference is that QRs are using oil to produce electricity.

Finally, for a shock to technology in CPPs (Figure A.7a and A.7b), the responses are very different depending on whether the CPPs are grid connected. While GDP, consumption, and the service sector increase when CPPs are not grid connected, they fall in the economy with grid connection. With no grid connection, sector 2 expands more, reaping the full benefit of the productivity shock. On the other hand, with grid connection, the shock induces CPPs to sell more to the grid, at distorted prices, creating a more inefficient allocation. The net result is a fall in GDP.

6. Conclusions

Having maintained an impressive growth rate for the last decade, Bangladesh plans to become a high-income country by 2041. Since the country greatly relies on industry and mainly on RMGs export since the mid-1990s, the CPPs have made a significant contribution to the country’s development journey by supplying electricity to industries. However, there is a growing consensus in policy circles that the importance of the CPPs for the Bangladesh economy has substantially decreased in recent years as the national grid connectivity capacity has increased. Given the present power generation capacity of 20,383 MW, against a demand of 13,300 MW as reported in the 2019-2020 annual report of the BPDB, the government is discussing the option of shutting down the CPPs. This discussion is further fuelled by the fact that CPPs use low efficiency technologies to generate electricity, typically Open Cycle Gas Turbine (OCGT).[44]

The role of CPPs in an economy characterised by distortions due to regulated prices, has already been studied by Amin et al. (2019). In that paper it is found that shutting down the CPPs caused GDP to fall by 1.64 percent in the long run. A more urgent policy was that of removing the price distortions by incorporating market mechanisms into the Bangladesh energy market. Furthermore, energy experts are adamant that it would not be wise to shut down the CPPs without improving the country’s distribution system.[45]

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[44] The national power plant efficiency is 27-30 percent higher than that of the CPPs

[45] For more details, see: https://ep-bd.com/view/details/article/NTUzOQ%3D%3D/popular-article/title?q=stop+captive+generation+after+ensuring+quality+power+supply%3a++experts

In this paper we use the same framework as in Amin et al. (2019) to investigate the alternative policy option of connecting the CPPs to the grid. This is consistent with the current Bangladesh CPPs regulatory framework, although in practice it is not profitable for the CPPs to do so.

Differently from Amin at al. (2019), the model's parameter values are set through a combination of calibration and Bayesian estimation. Simulations with the model produce moments of the endogenous variables close to those of the data. A comparison of the key variables' second order moments reveals that the model replicates well the volatilities in the data. Furthermore, variance decomposition analysis finds that output fluctuations in Bangladesh are mainly driven by productivity shocks as in Amin and Marsiliani (2015).

Our policy simulations reveal that, since the controlled prices on the grid fail to reflect the true cost of production, connecting CPPs to the grid has negative effects: household electricity consumption, industrial output and GDP decrease by 1.74 percent, 1 percent, and 1.2 percent respectively at the steady state. The Impulse Response Functions (IRFs) show that Bangladesh economy does not respond differently to stationary oil price shocks in the non-grid connected model. However, if shocks are near non stationary, the grid connected model shows more persistence in the responses that the non-grid connected one.

Given our results, we suggest that before undertaking any reforms in connection to the CPPs, the Bangladesh government should aim at ameliorating the existing distortions by creating a competitive market environment for cost-reflective tariffs. It would then be up to market forces to determine whether the CPPs would be scrapped or connected to the grid.

Equally important is the need for the government to ensure that the energy sector is environmentally sustainable, by for example encouraging fuel efficiency and the use of renewable resources in electricity generation. At the same time continuous effort should be devoted to strengthening the power distribution system in order to mitigate energy inequalities among consumers (e.g., urban versus rural).

The recent Covid-19 pandemic has stalled the economic growth of Bangladesh and caused many job losses prompting previously city dwellers to move to rural areas. The Bangladesh government faces a new challenge in providing job opportunities for these people and should now focus on improving access to electricity in rural areas (currently only 78 percent of the rural population has access to grid electricity). At least as an interim measure, the government may consider standalone (off-grid and mini-grid) CPPs support policies to tackle the Covid-19 induced electricity demand. In this regard, Africa can be a good example, where standalone CPPs are helping rural communities and businesses to prosper.[46] If those policies were also to promote renewable energy (solar, biogas, and bagasse)-based hybrid CPPs installation (like for example in India), the goals of recovering from the Covid-19 pandemic and greening the economy could be achieved at the same time.

Acknowledgement

We like to thank Naoyuki Yoshino, Donghyun Park, Farhad Taghizadeh-Hesary, and Rabindra Nepal for their useful comments, which has significantly improved the paper. We are also thankful to the Asian Development Bank Institute (ADBI) for publishing an earlier version of this paper in their working paper series.[47]

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[46] For more detail, see: https://www.esi-africa.com/top-stories/off-grid-captive-power-solutions-sustain-investment-in-africa/?fbclid=IwAR0ZAAFjW3yrz-1xn8RcgQ4h5mfEI82rmtyNkxoXWt77ZTyzaNnqLeohSuI.

[47] Amin, S., T. Jamasb, M. Llorca, L. Marsiliani, and T. Renström. 2021. The Role of Captive Power Plants in the Bangladesh Electricity Sector. ADBI Working Paper 1238. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/role-captive-power-plants-bangladesh-electricity-sector

References

Amin, S.B. 2015. The macroeconomics of energy price shocks and electricity market reforms: the case of Bangladesh. Ph.D. Thesis. Durham University. http://etheses.dur.ac.uk/11241/.

Amin, S.B. and Marsiliani, L. 2015. Energy price shocks in dynamic stochastic general equilibrium: the case of Bangladesh. *Review of Business and Economics Studies* 30(3): 12-21. https://rbes.fa.ru/jour/article/view/24/24.

Amin, S.B., and Rahman, S. 2019. Energy: The lifeblood of Bangladesh economy. In: Energy Resources in Bangladesh. Springer, Cham. https://doi.org/10.1007/978-3-030-02919-7_1.

Amin, S.B., Jamasb, T., Llorca, M., Marsiliani, L. and Renström, T., 2019. Combining private and public resources: captive power plants and electricity sector development in Bangladesh. *Emerging Markets Finance and Trade*. https://doi.org/10.1080/1540496X.2019.1703107.

Amin, S.B., Jamasb, T., Llorca, M., Marsiliani, L. and Renström, T., 2021. The Role of Captive Power Plants in the Bangladesh Electricity Sector. ADBI Working Paper 1238. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/role-captive-power-plants-bangladesh-electricity-sector

Aminu, N. 2019. Energy prices volatility and the United Kingdom: Evidence from a dynamic stochastic general equilibrium model. *Energy* 172: 487-497.

