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July 2017

GRIPS

NATIONAL GRADUATE INSTITUTE
FOR POLICY STUDIES

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Abstract

This study develops a computable general equilibrium model for Nigeria to study the impact of fossil fuel subsidy reform – and energy taxes – on key economic parameters, including consumption, income distribution, tax incidence, and fiscal efficiency. The model also examines the role of informality, tax evasion, and fuel smuggling, and shows that these factors can substantially strengthen the argument in favour of subsidy reform. The study shows that redistributing revenues from subsidy reform using uniform cash transfers has a strong progressive (i.e. pro-poor) distributional effect. Moreover, redistributing reform revenues by cutting pre-existing labour taxes not only increases fiscal efficiency, but also reduces the welfare losses associated with tax evasion, which in turn reduces the welfare costs of reform by up to 40%. Regardless of the method of revenue redistribution, reducing subsidies diminishes the incentives for fuel smuggling, and hence the welfare losses associated with it.

Keywords: Fossil fuel subsidies, reform, tax evasion, smuggling

1. Introduction

Global subsidies to fossil fuel consumption amounted to $493 B in 2014 (IEA, 2015) – i.e. exceeding the climate finance commitment of $100 B agreed under the Paris Agreement by a factor five. However, the true economic and societal cost is bound to be far higher than this figure, since fossil fuel subsidies (FFS) cause countless adverse effects, including the lock-in of inefficient technology and behaviour, crowding out of funds for public spending such as education and health care, an erosion of competitiveness, exacerbating environmental pressures, and regressive wealth transfer to the rich (Rentschler and Bazilian, 2016). In addition to these adverse effects, FFS are also frequently

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argued to be associated with illicit activities, including corruption, fuel smuggling, and tax evasion. However, no systematic study exists exploring the role of such activities in determining the outcomes FFS reforms.

Against this background, this study develops a dedicated computable general equilibrium (CGE) model to provide estimates of the orders of magnitude of the tax evasion and smuggling effects associated with FFS reform. More specifically, this study addresses the following interrelated questions: (i) What are the effects of FFS reform on key economic parameters, including income distribution, consumption, and output? (ii) How do effects differ when illicit market activities are taken into account, in particular tax evasion and rampant fuel smuggling? (iii) How do effects differ when FFS are not only removed, but replaced by fuel taxes? (iv) How do different methods of revenue re-distribution affect households?

To address these questions, this study develops a small open economy general equilibrium model, calibrated to reflect the characteristics of Nigeria. The model features six representative households (reflecting income quintiles and a smuggling household), a government which collects taxes, consumes, and provides cash transfers and fossil fuel subsidies, as well as four economic sectors. While building on the standard model outlined by Hosoe et al. (2010), this study introduces several innovative model features which distinguish this model from previous analyses (e.g. Plante, 2014). In particular, it introduces a large informal sector, evasion of labour and production taxes, and fuel smuggling.

Overall, the study presented in this discussion paper finds that replacing FFS with cash transfers results in substantial progressive redistribution. While the top income quintile incurs a reduction in consumption, all other income quintiles gain, with the poorest income quintile benefitting from the largest relative consumption increase. Moreover, using revenues from FFS reform to cut labour taxes results in an improvement of fiscal efficiency. Crucially, this study finds that taking into account illicit activities can lower the social welfare costs of FFS reform by up to 40%. Moreover, by going beyond FFS reform and also considering the introduction of fuel taxes, this study finds that the above mentioned benefits can be extended further: A revenue neutral shift of the tax base from income to fuel taxes can significantly reduce illicit activities and their associated welfare costs. However, this move may also incentivise a reversal of the fuel smuggling direction from out- to inbound.

2. Relation to prior literature

2.1. Fossil fuel subsidies

A large body of literature and numerous case studies have helped to document the adverse effects of FFS. Often used as a political tool, FFS have been justified by objectives such as alleviating poverty, redistributing natural resource revenues to citizens, and promoting industrialization and economic development (Strand, 2013).

However, the evidence is very clear in showing that FFS are a very ineffective way of achieving these objectives, and cause a wide range of adverse side effects

pertaining to all dimensions of sustainable development: economic, social, and environmental (Rentschler and Bazilian, 2016). These side effects include economic and technological inefficiency, fiscal imbalances, crowding out of public funds for innovation and social services, pollution, climate change, fuel smuggling, and corruption (IMF, 2013; Coady et al., 2015b,a; ADB, 2015).

In addition to the fiscal pressure they place on national budgets, FFS are also particularly problematic because of their highly regressive nature. In reviewing FFS schemes in a range of developing countries, Arze del Granado et al. (2012) found that the top income quintile receives on average six times more in absolute subsidy benefits than the poorest income quintile. In this way, FFS continuously reinforce and exacerbate existing patterns of income and wealth inequality. A comprehensive overview of FFS definitions, adverse side effects, reform progress and barriers is provided by Rentschler and Bazilian (2016).

In light of mounting evidence in favour of FFS reform, the key question for policy makers has been *how* to design and implement reforms in a way that ensures public support for reform and protects livelihoods of vulnerable households.

2.2. Fossil fuel subsidy reform simulations

Econometric reform simulations typically focus on changes in household consumption, and are useful for understanding the welfare and distribution effects of FFS reform. Various such empirical ex-ante impact assessments of FFS reforms have been conducted to provide useful guidance for policy makers seeking to estimate reform impacts. For example, several studies – including IMF working papers – provide econometric analyses of the welfare impacts of FFS reforms, and highlight the need to provide adequate social protection (e.g., in the form of cash compensation) along with FFS reform (Anand et al., 2013; Araar et al., 2015; Zhang, 2011; Coady et al., 2010; Verme and El-Massnaoui, 2015).[1]

Both the IMF and World Bank provide analytical toolkits for the empirical simulation of FFS reforms using household expenditure surveys and input-output models (Verme and El-Massnaoui, 2015; IMF, 2016). The approach taken by these models enables swift and consistent analyses with relatively few data requirements.

However, as Plante (2014) points out, these models also strongly simplify complex interactions, as they overlook the fiscal policy and general equilibrium perspective on subsidies: These models focus exclusively on the fact that the removal of FFS leads to energy price shocks, which in turn reduce purchasing power and aggregate consumption of households. Thus, FFS removal necessarily and exclusively has negative consequences, while benefits such as reduced deadweight losses or increased economic efficiency are not taken into account. Similarly, general equilibrium effects on key macro-economic parameters cannot be captured in models based on household surveys, including changes in government expenditure, output, and tax revenues.

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[1]For additional empirical impact assessments of FFS reforms, see Jiang et al. (2015) and Ouyang and Lin (2014) for China, and Solaymani and Kari (2014) for Malaysia.

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To address the above mentioned shortcomings, Plante (2014) developed a general equilibrium model aimed at capturing the fiscal policy aspect of FFS reform. It is a standard small open economy model with two sectors, and a single representative household. FFS reductions are balanced in the government's budget constraint through tax adjustments or lump-sum cash transfer provision. Using this model, it is shown that FFS cause distortions of relative prices, which are identified as the main reason for substantial aggregate welfare losses. Moreover, FFS are shown to aggravate fiscal imbalances, crowd out non-energy consumption, and cause inefficient allocation of labour across sectors, regardless of whether the country is an oil importer or exporter (Plante, 2014). The model also suggests that permanent cash transfers can be an efficient and equitable tool for redistributing resource revenues, consistent with overarching development objectives of reducing poverty and inequality.

At least two other general equilibrium models have followed: Durand-Lasserve et al. (2015) offer an analysis for Indonesia based on the OECD's ENV-Linkages model, a global CGE model. This study focusses in particular on distributional effects of FFS reform, considering redistribution of reform revenues through cash transfers or food subsidies. Siddig et al. (2014) use the CGE model by the Global Trade Analysis Project (GTAP) to analyse subsidy reform in Nigeria. They distinguish twelve households, each representing a region rather than an income group. Using this set-up they consider the impact of FFS reform on several standard macro-economic parameters, such as consumption and GDP.

While the above mentioned models differ in the complexity of their modelling set-ups, they coincide in their focus on key macro-economic parameters, in particular output, consumption, trade and fiscal balances, and income distribution. Hence, these studies must also be seen in the broader context of – not only FFS reform – but the environmental taxation literature.

In particular, there is a prominent strand in this literature suggesting that there is a "double dividend" – i.e., that if environmental taxes are increased, but other distortionary taxes are reduced (while maintaining revenue neutrality), then not only can environmental benefits be reaped, but also fiscal efficiency can be increased (Goulder, 1995a; Fullerton and Metcalf, 1997; Bovenberg, 1999). However, Parry and Williams (2010) also show that there is a considerable trade-off between efficiency and distributional effects. That is, income tax reductions are economically efficient, but regressive, while cash transfers are progressive, but less efficient. Since FFS are (at least theoretically) equivalent to a negative carbon tax, this study gives thorough consideration to the double dividend argument in the context of FFS reforms.

2.3. Tax evasion and smuggling

More recent studies have contributed an additional perspective, which significantly strengthened the double dividend argument. Liu (2013) observes that energy (or carbon) taxes are more difficult to evade than labour or income taxes. Using a simple CGE model, the author shows that a revenue neutral shift from labour to carbon taxes can substantially reduce tax evasion and the welfare cost

of climate change mitigation policy.[2] Especially when pre-existing tax evasion is high, this argument can significantly strengthen both the environmental and fiscal case for carbon taxes (Kuralbayeva, 2013; Liu, 2013; Bento et al., 2013; Carson et al., 2014; Vasilev, 2016).

Even though tax evasion tends to be particularly high in developing countries – large informal sectors are symptomatic for this – the "tax evasion effect" has not been studied in the context of FFS reform. Similarly, despite being a frequently cited side-effect of fossil fuel subsidies, smuggling has also received little attention from researchers (Mlachila et al., 2016; Rentschler and Bazilian, 2016). As subsidised fuels are smuggled out of a country, the government is directly subsidising fuel consumption in neighbouring countries; in other words public funds intended for domestic beneficiaries are continuously leaking out of the country (ADB, 2015). Mlachila et al. (2016) offer one of the few studies that systematically analyse the magnitude and implications of fuel subsidies on smuggling activities. They show that fuel smuggling can severely undermine the effectiveness of fuel price adjustment mechanisms and energy tax collection, when neighbouring countries subsidise their domestic fuel consumption.

The model presented in this study contributes to the literature on FFS reform and the double dividend, by providing a systematic account of tax evasion, the informal sector, and fuel smuggling in the case of Nigeria. These issues are of great significance in developing countries, especially when considering that the informal economy in Nigeria is estimated at 50% of GDP, and that 85% of fuel consumed in Benin is smuggled from (and thus subsidised by) Nigeria (Mlachila et al., 2016; Hassan and Schneider, 2016).

