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Global shocks and fiscal stimulus: a tale of an oil-dependent-exporting country

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Abstract

Global shocks potentially distort economy's achieved equilibria. Considering the 2020 global crude oil price shock and the 2019 coronavirus disease pandemic, this study proposes an energy and environment integrated general equilibrium model to analyze the economic, energy, and environmental effects of these global shocks on Nigeria, a developing, oil-producing, oil-dependent, and oil-exporting country. Furthermore, the mitigating roles of a fiscal stimulus–response package (palliative) are investigated and analyzed. Generally, the developed model predicts a decline in the level of economic activities. The study results are unsurprising due to Nigeria's heavy reliance on crude oil. However, sectorial-specific impacts exist as some sectors experience output declines while others do not. Environmental quality is improved since more carbon is abated, nonetheless. Carbon intensities increased given that the price effects outweighed the quantity effects— reduced emission results from reduced economic activities and not from technological progress. The results further show a revenue-abatement paradox; a fixed carbon tax approach minimizes the tax revenue loss but may discourage carbon abatement. Conversely, the ad valorem and specific carbon tax systems encourage carbon abatement but reduce carbon tax revenues. The government's fiscal policy stimulus–response (palliative) action dampens the impact of these global shocks on both the domestic agents and the overall economy. The results are robust and can be applied to the experiences of other developing oil-producing, oil-exporting, and oil-dependent economies.

Keywords: CGE, Crude oil, Coronavirus, Fiscal stimulus, Simulation, Nigeria

Introduction

Several contributing events made 2020 unique and remarkable, especially for a heavily dependent oil-producing and exporting country like Nigeria, which depends heavily on its oil revenue. Among these events, the 2020 global crude oil price shock and the coronavirus disease (COVID-19) pandemic significantly affected the Nigerian economy. The substantial impacts of these global exogenous shocks on an economy cannot be over-emphasized. Many empirical studies have investigated the impacts of the 2020 crude oil price shock and the COVID-19 (2019 coronavirus disease) pandemic on economies and markets. Examples include the studies on crude oil price shocks (Garzon and Hierro 2021; Gong et al. 2021), crude oil markets (Okorie and Lin 2020a, 2020b), and the

COVID-19 pandemic (Okorie and Lin 2021a, 2021b). These studies validate the significant impact of these shocks on an economy (or markets); hence, it is almost a given that the crude oil price fall and COVID-19 pandemic would substantially affect an economy, especially an oil-producing, exporting, and oil-dependent economy like Nigeria. Thus, this article studies the (combined) effects of the COVID-19 pandemic and the global crude oil price on Nigeria, an oil-producing, dependent, and exporting economy. Second, these impacts are broadly investigated via the economic and environmental channels and performances. Third, this study confirms whether the 2020 Nigerian carbon abatement is due to technological progress or economic decline. Finally, given these shocks, the saving roles of a targeted fiscal stimulus policy response are proposed and investigated.

Nigeria is the leading oil-producing and exporting country in Africa and the eleventh in the world.[1] It is equally dependent on the oil revenue for financing its needs. Based on historical events and stylized facts, Nigeria's crude oil export revenue accounts for about 95% of the foreign or international exchange earnings, 98% of the total earnings from exports, 65% of the budgetary revenue, about 14% of the gross domestic product (GDP), and about 83% of the central government revenue.[2] As such, the drastic fall in the global export price of crude oil in 2020 was a heavy blow to the Nigerian economy. Then, the COVID-19 pandemic hit just as the country attempted to adjust to the crude oil price shock. The effects were intense for the Nigerian crude oil sector, all sectors and agents in the economy, and the rest of the world. These significant impacts resulted largely from the consequences of the spreading coronavirus, such as lockdowns, loss of jobs, and business closures.

Existing studies have generally examined the effects of the global oil price shock or the COVID-19 pandemic on an economy or market, and different methodologies have been adopted in examining the impact of these shocks on an economy. These methods range from (non-)parametric estimations to calibration techniques; among these techniques, this study adopts a computable general equilibrium (CGE) model. CGE models rarely hold determining factors constant while investigating the effects of shocks or policies in an economy; however, CGE models adopt a holistic approach that incorporates the whole of the economy (agents, industries, international markets, and domestic markets) while examining the effects of shocks or policy changes. Hence, it is noteworthy to investigate the effect of these shocks on the Nigerian economy using the CGE framework. As such, this study provides a brief preview of research using similar calibration techniques to investigate the impact of these shocks, crude oil prices, and the COVID-19 pandemic. For instance, using the CGE modeling framework, Jia et al. (2021) investigated the effects of the crude oil price and the COVID-19 pandemic on China, concluding that these shocks adversely hurt China's economic performance. Liu et al. (2015) isolated the single impact of the crude oil price shock on an economy and arrived at a similar conclusion using a CGE modeling framework. Their findings also support that the crude oil price shock affects economies adversely, with China as their case study.

[1] See https://www.indexmundi.com/g/r.aspx?v=88&t=20 (accessed in July 2021).

[2] See Doris Dokua Sasu's article on Statista, 'Contribution of oil sector to GDP in Nigeria 2018–2021' (https://www.statista.com/statistics/1165865/contribution-of-oil-sector-to-gdp-in-nigeria/).

Similarly, Pradhan and Ghosh (2021a) isolated the single impact of the COVID-19 pandemic in a CGE model framework, determining that the pandemic adversely affected both the economic agents and the overall economy.

Little or nothing exists on the combined impacts of these shocks on an economy, especially concerning an economy heavily dependent on crude oil products and exports. Limited studies have evaluated the environmental effects of these shocks on an economy. Existing studies mainly investigated the economic implications of these shocks while ignoring their environmental effects, even for a heavily dependent economy. Furthermore, existing studies have failed to sufficiently determine how these shocks affect the economic performance of a heavily oil-producing, dependent, and exporting country. The extant literature is also unclear on the environmental effects of these shocks on an oil-dependent, producing, and exporting economy and whether the reduced carbon emissions are due to technological progress or economic downturn. Other unexplored areas include possible and targeted fiscal stimulus policy responses the governments can adopt to save the situation and how such a fiscal stimulus package would improve the economic welfare situation.

This study provides evidence-based answers to these questions; therefore, the significance and rationale of this study are evident in its state-of-the-art contributions in terms of the (joint) environmental and economic impact of the two global shocks (oil price and COVID-19) on an oil-producing, dependent, and exporting country. Furthermore, this research investigates whether the reduced carbon emission results from technological progress or production decline and the saving role of the fiscal stimulus package in such situations. This study provides empirical evidence of the responses of an oil-producing, dependent, and exporting economy toward the global oil price shock and the COVID-19 pandemic. Next, this study reveals the economic effects of these shocks and further shows the accompanying environmental effects on an oil-dependent, producing, and exporting nation. Furthermore, this study reveals the cause of the reduced emissions between technological progress and reduced production activities. Finally, this article proposes and evaluates the effects of targeted fiscal stimulus policy action and palliatives toward remedying the economy, given these global shocks. Analytically, an energy and environment integrated computable general equilibrium (EEICGE) model was developed for this purpose and adapted to the Nigerian data. Then, eight different scenarios were designed, aside from the business-as-usual (BAU) scenario, to reflect the effect of these shocks and the role of a fiscal stimulus package response on an oil-dependent, producing, and exporting economy like Nigeria.

The rest of this scientific study is structured as follows. Section "Literature review" presents a discussion of existing studies that are related and relevant to this study. Section "Empirical strategy" develops the EEICGE model and discusses the Nigerian Social Accounting Matrix (SAM) and the scenario designs. The discussion of the simulation results and findings, robustness tests, and presentation of study strengths and weaknesses are presented in Section "Results and discussions", while Section "Conclusion and policy implications" concludes on the aim and results of this study and provides suggestions based on the findings.

Literature review

Existing studies have shown that both the crude oil price shocks and the COVID-19 pandemic have substantial effects on different economies and financial markets (Okorie and Lin 2021a, 2021b, 2020a, 2020b; Liu et al. 2015). Furthermore, crude oil prices also substantially affect other markets (Demirer et al. 2021; Jammazi and Nguyen 2017). In investigating the impacts of exogenous shocks on an economy, the CGE modeling approach has been utilized (Agbahey et al. 2020). The CGE model has been a powerful policy evaluation and shock analysis tool. Many fields have adopted CGE because it can capture flows and relationships within economic agents and between an economy and other economies or the rest of the world. It has been adopted in the area of energy economics (Lin and Jia 2019b, 2019a), energy finance (Liu et al. 2015), climate economics (Mayer et al. 2021; Pradhan and Ghosh 2021b), labor economies (Agbahey et al. 2020; Okorie 2019), and macroeconomic policies (Andre et al. 2008). It has also been used for crude oil shock (Liu et al. 2015), COVID-19 pandemic shock analysis (Pradhan and Ghosh 2021a), and combined shocks (Jia et al. 2021). Jia et al. (2021) noted that the crude oil price shock and the COVID-19 pandemic created an economic downturn, championed by the factor input effects and a reduction in carbon emissions. Similarly, Pradhan and Ghosh (2021a) pointed out that the pandemic had a long run effect on the national economic output, income of the households, carbon emissions, and prices.

Existing studies have explored the linkages between crude oil price changes and the environment (Jakada et al. 2020; Verleger 2011). One of the key aspects of this study is examining the causal link between the crude oil price and environmental quality in the presence of the COVID-19 pandemic. In the absence of the COVID-19 pandemic, the intuitive link illustrating the relationship between the oil price and environmental quality is from the crude oil price changes to crude oil output changes, then to carbon emissions (a measure of environmental quality); however, the COVID-19 pandemic enhances the impact because of its effects on the overall output level. For instance, Aljadani et al. (2021) showed that the crude oil price shock significantly affects both environmental quality and economic growth, and the COVID-19 pandemic validates the environmental Kuznets curve in the long run. Their study was performed for the Kingdom of Saudi Arabia; however, similar findings held for other economies. Jakada et al. (2020) confirmed a substantial effect of the oil price on the environmental quality in Nigeria, which also holds for the top 10 global emitters of carbon (Ullah et al. 2020) in the Gulf Cooperation Council countries (Ebaid et al. 2022).

Fiscal policy stimulus packages and other recovery strategies are essential during these shocks. For instance, the COVID-19 pandemic has significantly impacted sustainable and fossil fuel energy sources (Rempel and Gupta 2021; Kuzemko et al. 2020). There is a need for targeted stimulus package responses or interventions on renewable energies, especially in economies with developing renewable energy prospects (Akrofi and Antwi 2020). The impacts of these global shocks also trickle down to the stock markets (Gregory 2022; Chen et al. 2021; Wu et al. 2021; Youssef et al. 2021), financial markets (Shahzad et al. 2021; Rahman and Mamun 2021; Harjoto et al. 2021), crude oil and gas markets (Ahundjanov et al. 2021; Alqahtani et al. 2021; Bourghelle et al. 2021; Ma et al. 2021; Xu et al. 2021; Corbet et al. 2021), market connections (Tiwari et al. 2022; Ali et al. 2021; Bouri et al. 2021), solid waste management (Sarmento et al. 2022; Richter et al.

2021; Wang et al. 2021; Dharmaraj et al. 2021; Sharma et al. 2020), energy trade and returns (Michail and Melas 2021; Saif-Alyousfi and Saha 2021; Szczygielski et al. 2021), sustainable development goals, (Fenner and Cernev 2021), the environmental and economic domain (Mofijura et al. 2021; Nundy et al. 2021; Wang and Su 2020), mobility (Thombre and Agarwal 2021), and psychological effects (Wang and Xue 2021).

These studies present evidence to support the effect of the crude oil price shock and the COVID-19 pandemic on economies and markets; however, none have considered their (combined) effects on an oil-dependent, producing, and exporting country that depends heavily on oil revenue. Furthermore, existing studies fail to introduce and evaluate the remedying effect of a fiscal stimulus policy package, or palliatives, given these shocks. This study fills these gaps by designing eight scenarios to capture these exogenous shocks in the Nigerian economy. The results confirm that there are aggregate economic downturns and environmental and climate conditions improvements since the level of carbon emissions is reduced. Some industries recorded positive growth at the firm level, while those closely associated with the crude oil industry had negative growth. Furthermore, the Nigerian government's palliatives dampened the effect of these shocks on the country's economy. The rest of the details are presented in the following sections.

Empirical strategy

The EEICGE model

The CGE modeling approach has been widely applied for policy analysis and evaluations (Zhai et al. 2021; Pradhan and Ghosh 2021a, b; Okorie 2019; Lin and Jia 2019a, b, 2016). A CGE model is a system of equations that describes an economy concerning the agents' decisions, choices, and optimization behaviors, otherwise called the Walras Paradigm. The CGE model adopted to analyze the impact of the 2020 global crude oil and COVID-19 shocks on the Nigerian economy is a modification of the version 2.1 standard partnership for economic policy (PEP) model (Decaluwe et al. 2013), otherwise called the EEICGE model. The EEICGE model captures the environmental quality effects of global shocks and the fiscal policy stimulus actions on a given economy.