Aminu, N., Meenagh, D. and Minford, P. 2018. The role of energy prices in the great recession– a two-sector real business cycle (RBC) model of energy in United Kingdom with unfiltered data. *Energy Economics* 71(C): 14-34.

Aminu, N. 2018. Evaluation of a DSGE model of energy in the United Kingdom using stationary data. *Computational Economics* 51(4): 1033-1068.

Balke, N.S. and Brown, S.P. 2018. Oil supply shocks and the US economy: An estimated DSGE model. *Energy Policy* 116: 357-372.

Bangladesh Energy Regulatory Commission. 2020. Annual Report 2019-2020. http://www.berc.org.bd/sites/default/files/files/berc.portal.gov.bd/annual_reports/b02cf4c0_f55b_4a9a_8f58_eff25be80ce4/2021-04-26-04-40-7b86ad6519b8d2fe61987c6e30bc1589.pdf

Chang, Y., Doh, T. and Schorfheide, F. 2007: Non-stationary hours in a DSGE model. *Journal of Money, Credit and Banking* 39(6): 1357-1373.

Bangladesh Power Development Board. 2017. Annual Report 2016-2017. http://www.bpdb.gov.bd/download/annual_report/Annual%20Report%202016-17%20(2).pdf.

Dhawan, R. and Jeske, K. 2008. Energy price shocks and the macroeconomy: the role of consumer durables. *Journal of Money, Credit and Banking* 40(7): 1357-1377. https://doi.org/10.1111/j.1538-4616.2008.00163.x.

Hansen, C.J. 2008. Bottom-up electricity reform using industrial captive generation: a case study of Gujarat, India. Oxford Institute for Energy Studies, EL 07. https://ora.ox.ac.uk/objects/uuid%3Adf354667-e08e-4e74-935a-c522f1a1fc5d.

IEA, 2020. India 2020: Energy Policy Review. International Energy Agency, IEA, 2020.

Jaaskela, J.P. and Nimrak, K. 2011. A medium-scale new Keynesian open economy model of Australia. *The Economic Record* 87(276): 11-36. https://doi.org/10.1111/j.1475-4932.2010.00688.x.

Jamasb, T. and Sen, A. 2012. Diversity in unity: An empirical analysis of electricity deregulation in Indian states. *The Energy Journal* 33(1): 83-130.

Joseph, K.L. 2010. The politics of power: electricity reform in India. *Energy Policy* 38(1): 503-511. https://doi.org/10.1016/j.enpol.2009.09.041.

Kim, I.M. and Loungani, P. 1992. The role of energy in real business cycles. *Journal of Monetary Economics* 29: 173-189.https://doi.org/10.1016/0304-3932(92)90011-P.

Millard, S. 2011: An estimated DSGE model of energy, costs and inflation in the United Kingdom. Bank of England Working Paper No.432. Bank of England, Threadneedle St, London.

Nag, T. 2010. Captive generation in India: the dilemma of dualism. India Infrastructure Report, 2010. http://www.idfc.com/pdf/report/Chapter-12.pdf.

Roberts, J. and Fagernas, S. 2004. Why is Bangladesh outperforming Kenya? a comparative study of growth and its causes since the 1960s. ODI Strategic Policy Impact and Research Unit (SPIRU) Papers 5. https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/2499.pdf.

Rotemberg, J.J. and Woodford, M. 1996. Imperfect competition and the effects of energy price increases on economic activity. *Journal of Money, Credit and Banking* 28: 549-577. http://links.jstor.org/sici?sici=0022-2879%28199611%2928%3A4%3C549%3AICATEO%3E2.0.CO%3B2-7.

Shukla, P.R., Biswas, D., Nag, T., Yajnic, A., Heller, T., and Victor, D.G. 2004. Captive power plants: case study of Gujarat, India. Programme on Energy and Sustainable Development Working Paper 22, Stanford University, March 2004. https://www.researchgate.net/publication/316933453.

Yisheng, B. 2006. Fixed capital stock depreciation in developing countries: some evidence from firm level data. *Journal of Development Studies* 5: 881-901. https://doi.org/10.1080/00220380600742183.

Appendix A

Figure A.1a: Impulse Responses to an Oil Price Shocks in the Benchmark Model (Stationary Shock)

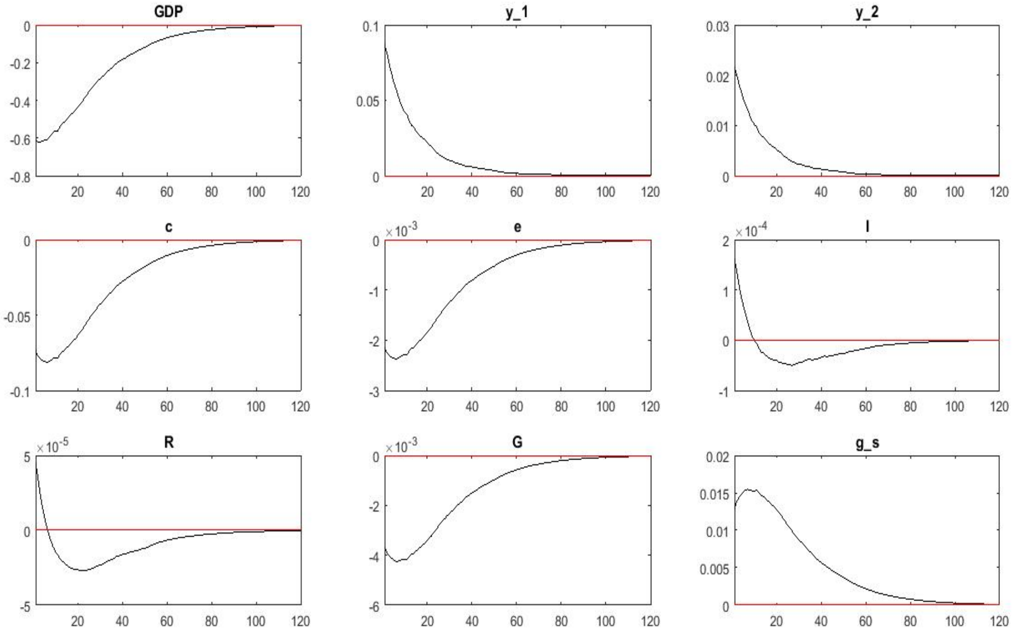


Figure A.1b: Impulse Responses to an Oil Price Shocks in the Grid-connected Model (Stationary Shock)