3. The societal cost of illicit activities

A key assumption by Liu (2013) is that tax evasion (and legal tax avoidance) activities incur real cost. The reason for this is that tax evasion efforts require real resources, and thus compete for production factors with real productive activities (ADB, 2015). Bribes paid to tax officials, the employment of tax lawyers and advisors, or the complex shifting of profits between international subsidiaries are examples of costly tax avoidance or evasion activities. In addition, taxes may reduce economic efficiency by distorting business decisions and production processes. In practice, the increased need for fiscal audits and monitoring may also impose a costly burden on authorities. Overall, tax evasion imposes real costs on society, not only because productive resources are allocated to unproductive evasion activity, but also because of foregone tax revenues.

Analogously, fuel smuggling activities also represent a loss to society. Fuel subsidies that are intended for the benefit of a country's own citizens are smuggled abroad; in other words, the government is directly subsidising the energy consumption for foreign consumers. In addition, the smuggling activity itself is costly, as significant resources are used on transporting fuel, and avoiding and bribing border and customs controls (Mlachila et al., 2016). As in the case of tax

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[2]Liu (2013) shows that costs can be lowered by 89% in China and 97% in India.

evasion, these resources are lost and thus unavailable to productive economic activities.

A key argument considered in this study is that reducing FFS and using revenues to cut distortionary labour taxes can be welfare-enhancing, since welfare losses associated with smuggling and tax evasion are also reduced. In line with Parry and Williams (2010), this study contrasts such labour tax cuts with other ways of recycling reform revenues: increasing public expenditure, or the provision of uniform lump-sum transfers to citizens.

4. Energy subsidies in Nigeria

As a developing country with substantial fossil resource wealth and a mixed track record of fiscal prudence and transparency, Nigeria is a frequently cited case for studying FFS and natural resource management (Rentschler, 2016). Through the Petroleum Products Pricing Regulatory Agency, Nigeria maintains artificially low energy prices – most notably for kerosene and petrol. The gap between fuel import costs and regulated prices are financed through the Petroleum Support Fund, which administers fuel subsidies.[3]

At nearly 5% of GDP in 2011 subsidies are a significant expense for the government, and fail to reach Nigerians in more than one sense (IMF, 2013; Soile and Mu, 2015): As with all FFS schemes, the direct financial benefits to households are concentrated on the rich, thus failing to benefit the absolute poor (who constitute 61% of the population[4]). In addition, a complex and opaque system of intermediary dealers and political influence means that, instead of lowering the market price, subsidies are often privately appropriated before the fuel reaches the market. Finally, rampant fuel smuggling means subsidy benefits are leaking out of the country.

Facing mounting fiscal pressures and recognising the inefficiencies of its subsidy scheme, Nigeria attempted a radical subsidy reform in 2012. While the need for such reform was pressing, the government failed to garner sufficient public support for its reform efforts. Public opposition to the reform had two key reason in particular: (i) A lack of credibility and transparency with respect to the handling of reform revenues, and (ii) inadequate plans for compensation and social protection, resulting from a poor understanding of the needs and vulnerability of affected energy consumers. Subsidy removal was met with extensive strikes and violent public protests, and prompted the government to swiftly reintroduce subsidies (Bazilian and Onyeji, 2012; Siddig et al., 2014).

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[3]The Petroleum Support Fund is managed by the Petroleum Products Pricing Regulatory Agency, and receives a set allocation in the federal budget. Contributions to the fund are made by the federal, state, and local governments. Moreover, the fund is supplemented by subsidy "surpluses", which essentially occur when international market prices exceed the government-set fuel price (GSI, 2012).

[4]This figure is based on the national absolute poverty definition, using an absolute poverty line of N54,401 (National Bureau of Statistics, 2010)

5. Illicit dealings: A Computable General Equilibrium model

The basic structure of this model builds on Hosoe et al. (2010), who offer a small open economy CGE model featuring a representative household, two sectors, and a government. The model in this study distinguishes five income quintiles, introduces fossil fuel subsidies, and adds several non-standard features: A small group of households is modelled to engage in fuel smuggling activities. The profits of smuggling depend on the price differential between the domestic and international price of fuel, which is determined through the level of subsidies paid. Moreover, the model allows for the evasion of production and factor taxes. In order to represent different policy options for using reform revenues, the model considers (1) government expenditure, (2) direct cash transfers, and (3) reductions of pre-existing taxes.

5.1. Tax evasion: Representation in the model

In this model it is assumed that firms choose to evade taxes on different factors and on production, while incurring a real cost of evasion. Formally, factor taxes $\tau_{h,j}^f$ on factor h and sector j are evaded at the rate $e_{h,j}^f$. Similarly, production taxes τ_j^z are evaded at the rate e_j^z.

In line with Liu (2013), tax evasion activities incur real costs $F_{h,j}^{loss}$ and X_j^{loss}:

$$F_{h,j}^{loss} = c(e_{h,j}^f)F_{h,j} \qquad \text{with} \qquad c(e_{h,j}^f) = \frac{A_{h,j}^f}{N_{h,j}^f + 1}(e_{h,j}^f)^{N_{h,j}^f+1} \tag{1}$$

$$X_j^{loss} = c(e_j^z)Z_j \qquad \text{with} \qquad c(e_j^z) = \frac{A_j^z}{N_j^z + 1}(e_j^z)^{N_j^z+1} \tag{2}$$

This setting implies that the cost of tax evasion is measured as a share $c(e)$ of either factor inputs $F_{h,j}$ (in the case of factor tax evasion) or production Z_j (for production tax evasion). Parameters $A_{h,j}^f$, A_j^z, $N_{h,j}^f$, and N_j^z characterise the cost function and are determined during calibration (section 6). The total net benefit to firm j from evading factor taxes is $\sum_h F_{h,j}(\tau_{h,j}^f e_{h,j}^f p_h^f - c(e_{h,j}^f))$.

Evasion losses reflect the extra (unproductive) "self-input" due to evasion efforts. Specifically, if a firm engages in evasion activities, a share of its resources will be directed towards this evasion activity rather than production (e.g. labour hours). This unproductive evasion activity means that fewer resources are available for producing output, thus resulting in the output loss X_j^{loss}.

Moreover, the marginal costs of evading taxes can be expressed as

$$\frac{\partial c(e_{h,j}^f)}{\partial e_{h,j}^f} = A_{h,j}^f(e_{h,j}^f)^{N_{h,j}^f} \qquad \text{and} \qquad \frac{\partial c(e_j^z)}{\partial e_j^z} = A_j^z(e_j^z)^{N_j^z}. \tag{3}$$

Since these marginal costs are increasing in $e_{h,j}^f$ or e_j^z, firms choose evasion rates and factor input quantities as to maximise profits (Section 5.3).

5.2. Smuggling: Representation in the model

In practice, fuel subsidies often incentivise smuggling, as subsidised domestic energy prices are significantly lower than in neighbouring countries, where fuel prices are unregulated. This price gap presents a lucrative opportunity for smugglers, who buy energy at the subsidised domestic price and sell it abroad at the unregulated market price. However, in doing so smugglers are likely to incur real costs, e.g. in the form of bribes or transport costs (Mlachila et al., 2016).

For the sake of consistency, this model not only allows such *outbound* smuggling (smuggling "exports"); it also considers the possibility of *inbound* smuggling ("imports"), which may occur by the same logic when domestic fuel subsidies are removed and fuel taxes imposed.

In this model, smugglers are assumed to choose the smuggling quantity E_j^{SM} ("exports", i.e. *outbound* smuggling) as to maximise their profit. They purchase fuel for smuggling in the domestic market at the subsidised price $(1 - s_j^e)p_j^q$ (where s_j^e is the subsidisation rate), and sell it abroad at the export price p_j^e. In addition, smugglers incur smuggling costs E_j^{loss}, e.g. transportation costs. Analogously, they may also choose to conduct *inbound* smuggling M_j^{SM} ("imports"). In this case they will purchase fuel abroad at the import price p_j^m, and sell it domestically at the subsidised (or taxed) price $(1 - s_j^e)p_j^q$. Thus, the smugglers optimisation problem is given by

$$\max_{E^{SM}, M^{SM}} \pi^{SM} = \left(p_j^e - (1 - s_j^e)p_j^q\right) E_j^{SM} - (1 - s_j^e)p_j^q E_j^{loss}$$
$$+ \left((1 - s_j^e)p_j^q - p_j^m\right) M_j^{SM} - p_j^m M_j^{loss} \tag{4}$$

$$\text{subject to} \quad E_j^{loss} = \frac{A_j^{SM}}{r} \left[E_j^{SM}\right]^r \tag{5}$$

$$M_j^{loss} = \frac{A_j^{SM}}{r} \left[M_j^{SM}\right]^r \tag{6}$$

E_j^{SM} (or M_j^{SM}) denotes the smuggled quantity from sector j, while the total cost of smuggling is denoted by E_j^{loss} (or M_j^{loss}) expressed as a share of the total smuggled quantity. The shape of the cost function is characterised by parameters A_j^{SM} and r, both of which are determined during calibration (section 6).[5]

The smuggler's profit is maximised under following first order conditions:

$$\frac{\partial \pi_j^{SM}}{\partial E_j^{SM}} = p_j^e - (1 - s_j^e)p_j^q = (1 - s_j^e)p_j^q A_j^{SM} \left(E_j^{SM}\right)^{r-1} \tag{FOC 1.1}$$

$$\frac{\partial \pi_j^{SM}}{\partial M_j^{SM}} = (1 - s_j^e)p_j^q - p_j^m = p_j^m A_j^{SM} \left(M_j^{SM}\right)^{r-1} \tag{FOC 1.2}$$

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[5]A sensitivity analysis for these parameters is provided in section 10.

For both FOC 1.1 and FOC 1.2, π_j^{SM} is maximised when the marginal benefit of smuggling (LHS) is equal to its marginal cost (RHS). Note that the sign of the subsidisation rate s_j^e plays a key role in determining whether the smuggler chooses inbound or outbound smuggling. Solving the first order conditions yields the profit maximising smuggling quantities E_j^{SM} and M_j^{SM}.

$$E_j^{SM} = \left[\frac{p_j^e - (1 - s_j^e)p_j^q}{(1 - s_j^e)p_j^q A_j^{SM}} \right]^{\frac{1}{r-1}} \tag{7}$$

$$M_j^{SM} = \left[\frac{(1 - s_j^e)p_j^q - p_j^m}{p_j^m A_j^{SM}} \right]^{\frac{1}{r-1}} \tag{8}$$

5.3. Domestic production

The comparably simplistic model by Liu (2013) is extended to include intermediate inputs. A neat way of modelling intermediate inputs is by distinguishing two stages of the production process. In the first stage, the firm uses primary factors (i.e. labour, capital) to produce a composite factor. In the second stage, the firm combines the composite factor with intermediate inputs to produce its output. This section formally describes the firm's profit maximisation problem.