Figure 1 shows the nine-step flowchart procedure for developing and conducting the analysis used in this study, starting from the model building to the execution of the scenarios and compiling the results for discussion. These steps should be followed to replicate this study and develop similar CGE models. The developed EEICGE model comprises nine blocks: the production block; income and savings block, subdivided into households, firms, government, transfers, and rest of the world; domestic demand block; supply and international trade block; price block, subdivided into production, international trade, and price indexes; national output block; real volume block; energy policy block; and market clearing equilibrium block. For these blocks, the sector-specific constant elasticity of technology (CET) and constant elasticity of substitution (CES) functions, τ_j and σ_j respectively, are used to model the relative choices of the EEICGE model agents. For calibration, these elasticities (for the CES and CET functions) follow the standard PEP model and the study of Okorie (2021) on the empirical production function of the Nigerian economy. Thus, the value-added elasticities follow the empirical Nigerian CES production elasticities in Okorie (2021). The extensions and improvements proposed in this EEICGE model include but are not limited to, the further

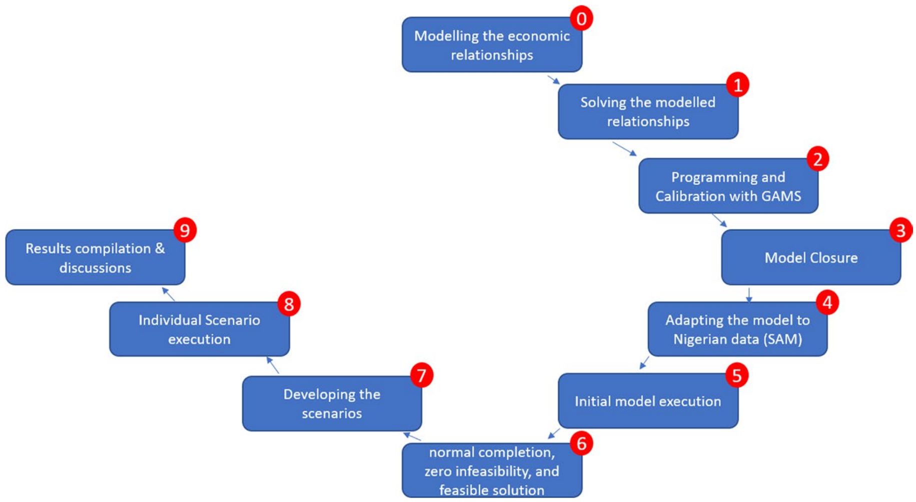


Fig. 1 Analytical procedure

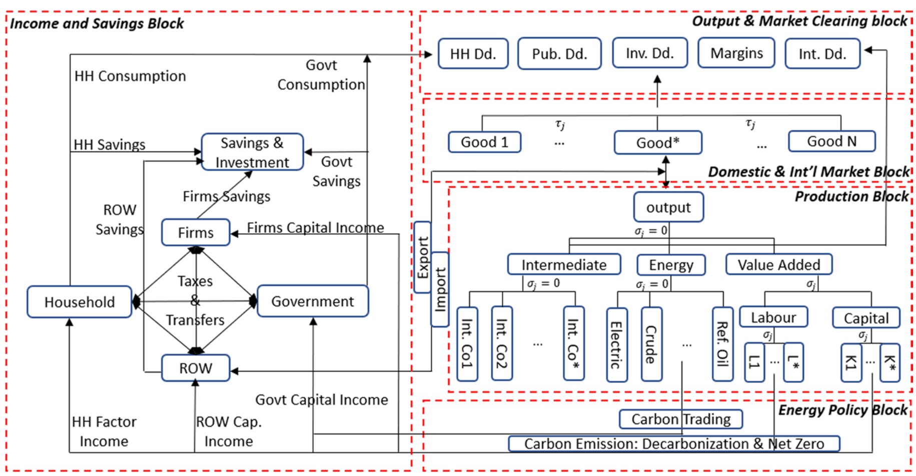


Fig. 2 Schematic framework of the EEICGE model

disaggregation of the aggregate output into a complementary function of non-energy intermediate inputs, intermediate energy inputs, value-added, modeling of the environmental (quality) block to depict the carbon emissions behavior and that of the emission intensities, and modeling the carbon trading system behavior. Figure 2 shows the proposed EEICGE model's schematic framework, and a summary of the blocks is detailed hereafter.

Production block

We assume a one-to-one mapping exists between the goods or commodities produced in the economy and the industries. The economy's output is a Leontief function of the value-added by the factors of production, the energy inputs, and the intermediate inputs. The Leontief function is also used at the second level for the energy and intermediate inputs, as these inputs are demanded complementarily for producing goods and services. In contrast, the value-added is a CES function of capital and labor. It has equally been shown that the production process of Nigeria exhibits the CES and Cobb–Douglas production properties (Okorie 2021, 2017). This model considers heterogeneities like capital and labor; thus, the model disaggregates the labor inputs as a CES function of skilled and unskilled labor input. Similarly, the capital input is a CES function of different capital input demands. Following the standard CGE model of Decaluwe et al. (2013), the EEICGE model also allows for land as a factor input; however, this depends on whether or not the factor input data for land is readily available in the SAM.

Unlike most studies (Lin and Jia 2019a, b, 2016), this model uses energy as an intermediate input demand because, while intermediate inputs get consumed for production purposes, the primary inputs are not expended, at least not in the current period. As such, the demand for primary input is a derived demand relative to intermediate input demands. Therefore, it is intuitive and economically significant that the energy inputs in producing goods and services are considered an intermediate input demand against a primary input demand. This idea is equally supported by the augment that the primary capital input for the production is nested with energy inputs, as it is not a primary input by itself (Okorie 2021). The energy inputs used in this study are crude oil, solid and other minerals, metal/iron/steel, refined oil, and electricity. The intermediate inputs include all other commodities required to produce the goods and services. These are the intermediate consumptions (Int. Co.). Nevertheless, it is essential to state that based on the nature of the electricity supply in Nigeria, this model assumes that electricity and fossil fuel are complementarily demanded, as inputs, for producing goods and services.

Income and savings block

This model includes four agents: the household (HH), firms (F), government (Govt), and the rest of the world (ROW). The household is further disaggregated into four subgroups: urban rich, urban poor, rural rich, and rural poor. These agents transfer and receive flows from one another, including other economic activities, and their relationship is captured and balanced in this model. These households receive income from their labor supply, capital ownership, and transfers from the other agents. From their income, they make consumptions, save, and pay taxes. Similarly, the firms obtain income from capital ownership and transfer income from the other agents, and the government makes its income from capital ownership and taxes from the other agents. Conversely, the government makes consumption expenditures in the form of budgets. Finally, the ROW makes income from exports to Nigeria, capital ownership, and transfers from other agents; their expenditure comprises imports from Nigeria and transfers to the other agents.

Domestic demand, supply, and international trade blocks

This block comprises domestic and imported demands because Nigeria is an open economy like most economies. As such, the domestic demand consists of partly domestically produced and foreign-imported goods. This domestic demand is further grouped into household consumption, government or public demand, investment demand, margins, and intermediate demands. This block explains the sources and use of domestic demand and their economic relationships. Since the economy is open, domestically produced goods and services can be sold abroad, outside the economy; therefore, this block deals with the supply of domestically produced goods and the exportation quantities. This relationship is analyzed using the constant elasticity of the transformation function.

Price, nominal, and real blocks

Several prices exist in an economy, as captured by the model. Generally, these prices are subdivided into three groups: domestic production prices, international prices, and aggregate price indexes. Domestic production prices include the basic, producer, and input prices. The international prices include import and export prices and free-on-board prices. Similarly, the price indexes include the deflator, investment, government, and consumer price indexes. The basic data supply the nominal values of all the variables in the system; however, some variables are normalized to real values in quantities using their prices. These may include the national output at basic price and market prices, the gross fixed capital formation (GFCF), government expenditure, and household consumption budget.

Energy policy and market clearing blocks

This energy policy block represents the carbon emission from the production activities of the industries. That is, the industries have to use some inputs in producing their output. Some of the inputs are energy inputs (fossil fuel and electricity), which implies that using these energies for production leads to carbon emission intensity and carbon trading. The emissions of carbon and its intensity are modeled as in Eqs. (1) and (2) following Li and Jia (2016). Three different forms or systems of the carbon tax are modeled: fixed, specific, and ad valorem carbon tax structures or systems. Following Zhai et al. (2021) and Lin and Jia (2019a; 2019b), these tax structures adopted in the carbon tax system are explained in Eqs. (3)–(6).

$$CE_j = \sum_{i \in EN_j} \beta_j IC_j \tag{1}$$

$$CEI = \frac{\sum_j CE_j}{\sum_j VA_j P_j^{va}} \tag{2}$$

where EN_j is the industries' energy input demands or consumption. These are a subset of the intermediate commodity demand, i, in the economy. CE_j is the carbon emission of industry j, IC_j is the intermediate input consumption of industry j, and β_j is their carbon emission coefficients or factors for the industries' energy inputs. VA_j and ${P^{va}}_j$ are value-added and the price for industry j. The total tax revenue, CTR, is a function of the carbon tax for industry j, ctx_j, and the energy use or consumption by industry j, as shown in the Eq. (3); the carbon tax systems for the ad valorem, specific, and fixed taxes are shown in Eqs. (4)–(6), respectively. t_j is the industry-specific tax rates. It is essential to point out that the fixed, specific, and ad valorem are tax structures or forms adopted to design the carbon tax system in this study (Zhai et al. 2021). As such, they could be referred to as specific carbon tax structures, forms, or systems.

$$CTR = \sum_{j} ctx_j \sum_{i \in EN_j} \beta_j IC_{ij} \tag{3}$$

$$ctx_j = \sum_{j} t_j \sum_{i \in EN_j} P_i^{EN} IC_{ij} \tag{4}$$

$$ctx_j = \sum_{j} t_j \sum_{i \in EN_j} IC_{ij} \tag{5}$$

$$ctx_j = Fix_j \tag{6}$$

Model closure

As expected, equilibrium must be attained in every CGE model to guarantee a feasible solution set; therefore, this model clears the labor market by making the exogenous labor supply for all types of labor (skilled and unskilled) equal to their industrial demand. Similarly, the capital market is also cleared; total investment equals total savings in the economy, which clears the investment market. The domestic goods market is cleared by equating domestic demand with domestic supply. Furthermore, the international market cleared by equating the export traded values with its international demand. On an aggregate level, total output equals the consumption demand of the households, investment demand, government consumption, intermediate input demand, and inventory demand. Finally, it is important to mention the Walras–Leon theory, which shows that in an $n-$ market economy, when $(n-1)$ markets are in equilibrium, the *nth* market is equally in equilibrium and is satisfied.

Empirical data

The data set for a CGE model is the SAM, which shows and summarizes the flow of funds within the economy and other ROW economies. This analysis uses the 2019 updated version of the Nigerian SAM[3]; the original 2014 SAM was built with a multi-country or regional structure, which this study updates into a single-country SAM structure by lumping other regions into the ROW. However, a SAM must be balanced before adapting it to and running a CGE model, and several balancing techniques have been developed. These techniques include manual, ordinary least squares, RAS, linear programming, and cross-entropy techniques. This article adopts the cross-entropy approach, a generalization of the RAS approach, to balance the SAM before its adaptation and the (simulation) executions of the developed EEICGE model. The cross-entropy method has been proven to outperform the other approaches (Lee and Su 2014). The SAM has 21 aggregated sectors: agriculture, crude, solid minerals, refined oil, food-beverage-tobacco,

[3] The original 2014 Nigerian SAM was constructed during the PEP programme at Addis Ababa by Henry Okodua and his team. This 2014 version is not yet published, as such, there is/are no available reference(s). Access requests can be made directly to the team. The structure of the 2014 SAM was updated from that of a multi-country/region to the case of a single country by lumping other regions/countries into the rest of the world. Also it's arguable that the structure of the Nigerian economy has not strategically and substantially changed since 2014. As such the 2014 flows are updated to their corresponding 2019 values using information from the Nigerian Bureau of Statstics (NBS), Central Bank of Nigeria (CBN) bulletin, World Bank (WB) datasets on Nigeria, etc.

Table 1 Scenarios simulation designs

Shocks	Crude	Cons	HH Sav	Prod	Lab-Sav	Import	Palliatives
BAU	X	X	X	X	X	X	X
CRD	✓	X	X	X	X	X	X
CRD-COV(C,S,M)	✓	✓	✓	X	X	✓	X
CRD-COV(S,M,P)	✓	X	✓	✓	X	✓	X
CRD-COV(S,M,P,E)	✓	X	✓	✓	✓	✓	X
CRD-COV(S,M,P,C)	✓	✓	✓	✓	X	✓	X
CRD-COV(C,S,P,E)	✓	✓	✓	✓	✓	X	X
CRD-COV(C,S,P,E,M)	✓	✓	✓	✓	✓	✓	X
CRD-COV(C,S,P,E,M)-F	✓	✓	✓	✓	✓	✓	✓

BAU = Business As Usual, CRD = Crude Oil shock, CRD-COV(C,S,M) = Crude & COVID (Consumption, Savings, Import) shocks, CRD-COV(S,M,P) = Crude & COVID (Savings, Import, Production) shocks, CRD-COV(S,M,P,E) = Crude & COVID (Savings, Import, Production, Employment) shocks, CRD-COV(S,M,P,C) = Crude & COVID (Savings, Import, Production, Consumption) shocks, CRD-COV(C,S,P,E) Crude & COVID (Consumption, Savings, Production, Employment) shocks, CRD-COV(C,S,P,E,M) = Crude & COVID (Consumption, Savings, Production, Employment, Import) shocks, CRD-COV(C,S,P,E,M)-F = Crude, COVID (Consumption, Savings, Production, Employment, Import) shocks, & Fiscal stimulus

clothing, iron/metals/steel, other industries, electricity, other utilities, construction/cement, trade, transportation, communications, arts/entertainment/recreation, finance-insurance, real estate, education, health, other services, and government. Each sector produces only one good or service, traded domestically, exported to the international market, or both. It is important to know that the government or public sector's goods (public services) are consumed domestically, not exported. The SAM also captures four disaggregated households: poor households (rural and urban) and rich households (rural and urban). There is only one firm representative, just like the government; therefore, the SAM does not consider different levels of government and firms. Finally, the investments from all the domestic economic agents (households, firms, and governments) are captured in the SAM.