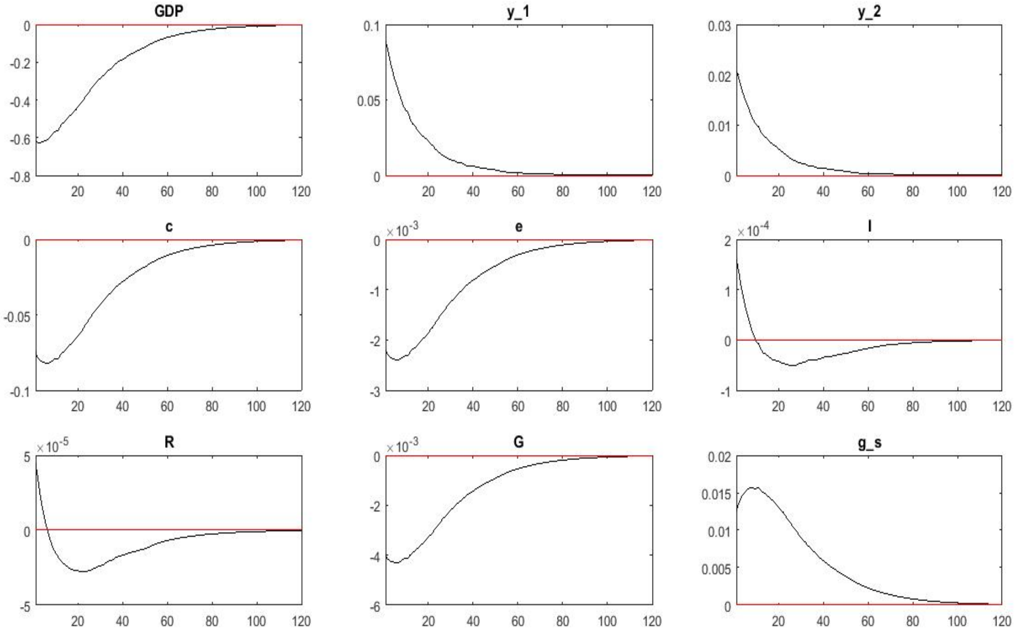


Figure A.1c: Impulse Responses to an Oil Price Shocks in the Benchmark Model (Non-Stationary Shock)

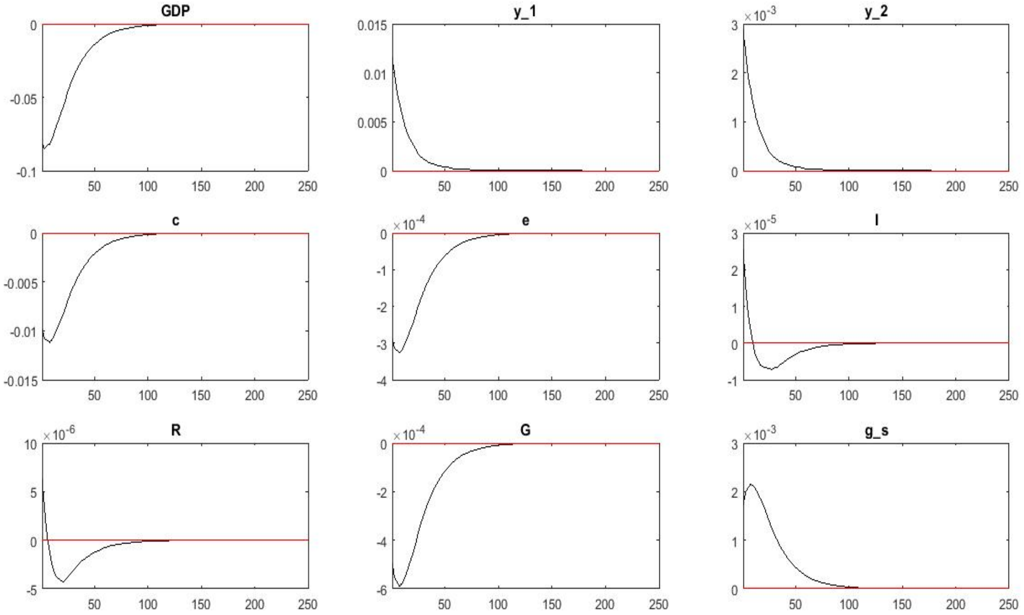


Figure A.1d: Impulse Responses to an Oil Price Shocks in the Grid-connected Model (Non-Stationary Shock)

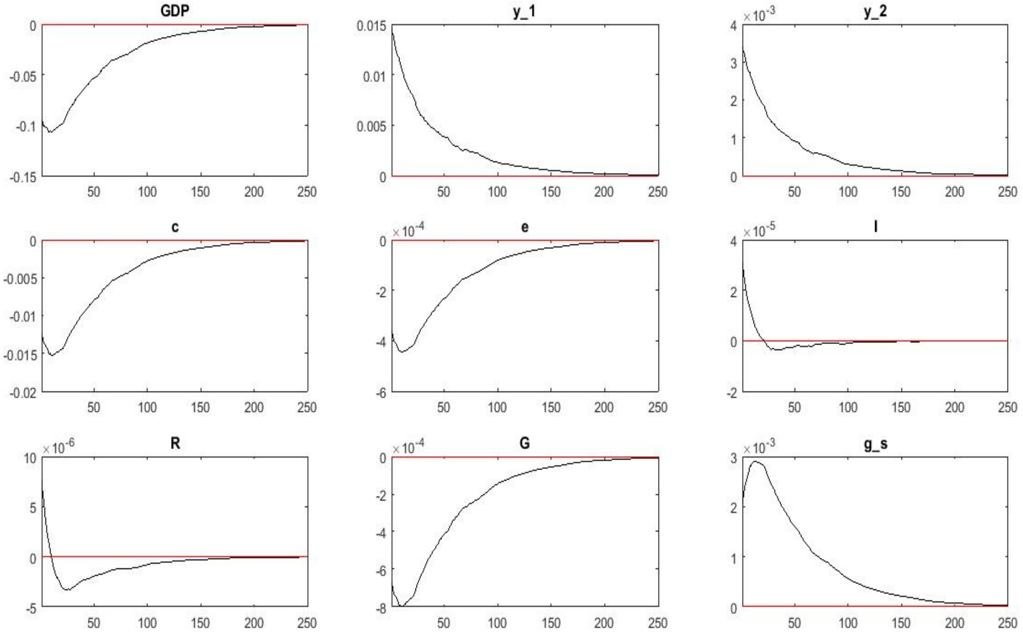


Figure A.2a: Impulse Responses to Industry 1 Productivity Shock in the Benchmark Model