First stage:
The firm's first production stage is described by a Cobb-Douglas production function, which is homogeneous of degree one and exhibits constant returns to scale. It maximises profits by choosing the quantity of its output (i.e. the composite factor Y_j), of its inputs (i.e. production factors $F_{h,j}$), and the factor tax evasion rate $e_{h,j}^f$.

$$\max_{Y,F,e^f} \quad \pi_j^y = \left\{ p_j^y Y_j - \sum_h \left(1 + \tau_{h,j}^f \left(1 - e_{h,j}^f \right) \right) p_h^f F_{h,j} - p_h^f F_{h,j}^{loss} \right\} \tag{9}$$

$$s.t. \quad Y_j = b_j \prod_h F_{h,j}^{\beta_{h,j}} \tag{10}$$

The first term of the profit function reflects revenues from the sale of the composite factor Y_j at the price p_j^y. The second term is the sum of the post-tax costs of factor inputs (net of tax evasion), with $\tau_{h,j}^f$ representing factor taxes and $e_{h,j}^f$ the tax-specific evasion rate for factor h and sector j. Note that $F_{h,j}$ denotes total factor inputs, out of which the amount $F_{h,j}^{loss}$ (the third term) is lost due to evasion activities.

Standard Lagrangian optimisation yields the following first order conditions:

$$\frac{\partial \pi_j^y}{\partial e_{h,j}^f} = A_{h,j}^f (e_{h,j}^f)^{N_{h,j}^f} = \tau_{h,j}^f \qquad \text{(FOC 2.1)}$$

$$\frac{\partial \pi_j^y}{\partial F_{h,j}} = p_h^f \left(1 + \tau_{h,j}^f (1 - e_{h,j}^f) + c(e_{h,j}^f) \right) = p_j^y \beta_{h,j} \frac{Y_j}{F_{h,j}} \qquad \text{(FOC 2.2)}$$

Note that FOC 2.1 states that at optimum the firm's marginal cost of evasion (LHS) is equal to the marginal benefit of evading tax (RHS). Similarly, FOC 2.2 states that the marginal cost of an additional unit of input (LHS) equals the its marginal cost (RHS).

Moreover, using FOC 2.1 the optimal evasion rate $e_{h,j}^f$ can be derived:

$$e_{h,j}^f = \left(\frac{\tau_{h,j}^f}{A_{h,j}^f} \right)^{\frac{1}{N_{h,j}^f}} \qquad (11)$$

Equation 11 shows that the optimal evasion rate is increasing in the factor tax rate $(\tau_{h,j}^f)$.

By plugging $e_{h,j}^f$ into the original cost equation (1), the cost of evasion at optimum can be determined. This also allows solving for and calibrating parameter $A_{h,j}^f$, as all other parameters are known (section 6.2). FOC 2.2 allows solving for the optimal factor demand $F_{h,j}$:

$$F_{h,j} = \beta_{h,j} \frac{p_j^y}{p_h^f (1 + \tau_{h,j}^f (1 - e_{h,j}^f) + c(e_{h,j}^f))} Y_j \qquad \forall h,j \qquad (12)$$

Second stage:
The firm's second production stage is described by a Leontief production function, which is homogeneous of degree one and exhibits constant returns to scale. Note that the Cobb-Douglas production function in the first stage can describe substitution between factors, while a Leontief function cannot. However, by applying a Leontief production function in the second stage the computational complexity of the model can be reduced considerably (Hosoe et al., 2010).

The firm maximises profits by choosing the quantity of output (Z_j), of intermediate inputs $(X_{i,j})$, of the composite factor (Y_j), and the production tax evasion rate e_j^z.

$$\max_{Z,Y,X,e^z} \ \pi_j^z = \Bigg\{ p_j^z Z_j + \tau_j^z e_j^z p_j^z Z_j$$
$$- p_j^y Y_j - \sum_i p_i^q (1 - s_i^e) X_{i,j} - p_j^q (1 - s_i^e) X_j^{loss} \Bigg\} \qquad (13)$$

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$$s.t. \quad Z_j = \min\left[\frac{X_{i,j}}{ax_{i,j}}, \ \frac{Y_j}{ay_j}\right] \tag{14}$$

The first term of the profit function denotes revenues from the sale of outputs, the second term denotes the benefit from tax evasion, the third and fourth terms denote the cost of composite and intermediate inputs, while the last term is the cost of evasion. Moreover, $ax_{i,j}$ (or ay_j) is the input requirement coefficient of the i-th intermediate input (or j-th composite factor) for one unit of the output j.

The production function (equation 14) can be used to replace $X_{i,j}$ and Y_j, and thus derive an unconstrained maximisation problem:

$$\max_{Z,e^z} \quad \pi_j^z = \left\{ p_j^z Z_j + \tau_j^z e_j^z p_j^z Z_j - p_j^y ay_i Z_j \right.$$
$$\left. - \sum_i \left(1 - s_i^e\right) p_i^q ax_{i,j} Z_j - \left(1 - s_j^e\right) p_j^q c(e_j^z) Z_j \right\} \tag{15}$$

This yields the following first order conditions:

$$\frac{\partial \pi_j^z}{\partial e_j^z} \quad = p_j^z \tau_j^z = \left(1 - s_j^e\right) p_j^q A_j^z (e_j^z)^{N_j^z} \tag{FOC 3.1}$$

$$\frac{\partial \pi_j^z}{\partial Z_{h,j}} \quad = (1 + \tau_j^z e_j^z - c(e_j^z)) p_j^z = p_j^y ay_j + \sum_i (1 - s_i^e) p_i^q ax_{i,j} \tag{FOC 3.2}$$

As in the case with factor tax evasion, the firm chooses production tax evasion such that the marginal benefit of tax evasion (LHS of FOC 3.1) is equal to the marginal cost (RHS of FOC 3.1). This means that the firm's optimal level of production tax evasion e_j^z can be expressed as

$$e_j^z = \left(\frac{p_j^z}{\left(1 - s_j^e\right) p_j^q} \frac{\tau_j^z}{A_j^z}\right)^{\frac{1}{N_j^z}}. \tag{16}$$

Note that the optimal evasion rate is increasing in the production tax rate (τ_j^z).

To summarise, the following set of equations describes the firms' behaviour for optimising its two stage production process:

$$F_{h,j} = \beta_{h,j} \frac{p_j^y}{p_h^f(1 + \tau_{h,j}^f(1 - e_{h,j}^f) + c(e_j^f))} Y_j \qquad \forall h,j \qquad (17)$$

$$X_{i,j} = ax_{i,j} Z_j \qquad (18)$$

$$Y_j = ay_j Z_j \qquad (19)$$

$$Y_j = b_j \prod_h F_{h,j}^{\beta_{h,j}} \qquad (20)$$

$$Z_j = \min\left[\frac{X_{i,j}}{ax_{i,j}}, \; \frac{Y_j}{ay_j} \right] \qquad (21)$$

$$e_{h,j}^f = \left(\frac{\tau_{h,j}^f}{A_{h,j}^f} \right)^{\frac{1}{N_{h,j}^f}} \quad \text{and} \quad e_j^z = \left(\frac{p_j^z}{(1 - s_j^e)p_j^q} \frac{\tau_j^z}{A_j^z} \right)^{\frac{1}{N_j^z}} \qquad (22)$$

Lastly, note that the Leontief production function implies rectangular isoquants, which are prone to computational problems due to their kinks. Thus, as suggested by Hosoe et al. (2010), equation 21 is replaced with a unit cost function for computational purposes. This unit cost function can be obtained by transforming the zero profit condition $\pi_j^z = 0$ using functions 18 and 19:

$$p_j^z = ay_j p_j^y + \sum_i p_i^q(1 - s_i^e)ax_{i,j} + p_j^q(1 - s_j^e)c(e_j^z) \qquad (23)$$

5.4. Government

The government in this model takes the role of levying taxes, consuming goods, and providing subsidies and direct cash transfers. Formally, government consumption X_i^g is a sum of its revenues from different tax sources, net of subsidy payments (S_f^e) and cash transfers (Ct_l^{tax}):

$$X_i^g = \frac{\mu_i}{p_i^q} \left(\sum_l T_l^d + \sum_h \sum_j T_{h,j}^f + \sum_j T_j^z + \sum_j T_j^m - \sum_j S_j^e - \sum_l Ct_l^{tax} \right) \qquad (24)$$

The share of the i-th good in government expenditure is denoted μ_i. Prices are denoted p_i^q for the i-th composite good, p_h^f for production factors, p_j^z for output, and p_j^m for imports. Direct taxes T_l^d are levied on the factor endowment $FF_{h,l}$ of household l at the rate τ_l^d.

$$T_l^d = \tau_l^d \left(\sum_h p_h^f FF_{h,l} \right) \qquad (25)$$

Factor taxes $T_{h,j}^f$ are levied on firms' factor inputs at the rate $\tau_{h,j}^f$ and are subject to evasion.

$$T_{h,j}^f = (1 - e_{h,j}^f)\tau_{h,j}^f p_h^f F_{h,j} \tag{26}$$

Production taxes T_j^z are levied on output Z_j by firm j at the effective tax rate $(1 - e_j^z)\tau_j^z$ after evasion.

$$T_j^z = (1 - e_j^z)\tau_j^z p_j^z Z_j \tag{27}$$

Import taxes are levied on imports M_j at the rate τ_j^m.

$$T_j^m = \tau_j^m p_j^m M_j \tag{28}$$

Besides public expenditure on goods (X_i^g), the government also provides energy subsidies S_j^e at the rate s_j^e.

$$S_j^e = s_j^e p_j^q \left(\sum_l X_{j,l}^p + \sum_i X_{j,i} + X_j^{loss} \right) \tag{29}$$

Note that the subsidy s_j^e is provided for household consumption ($X_{j,l}^p$) and for energy as an intermediate input ($X_{j,i}$). Government and investment demand (X_i^g and X_i^v) are not subsidised. Cash transfers Ct_l^{tax} are defined in section 5.6.

5.5. Investments and savings

Given the static setting of the model, dynamic aspects such as investment and savings cannot be reflected in their strict sense. However, recognising that these activities can constitute significant shares of final demand, a virtual investment account is incorporated (Hosoe et al., 2010). This account is modelled to use savings from households and abroad to invest these in investment goods. Formally, investment demand X_i^v is given by

$$X_i^v = \frac{\lambda_i}{p_i^q} \left(\sum_l Ss_l^p + \varepsilon Ss^f \right) \tag{30}$$

$$Ss_l^p = ss_l^p \left(\sum_h p_h^f FF_{h,l} + Ct_l^{tax} + Ct_l^z + \sum_h Ct_{l,h}^f \right) \tag{31}$$

To avoid confusion with subsidies (S^e), savings are denoted Ss^f for the foreign sector (at exchange rate ε), and Ss^p for households. Moreover, the parameter λ_i denotes the expenditure share of the i-th good in overall investment; the average propensity to save is denoted ss^g for the government and ss_l^p for households. Household income from cash transfers (Ct_l) are detailed in the following subsection.