Scenario designs

Generally, nine scenarios, including BAU, are simulated for the Nigerian economy, as shown in Table 1. These are the world crude oil price shock (Crude), consumption shock (Cons.), production shock (Prod.), labor-saving shock (Lab-Sav.), import shocks (Import), households savings shock (HH Sav.), and governmental incentives (Palliatives). The crude oil price shock depicts the 2020 drastic fall in the global crude oil price, which created the first-ever negative crude oil prices in the US and West Texas Intermediate markets. The cause of this is primarily attributed to the price war in March 2020 between Saudi Arabia and Russia due to their inability to reach a production-level quota and the drastic fall in the global demand for crude oil. According to Statista,[4] a fall of about 35% occurred in the average price of crude oil from 2019 to 2020.

Second, due to the total lockdown approach adopted to control the spread of the coronavirus in 2020, movements were restricted and pushable by the government; thus, some households could stock up before the lockdown commenced, while others could not. Generally, the uncertainty of the time frame before the lockdown was

[4] See https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/.

lifted made the households reduce their real consumption for sustainability purposes; therefore, consumption of commodity quantities fell during these lockdown periods. When it became more difficult to eat due to not having any food at home, some kiosks started selling food at a very high price, which the households had no choice but to pay, reducing the household savings. In other words, both the average propensity to save and the marginal propensity to save dropped substantially. Furthermore, this lockdown equally affected the Nigerian production sector, evidenced by lags in sales, turnover, and quantities sold. As such, the inventory levels substantially increased as production slowed and sales reduced, which trickled down to labor-saving alternatives. Since the firms' revenue decreased, they reduced their costs and expenses, which included retrenching workers and using labor-saving outlets. Due to the virus's rapid spread, as one economy is on lockdown, others are too. As such, international trade was affected. Prices of imports increased, and only a few imports were feasible in the country. During these periods, the Nigerian government and well-meaning private Nigerian netizens raised funds to assist households in all 37 Nigerian states. These are the scenarios designed in this paper, which evaluate their impact on the economy, environment, and climate.

The general BAU scenario captures the state of the Nigerian economy in the absence of any exogenous or external shock(s). As such, it is the endogenous calibration of the EEICGE model with the Nigerian SAM. The first (shock) simulation scenario (CRD) captures and introduces a 35% decline in the global crude oil benchmark (world crude oil export) price. In addition to the crude oil price shock, the second scenario, CRD-COV (C, S, and M), captures and introduces various COVID-19 situations. These scenarios manifest in a 5% decline in the benchmark households' consumption of goods and services, a 5% decline in the households' marginal propensity to save (MPS) and (price) adjusted average propensity to save, and a 5% increase in the benchmark global import price of goods and services. Therefore, CRD-COV (C, S, and M) consists of crude oil and COVID-19 shocks (consumption, savings, and import shocks). On this note, the third to the sixth simulation scenarios also capture the crude oil price and the COVID-19 pandemic shocks; however, the structures for the COVID-19 shocks are captured slightly differently.

The third scenario, CRD-COV (S, M, and P), interchanges the 5% shock on the households' benchmark consumption with a 5% increase in the benchmark industrial inventory change of goods and services. CRD-COV (S, M, and P) introduces and captures the fall in the production of goods and services, increased inventories, reduced sales, and a decline in firms' revenue or income. In addition to the shock composition of the third scenario, the fourth scenario, CRD-COV (S, M, P, and E), captures and introduces increased unemployment in the economy via a 5% fall in the market clearing or equilibrium level of labor supplied and demanded, evident during the sit-at-home period. Most workers lost their jobs, especially non-remote and physically present or "at-the-site" jobs. By including (excluding) a 5% household benchmark consumption (unemployment) shock in (from) the fourth scenario, the fifth scenario, CRD-COV (S, M, P, and C), is created. As such, the fifth scenario, CRD-COV (S, M, P, and C), seeks to capture a variant case of the exogenous oil price and COVID-19 pandemic shock in an economy. Similarly, the sixth scenario, CRD-COV (C, S, P, and

Table 2 Parameters calibration for factor income & transfers shares

Parameter	Rural poor	Urban poor	Rural rich	Urban rich	Firm	ROW
γ^{k}_{agent}	0.000225	0.000225	0.13545	0.3141	0.35	0.2
γ^{l}_{agent}	0.423	0.4906	0.027	0.0594		
γ^{tf}_{agent}	0.080144	0.049543	0.29612	0.359907	0.071429	0.080144

E), combined the fourth and fifth scenarios without the 5% importation shock. Again, this captures another variant scenario of the combined shocks in an economy.

The seventh scenario, CRD-COV (C, S, P, E, and M), aggregates all variances; thus, it includes all the different forms of the shocks depicting the combined effect of both the coronavirus and the crude oil price shock effect on an economy. Intuitively, CRD-COV (C, S, P, E, and M) is a more comprehensive scenario of the combined effects of the crude oil price shock and the COVID-19 pandemic shock on a conventional economy. Finally, given these shocks, the eighth scenario, CRD-COV (C, S, P, E, and M)-F, captures and introduces the fiscal policy stimulus–response and intervention action of the government to mitigate the impact of these shocks on an economy, which is otherwise called palliative. These palliatives are in the form of free food items and monies from the Nigerian government, at all levels, to households during the lockdown periods, captured by a 5% increase in the transfer payment from the governments to households. Generally, due to the similarities in the results, the primary analysis section only presents the outcomes of scenarios: CRD, CR-COV (C, S, and M), CRD-COV (C, S, P, E, and M), and CRD-COV (C, S, P, E, and M)-F. The rest of the results are provided in "Appendix 3, Figs. 11, 12, 13, 14, 15, 16, 17, and 18".

The model's parameters are calibrated for all 21 industries and 4 households. Due to space and article restrictions, Table 2 reports the capital and labor income share-calibrated values, from the Nigerian SAM data, for all agents. The income shares received by the agents due to their supply of capital and labor are represented as γ^{k}_{agent} and γ^{l}_{agent}, respectively, and the transfers share parameter is γ^{tf}_{agent}. It is important to state that the income share parameter for labor supply is the same for the two kinds of labor supply in the economy: skilled and unskilled labor. The model's simulations are conducted, and the results are presented in the next section.

Results and discussions

Economic impacts

National outputs and capital formation

The effects of the pandemic outbreaks and crude oil global price shocks on the Nigerian economy are segregated into two broad categories: economic and environmental impacts. Each of these sections is further subdivided into different measuring indicators; this subsection presents and discusses the effect of these shocks on Nigeria's national output level. All the values represent the deviation of the scenarios from the BAU scenario. Figure 2 shows the model predictions for the nominal values, and Fig. 3 shows the real or volume values for the GDP and the GFCF. GDP is measured using the three classical approaches: income, expenditure, and output. The results are all approximately equal, as expected, and the values for the

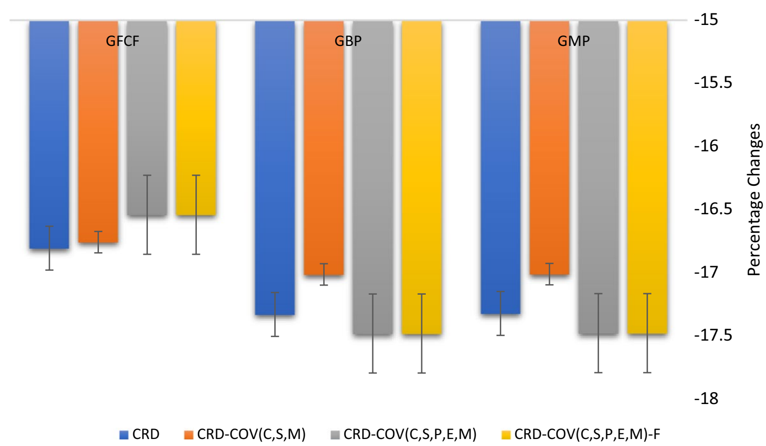


Fig. 3 Nominal output and capital formation

output-based approach are reported; thus, Figs. 2 and 3 show the GFCF, basic price GDP (GBP), and market price GDP (GMP) for the nominal and real values.

Figure 3 indicates an overall decline in the GFCF and GDP levels based on basic and market prices. This result is intuitive as it depicts the aggregate adverse effect of the coronavirus and the crude oil price shock on the Nigerian economy. The Nigerian economy is mostly labor-intensive (Okorie 2021); thus, the lockdown responses to the COVID-19 pandemic and the labor-saving alternatives resulted in a decrease in the labor market's equilibrium (labor demand and supply). These shocks were exogenously sudden; therefore, the industries had no chance or opportunity to readjust their capital-labor mix or substitution ratios such that production processes were not affected adversely during the pandemic. Instead, due to the sudden shock, businesses closed, and little or no production, selling, and marketing activities were conducted, leading to firms having many inventories and trickling down to a decline in the Nigerian national output levels. Being alive and surviving the pandemic became the main objection, and everything else became secondary. The model predicts about a 17% and 16% decline in the GDP and GFCF levels, respectively, due to the 2020 crude oil and COVID-19 pandemic shocks.

Generally, the GDP and GFCF comprise the nominal (price) and real (volume) components; therefore, the decline in the overall nominal values of the GDP and GFCF could result from one or two of the components. Figure 4 presents the model's prediction for the impact on the real or volume quantities based on the effects of the 2020 crude oil price and the COVID-19 pandemic on the Nigerian economy. As shown, the real GFCF and GDP (basic and market) quantities both declined; however, these declines were relatively small compared to the overall effects on their nominal values. On average, the model predicted about a 0.5% decline in the real GDP quantities at the basic price, about a 3% decline in the real GDP volume at the market price, and a 9% decline in the real GFCF quantities. Therefore, to thoroughly explain the changes in the nominal output values, we must consider the other component, the price factor in the nominal national output levels, as shown in the preceding subsection.

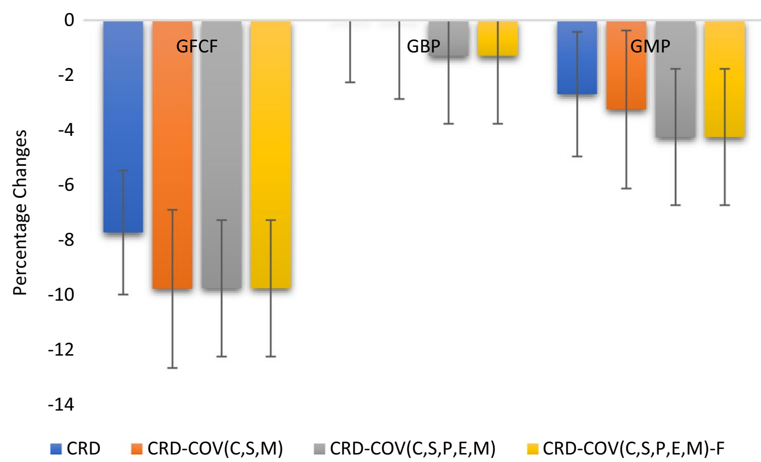


Fig. 4 Real output and capital formation

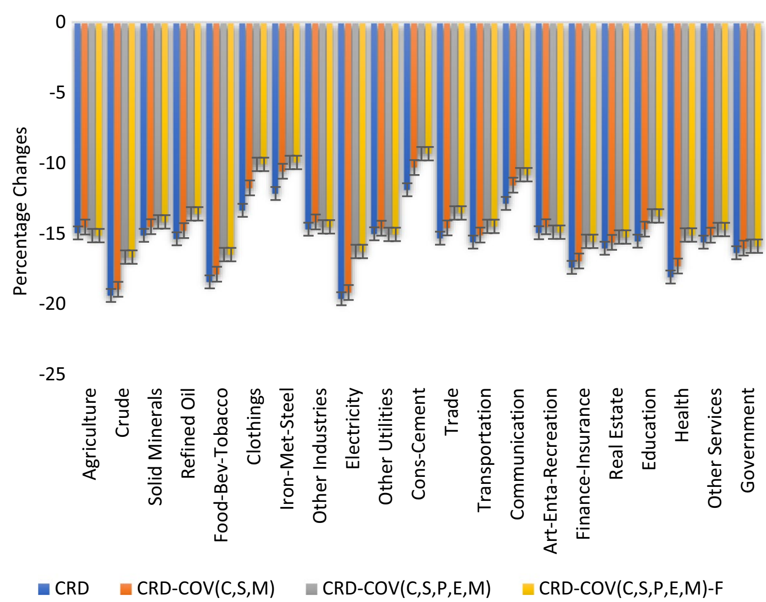


Fig. 5 Industrial basic prices

Prices

Different price prices are presented at different levels to understand the dynamics of the price system. Figure 5 presents the basic industrial or sectorial price changes for the 21 sectors, and Fig. 6 presents the aggregate price indexes. That is to say that the aggregate price indexes are summaries of the sectorial prices in the economy. The sectorial price results in Fig. 5—indicate an overall price of goods and services. This finding is not unreasonable given that the pandemic and crude oil shocks resulted in a fall in real consumption due to lockdowns, a fall in income for all agents (especially domestic agents), a decline in savings (both the average and MPS), positive inventory changes for the industries, and a decline in production activities. As such, the goods and service markets found a lower new equilibrium.