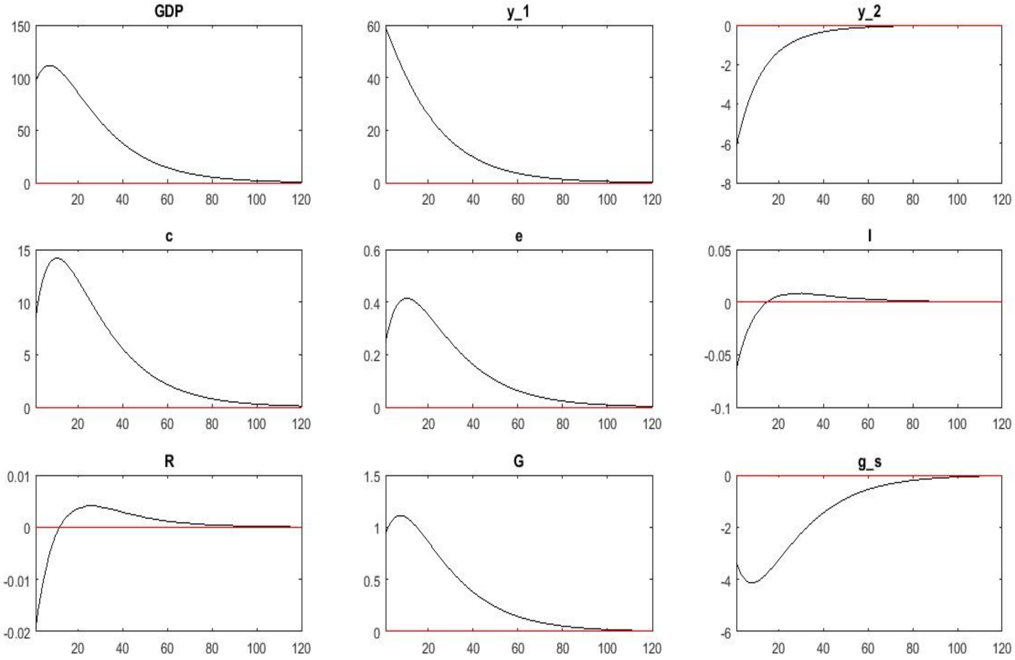


Figure A.2b: Impulse Responses to Industry 1 Productivity Shock in the Grid-connected Model

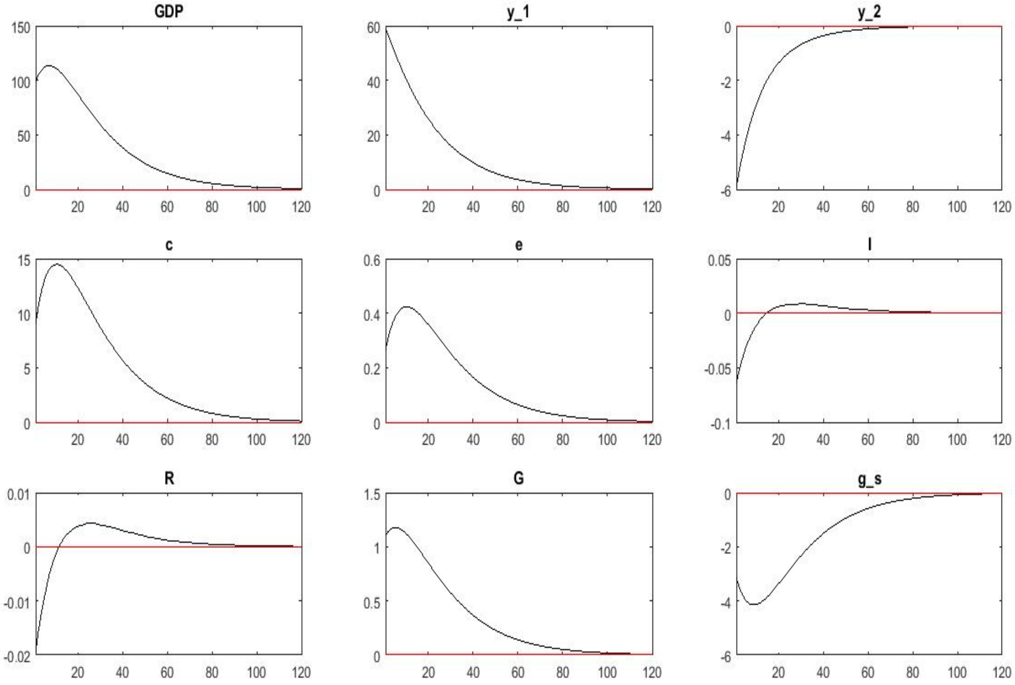


Figure A.3a: Impulse Responses to Industry 2 Productivity Shock in the Benchmark Model

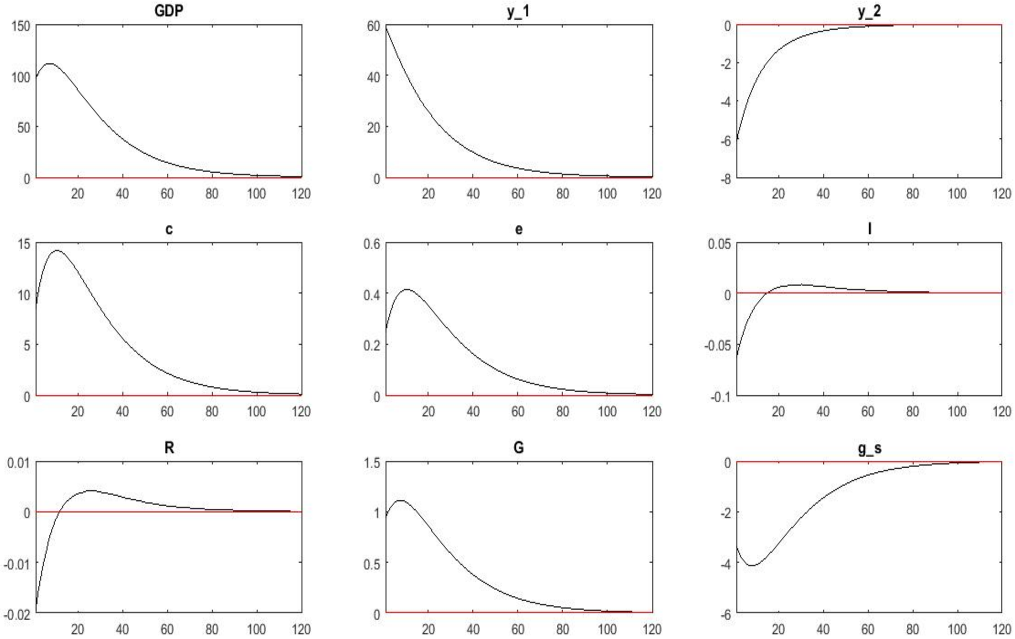


Figure A.3b: Impulse Responses to Industry 2 Productivity Shock in the Grid-connected Model