5.6. Households

This study distinguishes five households, each representing an income quintile, as well as an additional smuggler, representing a relatively small number of households engaged in fuel smuggling activities. Households are modelled to maximise their utility subject to a standard budget constraint. The optimised consumption choice $X_{i,l}^p$ can be expressed as

$$X_{i,l}^p = \frac{\alpha_{i,l}}{p_i^q(1-s_i^e)} \left(\sum_h p_h^f FF_{h,l} + Ct_l^{tax} + Ct_l^z + \sum_h Ct_{l,h}^f - Ss_l^p - T_l^d \right). \tag{32}$$

The first term in the round parentheses reflects income from factor income (e.g. wages); the second term reflects direct government transfers for redistributing tax revenues; and the third and fourth terms reflect the benefits of production (Ct_l^z) and factor ($Ct_{l,h}^f$) tax evasion which ultimately accrue to households. These income sources are balanced by savings (Ss_l^p), direct tax payments (T_l^d), and consumption ($X_{i,l}^p$) of good i which is determined by $\alpha_{i,l}$, the share parameter in the utility function.

Government cash transfers for redistributing tax revenues are implied by equation 24 and can be expressed as:

$$Ct_l^{tax} = R_l^{tax} \bigg(\sum_l T_l^d + \sum_h \sum_j T_{h,j}^f + \sum_j T_j^z + \sum_j T_j^m$$
$$- \sum_j S_j^e - \sum_i p_i^q X_i^g \bigg) \tag{33}$$

The overall budget for these redistribution transfers is given by tax revenues from four different tax types, from which subsidy payments and government consumption must be subtracted. The redistribution rule R_l^{tax} determines the share of the overall redistribution budget obtained by each household. Cash transfers Ct_l^{tax} will play a key role as a means for redistributing subsidy reforms revenues in the policy simulations of this study.

Moreover, household income from tax evasion activities are defined as

$$Ct_l^z = R_l^z \sum_j \tau_j^z e_j^z p_j^z Z_j \tag{34}$$

for the evasion of production taxes, and

$$Ct_{l,h}^f = R_{l,h}^f \sum_j \tau_{h,j}^f e_{h,j}^f p_h^f F_{h,j} \tag{35}$$

for factor tax evasion. The benefits of tax evasion are distributed across households according to redistribution rules R_i^z and R_i^f. The numerical values of these parameters are chosen to reflect the distribution of consumption and factor endowments.

In addition to the five households, this model considers a smuggler who consumes the same goods as all other households, but earns income from fuel smuggling activities. Thus, the smuggler's budget constraint prescribes that his consumption expenditure equals smuggling profits:

$$X_j^{SM} = \frac{\alpha_j}{p_j^q(1 - s_j^e)} \sum_j \pi_j^{SM} \tag{36}$$

Based on anecdotal evidence that fuel smuggling is typically done by low income households, the smuggler's share parameter α_j is calibrated according to the share paramenter of the 2nd income quintile household. Note that for consistency, the above notation allows smuggling in all sectors j, yet the empirical evidence suggests that it is a relevant consideration only in the petrol sector.

5.7. Exports, imports, and the balance of payments

For considering the implications of cross-border smuggling, the use of an open economy model is necessary. This section briefly sets out the interaction between the model economy and the rest of the world. For this purpose a small open economy set-up is used, which implies that import and export prices (denominated in foreign currency terms) are exogenously given. Formally, domestic import (p_i^m) and export prices (p_i^e), are linked to their corresponding world prices $(p_i^{Wm}$ and $p_i^{We})$ through the exchange rate ε.

$$p_i^e = \varepsilon p_i^{We} \tag{37}$$
$$p_i^m = \varepsilon p_i^{Wm} \tag{38}$$

The balance of payments condition requires that monetary outflows (i.e. due to imports M_i, and inbound smuggling M_i^{SM} and M_i^{loss}) equal inflows.

$$\sum_i p_i^{Wm} \left(M_i + M_i^{SM} + M_i^{loss} \right) = \sum_i p_i^{We} E_i + Ss^f + \sum_i p_i^{We} E_i^{SM} \tag{39}$$

Monetary inflows comprise exports (E_i), "foreign savings" or the current account deficit (Ss^f), and gross earnings from the foreign sale of smuggled fuel (E_i^{SM}).

Substitution between imports and domestic goods

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Moreover, an "Armington composite good" is introduced to reflect the widely accepted notion that imports and domestic goods are imperfect substitutes (Armington, 1969). Thus, this reflects a modelling approach which allows endogenous market shares for imported goods, as opposed to a "cheapest takes all" setting.

In its essence, this approach introduces profit maximising firms which choose a combination of imported and domestic goods to produce the Armington composite – which is then consumed by households, firms, and the government. Thus, the solution of their profit maximisation determines the demand for imports and domestic goods (and is thus also directly influenced by the respective prices).

Using the constant elasticity of substitution (CES) production function

$$Q_i = \gamma_i \left(\delta m_i M_i^{\eta_i} + \delta d_i D_i^{\eta_i} \right)^{\frac{1}{\eta_i}} \tag{40}$$

a standard profit maximisation procedure yields demand functions for imports and the domestic good:

$$M_i = \left(\frac{\gamma_i^{\eta_i} \delta m_i p_i^q}{(1 + \tau_i^m) p_i^m} \right)^{\frac{1}{1 - \eta_i}} Q_i \tag{41}$$

$$D_i = \left(\frac{\gamma_i^{\eta_i} \delta d_i p_i^q}{p_i^d} \right)^{\frac{1}{1 - \eta_i}} Q_i \tag{42}$$

In terms of notation, Q_i denotes the i-th Armington composite good, which is composed of imports (M_i) and domestic goods (D_i). The coefficients δm_i and δd_i denote the respective input shares of the composite good (fulfilling $0 \leq \delta m_i \leq 1$, $0 \leq \delta d_i \leq 1$, and $\delta m_i + \delta d_i = 1$); while γ_i is the scaling coefficient in the composite production function. Prices are defined for the Armington composite good (p_i^q), imports (p_i^m), and domestic goods (p_i^d). Lastly, η_i is a parameter defined by the elasticity of substitution σ_i ($\eta_i = (\sigma_i - 1)/\sigma_i$, with $\eta_i \leq 1$).

Transformation between exports and domestic goods

In direct analogy to the demand side, imperfect transformation on the supply side (i.e. between exports and domestic goods) is reflected using a constant elasticity of transformation (CET) production function. Similar to the CES function, this setting allows that the gross domestic output of a good comprises both exports and domestic supply, the ratio of which is determined by their relative prices.

Formally, this is modelled by introducing a "virtual" profit maximising firm, which transforms the gross domestic output (Z_i) into exports (E_i) and domestically supplied goods (D_i) according to following CET production function:

$$Z_i = \theta_i \left(\xi e_i E_i^{\phi_i} + \xi d_i D_i^{\phi_i} \right)^{\frac{1}{\phi_i}} \tag{43}$$

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By solving a standard profit maximisation problem following supply rules for exports and domestic goods are obtained:

$$E_i = \left(\frac{\theta_i^{\phi_i} \xi e_i (1 + \tau_i^z (1 - e_j^z)) p_i^z}{p_i^e} \right)^{\frac{1}{1 - \phi_i}} Z_i \tag{44}$$

$$D_i = \left(\frac{\theta_i^{\phi_i} \xi d_i (1 + \tau_i^z (1 - e_j^z)) p_i^z}{p_i^d} \right)^{\frac{1}{1 - \phi_i}} Z_i \tag{45}$$

In terms of notation, Z_i denotes the gross domestic output of the i-th good, which can either be exported (E_i) or supplied domestically (D_i). The coefficients ξe_i and ξd_i are the share coefficient of the transformation process (fulfilling $0 \leq \xi e_i \leq 1$, $0 \leq \xi d_i \leq 1$, and $\xi e_i + \xi d_i = 1$). Moreover, θ_i is the scaling coefficient characterising the transformation. Prices are defined for gross domestic output (p_i^z), exports (p_i^e), and domestic goods (p_i^d). Lastly, ϕ_i is a parameter defined by the elasticity of transformation ψ_i ($\phi_i = (\psi_i + 1)/\psi_i$, with $\phi_i \leq 1$).

5.8. Market clearing

To reach an equilibrium, conditions need to be formulated that ensure the equivalence of demand and supply in goods and factor markets. The goods market equilibrium is achieved when following condition is met:

$$Q_i = \sum_l X_{i,l}^p + X_i^g + X_i^v + \sum_j X_{i,j} + X_i^{SM} + X_i^{loss} + E_i^{loss} \tag{46}$$

This condition implies that the supply of the i-th Armington composite good must equal its aggregate demand. Demand is composed of demand by households ($X_{i,l}^p$), the government (X_i^g), investment (X_i^v), firms ($X_{i,j}$), and the smuggler (X_i^{SM}); in addition some of the goods are lost as inputs to tax evasion (X_i^{loss}) and smuggling (E_i^{loss}) activities.

The second market clearing condition ensures an equilibrium in the factor market:

$$\sum_l FF_{h,l} = \sum_j \left(F_{h,j} + F_{h,j}^{loss} \right) \tag{47}$$

This implies that the sum of endowments of the h-th factor ($FF_{h,l}$) must equal the aggregate factor demand. Note that firms' total factor demand is the sum of standard factor demands for production ($F_{h,j}$) and factors used for the purpose of tax evasion activities (e.g. labour), denoted $F_{h,j}^{loss}$.

6. Calibration and data

Section 6.1 describes data sources used for this study. Sections 6.2 and 6.3 provide detailed derivations for the calibration of latent parameters.

6.1. Data

6.1.1. Economic variables

The baseline values for macro-economic parameters have been obtained from the GTAP 9 database – in particular, Nigeria's social accounting matrix (SAM) for the 2011 reference year. These macro-economic parameters are the size of economic sectors (i.e. output), intermediate inputs, capital and labour inputs, taxes, government expenditure, household consumption, imports, exports, and the current account balance. Four sectors are distinguished: (i) the (subsidised) petrol sector, (ii) the (unsubsidised) energy sector, which excludes petrol, (iii) the formal (non-energy) sector, and (iv) the informal (non-energy) sector. The parameters and coefficients $\alpha_{i,l}$, $\beta_{h,j}$, b_i, γ_i, μ_i, λ_i, θ_i, $ax_{i,j}$, ay_j, δm_i, δd_i, ξe_i, ξd_i, ssp_l, and ssg have been calibrated on the basis of the 2011 baseline data, and the model equations set out in Section 5.

Since the GTAP 9 SAM does not provide information on the distribution of income and consumption, overall household consumption figures have been split into income quintiles according to expenditure shares contained in the Harmonised Nigeria Living Standards Survey 2010. Across income quintiles, this household expenditure survey provides details on the level of spending on petrol, other energy, and non-energy consumption goods. It is thus essential for the distributional aspects considered in this study.

Data on FFS in Nigeria have been obtained from the International Energy Agency's World Energy Outlook 2015 Fossil Fuel Subsidies database (IEA, 2015). Based on the *price gap* definition, the IEA provides an estimate of $7.1 bn of fossil fuel consumption subsidies in 2011, of which over $6.5 bn are paid to subsidise oil (primarily petrol). This figure, in combination with the estimated size of the petrol sector, translates to a baseline subsidisation rate of 17.8%.[6] Finally, population data has been obtained from the World Bank's World Development Indicators database.