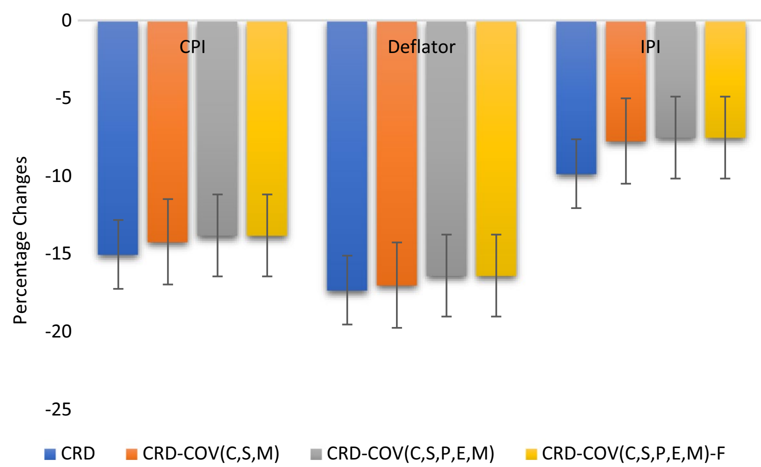


Fig. 6 Aggregate price indexes

Figure 5 shows that the first (CRD) and fifth scenarios—CRD-COV (S, M, P, and C) (see "Appendix 3, Fig. 13")—predicted the largest fall in the industrial output price levels, mainly for the crude oil and electricity sectors. From the Nigerian data (SAM), crude oil takes up about 72% of the intermediate input of the electricity sector.[5] As such, shocks that affect the crude oil extraction industry trickle down to the electricity sector; thus, only the crude oil price shock (captured in the CRD) dampened the output price of the crude oil products and the electricity industry. If we include the COVID-19 pandemic effects captured in CRD-COV (S, M, P, and C), these two industries tend to feel the impact more relative to the other industries. It is also very intuitive that when the government steps in to calm the storm in the form of providing incentives and palliatives, captured in CRD-COV (C, S, P, E, and M)-F, the effect is drastically and substantially reduced, as shown in Fig. 5.

Conversely, aggregate price levels are summary statistics of an economy's micro or sub-micro-level prices. Since price declines at the industrial levels, the aggregate price levels are also expected to decrease, which is confirmed in Fig. 6. Figure 6 shows the model's scenario results for the consumer price index (CPI), the (GDP) deflator, and the investment price index (IPI). The decline in the investment index, IPI, is the least (about 8%), and the deflator shows the highest decline of about 17%. The CPI is in the middle of the model's price index predictions. The scenarios predict about a 15% decline in the CPI of the Nigerian economy due to the effects of the 2020 global crude oil price and the COVID-19 pandemic; therefore, this implies that the price changes account for most of the decline in Nigeria's aggregate (nominal) national output level against the real output quantities.

Sectoral outputs

A closer look at the output levels of the different sectors shows an industrial-specific effect of the global crude oil price fall and the impact of the COVID-19 pandemic. The model recorded negative total aggregate output changes for the crude oil extraction

[5] This value is from the Nigerian SAM which is later presented in Table 3 of this paper.

industry and trade, which is intuitive and clearly due to the drastic global crude oil price fall and the country lockdown effects of the COVID-19 pandemic. For other sectors, such as the agricultural sector, communication, and other services, the model scenarios predicted a zero percent comparative change, while the other sectors experienced a positive comparative change in their overall output level. The agricultural sector's production and output changes do not happen instantaneously but take time from planting to harvesting seasons. In the same light, the communication and other services sectors are relatively unrelated to the crude oil crisis and the COVID-19 pandemic lockdown effects. Communication continued during the lockdown and most other services, including essential services. For the rest of the economy that experienced positive comparative change, this could be explained by the basic supply law. The fall in crude oil price reduced their production cost; as such, quantities produced are expected to increase and vice versa. Furthermore, most services, such as health and education, were not affected so much as they continued (physically or online) since they are essential services; thus, they recorded positive comparative static changes during the period.

Environmental quality impacts

Carbon emission abatement

As an oil-producing economy, the crude oil sector is significant in the Nigerian economy because it provides significant revenue for the Nigerian government and its interconnections, as an intermediate input, for the other sectors of the Nigerian economy. Table 3 shows the energy intermediate input demands for all 21 sectors of the Nigerian economy. The second column shows the proportions, in percentages, of the crude oil

Table 3 Sectorial intermediate energy input proportions (%)

Sectors	COIP	TEIP
Agriculture	0.07	1.05
Crude	41.22	43.12
Solid Minerals	12.76	63.85
Refined Oil	70.7	88.97
Food-Bev-Tobacco	1.86	3.09
Clothings	31.7	36.57
Iron-Met-Steel	31.07	89.48
Other Industries	17.13	34.54
Electricity	72.26	80.56
Other Utilities	6.58	30.56
Cons-Cement	29.89	37.08
Trade	23.85	26.18
Transportation	41.37	42.79
Communication	16.54	17.01
Art-Enta-Recreation	13.3	16.64
Finance-Insurance	23.85	25.25
Real Estate	30.47	32.75
Education	4.53	16.3
Health	17.29	23.4
Other Services	24.65	35.22

COIP is the Crude Oil Input Proportion and TEIP is the Total Energy Input Proportion

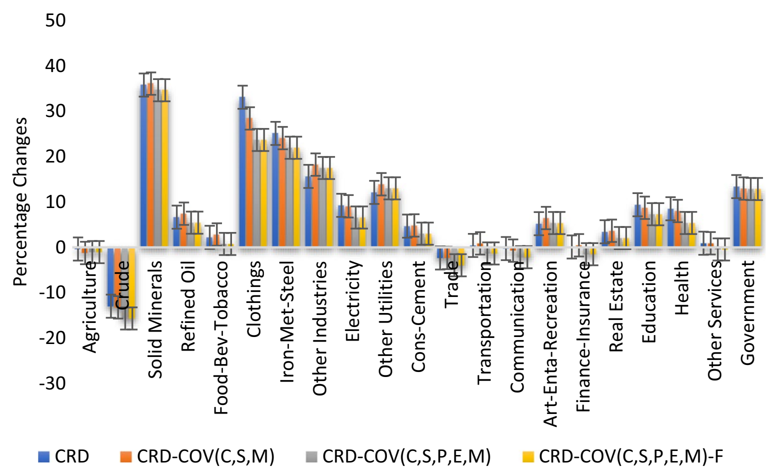


Fig. 7 Aggregate industrial outputs

intermediate demand to the total intermediate demands of all the sectors or industries; the third column shows the proportion of all the energy intermediate input demands for the industries. These are the crude oil input proportion (COIP) and the total energy input proportion (TEIP). Table 3 shows that crude oil alone is a key intermediate input consumption for most industries. Overall, the energy intermediate demand inputs take up the majority of the overall industrial intermediate demand inputs; therefore, energy policies or things that affect the energy sector of the Nigerian economy substantially affect the sectors and the level of carbon emissions or abatement.

Figure 7 confirms a reduction in the aggregate output level of the crude oil sector due to the global crude oil price and the COVID-19 pandemic; thus, the carbon emission level, a function of the energy demand or input consumption, is directly or proportionally affected. Generally, the model scenarios predict a reduction in carbon emissions. Scenario 4, CRD-COV (S, M, P, and E), predicts the largest carbon abatement of about 2.6% (see "Appendix 3, Fig. 15"). This scenario depicts the effects of the global crude oil price and the pandemic effects, except for real consumption and palliative shocks. With these two shocks, the predicted level of carbon abatement was about 2.4%. Therefore, the effects of the global crude oil price fall and the COVID-19 pandemic (via the production channel) decreased the intermediate consumption levels of crude and the overall total energy intermediate input, trickling down to emitting less carbon and abating more, as shown in Fig. 8.

Carbon intensity

The carbon emission or abatement levels only consider carbon usage without considering the output levels or value-added as a result of these energy input demands; hence, carbon intensity solves this problem, as shown in Eqs. (1) and (2). From Fig. 9, given the increase in carbon emission abatement, the overall increase in carbon intensity only suggests a relatively more decrease in the levels of the aggregate value-added. Taking the eighth scenario, CRD-COV (C, S, P, E, and M)-F, for example, the model predicts an overall 18% fall in the price of the value-added and sector-specific changes in the value-added level of the Nigerian economy due to the effects of the global crude oil price and

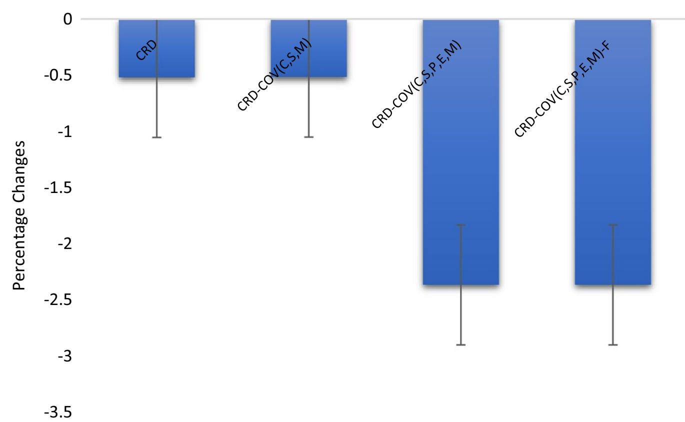


Fig. 8 Carbon emission abatement (CEA)

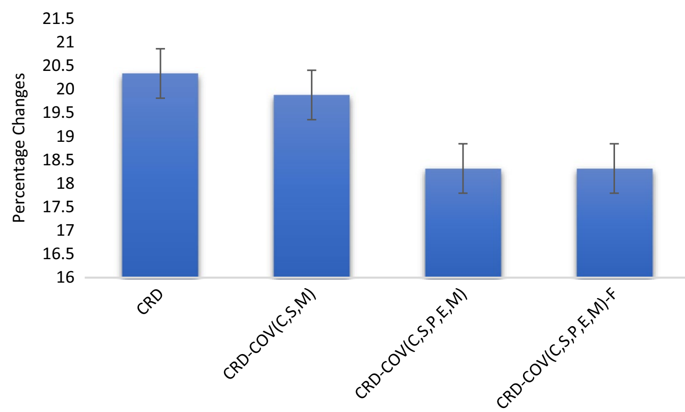


Fig. 9 Carbon emission abatement intensity (CEAI)

COVID-19 pandemic effects. Therefore, the 18% price decline in the value-added outweighs the about 2.5% carbon abatement level and thus, increasing the carbon intensity levels. It is important to mention that most sectors recorded positive growths or changes in their levels of value-added; hence, the changes in the carbon intensity are primarily nominal, driven by the value-added price changes.

Carbon trading system

Finally, for the impact of the 2020 global crude oil price and 2019 coronavirus shocks on the Nigerian economy, we present the carbon trading system behavior or changes due to these exogenous shocks. Figure 10 presents the model's scenario results. Carbon trading primarily deals with the sale of carbon emission permits or rights to the industries in an economy, which can be done through the taxation system, otherwise, the carbon tax system. Furthermore, there is no clear distinction between the Nigerian carbon trading system and the carbon tax system because the Nigerian carbon trading market is not yet well developed. Therefore, the carbon taxation system is adopted as a proxy for the overall carbon trading system. This model considered three different tax structures or forms in designing the carbon tax system—the fixed, specific, and ad valorem carbon tax structures or systems—shown in Eqs. (4), (5), and (6), respectively. Generally, the

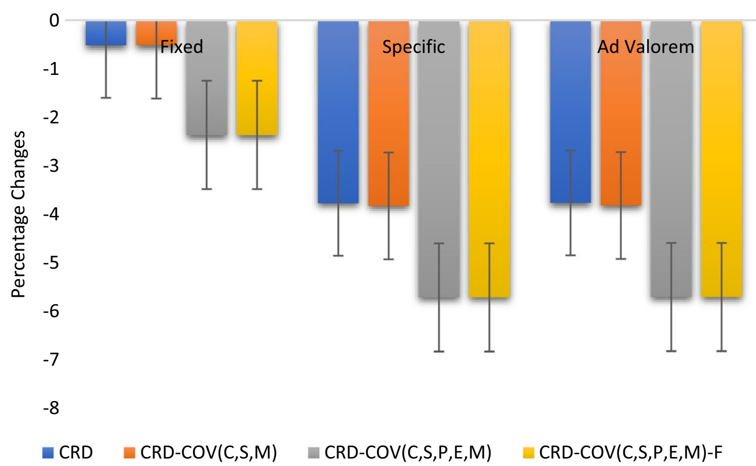


Fig. 10 Carbon emission taxation systems

ad valorem carbon tax mechanism shows a substantial fall in the carbon tax revenue or income, while the fixed carbon tax system presents the least. This result is intuitive, as the price component in the ad valorem approach drives most of these changes; therefore, under the crude oil price and COVID-19 pandemic scenarios, the concerned authorities should instead adopt the fixed carbon tax structure since it experiences the most negligible decline in the tax revenue and thus minimize the losses or costs for the authorities. However, there are no guarantees that the fixed carbon tax structure can encourage carbon abatement because the firms might aim to reduce per-unit carbon tax expenditure on their energy use, discouraging carbon abatement; therefore, a trade-off or paradox is depicted. That is to say that the fixed carbon tax structure improves carbon tax revenue and might discourage carbon abatement. Conversely, the specific and ad valorem carbon tax structures encourage carbon abatement and hurt carbon tax revenues; hence, the choice of the carbon tax structure or system depends on the set targets or goals of the authorities or governments.