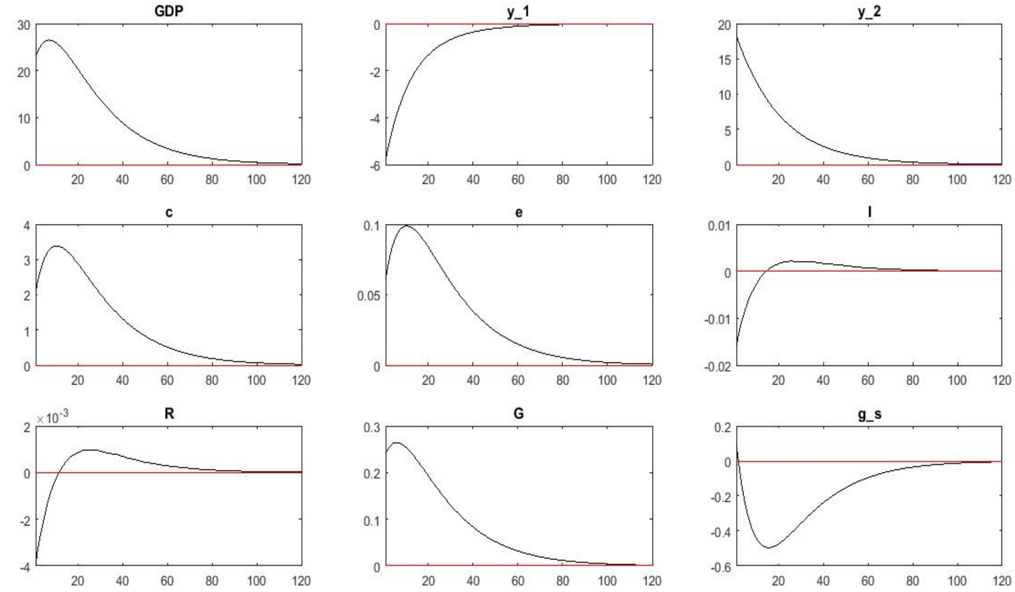


Figure A.4a: Impulse Responses to Government Generators Productivity Shock in the Benchmark Model

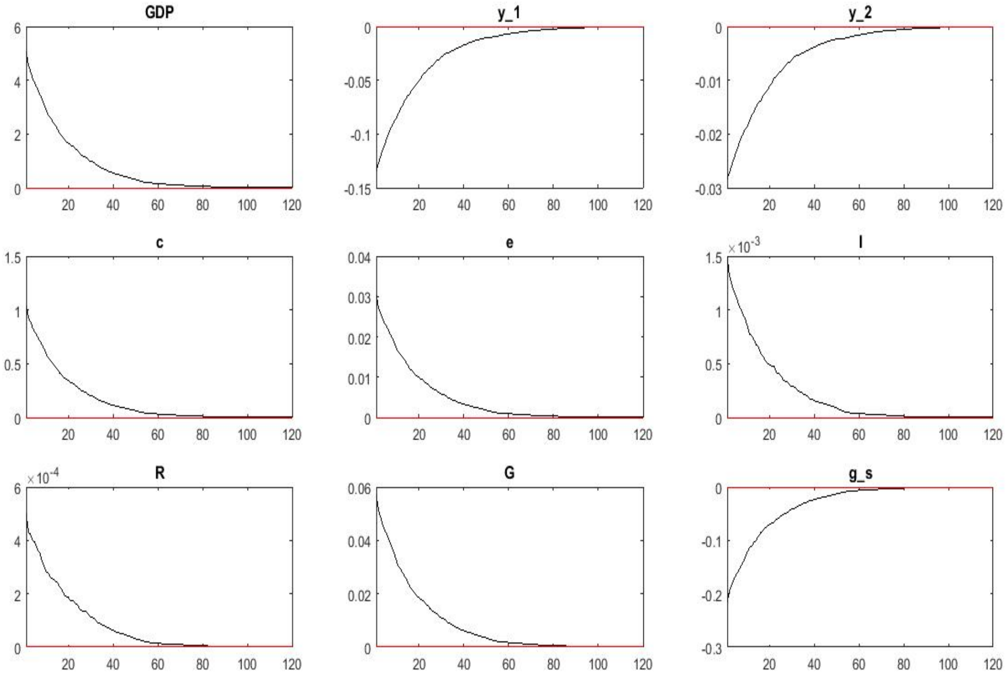


Figure A.4b: Impulse Responses to Government Generators Productivity Shock in the Grid-connected Model