6.1.2. Tax evasion

For the purpose of comparing sectors with high and low tax evasion, Liu (2013) uses the self-employment rate of an economy to approximate the size of the high-evasion sector. This approach works particularly well in developed and emerging economies, for which reasonably reliable estimates of self-employment are available from sources such as the International Labour Organization (ILO). However, the ILO's Labour Statistics database offers no estimate of the self-employment rate in Nigeria.

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[6] For clarity, the baseline subsidisation rate is indicated in the results (rounded to 18%).

Instead of relying on uncertain alternative estimates for self-employment, this study uses the size of the informal sector as a proxy for the high-evasion sector. The advantage of this approach is that estimates of informal economic sectors exist for a wide range of countries – including developing countries – and are based on a consistent estimation procedure. Specifically, the formal economy estimates from the GTAP 9 database are supplemented by including an informal sector, which in 2011 measured 50% of GDP in Nigeria according to the comprehensive analysis by Hassan and Schneider (2016).

This study uses a very conservative estimate of 2% for the tax evasion rate in the formal economy. For comparison, Liu (2013) uses a 5% evasion rate in a selection of 27 developed and emerging economies, based on estimates by Slemrod (2007). The Swedish National Tax Agency (2008) reports a 4.8% evasion rate for income taxes in its jurisdiction. In line with the notion of informality, this study assumes that the informal sector does not pay any taxes. Moreover, this study uses the conservative assumption by Liu (2013), that 10% of evaded taxes are spent on non-productive evasion activities (see Section 3). The net benefits of tax evasion are assumed to ultimately accrue to households; in line with the distribution shares of regular income, the top income quintile is assumed to benefit disproportionately more than lower quintiles.

Based on these numbers, the evasion parameters $A_{h,j}^f$, $N_{h,j}^f$, A_j^z, and N_j^z can be calibrated to characterise the evasion cost functions (Eq. 1 and 2). Section 6.2 provides detailed derivations associated with the calibration of these parameters.

6.1.3. Smuggling

This section outlines the steps taken to estimate the baseline magnitude of fuel smuggling out of Nigeria.

The first step is to focus on smuggling activity from Nigeria to Benin (and from there to Togo), as detailed estimates are available from the IMF (Mlachila et al., 2016). While Togo does not share a border with Nigeria, its distance to the Nigerian border is under 120 km, and thus extensive smuggling occurs via Benin (Figure 1). The IEA (2016) reports total gasoline consumption for Benin (616 k tonnes) and Togo (175 k tonnes) in 2011. The IMF outlines that in both Benin and Togo respectively, gasoline is sold on two separate markets (Mlachila et al., 2016): an official market for the sale of legal and regulated gasoline, as well as an informal market for the sale of gasoline smuggled from Nigeria. Mlachila et al. (2016) estimate that the informal market constituted about 85% of total gasoline consumption in Benin in 2011, and 70.7% in Togo. This allows the computation of the absolute size of the informal markets (in physical units), which reflects the quantity of smuggled fuel.

The revenues earned by smugglers are then estimated by multiplying the total smuggled quantity of gasoline with the respective price differential between Nigeria's official subsidised market price and Benin's (or Togo's) informal market price. These informal market prices are also reported by Mlachila et al. (2016).

The second step is to extrapolate the smuggling estimates for Benin (and Togo)

to Nigeria's remaining neighbouring countries Niger and Cameroon.[7]   Using the border length between Benin and Nigeria (773 km), and by assuming that the smuggled quantity is proportional to the length of the external border, a rough estimate of total smuggling can be obtained. In other words, the longer the border between Nigeria and a neighbouring country, the more smuggling activity takes place towards this country. For instance, Nigeria shares a 773 km border with Benin and 1,497 km with Niger, thus the quantity of fuel smuggled to Niger should be roughly twice as large.

	Nigeria	Benin	Togo	Niger	Cameroon	Chad
Border with Nigeria (km)	–	773	–	1,497	1,690	89
Gasoline price (N/litre)	97.4	162.8	182.9	167.4	186.8	204.6
Pop. in bordering Nigerian states (m)	–	27.9	–	23.6	16.5	6.1
Av. fuel consumption in bordering Nigerian states (N/month)	–	286	–	100	175	insig.

Table 1: Parameters used for refining extrapolated smuggling estimates

The third step is to refine this extrapolation by making two further adjustments:

- *Population:* Since the states bordering Benin are particularly populous (and states in Northern Nigeria are sparsely populated), the smuggling estimate is further adjusted proportional to the population size in Nigerian border states. This reflects the presumption that a larger population means that more smugglers are present and that more smuggling takes place. Moreover, this accounts for the fact that population densities on two sides of a border tend to be correlated; thus taking into account the number of foreign consumers demanding smuggled fuel.

- *Availability of energy:* Furthermore, the availability of gasoline varies significantly across Nigeria, and directly affects the quantity of gasoline available for smuggling: The states bordering Benin are more developed and urbanised, and offer better access to energy goods. This is not least due to proximity to harbours, where imported gasoline is landed, and better distribution infrastructure. In more remote states gasoline tends to be less widely available and more expensive (reflecting domestic transport costs), thus reducing smugglers' profit margins. To reflect these factors, smuggling estimates are further adjusted in line with the average per capita expenditure on gasoline in each of the relevant bordering states (Figure 1).

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[7]Chad shares a 89 km border with Nigeria. This implies that smuggling quantities to Chad are negligible for the purpose of this study.

To summarise the three estimation steps outlined above, the total quantity of smuggled fuel is estimated as

$$E_{Petrol}^{SM} = \sum_c SQ_c$$

$$= \sum_c \left[\frac{BL_c}{BL_{Benin}} \ \frac{AFC_c}{AFC_{Benin}} \ \frac{Pop_c}{Pop_{Benin}} \ SQ_{Benin} \right] \qquad (48)$$

where:

- SQ_{Benin} = Petrol quantity smuggled to Benin (and from there also to Togo)

- SQ_c = Estimated petrol quantity smuggled to neighbouring country c

- BL_c = Length of external border shared by Nigerian states and country c

- AFC_c = Average petrol consumption per capita in Nigerian states sharing a border with country c

- Pop_c = Population in Nigerian states sharing a border with country c.

Based on this method a total petrol smuggling estimate of $ 641 m is obtained, about 43% of which is smuggled to Benin and Togo, 33% to Cameroon, 24% to Niger, and less than 1% to Chad.

Mlachila et al. (2016) report that petrol smuggled from Nigeria is sold in Benin with an average mark-up ranging between approximately 20% and 40%. They note that informal prices in Benin are lower (i.e. the mark-up smaller) closer to the Nigerian border. This mark-up contains the cost of smuggling (including transport costs), but also profits by smugglers and middlemen. This study makes the assumption that the cost of smuggling corresponds to 10% of the smuggling value.[8]

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[8]The overall results of this study are not found to be influenced significantly by increasing the cost of smuggling to 20% or 30%.
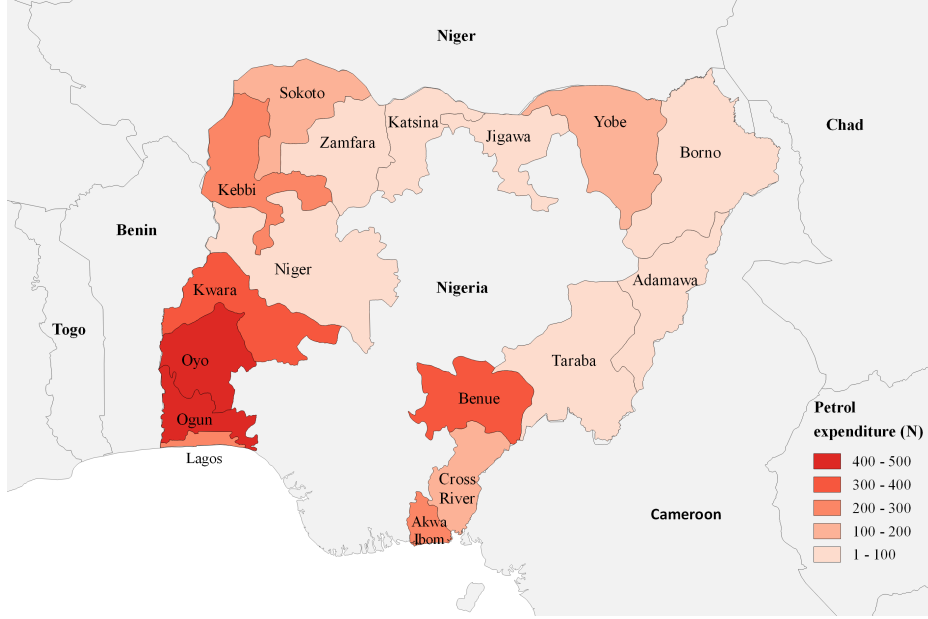
Figure 1: Monthly per capita petrol expenditure in Nigerian border states (in Naira).

6.2. Calibration of evasion parameters $A_{h,j}^f$, $N_{h,j}^f$, A_j^z, and N_j^z

Following parameter calibrations are based on the SAM, constructed for the purpose of this CGE model using the data described above. The benefit of factor tax evasion is recorded in the SAM as the entry $SAM_{EV\_h,j}$, which is equivalent to $\tau_{h,j}^f e_{h,j}^{f0} p_{h,j}^{f0} F_{h,j}^0$ in the model's notation. Superscripts 0 denote baseline (i.e. observed) values. By replacing $e_{h,j}^{f0}$ with equation 11, $A_{h,j}^f$ can be expressed and calibrated as

$$A_{h,j}^f = \frac{\left(\tau_{h,j}^f\right)^{N_{h,j}^f+1}\left(F_{h,j}^0\right)^{N_{h,j}^f}}{SAM_{EV\_h,j}^{N_{h,j}^f}}.\tag{49}$$

The cost of factor tax evasion is recorded in the SAM as $SAM_{EC\_h,j} = p_h^{f0} c(e_{h,j}^{f0}) F_{h,j}^0$. This can be re-written as

$$SAM_{EC\_h,j} = p_h^{f0} \frac{A_{h,j}^f}{N_{h,j}^f+1}\left(e_{h,j}^{f0}\right)^{N_{h,j}^f+1} F_{h,j}^0.$$

By replacing $e_{h,j}^{f0}$ this can be written as

$$SAM_{EC\_h,j} = p_h^{f0} \frac{A_{h,j}^f}{N_{h,j}^f + 1} \left(\frac{\tau_{h,j}^f}{A_{h,j}^f} \right)^{\frac{N_{h,j}^f+1}{N_{h,j}^f}} F_{h,j}^0.$$

Since at the baseline equilibrium $p_h^{f0} = 1$, the expression can be re-written further:

$$SAM_{EC\_h,j} = \frac{\left(\tau_{h,j}^f \right)^{\frac{N_{h,j}^f+1}{N_{h,j}^f}} F_{h,j}^0}{\left(A_{h,j}^f \right)^{\frac{1}{N_{h,j}^f}} \left(N_{h,j}^f + 1 \right)}$$