Generally, the findings of this study agree with similar studies that investigate the economic and environmental effects of the crude oil price shock and the COVID-19 pandemic on an economy. The economic output and the welfare of the economic agents deteriorated due to these shocks, similar to the findings by Jia et al. (2021) and Pradhan and Ghosh (2021a). These shocks also improved the quality of the environment by reducing carbon emissions, mainly due to a decline in production activities against technological progress. These effects were also the outcome of existing similar studies (Jia et al. 2021; Pradhan and Ghosh 2021a; Norouzi et al. 2020a); therefore, it is plausible to conclude that these global shocks adversely impacted the national output, agents' welfare, carbon emission, and prices. Moreover, the impact on Nigeria is relatively higher due to the heavy reliance of the Nigerian economy on crude oil. The extent of the comparative static changes for Nigeria is relatively greater than the other economies examined in similar studies. Similarly, aside from the overall economic impacts, the COVID-19 pandemic has impacted other sectors, such as the oil and gas sector (Norouzi 2021), stock markets (Okorie and Lin 2021a, 2021b), and electricity sector (Norouzi et al. 2020a, b). In contrast, crude oil shocks substantially affect economies (Liu et al. 2015) as well as

Table 4 Interval robustness shocks

Panel A	CES Sigma						
Main Analysis	1.00026						
Robustness X	1.200312						
Robustness Y	0.800208						
Panel B	Crude	Cons	HH Sav	Prod	Lab-Sav	Import	Palliatives
Main Analysis	35%	5%	5%	5%	5%	5%	5%
Robustness A	33%	3%	3%	3%	3%	3%	3%
Robustness B	37%	7%	7%	7%	7%	7%	7%

other markets such as the stock markets (Okorie and Lin 2020a), exchange markets (Jammazi and Nguyen 2017), and cryptocurrency markets (Okorie and Lin 2020b).

Robustness tests

Okorie (2021, 2017) states that the Nigerian production behavior exhibits both the CES and CD production functions; therefore, based on the elasticity parameter (rho) in Okorie (2021), a CES elasticity parameter (sigma) value of 1.00026 is computed and applied in the EEICGE model, as shown in Table 4. Moreover, this suggests that the factor inputs are suitable substitutes. First, a couple of robustness tests were carried out on the EEICGE model's predictions by varying the CES sigma parameter values around the initially computed value while maintaining the CES nature of the production function. In particular, the sigma was set to 1.200312 (Robustness X) and 0.800208 (Robustness Y), signifying a ±20% change from the original sigma value. These robustness results are presented in "Appendix 1, Tables 5, 6, 7, 8, 9 and 10". Second, two other approaches are used to conduct robustness checks on a CGE model's scenario predictions: Monte Carlo and Range checks. The former assigns random values, and the latter uses a range or confidence intervals to check the robustness of the model predictions. This paper also adopts the range-checking approach, captured in Robustness A and B, signifying a ±2 percentage point change from the primary analysis shock levels. These robustness results are presented in "Appendix 2, Tables 11, 12, 13, 14, 15, and 16". Generally, the EEICGE model's predictions are in the same direction, and the magnitudes are relatively equal for all the scenarios conducted in this study. These findings support and reaffirm that the EEICGE model's predictions are robust and reliable.

Study strengths and weaknesses

This study investigates the economic and environmental effects of the crude oil price shock and the COVID-19 pandemic. This study's key strengths can be broadly categorized into three forms. First, the analysis of the (combined) effects of two exogenous shocks (oil price and COVID-19) on an oil-producing, oil-exporting, and oil-dependent economy. Second, we investigated these effects on environmental quality and economic performance. It is understood that both the COVID-19 pandemic and the crude oil price shocks impact an economy environmentally, economically, and otherwise; thus, it is noteworthy to itemize the economic and environmental effects of these shocks on an economy that heavily depends on and produces and exports crude oil. Finally, this study makes a state-of-the-art contribution in introducing the EEICGE model (static version), which integrates the energy block into the standard CGE model. As such, it models behaviors, such as intermediate energy input demands and prices, carbon emissions, emission intensities, and carbon taxation, allowing researchers and scholars to investigate the environmental quality effects of some shocks in an economy.

Notwithstanding, one of this study's inherent weaknesses is assessing existing and available SAM data for Nigeria. The major challenge is the nonexistence of publicly available Nigerian SAM from the Nigerian statistical data agencies, which limits the ability of studies depending on the SAM. Next, this current EEICGE model does not disintegrate the carbon emission contributions due to the consumption of the different energy sources in an economy like Nigeria, and it does not include proper modeling of an economy's conventional carbon trading system. Currently, these shortfalls are being integrated into the new version(s) of the EEICGE model.

Conclusion and policy implications

The Nigerian economy is a major oil-producing economy in Africa and worldwide, and the oil sector accounts for a considerable share of the national income in Nigeria. This study examines the impact, economically and environmentally, of the 2020 global crude oil price shock and the COVID-19 pandemic on the Nigerian economy. The results are robust and confirm that these shocks resulted in an overall decline in the price levels and the aggregate output measures of the economy; however, there were sector-specific effects. The crude oil sector and other sectors that mainly depend on crude oil, like the electricity sector, recorded a sectorial output decline, and the output of the other sectors grew positively. Fewer carbon emissions were noted, implying more carbon abatement and increased carbon intensity, mainly accounted for by the sharp price declines. Generally, the government's incentives in the form of palliatives dampened the effects of these exogenous global shocks on the domestic agents and the overall economic performance of the Nigerian economy. These findings support other studies that adopted the CGE model to explain the economic impacts of the crude oil price shock and the COVID-19 pandemic (Jia et al. 2021; Pradhan and Ghosh 2021a). Moreover, the impact in this study is relatively higher due to the heavy reliance of the Nigerian economy on crude oil. Based on these results, these are some recommendations to consider.

1. The Nigerian government's palliative is a welcome development and steps in the right direction as it dampens the impact of the global crude oil price shock and the COVID-19 pandemic on the domestic agents and the overall economy of Nigeria.
2. Regarding minimizing losses for the concerned authorities, the carbon tax system suitable for this period is a fixed carbon tax system against the specific and ad valorem carbon tax systems.
3. A price floor mechanism above the equilibrium point can be another step in the right direction for the Nigerian economy. Already most sectors recorded a positive aggregate output, and a price floor on the sectorial outputs can encourage producers,

revitalize the economy, and initiate recovery from the effects of these global shocks (crude oil and COVID-19).

4. Efforts should be intensified toward providing alternative renewable energy sources against crude oil, which can reduce the extent to which the Nigerian economy responds to global crude oil price shocks and the effect on national revenue.
5. On environmental levels, these alternative energy sources can result in more carbon abatement and a substantial decline in the levels of carbon emission intensity for the Nigerian economy.

Appendix 1

See Tables 5, 6, 7, 8, 9 and 10.

Table 5 Nominal national output and gross fixed capital formation

	Robustness X			Robustness Y		
	GFCF	GBP	GMP	GFCF	GBP	GMP
CRD	−16.756	−17.232	−17.224	−16.866	−17.454	−17.445
CRD-COV(C,S,M)	−16.710	−16.911	−16.909	−16.816	−17.142	−17.139
CRD-COV(S,M,P)	−16.085	−16.923	−16.923	−16.193	−17.160	−17.158
CRD-COV(S,M,P,E)	−16.498	−17.404	−17.408	−16.554	−17.530	−17.529
CRD-COV(S,M,P,C)	−16.104	−16.945	−16.942	−16.209	−17.175	−17.171
CRD-COV(C,S,P,E)	−16.957	−17.730	−17.721	−17.003	−17.833	−17.823
CRD-COV(C,S,P,E,M)	−16.517	−17.429	−17.427	−16.569	−17.544	−17.541
CRD-COV(C,S,P,E,M)-F	−16.517	−17.429	−17.427	−16.569	−17.544	−17.541

Table 6 Real national output and gross fixed capital formation

	Robustness X			Robustness Y		
	GFCF	GBP	GMP	GFCF	GBP	GMP
CRD	−7.689	0.000	−2.643	−7.753	0.000	−2.746
CRD-COV(C,S,M)	−9.743	0.000	−3.201	−9.798	0.000	−3.307
CRD-COV(S,M,P)	−9.063	0.000	−3.213	−9.119	0.000	−3.322
CRD-COV(S,M,P,E)	−9.737	−1.297	−4.241	−9.761	−1.288	−4.286
CRD-COV(S,M,P,C)	−9.064	0.000	−3.201	−9.118	0.000	−3.306
CRD-COV(C,S,P,E)	−8.127	−1.301	−3.670	−8.148	−1.294	−3.708
CRD-COV(C,S,P,E,M)	−9.738	−1.299	−4.230	−9.761	−1.291	−4.273
CRD-COV(C,S,P,E,M)-F	−9.738	−1.299	−4.230	−9.761	−1.291	−4.273

Table 7 Industrial basic prices

	Robustness X								Robustness Y							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Agriculture	− 15.1	− 14.7	− 14.7	− 15.1	− 14.8	− 15.7	− 15.2	− 15.2	− 14.7	− 14.3	− 14.2	− 14.9	− 14.3	− 15.5	− 15	− 15
Crude	− 18.9	− 18.5	− 18.6	− 16.5	− 18.5	− 16.7	− 16.4	− 16.4	− 20	− 19.6	− 19.7	− 17.1	− 19.6	− 17.3	− 17	− 17
Solid Minerals	− 15.1	− 14.5	− 14.5	− 14.1	− 14.5	− 14.7	− 14.1	− 14.1	− 15.2	− 14.6	− 14.6	− 14.2	− 14.6	− 14.8	− 14.2	− 14.2
Refined Oil	− 15.1	− 14.5	− 14.6	− 13.5	− 14.6	− 14	− 13.5	− 13.5	− 15.7	− 15.1	− 15.2	− 13.8	− 15.1	− 14.3	− 13.8	− 13.8
Food-B-T	− 18.1	− 17.6	− 17.6	− 16.4	− 17.6	− 16.8	− 16.3	− 16.3	− 18.8	− 18.3	− 18.3	− 16.7	− 18.3	− 17.2	− 16.7	− 16.7
Clothing	− 13	− 11.4	− 11.5	− 10	− 11.4	− 11.4	− 9.9	− 9.9	− 13.8	− 12.2	− 12.3	− 10.4	− 12.2	− 11.8	− 10.3	− 10.3
Iron-M-S	− 12	− 10.5	− 10.5	− 9.9	− 10.5	− 11.4	− 9.9	− 9.9	− 12.3	− 10.7	− 10.8	− 10	− 10.7	− 11.6	− 10	− 10
Other Ind	− 14.8	− 14.3	− 14.3	− 14.5	− 14.3	− 15.1	− 14.6	− 14.6	− 14.5	− 14	− 14	− 14.3	− 14	− 15	− 14.4	− 14.4
Electricity	− 19	− 18.5	− 18.7	− 16.1	− 18.5	− 16.2	− 15.9	− 15.9	− 20.5	− 20	− 20.2	− 16.9	− 20.1	− 16.9	− 16.7	− 16.7
Other Utl	− 15.2	− 14.8	− 14.7	− 15	− 14.8	− 15.6	− 15.1	− 15.1	− 14.8	− 14.4	− 14.4	− 14.9	− 14.5	− 15.4	− 15	− 15
Cons-Cement	− 11.7	− 10.1	− 10.2	− 9.3	− 10.1	− 10.7	− 9.2	− 9.2	− 12.1	− 10.6	− 10.6	− 9.5	− 10.6	− 11	− 9.5	− 9.5
Trade	− 15.1	− 14.4	− 14.4	− 13.4	− 14.4	− 14.1	− 13.4	− 13.4	− 15.6	− 14.9	− 14.9	− 13.7	− 14.9	− 14.3	− 13.7	− 13.7
Transportation	− 15.5	− 15	− 15	− 14.4	− 15	− 14.9	− 14.4	− 14.4	− 15.7	− 15.2	− 15.3	− 14.6	− 15.3	− 15	− 14.6	− 14.6
Communication	− 12.7	− 11.4	− 11.5	− 10.8	− 11.4	− 12	− 10.7	− 10.7	− 13	− 11.7	− 11.8	− 10.9	− 11.8	− 12.2	− 10.9	− 10.9
Art-E-R	− 15.1	− 14.6	− 14.6	− 14.9	− 14.7	− 15.4	− 15	− 15	− 14.8	− 14.3	− 14.3	− 14.7	− 14.4	− 15.3	− 14.8	− 14.8
Fin-Ins	− 17.1	− 16.7	− 16.7	− 15.4	− 16.7	− 15.8	− 15.4	− 15.4	− 17.8	− 17.3	− 17.4	− 15.8	− 17.3	− 16.1	− 15.7	− 15.7
Real Estate	− 16	− 15.6	− 15.6	− 15.2	− 15.6	− 15.6	− 15.2	− 15.2	− 16.1	− 15.7	− 15.7	− 15.2	− 15.7	− 15.7	− 15.3	− 15.3
Education	− 15.4	− 14.5	− 14.5	− 13.7	− 14.5	− 14.5	− 13.6	− 13.6	− 15.8	− 14.9	− 15	− 13.9	− 14.9	− 14.7	− 13.9	− 13.9
Health	− 17.6	− 16.8	− 16.9	− 14.9	− 16.8	− 15.5	− 14.8	− 14.8	− 18.7	− 17.9	− 18.1	− 15.6	− 18	− 16.1	− 15.4	− 15.4
Other Services	− 15.6	− 15.1	− 15.1	− 14.7	− 15.1	− 15.2	− 14.7	− 14.7	− 15.7	− 15.2	− 15.2	− 14.7	− 15.2	− 15.2	− 14.7	− 14.7
Government	− 16.4	− 16	− 16	− 15.8	− 16.1	− 16.2	− 15.9	− 15.9	− 16.3	− 16	− 16	− 15.8	− 16	− 16.2	− 15.9	− 15.9