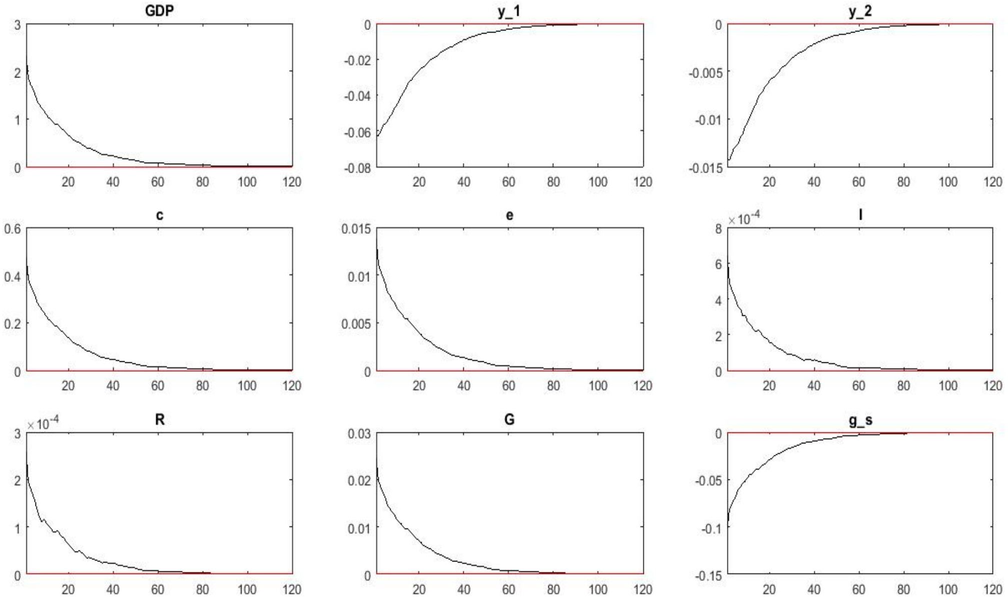


Figure A.5a: Impulse Responses to IPPs Productivity Shock in the Benchmark Model

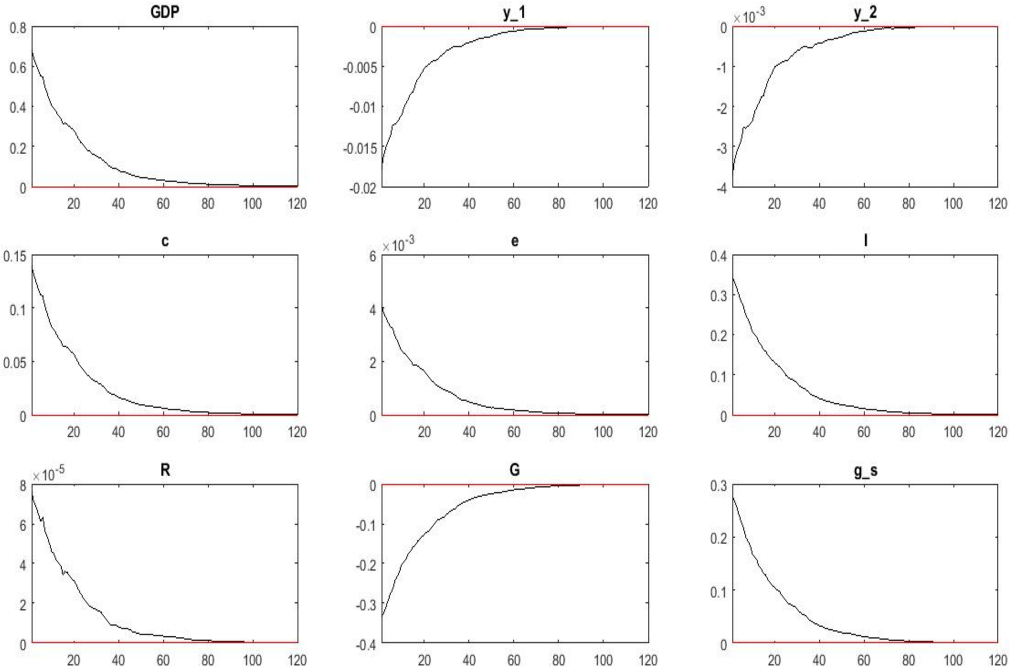


Figure A.5b: Impulse Responses to IPPs Productivity Shock in the Grid-connected Model

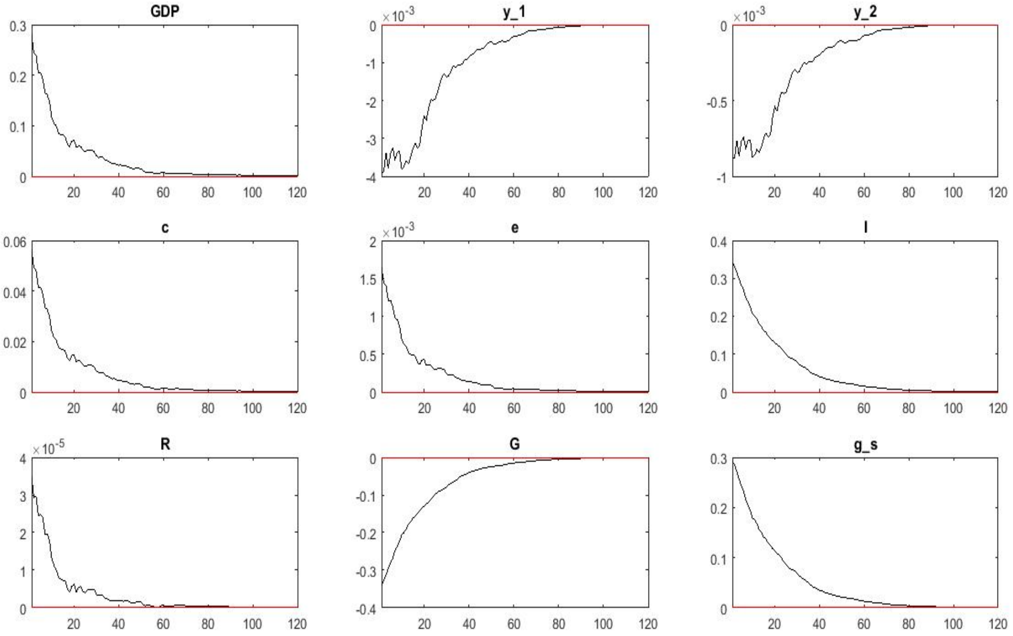


Figure A.6a: Impulse Responses to QRs Productivity Shock in the Benchmark Model

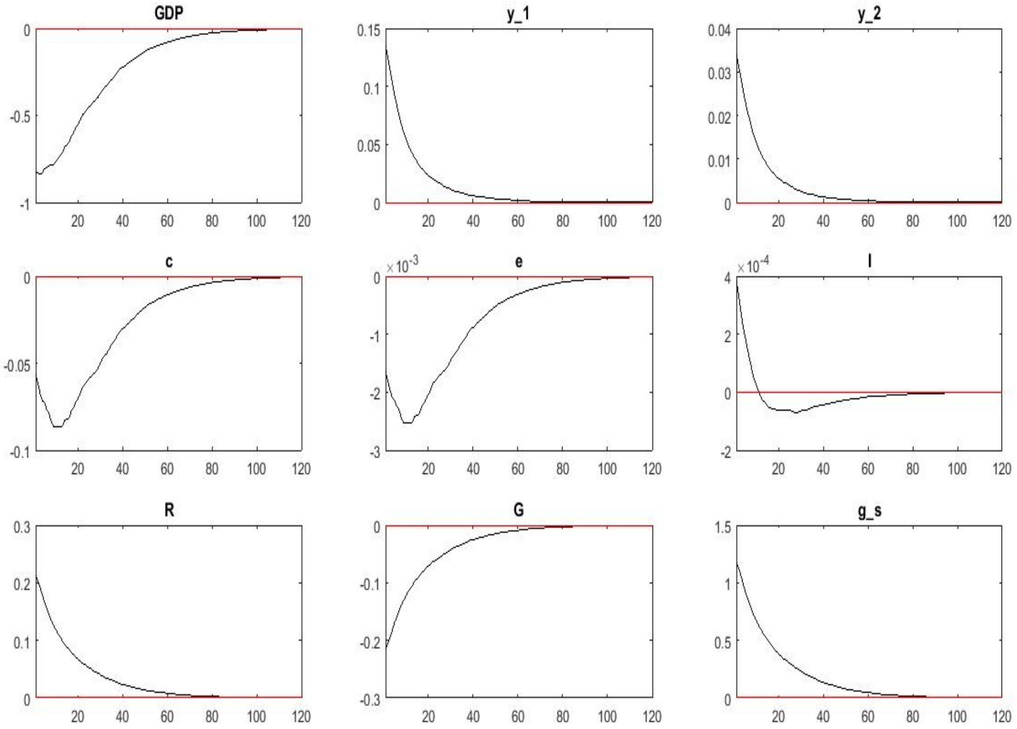


Figure A.6b: Impulse Responses to QRs Productivity Shock in the Grid-connected Model