Furthermore, by using equation 49 the term $\left(A_{h,j}^f \right)^{\frac{1}{N_{h,j}^f}}$ can be replaced:

$$SAM_{EC\_h,j} = \frac{SAM_{EV\_h,j}}{\left(\tau_{h,j}^f \right)^{\frac{N_{h,j}^f+1}{N_{h,j}^f}} F_{h,j}^0} \frac{\left(\tau_{h,j}^f \right)^{\frac{N_{h,j}^f+1}{N_{h,j}^f}} F_{h,j}^0}{N_{h,j}^f + 1}.$$

Thus, $N_{h,j}^f$ can be expressed and calibrated as:

$$N_{h,j}^f = \frac{SAM_{EV\_h,j}}{SAM_{EC\_h,j}} - 1 \tag{50}$$

Analogously, the same procedure is used to calibrate parameters A_j^z and N_j^z associated with the production tax evasion function:

$$A_j^z = \frac{\left(\tau_j^z \right)^{N_j^z+1} \left(Z_j^0 \right)^{N_j^z}}{SAM_{EV\_ENE,j}^{N_j^z}} \tag{51}$$

$$N_j^z = \frac{SAM_{EV\_ENE,j}}{SAM_{EC\_ENE,j}} - 1 \tag{52}$$

6.3. Calibration of smuggling parameters A_j^{SM}

The smuggling parameter A_j^{SM} can be calibrated based on the smuggler's profit maximisation expression in section 5.2 (in particular FOC 1.1):

$$A_j^{SM} = \frac{p_j^e - (1 - s_j^e)p_j^q}{(1 - s_j^e)p_j^q (E_j^{0SM})^{r-1}} \tag{53}$$

E_j^{0SM} is recorded in the SAM as the baseline value of smuggled goods.

7. Simulation scenarios

Scenario 1: Baseline

This scenario reproduces the baseline economy observed in the data. It serves as a reference point for evaluating the results in the subsequent simulation scenarios. It also enables a baseline evaluation of the regressivity of fossil fuel subsidies.

Scenario 2: Uncompensated subsidy reform

This scenario simulates an uncompensated petrol subsidy reduction and petrol tax increase (from $s^e_{Petrol} = 0.22$ to $s^e_{Petrol} = -0.22$).[9] The government uses reform revenues to increase government spending. Households receive no compensation.

Scenario 3: Subsidy reform with cash transfers

This scenario simulates a petrol subsidy reduction and petrol tax increase, in which reform revenues are redistributed to households uniformly in the form of direct cash transfers. Each household – no matter the income level – receives the same amount.

Scenario 4: Subsidy reform with labour tax reduction

This scenario simulates a petrol subsidy reduction and petrol tax increase, in which reform revenues are used to reduce labour taxes (i.e. a double dividend style fiscal reform). Labour taxes across all sectors are reduced.

Counter-factual scenario: Revenue neutral subsidy reform ignoring tax evasion and smuggling

This scenario repeats the simulation of a double dividend style fiscal reform (Scenario 4), but disregards tax evasion and smuggling activities. This enables an assessment of the size of the evasion and smuggling effects on estimated reform benefits.

8. Assessing welfare effects

8.1. Fiscal efficiency and social welfare

As Liu (2013) shows, a "double dividend" style tax reform – i.e. using environmental tax revenue to reduce pre-existing taxes – can reduce, but not fully

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[9]Note that, as mentioned previously, the baseline subsidisation rate observed in the data is $s^e_{Petrol} = 0.18$. This means that the simulation range mainly focusses on the FFS reduction (0.18 to -0.22), but also provides estimates for the effects of an increase in FFS (from 0.18 to 0.22).

eliminate, the social welfare cost of environmental taxes (Bovenberg and Goulder, 1996; Goulder, 1995b). The same welfare costs must be expected when FFS reform revenue is used to reduce pre-existing taxes (simulation scenario 4).

To confirm this, this study estimates the social welfare cost of a double dividend style FFS reform (i.e. scenario 4) by evaluating changes at the tax base.[10] For this purpose, this study adopts the approach taken by Williams (2002), Bento and Jacobsen (2007), and Liu (2013), who use the following expression to measure the welfare effect of a change in the environmental tax rate – in this case the subsidisation rate s_j^e:[11]

$$\text{Welfare impact} =$$

$$\text{Tax base effects} \begin{cases} \displaystyle\sum_j \sum_h \tau_{h,j}^f (1 - e_{h,j}^f) p_h^f \frac{\partial F_{h,j}}{\partial s_j^e} \\[2ex] + \displaystyle\sum_j \tau_j^z (1 - e_j^z) p_j^z \frac{\partial Z_j}{\partial s_j^e} \\[2ex] - \displaystyle\sum_j s_j^e p_j^q \frac{\partial \left(\sum_l X_{j,l}^p + \sum_i X_{j,i} + X_j^{loss} + X_j^{SM} \right)}{\partial s_j^e} \end{cases}$$

$$\text{Tax evasion effects} \begin{cases} - \displaystyle\sum_j \sum_h \frac{\partial c(e_{h,j}^f)}{\partial s_j^e} p_h^f F_{h,j} \\[2ex] - \displaystyle\sum_j \frac{\partial c(e_j^z)}{\partial s_j^e} p_j^z Z_j \end{cases}$$

$$\text{Smuggling effects} \begin{cases} - \displaystyle\sum_j p_j^q \frac{\partial E_j^{loss}}{\partial s_j^e} \\[2ex] - \displaystyle\sum_j p_j^m \frac{\partial M_j^{loss}}{\partial s_j^e} \end{cases} \tag{54}$$

The first line represents the marginal change in factor tax revenues following a change in the subsidisation rate. The second line represents the marginal change in production tax revenues. The third line represents the marginal change in subsidy payments (or petrol tax receipts, in the case of a negative subsidisation rate). The fourth line represents the marginal change in real factor losses associated with factor tax evasion. Similarly, the fifth line represents the marginal change in real output losses due to production tax evasion. Lastly, lines six and seven represent the marginal change in smuggling losses associated with outbound (E_j^{loss}) and inbound smuggling (M_j^{loss}). Note that Liu (2013) does not consider subsidies, production tax evasion, and smuggling; likewise, this study does not consider the environmental benefits due to emission reduction.

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[10]Note that the term "welfare" here is used – in line with the literature – to refer to the fiscal efficiency benefits of subsidy reform, and thus the associated increase in societal well-being. It does not refer to household level consumption, which is covered by Section 8.2.

[11]See Liu (2013) for a full analytical derivation.

8.2. Distribution and household welfare

In addition to the effects on fiscal efficiency and social welfare, this study considers the reform's effects on household welfare, i.e. utility. However, utility, being an ordinal measure, is not a practical measure for the purpose of quantitative policy evaluation. This is especially the case when welfare effects on heterogeneous households are to be quantified and compared.

Nevertheless, changes in utility levels can be monetised and thus consistently evaluated and compared by computing *Hicksian equivalent variations* (Mas-Colell et al., 1995; Hosoe et al., 2010; Durand-Lasserve et al., 2015). Equivalent variation measures by how much households' income would need to change (at original price levels) to induce the same welfare change as caused by the policy reform. As the original price levels are used to monetise both baseline and counter-factual utility, the equivalent variation measure allows consistent evaluation of fiscal reforms which directly affect prices.

The Hicksian equivalent variation for household l is obtained by minimising expenditure for a given level of utility U_l:

$$\min_{X_{i,l}^p} \quad exp_l = \sum_i p_i^q X_{i,l}^p \tag{55}$$

$$\text{subject to} \quad U_l = \prod_i (X_i^p)^{\alpha_i} \tag{56}$$

Simple optimisation yields following expenditure function:

$$exp_l = \frac{\prod_i \left(X_{i,l}^p\right)^{\alpha_i}}{\prod_i \alpha_i^{\alpha_i}} \tag{57}$$

Note that at the baseline prices are normalised to unity. Hicksian equivalent variation is defined as the difference between the baseline and counter-factual expenditure:

$$HEV_l = exp_l(p_i^{q0}, U_l) - exp_l(p_i^{q0}, U_l^0) \tag{58}$$

$$= \frac{\prod_i \left(X_{i,l}^p\right)^{\alpha_i}}{\prod_i \alpha_i^{\alpha_i}} - \frac{\prod_i \left(X_{i,l}^{p0}\right)^{\alpha_i}}{\prod_i \alpha_i^{\alpha_i}} \tag{59}$$

9. Results

This section presents the key results from the simulations, while distinguishing the different simulation scenarios wherever relevant or useful.

9.1. Effect on the distribution of petrol consumption

In Nigeria FFS are predominantly provided for petrol consumption, thus this section presents evidence on the inequality of petrol consumption across income groups – and how this pattern changes as FFS are removed. The results show that removing fuel subsidies (from a baseline subsidisation rate of 18%) will cause a 21% reduction in national petrol consumption. Increasing a petrol tax to 22% will cause an additional 36% reduction in consumption. Figure 2 shows that – in absolute terms – the reduction in petrol consumption mainly occurs in the top income quintile.
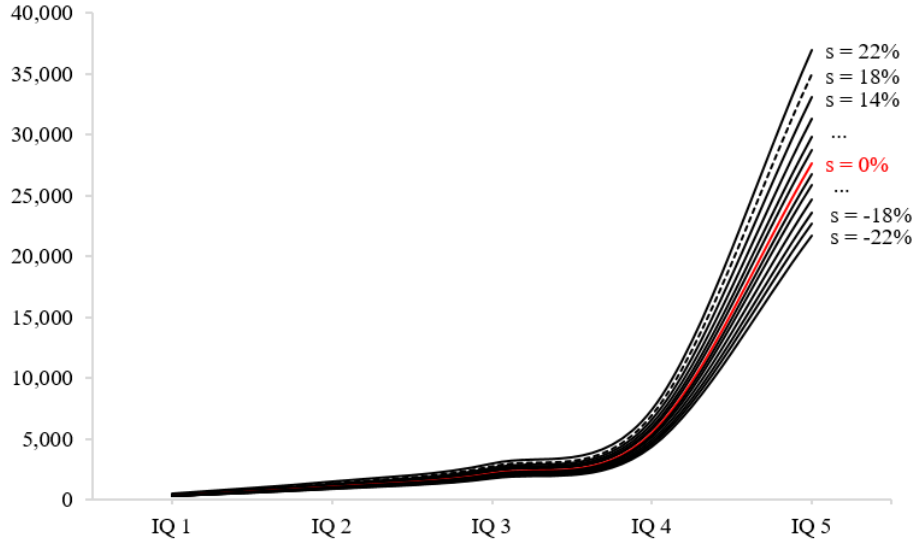
Figure 2: Annual per capita petrol expenditure by income quintiles (IQ) for different subsidisation rates (in Naira)[12].