S1 = CRD = Crude Oil shock, S2 = CRD-COV(C,S,M) = Crude & COVID (Consumption, Savings, Import) shocks, S3 = CRD-COV(S,M,P) = Crude & COVID (Savings, Import, Production) shocks, S4 = CRD-COV(S,M,P,E) = Crude & COVID (Savings, Import, Production, Employment) shocks, S5 = CRD-COV(S,M,P,C) = Crude & COVID (Savings, Import, Production, Consumption) shocks, S6 = CRD-COV(C,S,P,E) Crude & COVID (Consumption, Savings, Production, Employment) shocks, S7 = CRD-COV(C,S,P,E,M) = Crude & COVID (Consumption, Savings, Production, Employment, Import) shocks, S8 = CRD-COV(C,S,P,E,M)-F = Crude, COVID (Consumption, Savings, Production, Employment, Import) shocks, & Fiscal stimulus

Table 8 Aggregate price indexes

	Robustness X			Robustness Y		
	CPI	**Deflator**	**IPI**	**CPI**	**Deflator**	**IPI**
CRD	− 14.977	− 17.232	− 9.821	− 15.114	− 17.454	− 9.878
CRD-COV(C,S,M)	− 14.161	− 16.911	− 7.719	− 14.305	− 17.142	− 7.779
CRD-COV(S,M,P)	− 14.164	− 16.923	− 7.721	− 14.311	− 17.160	− 7.784
CRD-COV(S,M,P,E)	− 13.749	− 16.322	− 7.490	− 13.835	− 16.453	− 7.527
CRD-COV(S,M,P,C)	− 14.194	− 16.945	− 7.741	− 14.338	− 17.175	− 7.802
CRD-COV(C,S,P,E)	− 14.586	− 16.645	− 9.609	− 14.658	− 16.756	− 9.640
CRD-COV(C,S,P,E,M)	− 13.779	− 16.342	− 7.510	− 13.860	− 16.466	− 7.545
CRD-COV(C,S,P,E,M)-F	− 13.779	− 16.342	− 7.510	− 13.860	− 16.466	− 7.545

Table 9 Aggregate industrial output

	Robustness X								Robustness Y							
	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8
Agriculture	−0.7	0.1	0	−0.1	−0.7	−0.5	−0.8	−0.8	−1.0	−1.9	−1.2	−0.7	−1.9	−1.1	−1.4	−1.4
Crude	−13.6	−13.4	−13.7	−16	−13.6	−15.6	−15.9	−15.9	−12.4	−12.7	−12.7	−15.5	−12.6	−15.1	−15.4	−15.4
Solid Minerals	35.9	35.6	36.1	34.4	36.2	34.2	34.6	34.6	36	36.3	36.5	34.7	36.6	34.4	34.8	34.8
Refined Oil	7.3	6.5	7	5.1	7.3	4.9	5.4	5.4	6.9	7.6	7.4	5.3	7.7	5	5.6	5.6
Food-B-T	2.8	2.1	2.1	0.1	2.8	0.8	0.7	0.7	2.3	3	2.3	0.2	3	0.9	0.8	0.8
Clothing	27.4	32	27.6	23.4	27.4	27.3	23.2	23.2	34.5	29.8	30.1	24.7	29.8	28.5	24.4	24.4
Iron-M-S	23.8	24.8	23.8	21.7	23.9	22.8	21.8	21.8	25.5	24.5	24.6	22.1	24.6	23.2	22.2	22.2
Other Ind	18.4	15.8	18.2	17.3	18.4	15	17.6	17.6	15.4	18	17.8	17.1	18.1	14.9	17.4	17.4
Electricity	8.6	8.9	8.5	6.2	8.7	6.7	6.4	6.4	9.8	9.6	9.5	6.8	9.6	7.2	6.9	6.9
Other Utl	14	12.2	13.7	12.7	14	11.6	13	13	12.1	13.9	13.6	12.6	13.9	11.6	13	13
Cons-Cement	4.5	4.4	5	2.8	5.1	2.4	2.9	2.9	5.1	5.3	5.8	3.2	5.8	2.7	3.2	3.2
Trade	−2.4	−2.4	−2.8	−4.4	−2.4	−3.5	−4	−4	−2.2	−2.2	−2.6	−4.3	−2.2	−3.4	−3.9	−3.9
Transportation	0.6	0.1	0.4	−1.7	0.6	−1.8	−1.5	−1.5	0.8	1.3	1.2	−1.3	1.4	−1.4	−1.1	−1.1
Communication	−0.8	−0.3	−1.1	−2.5	−0.8	−1.4	−2.2	−2.2	−0.2	−0.6	−0.9	−2.4	−0.6	−1.3	−2.1	−2.1
Art-E-R	6.5	5.3	6.1	5	6.5	4.6	5.4	5.4	5.2	6.4	6.1	5	6.4	4.5	5.3	5.3
Fin-Ins	0.3	−0.1	−0.1	−2	0.3	−1.5	−1.6	−1.6	0.3	0.7	0.3	−1.8	0.7	−1.3	−1.4	−1.4
Real Estate	3.6	3.4	3	1.7	3.4	2.1	2	2	3.5	3.7	3.1	1.8	3.4	2.2	2.1	2.1
Education	8.5	9.2	8.4	7.1	8.6	8.1	7.2	7.2	9.6	9	8.8	7.3	9	8.3	7.4	7.4
Health	7.5	8	7.5	5.1	7.6	5.7	5.1	5.1	9.2	8.7	8.7	5.7	8.7	6.2	5.7	5.7
Other Services	0.8	0.8	0.6	−0.7	0.9	−0.2	−0.5	−0.5	1	1	0.8	−0.6	1	−0.1	−0.4	−0.4
Government	13	13.4	13.2	12.8	13.3	13.2	12.9	12.9	13.3	12.9	13.1	12.8	13.2	13.1	12.8	12.8

S1 = CRD = Crude Oil shock, S2 = CRD-COV(C,S,M) = Crude & COVID (Consumption, Savings, Import) shocks, S3 = CRD-COV(S,M,P) = Crude & COVID (Savings, Import, Production) shocks, S4 = CRD-COV(S,M,P,E) = Crude & COVID (Savings, Import, Production, Employment) shocks, S5 = CRD-COV(S,M,P,C) = Crude & COVID (Savings, Import, Production, Consumption) shocks, S6 = CRD-COV(C,S,P,E) Crude & COVID (Consumption, Savings, Production, Employment) shocks, S7 = CRD-COV(C,S,P,E,M) = Crude & COVID (Consumption, Savings, Production, Employment, Import) shocks, S8 = CRD-COV(C,S,P,E,M)-F = Crude, COVID (Consumption, Savings, Production, Employment, Import) shocks, & Fiscal stimulus

Table 10 Emissions, intensity, and taxation

	Robustness X					Robustness Y				
	CE	**CEI**	**Fixed**	**Specific**	**Ad Vol**	**CE**	**CEI**	**Fixed**	**Specific**	**Ad Vol**
CRD	−0.718	19.952	−0.718	−3.983	−3.975	−0.258	20.832	−0.258	−3.488	−3.479
CRD-COV(C,S,M)	−0.717	19.490	−0.717	−4.040	−4.032	−0.252	20.384	−0.252	−3.540	−3.531
CRD-COV(S,M,P)	−0.895	19.292	−0.895	−4.229	−4.220	−0.420	20.208	−0.420	−3.716	−3.706
CRD-COV(S,M,P,E)	−2.702	17.804	−2.702	−6.066	−6.058	−2.445	18.290	−2.445	−5.791	−5.782
CRD-COV(S,M,P,C)	−0.655	19.612	−0.655	−3.978	−3.970	−0.192	20.504	−0.192	−3.479	−3.469
CRD-COV(C,S,P,E)	−2.269	18.793	−2.269	−5.539	−5.533	−2.046	19.213	−2.046	−5.301	−5.294
CRD-COV(C,S,P,E,M)	−2.469	18.118	−2.469	−5.822	−5.814	−2.226	18.577	−2.226	−5.562	−5.554
CRD-COV(C,S,P,E,M)-F	−2.469	18.118	−2.469	−5.822	−5.814	−2.226	18.577	−2.226	−5.562	−5.554

Appendix 2

See Tables 11, 12, 13, 14, 15 and 16.

Table 11 Nominal national output and gross fixed capital formation

	Robustness A			Robustness B		
	GFCF	GBP	GMP	GFCF	GBP	GMP
CRD	− 15.890	− 16.389	− 16.381	− 17.711	− 18.261	− 18.252
CRD-COV(C,S,M)	− 15.861	− 16.195	− 16.191	− 17.646	− 17.824	− 17.823
CRD-COV(S,M,P)	− 15.485	− 16.203	− 16.2	− 16.775	− 17.847	− 17.847
CRD-COV(S,M,P,E)	− 15.728	− 16.472	− 16.47	− 17.301	− 18.435	− 18.437
CRD-COV(S,M,P,C)	− 15.496	− 16.216	− 16.211	− 16.799	− 17.871	− 17.868
CRD-COV(C,S,P,E)	− 16.003	− 16.665	− 16.656	− 17.932	− 18.867	− 18.856
CRD-COV(C,S,P,E,M)	− 15.738	− 16.485	− 16.48	− 17.324	− 18.459	− 18.457
CRD-COV(C,S,P,E,M)-F	− 15.738	− 16.485	− 16.48	− 17.324	− 18.459	− 18.457

Table 12 Real national output and gross fixed capital formation

	Robustness A			Robustness B		
	GFCF	GBP	GMP	GFCF	GBP	GMP
CRD	− 7.285	0.000	− 2.53	− 8.148	0.000	− 2.845
CRD-COV(C,S,M)	− 8.545	0.000	− 2.871	− 10.951	0.000	− 3.616
CRD-COV(S,M,P)	− 8.135	0.000	− 2.879	− 10.004	0.000	− 3.634
CRD-COV(S,M,P,E)	− 8.536	− 0.772	− 3.477	− 10.918	− 1.821	− 5.043
CRD-COV(S,M,P,C)	− 8.135	0.000	− 2.871	− 10.004	0.000	− 3.616
CRD-COV(C,S,P,E)	− 7.54	− 0.774	− 3.125	− 8.728	− 1.831	− 4.256
CRD-COV(C,S,P,E,M)	− 8.536	− 0.773	− 3.47	− 10.919	− 1.825	− 5.026
CRD-COV(C,S,P,E,M)-F	− 8.536	− 0.773	− 3.47	− 10.919	− 1.825	− 5.026