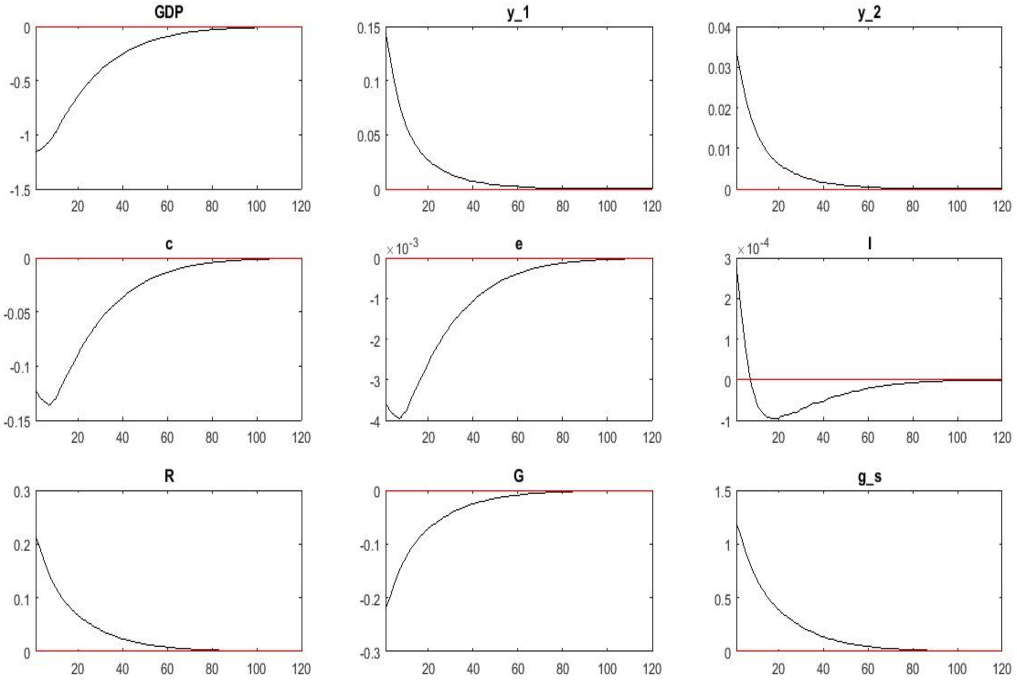


Figure A.7a: Impulse Responses to CPPs Productivity Shock in the Benchmark Model

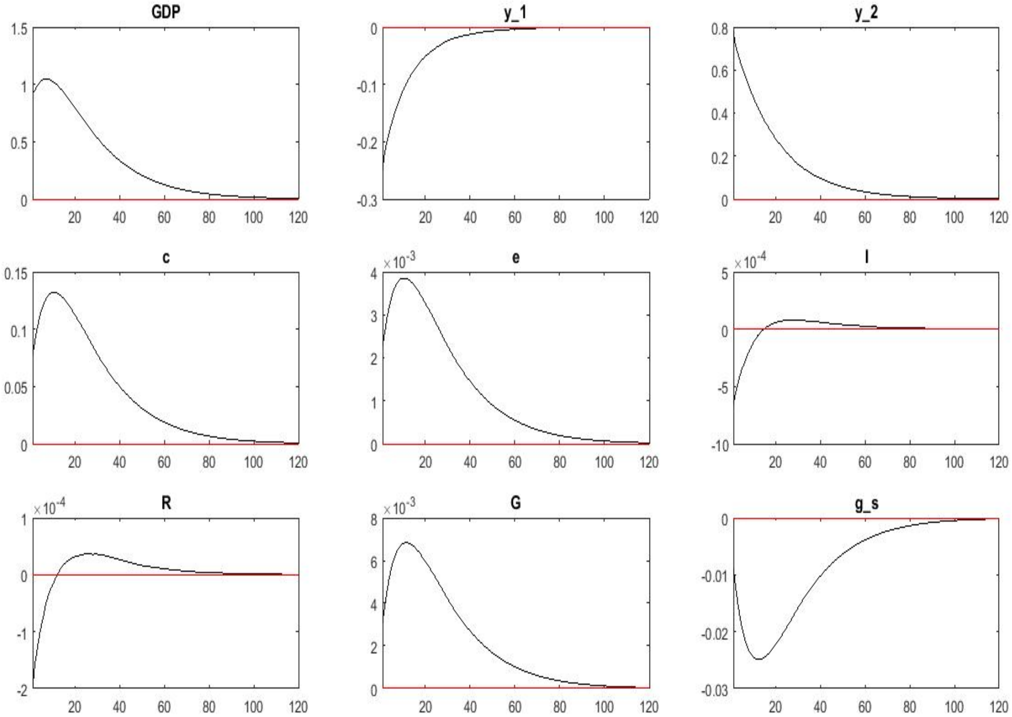
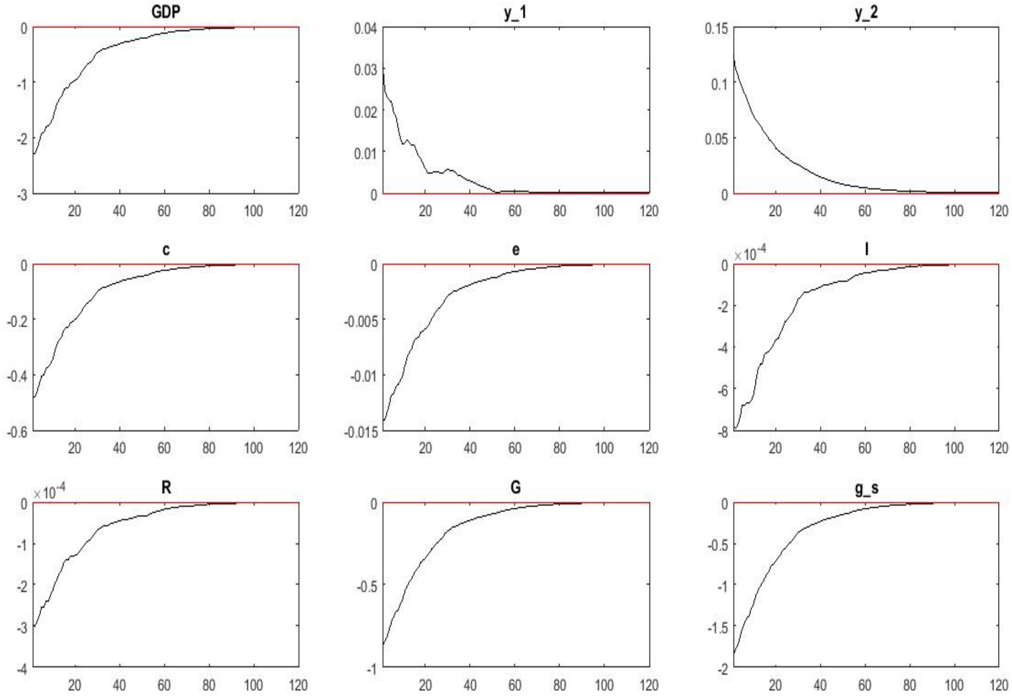