9.2. Effect on subsidy (or tax) incidence

From a distributional perspective the key criticism of FFS is their highly regressive nature (Arze del Granado et al., 2012). Figure 3 shows that in the baseline scenario ($s^e_{Petrol} = 18\%$) most of the subsidy benefits are indeed received by the top income quintile. Thus, in absolute terms, removing FFS and moving to fuel taxation predominantly affects the top income quintile. Likewise in absolute terms, imposing a fuel tax will also affect the top income quintile most heavily. This illustrates why FFS reform is considered to be a progressive tax reform – and why rich people and powerful political interest groups are often vocal opponents to reform.
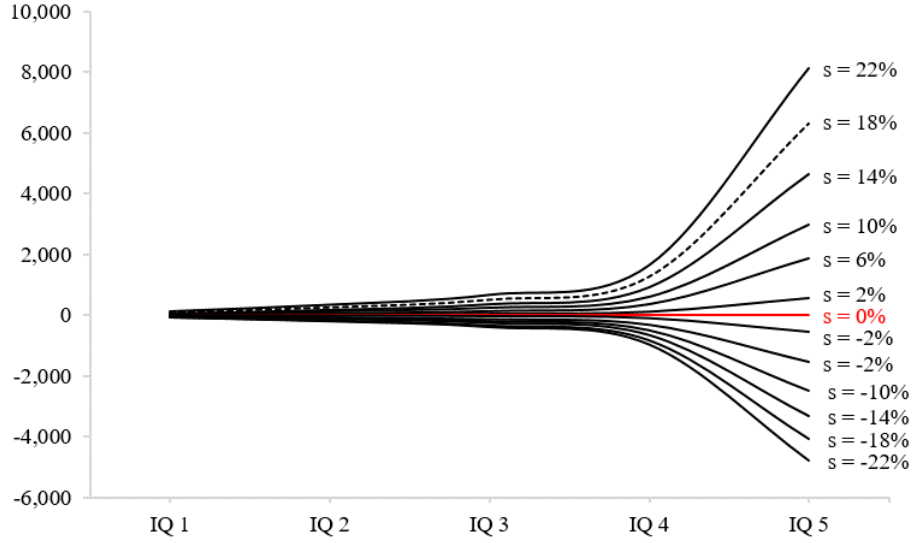
Figure 3: Annual receipt (or payment) of fossil fuel subsidies (or taxes) in N per capita for different income quintiles (IQ).

9.3. Effect on consumption

This section presents the estimated effects of subsidy reduction and energy tax increase on the consumption expenditure of different income groups. For this purpose distinguishing the different revenue redistribution mechanisms (i.e. simulation scenarios) is essential. All results in this section are presented as consumption gains (or losses) relative to income, as this also enables an insight into the vulnerability and exposure of different income groups.

Figure 4 presents relative consumption losses for an uncompensated subsidy reform and tax increase (scenario 2). Reform revenues are used by the government to increase public spending. The estimates show that reform induced consumption losses are relatively consistent at around 3-4% of income across the whole income distribution. The reason for this is that in the case of Nigeria, energy shares in total consumption expenditure are relatively even across income groups (ranging from about 4% to 7%; see Rentschler, 2016) – thus uncompensated FFS removal affects different income quintile to similar extents (relative to income).

Figure 5 presents relative consumption losses for a subsidy reform and tax increase, with reform revenues redistributed uniformly to all households using cash transfers (scenario 3). Note that this scenario does not simulate *targeted* cash transfers (i.e. to specific income or population groups), but *universal* transfers. While the highest income quintile (IQ 5) is estimated to incur consumption losses despite the cash compensation, the first, second and third income quintiles experience significant consumption increases. A full FFS removal ($s^e_{Petrol} = 0$) is estimated to increase consumption of the bottom income quintile by 3.4%, while the introduction of a fuel tax ($s^e_{Petrol} = -0.22$) increases this to 7%. The reason for this progressive effect is that the highly regressive distribution of

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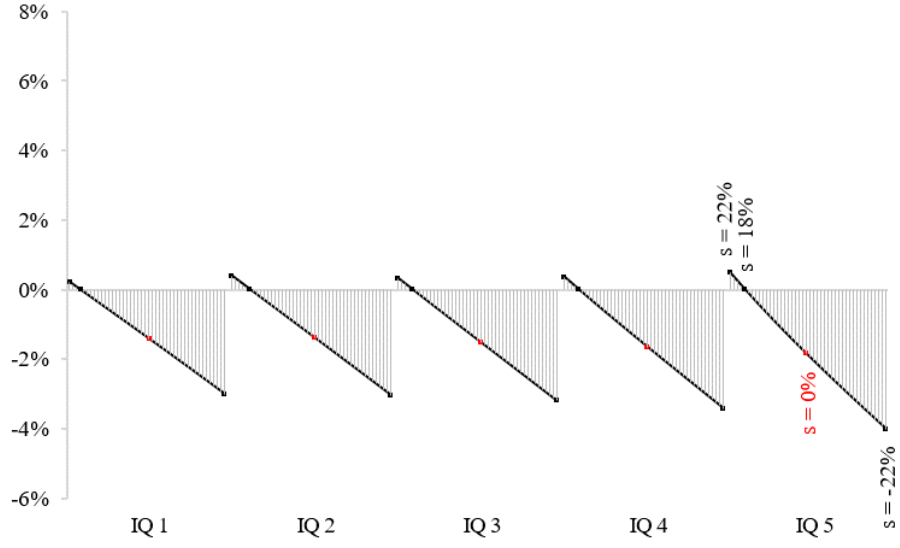
Figure 4: Scenario 2: Relative change in consumption for each income quintile.

benefits via FFS is replaced by a uniform distribution, such that post-reform benefits received by low-income households significantly exceed their receipts through FFS (vice versa for high-income households). Overall, this illustrates that replacing (highly regressive) fuel subsidies with uniform cash compensation is a progressive fiscal reform. This observation applies analogously to the imposition of petrol taxes, if the revenues are redistributed using uniform cash transfers.
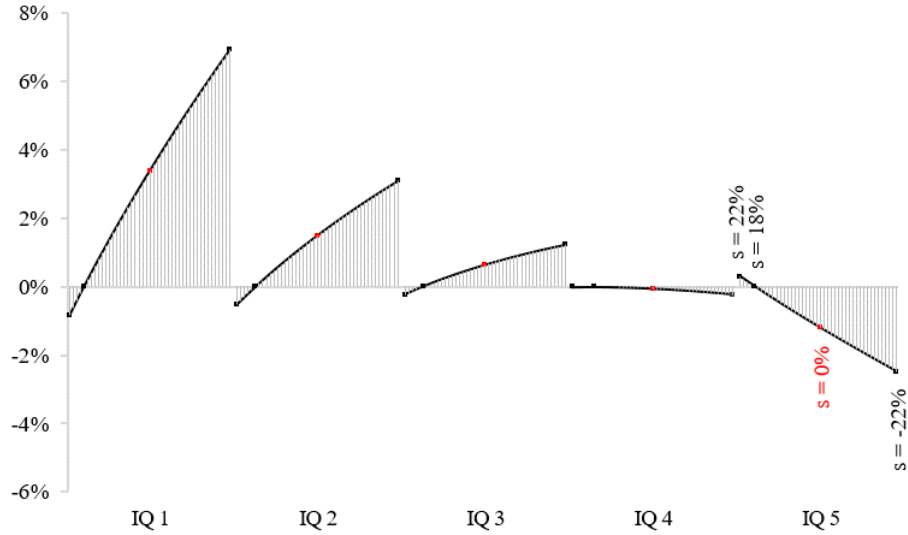
Figure 5: Scenario 3: Relative change in consumption for each income quintile.

Figure 6 presents relative consumption losses for a subsidy reform, in which reform revenues are used to reduce pre-existing labour taxes in all sectors (scenario 4). Falling in a range between 0.7% (IQ1) and -0.5% (IQ5), the estimated consumption changes are small compared to the other scenarios. The reason is that no significant redistribution of resources takes place across income groups, as in the case with cash transfers. Instead, households benefit from labour tax rate reductions proportional to their pre-reform consumption spending. However, not visible in Figure 6, a significant shift takes place within households' consumption bundles: As the tax base shifts, the aggregate consumption of petrol falls by 35.5%, while consumption of formal sector goods increases by 1.3%. The net change resulting from shifting consumption bundles is depicted in Figure 6.
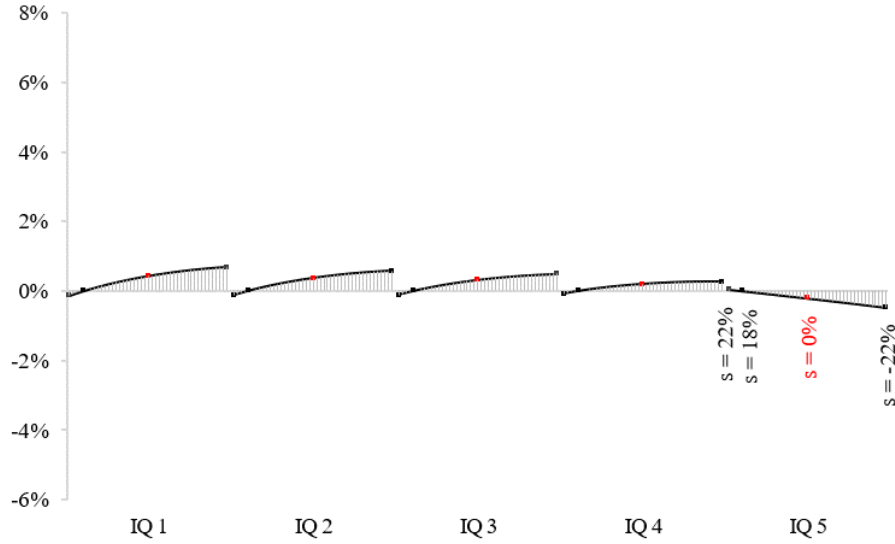
Figure 6: Scenario 4: Relative change in consumption for each income quintile.

9.4. Effect on household welfare

This section presents the estimated welfare effects of subsidy removal and fuel tax increases for each of the redistribution scenarios. As discussed in Section 8.2 welfare effects are measured as Hicksian equivalent variation.

Figure 7(a) shows that households across the entire income distribution incur welfare losses as subsidies are reduced (and fuel taxes increased) without compensation (scenario 2). A marginal welfare gain can be observed for all income quintiles for a subsidisation rate of 22%, as it is higher than the baseline subsidisation rate of 18%. Welfare losses are presented in absolute terms, and are thus largest for the top income quintile. In addition, Figure 7(b) presents the total welfare loss incurred by the whole population.