Table 13 Industrial basic prices

	Robustness A								Robustness B							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Agriculture	−14.1	−13.9	−13.8	−14.2	−13.9	−14.5	−14.3	−14.3	−15.8	−15.2	−15.1	−15.9	−15.2	−16.7	−16	−16
Crude	−18.3	−18.1	−18.1	−16.8	−18.1	−16.9	−16.7	−16.7	−20.4	−19.8	−20	−16.8	−19.9	−17	−16.6	−16.6
Solid Minerals	−14.3	−13.9	−13.9	−13.7	−13.9	−14.1	−13.7	−13.7	−15.9	−15.1	−15.1	−14.6	−15.1	−15.4	−14.6	−14.6
Refined Oil	−14.5	−14.2	−14.2	−13.5	−14.2	−13.8	−13.5	−13.5	−16.2	−15.4	−15.5	−13.7	−15.4	−14.4	−13.7	−13.7
Food-B-T	−17.4	−17.1	−17.1	−16.3	−17.1	−16.6	−16.3	−16.3	−19.4	−18.7	−18.8	−16.8	−18.7	−17.4	−16.7	−16.7
Clothing	−12.6	−11.7	−11.7	−10.7	−11.7	−11.6	−10.7	−10.7	−14.1	−11.9	−12	−9.6	−11.9	−11.6	−9.5	−9.5
Iron-M-S	−11.5	−10.5	−10.6	−10.2	−10.5	−11.1	−10.2	−10.2	−12.8	−10.6	−10.7	−9.7	−10.6	−11.9	−9.7	−9.7
Other Ind	−13.9	−13.6	−13.5	−13.7	−13.6	−14.1	−13.8	−13.8	−15.5	−14.8	−14.7	−15.1	−14.8	−16	−15.2	−15.2
Electricity	−18.6	−18.3	−18.4	−16.7	−18.3	−16.7	−16.6	−16.6	−20.7	−20.1	−20.3	−16.2	−20.1	−16.3	−15.9	−15.9
Other Utl	−14.2	−14	−13.9	−14.2	−14	−14.5	−14.2	−14.2	−15.8	−15.3	−15.2	−15.8	−15.3	−16.5	−15.9	−15.9
Cons-Cement	−11.2	−10.3	−10.3	−9.7	−10.3	−10.6	−9.7	−9.7	−12.5	−10.4	−10.5	−9	−10.4	−11.1	−9	−9
Trade	−14.5	−14	−14.1	−13.4	−14.1	−13.8	−13.4	−13.4	−16.2	−15.2	−15.2	−13.7	−15.2	−14.6	−13.6	−13.6
Transportation	−14.8	−14.4	−14.5	−14.1	−14.5	−14.4	−14.1	−14.1	−16.4	−15.8	−15.8	−14.9	−15.8	−15.5	−14.9	−14.9
Communication	−12.1	−11.4	−11.4	−10.9	−11.4	−11.7	−10.9	−10.9	−13.6	−11.8	−11.8	−10.7	−11.8	−12.4	−10.7	−10.7
Art-E-R	−14.1	−13.9	−13.8	−14	−13.9	−14.4	−14.1	−14.1	−15.7	−15.2	−15.1	−15.6	−15.2	−16.3	−15.7	−15.7
Fin-Ins	−16.4	−16.2	−16.2	−15.4	−16.2	−15.6	−15.3	−15.3	−18.3	−17.7	−17.8	−15.8	−17.8	−16.3	−15.7	−15.7
Real Estate	−15.2	−14.9	−14.9	−14.7	−14.9	−14.9	−14.7	−14.7	−16.9	−16.3	−16.3	−15.7	−16.4	−16.3	−15.8	−15.8
Education	−14.7	−14.2	−14.2	−13.6	−14.2	−14.1	−13.6	−13.6	−16.4	−15.2	−15.3	−13.9	−15.2	−15	−13.9	−13.9
Health	−17.1	−16.6	−16.7	−15.4	−16.6	−15.7	−15.3	−15.3	−19.1	−18	−18.2	−15	−18	−15.8	−14.9	−14.9
Other Services	−14.8	−14.5	−14.5	−14.2	−14.5	−14.5	−14.2	−14.2	−16.5	−15.8	−15.8	−15.2	−15.8	−15.8	−15.2	−15.2
Government	−15.5	−15.3	−15.3	−15.2	−15.3	−15.4	−15.2	−15.2	−17.2	−16.8	−16.8	−16.5	−16.8	−17.1	−16.6	−16.6

S1 = CRD = Crude Oil shock, S2 = CRD-COV(C,S,M) = Crude & COVID (Consumption, Savings, Import) shocks, S3 = CRD-COV(S,M,P) = Crude & COVID (Savings, Import, Production) shocks, S4 = CRD-COV(S,M,P,E) = Crude & COVID (Savings, Import, Production, Employment) shocks, S5 = CRD-COV(S,M,P,C) = Crude & COVID (Savings, Import, Production, Consumption) shocks, S6 = CRD-COV(C,S,P,E) Crude & COVID (Consumption, Savings, Production, Employment) shocks, S7 = CRD-COV(C,S,P,E,M) = Crude & COVID (Consumption, Savings, Production, Employment, Import) shocks, S8 = CRD-COV(C,S,P,E,M)-F = Crude, COVID (Consumption, Savings, Production, Employment, Import) shocks, & Fiscal stimulus

Table 14 Aggregate price indexes

	Robustness A			Robustness B		
	CPI	**Deflator**	**IPI**	**CPI**	**Deflator**	**IPI**
CRD	− 14.21	− 16.389	− 9.281	− 15.859	− 18.261	− 10.411
CRD-COV(C,S,M)	− 13.714	− 16.195	− 8	− 14.741	− 17.824	− 7.518
CRD-COV(S,M,P)	− 13.716	− 16.203	− 8.001	− 14.749	− 17.847	− 7.524
CRD-COV(S,M,P,E)	− 13.461	− 15.822	− 7.863	− 14.105	− 16.922	− 7.166
CRD-COV(S,M,P,C)	− 13.734	− 16.216	− 8.013	− 14.787	− 17.871	− 7.549
CRD-COV(C,S,P,E)	− 13.968	− 16.015	− 9.153	− 15.249	− 17.354	− 7.084
CRD-COV(C,S,P,E,M)	− 13.478	− 15.834	− 7.875	− 14.142	− 16.943	− 7.191
CRD-COV(C,S,P,E,M)-F	− 13.478	− 15.834	− 7.875	− 14.142	− 16.943	− 7.191

Table 15 Aggregate industrial output

	Robustness A								Robustness B							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Agriculture	− 0.3	− 0.9	− 0.4	− 0.3	− 0.8	− 0.6	− 0.8	− 0.8	− 0.4	− 1.6	− 0.6	− 0.4	− 1.5	− 0.9	− 1.3	− 1.3
Crude	− 12.1	− 12.3	− 12.3	− 13.8	− 12.2	− 13.6	− 13.8	− 13.8	− 13.8	− 14.2	− 14.2	− 17.7	− 14.1	− 17.2	− 17.6	− 17.6
Solid Minerals	33.4	33.5	33.6	32.7	33.7	32.5	32.7	32.7	38.3	38.7	38.9	36.4	39	36	36.6	36.6
Refined Oil	6.2	6.7	6.6	5.4	6.7	5.2	5.5	5.5	7.1	8.1	7.8	5	8.2	4.6	5.3	5.3
Food-B-T	2.1	2.4	2.1	0.8	2.4	1.3	1.2	1.2	2.4	3.2	2.4	− 0.5	3.2	0.4	0.3	0.3
Clothing	30.9	28.1	28.3	25.4	28.1	27.8	25.3	25.3	35.3	28.8	29.2	22.4	28.8	27.8	22.1	22.1
Iron-M-S	23.5	22.9	22.9	21.6	22.9	22.2	21.6	21.6	26.8	25.3	25.4	22.2	25.5	23.7	22.2	22.2
Other Ind	14.7	16.2	16.1	15.6	16.3	14.3	15.8	15.8	16.6	20.3	19.9	18.7	20.3	15.6	19.1	19.1
Electricity	8.7	8.5	8.5	7	8.5	7.3	7.1	7.1	9.9	9.6	9.5	5.9	9.6	6.5	6.1	6.1
Other Utl	11.4	12.5	12.3	11.7	12.5	11.1	12	12	12.9	15.3	14.9	13.6	15.4	12.1	14	14
Cons-Cement	4.4	4.5	4.8	3.4	4.8	3.1	3.4	3.4	5	5.2	5.9	2.6	5.9	1.9	2.6	2.6
Trade	− 2.2	− 2.2	− 2.4	− 3.4	− 2.2	− 2.9	− 3.2	− 3.2	− 2.5	− 2.4	− 3	− 5.3	− 2.5	− 4.1	− 4.7	− 4.7
Transportation	0.4	0.7	0.7	− 0.7	0.8	− 0.8	− 0.6	− 0.6	0.4	1	0.8	− 2.4	1.1	− 2.5	− 2.1	− 2.1
Communication	− 0.3	− 0.5	− 0.7	− 1.6	− 0.5	− 0.9	− 1.4	− 1.4	− 0.3	− 0.9	− 1.3	− 3.4	− 0.9	− 1.8	− 2.9	− 2.9
Art-E-R	4.9	5.7	5.5	4.8	5.7	4.5	5	5	5.5	7.2	6.7	5.1	7.3	4.6	5.7	5.7
Fin-Ins	0.1	0.3	0.1	− 1.1	0.3	− 0.8	− 0.9	− 0.9	0.1	0.6	0	− 2.7	0.6	− 2	− 2.2	− 2.2
Real Estate	3.2	3.4	3	2.2	3.2	2.4	2.4	2.4	3.7	4	3.1	1.2	3.6	1.8	1.7	1.7
Education	8.8	8.4	8.3	7.5	8.4	8.1	7.6	7.6	10	9.1	8.9	6.9	9.1	8.2	7.1	7.1
Health	8	7.7	7.7	6.1	7.7	6.4	6.1	6.1	9.1	8.4	8.4	4.6	8.4	5.3	4.6	4.6
Other Services	0.9	0.8	0.7	− 0.1	0.9	0.2	0	0	1	1	0.6	− 1.3	1	− 0.6	− 1	− 1
Government	12.5	12.3	12.4	12.2	12.4	12.4	12.2	12.2	14.3	13.7	14	13.4	14.1	13.9	13.5	13.5

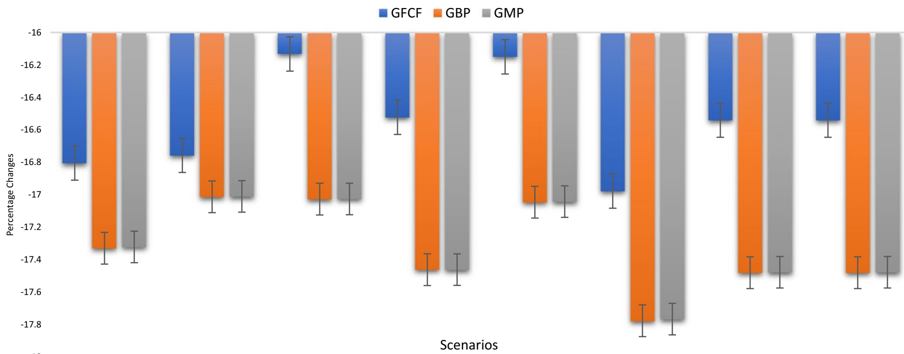
S1 = CRD = Crude Oil shock, S2 = CRD-COV(C,S,M) = Crude & COVID (Consumption, Savings, Import) shocks, S3 = CRD-COV(S,M,P) = Crude & COVID (Savings, Import, Production) shocks, S4 = CRD-COV(S,M,P,E) = Crude & COVID (Savings, Import, Production, Employment) shocks, S5 = CRD-COV(S,M,P,C) = Crude & COVID (Savings, Import, Production, Consumption) shocks, S6 = CRD-COV(C,S,P,E) Crude & COVID (Consumption, Savings, Production, Employment) shocks, S7 = CRD-COV(C,S,P,E,M) = Crude & COVID (Consumption, Savings, Production, Employment, Import) shocks, S8 = CRD-COV(C,S,P,E,M)-F = Crude, COVID (Consumption, Savings, Production, Employment, Import) shocks, & Fiscal stimulus

Table 16 Emissions, intensity, and taxation

	Robustness A					Robustness B				
	CE	**CEI**	**Fixed**	**Specific**	**Ad Vol**	**CE**	**CEI**	**Fixed**	**Specific**	**Ad Vol**
CRD	− 0.481	19.025	− 0.481	− 3.523	− 3.515	− 0.559	21.657	− 0.559	− 4.021	− 4.012
CRD-COV(C,S,M)	− 0.48	18.753	− 0.48	− 3.558	− 3.55	− 0.554	21.016	− 0.554	− 4.091	− 4.082
CRD-COV(S,M,P)	− 0.584	18.639	− 0.584	− 3.669	− 3.66	− 0.796	20.754	− 0.796	− 4.347	− 4.336
CRD-COV(S,M,P,E)	− 1.723	17.658	− 1.723	− 4.835	− 4.827	− 0.464	18.355	− 0.464	− 4.057	− 4.048
CRD-COV(S,M,P,C)	− 0.443	18.824	− 0.443	− 3.522	− 3.513	− 0.468	21.189	− 0.468	− 4.004	− 3.994
CRD-COV(C,S,P,E)	− 1.466	18.238	− 1.466	− 4.52	− 4.513	− 0.892	19.69	− 0.892	− 4.361	− 4.354
CRD-COV(C,S,P,E,M)	− 1.585	17.84	− 1.585	− 4.691	− 4.683	− 1.15	18.774	− 1.15	− 4.729	− 4.721
CRD-COV(C,S,P,E,M)-F	− 1.585	17.84	− 1.585	− 4.691	− 4.683	− 1.15	18.774	− 1.15	− 4.729	− 4.721

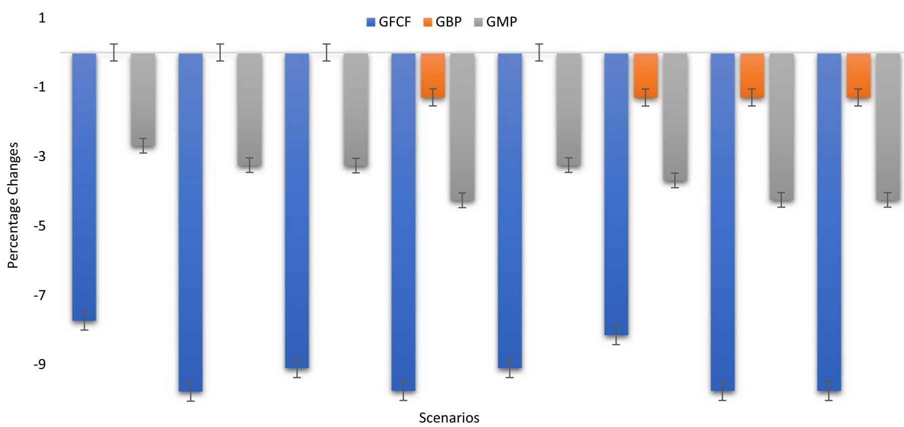
Appendix 3

See Figs. 11, 12, 13, 14, 15, 16, 17 and 18.