Figure A.7b: Impulse Responses to CPPs Productivity Shock in the Grid-connected Model



Technical Appendix

Derivation of Economy-Wide Resource Constraint

Household Resource Constraint:

$$k_{t+1} + c_t + n.X_t + q_t^e.e_t = (1-\tau^l)w.l_t + g\_t + (1-\tau^k)r.k_t + (1-\delta)k_t + \pi_t \tag{A.1}$$

Government Resource Constraint:

$$\tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G.G_t - r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - g\_t = g\_s \tag{A.2}$$

Total subsidy:

$$g\_s = P^G.G_t + P^I.I_t + P^R.R_t - q^e.e_t - q^s.s_t - q^{g_1}.g_t \tag{A.3}$$

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

$$\tau^l.w.l_t + \tau^k.r.k_t + (v^m - \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G.G_t - r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - \text{ъ} = P^G.G_t + P^I.I_t + P^R.R_t - q^e.e_t - q^s.s_t - q^{g_1}.g_t \tag{A.4}$$

Inserting the previous equation in the household resource constraint we find:

$$\begin{aligned}
& k_{t+1} + c_t + n.X_t + q_t^e.e_t \\
&\quad = (1-\tau^l)w.l_t + (1-\tau^k)r.k_t + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m \\
&\quad - \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G.G_t - r.k_{G,t} - w.l_{G,t} \\
&\quad - v^m.m_{G,t} - P^G.G_t - P^I.I_t - P^R.R_t + q^e.e_t + q^s.s_t + q^{g_1}.g_t + \pi_t
\end{aligned}$$

$$\begin{aligned}
\curlyeqsucc\ & k_{t+1} + c_t + n.X_t \\
&= (1-\tau^l)w.l_t + (1-\tau^k)r.k_t + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m \\
&- \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G.G_t - r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} \\
&- P^G.G_t - P^I.I_t - P^R.R_t + q^s.s_t + q^{g_1}.g_t + \pi_t
\end{aligned}$$

$$\begin{aligned}
\curlyeqsucc\ & k_{t+1} + c_t + n.X_t \\
&= \mathrm{w.l_t} - \mathrm{\tau^l.w.l_t} + \mathrm{r.k_t} - \mathrm{\tau^k.r.k_t} + (1-\delta)k_t + \tau^l.w.l_t + \tau^k.r.k_t + (v^m \\
&- \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} + P^G.G_t - r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} \\
&- P^G.G_t - P^I.I_t - P^R.R_t + q^s.s_t + q^{g_1}.g_t + \pi_t
\end{aligned}$$

$$\begin{aligned}
\curlyeqsucc\ & k_{t+1} + c_t + n.X_t \\
&= \mathrm{w.l_t} + \mathrm{r.k_t} + (1-\delta)k_t + (v^m - \delta^C)\left(m_{I,t} + m_{G,t} + m_{C,t}\right) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} \\
&+ P^G.G_t - r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - P^G.G_t - P^I.I_t - P^R.R_t + q^s.s_t \\
&+ q^{g_1}.g_t + \pi_t
\end{aligned}$$

$\succcurlyeq k_{t+1} + c_t + n.X_t$

$= \mathrm{w.l_t} + \mathrm{r.k_t} + (1-\delta)k_t + (v^m - \delta^C)\big(m_{I,t} + m_{G,t} + m_{C,t}\big) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h}$

$- r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - P^I.I_t - P^R.R_t + q^s.s_t + q^{g_1}.g_t + \pi_t$

$\succcurlyeq k_{t+1} + c_t + n.X_t = \mathrm{w.}(l_H + l_I + l_G + l_{Y,1} + l_{Y,2} + l_X + l_2 + l_C) + \mathrm{r.}(k_H + k_I + k_G +$
$k_{Y,1} + k_{Y,2} + k_X + k_2 + k_C) + (1-\delta)k_t + (v^m - \delta^C)\big(m_{I,t} + m_{G,t} + m_{C,t}\big) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} -$
$r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - P^I.I_t - P^R.R_t + q^s.s_t + q^{g_1}.g_t + \pi_t \qquad (A.5)$

Now, holding Decreasing Returns to Scale (DRS) we have:

$\pi_t = {\pi_t}^H + {\pi_t}^I + {\pi_t}^X + {\pi_t}^{Y,1} + {\pi_t}^{Y,2} + \pi_{g_2}$

$\succcurlyeq \pi_t = (P^H.H_t - w.l^H - r.k^H - \mathrm{v^h.h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m.m}_t^I) + (\mathrm{n.X_t} - w.l^X -$
$r.k^X - q^s.s_t) + (Y_{1,t} - w.l_{Y,1} - r.k_{Y,1} - q^{1,g}.g_{1,t}) + (Y_{2,t} - r(k_c + k_2) - w(l_c + l_2))$
$-v^m.m_{C,t} - q^g.g_g$

$\succcurlyeq k_{t+1} + c_t + n.X_t = \mathrm{w.}(l_H + l_I + l_G + l_{Y,1} + l_{Y,2} + l_X + l_2 + l_C) + \mathrm{r.}(k_H + k_I + k_G +$
$k_{Y,1} + k_{Y,2} + k_X + k_2 + k_C) + (1-\delta)k_t + (v^m - \delta^C)\big(m_{I,t} + m_{G,t} + m_{C,t}\big) + (\mathrm{v^h} - \mathrm{v^e})\mathrm{h} -$
$r.k_{G,t} - w.l_{G,t} - v^m.m_{G,t} - P^I.I_t - P^R.R_t + q^s.s_t + q^{g_1}.g_t + (P^H.H_t - w.l^H - r.k^H -$
$\mathrm{v^h.h}_t) + (P^I.I_t - w.l^I - r.k^I - \mathrm{v^m.m}_t^I) + (\mathrm{n.X_t} - w.l^X - r.k^X - q^s.s_t) + (Y_{1,t} - w.l_{Y,1} -$
$r.k_{Y,1} - q^{1,g}.g_{1,t}) + (Y_{2,t} - r(k_c + k_2) - w(l_c + l_2)) - v^m.m_{C,t} - q^g.g_g)$

$k_{t+1} = Y_{A,t} - c_t - \mathrm{v^e.h}_t + (1-\delta)k_t - \delta^C\big(m_{I,t} + m_{G,t} + m_{C,t}\big) \qquad (A.6)$