	CRD	CRD-COV(C,S,M)	CRD-COV(S,M,P)	CRD-COV(S,M,P,E)	CRD-COV(S,M,P,C)	CRD-COV(C,S,P,E)	CRD-COV(C,S,P,E,M)	CRD-COV(C,S,P,E,M)-F
GFCF	-16.80409218	-16.7565431	-16.13240586	-16.52250371	-16.15006088	-16.97691711	-16.53992585	-16.53992585
GBP	-17.32901354	-17.0119874	-17.02649726	-17.46105546	-17.04539912	-17.77551172	-17.47962648	-17.47962648
GMP	-17.32082799	-17.00965026	-17.02537626	-17.46073939	-17.04171109	-17.76551882	-17.47676676	-17.47676676

Fig. 11 Nominal output and capital formation



	CRD	CRD-COV(C,S,M)	CRD-COV(S,M,P)	CRD-COV(S,M,P,E)	CRD-COV(S,M,P,C)	CRD-COV(C,S,P,E)	CRD-COV(C,S,P,E,M)	CRD-COV(C,S,P,E,M)-F
GFCF	-7.717399679	-9.767237896	-9.087311065	-9.747552264	-9.087783426	-8.136890804	-9.748090525	-9.748090527
GBP	-7.49083E-06	5.80559E-05	2.54354E-05	-1.293881553	6.05579E-05	-1.298589688	-1.295872049	-1.295872049
GMP	-2.687598907	-3.246805405	-3.26017768	-4.26123812	-3.246857095	-3.686616309	-4.248924876	-4.248924876

Fig. 12 Real output and capital formation

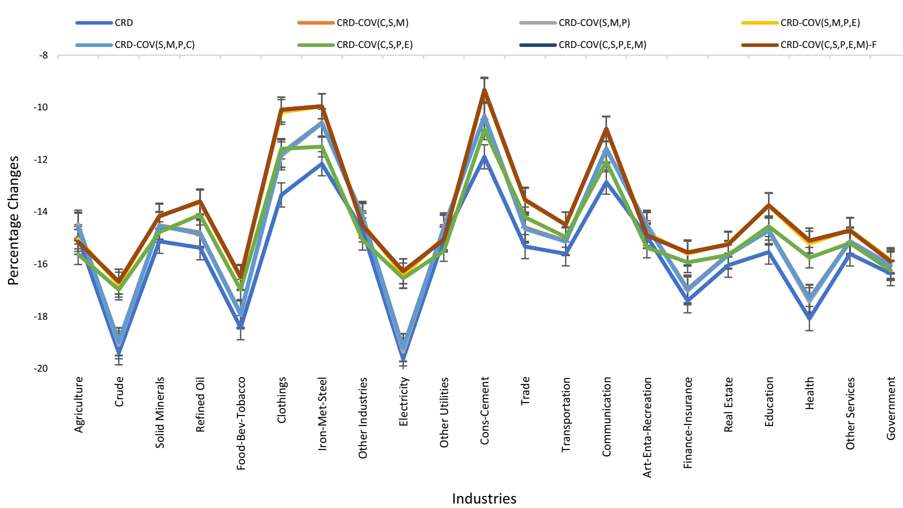
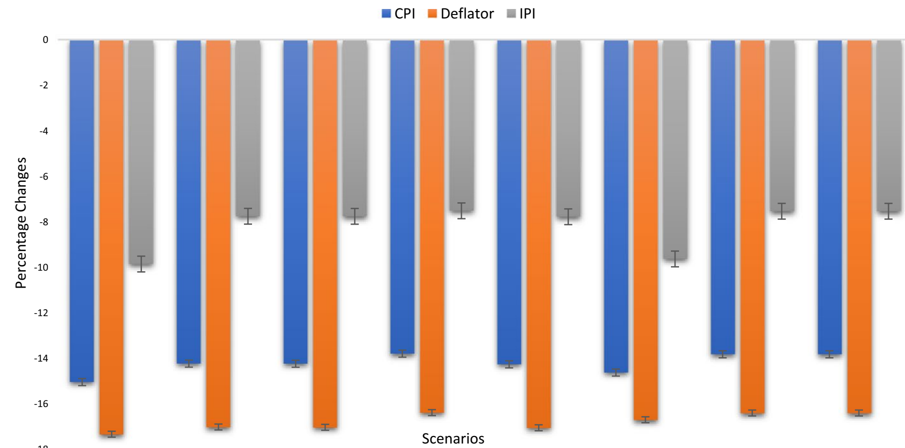


Fig. 13 Industrial basic prices



	CRD	CRD-COV(C,S,M)	CRD-COV(S,M,P)	CRD-COV(S,M,P,E)	CRD-COV(S,M,P,C)	CRD-COV(C,S,P,E)	CRD-COV(C,S,P,E,M)	CRD-COV(C,S,P,E,M)-F
CPI	-15.03737336	-14.22469295	-14.22909227	-13.78699809	-14.25778386	-14.61780489	-13.81482335	-13.81482335
Deflator	-17.32900734	-17.01203558	-17.02651837	-16.37910006	-17.04544936	-16.69370476	-16.39622857	-16.39622857
IPI	-9.846593474	-7.745861968	-7.749297566	-7.506667815	-7.768238111	-9.62304279	-7.525420086	-7.525420086

Fig. 14 Aggregate price indexes

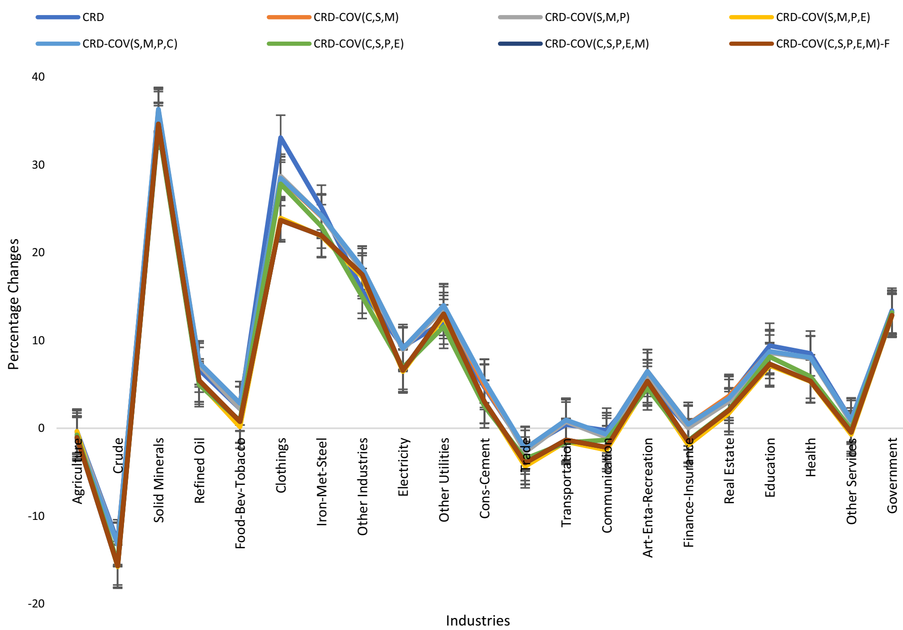
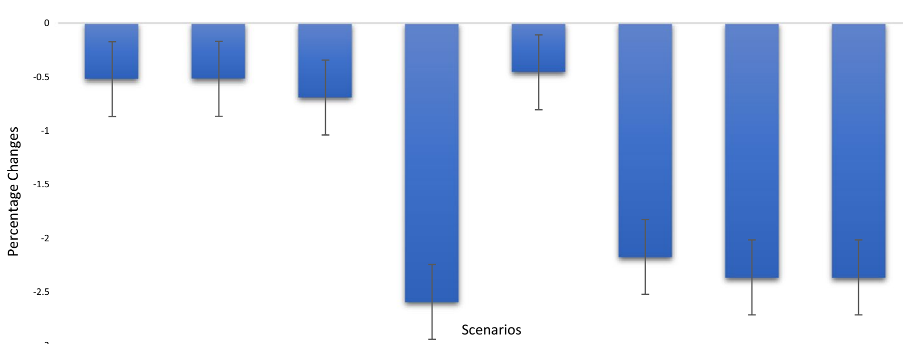


Fig. 15 Aggregate industrial outputs



	CRD	CRD-COV(C,S,M)	CRD-COV(S,M,P)	CRD-COV(S,M,P,E)	CRD-COV(S,M,P,C)	CRD-COV(C,S,P,E)	CRD-COV(C,S,P,E,M)	CRD-COV(C,S,P,E,M)-F
CAB	-0.51918404	-0.516338647	-0.690038385	-2.591877662	-0.455432858	-2.173261503	-2.364394362	-2.364394362

Fig. 16 Carbon emission abatement (CEA)

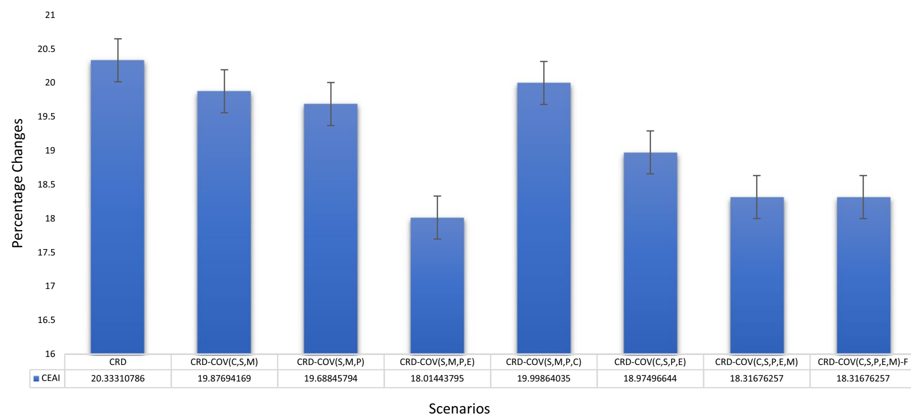


Fig. 17 Carbon emission abatement intensity (CEAI)

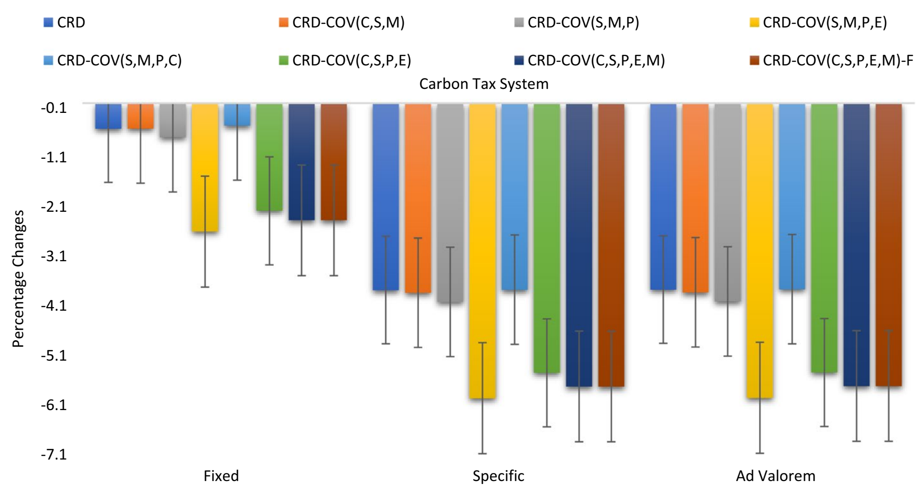


Fig. 18 Carbon emission taxation systems

Abbreviations

CGE	Computable general equilibrium
EEICGE	Energy and environment integrated computable general equilibrium
COVID-19	Corona virus disease of 2019
GDP	Gross domestic product
SAM	Social accounting matrix
CET	Constant elasticity of technology
CES	Constant elasticity of substitution
HH	Households
F	Firm
Govt.	Government
ROW	Rest of the world
CE	Carbon emission
CEI	Carbon emission intensity
CTR	Carbon total revenue
ctx	Carbon tax
EN	Energy intermediate input
IC	Intermediate consumption
VA	Value added
p^{va}	Price of value added
FOB	Free on board
GFCF	Gross fixed capital formation
CRD	Crude oil shock

CRD-COV(C,S,M)	Crude & COVID (s) shocks
CRD-COV(S,M,P)	Crude & COVID (savings, import, production) shocks
CRD-COV(S,M,P,E)	Crude & COVID (savings, import, production, employment) shocks
CRD-COV(S,M,P,C)	Crude & COVID (savings, import, production, consumption) shocks
CRD-COV(C,S,P,E)	Crude & COVID (consumption, savings, production, employment) shocks
CRD-COV(C,S,P,E,M)	Crude & COVID (consumption, savings, production, employment, import) shocks
CRD-COV(C,S,P,E,M)-F	Crude, COVID (consumption, savings, production, employment, import) shocks, & fiscal stimulus

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DIO: Conceptualization, Methodology, Software, Data curation, Writing—original draft, Writing—review & editing. BL: Software, Writing—original draft, Writing—review & editing.

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Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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