Figure 8 illustrated the redistribution of wealth associated with the uniform, universal cash compensation scheme (scenario 3). Compared to the baseline
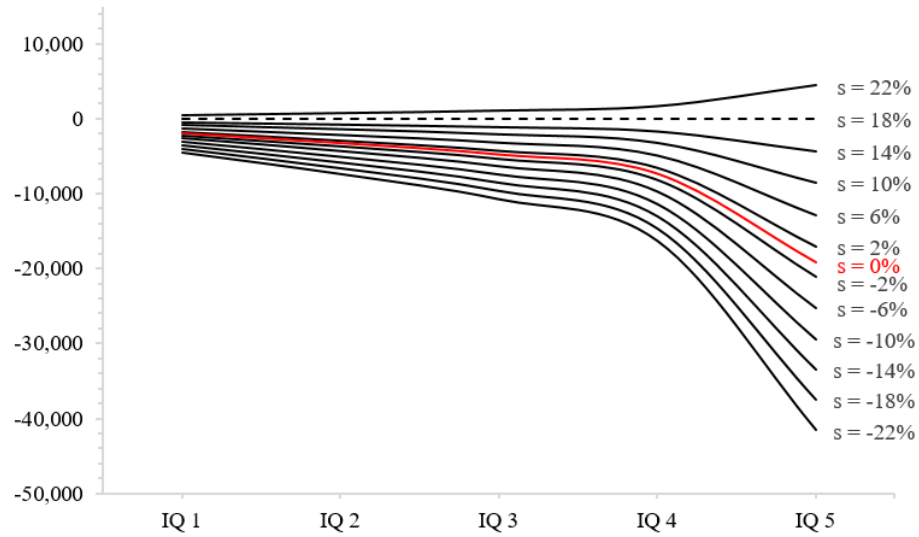
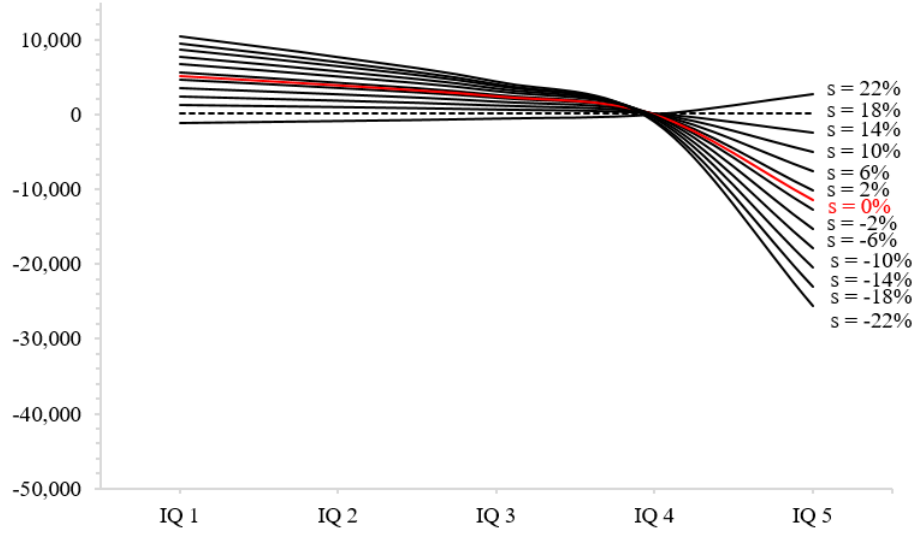**(a)** Equivalent variation by income quintiles (in N)
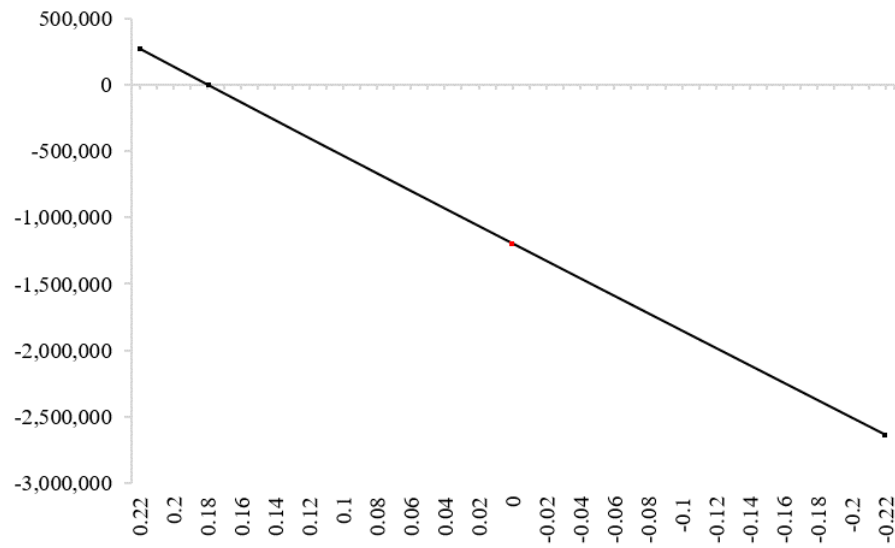
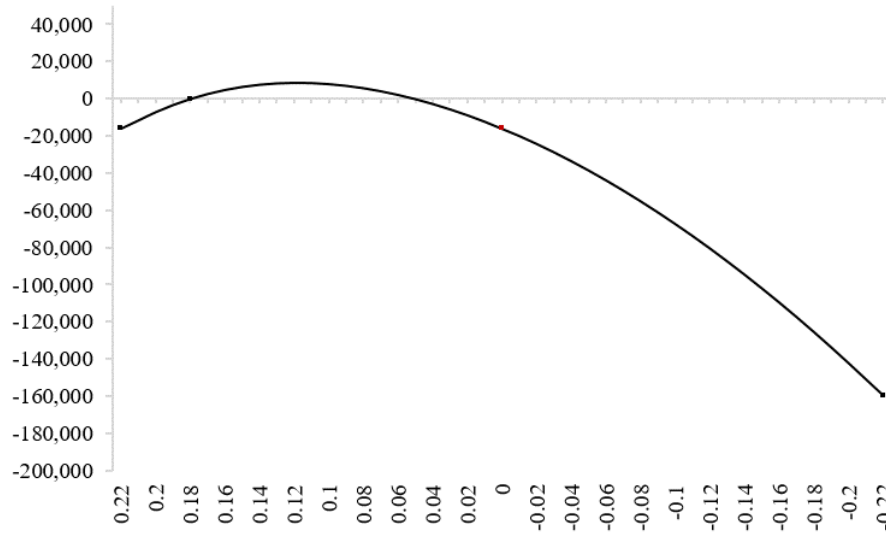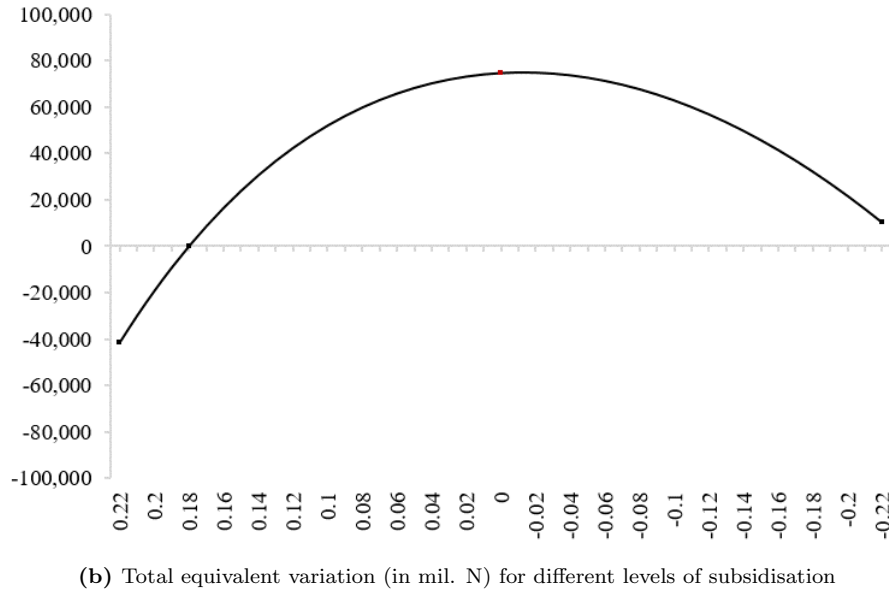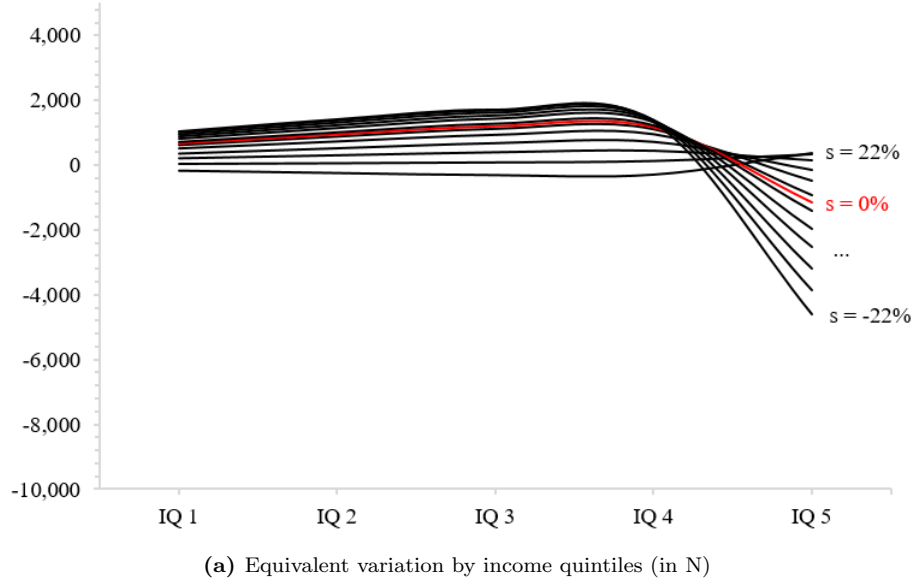**(b)** Total equivalent variation (in mil. N) for different levels of subsidisation

Figure 7: Scenario 2: Change in welfare, measured by Hicksian equivalent variation. (a) shows equivalent variation in per capita terms for each income quintile; (b) presents national aggregate equivalent variation in mil. Naira.

scenario, the bottom 60% (i.e. bottom three income quintiles) experience significant welfare gains, at the expense of the richest 20%. The fourth income quintile is barely affected in this scenario, as cash compensation offsets welfare losses due to energy price increases.

(a) Equivalent variation by income quintiles (in N)

(b) Total equivalent variation (in mil. N) for different levels of subsidisation

Figure 8: Scenario 3: Change in welfare, measured by Hicksian equivalent variation. (a) shows equivalent variation in per capita terms for each income quintile; (b) presents national aggregate equivalent variation in mil. Naira.

Welfare effects in scenario 4 (presented in Figure 9) are less pronounced than

in the first two scenarios, as previous results have also suggested (see Figure 6). The reason is that revenue redistribution using tax rate reductions benefits households proportionally to their pre-reform consumption expenditure - thus no significant redistribution across income groups takes place, and the reduction of disposable income due to FFS removal is mostly offset.

(a) Equivalent variation by income quintiles (in N)

(b) Total equivalent variation (in mil. N) for different levels of subsidisation

Figure 9: Scenario 4: Change in welfare, measured by Hicksian equivalent variation. (a) shows equivalent variation in per capita terms for each income quintile; (b) presents national aggregate equivalent variation in mil. Naira.

9.5. Effect on government expenditure

Figure 10 presents the estimated changes in government expenditure. The observed effect depends crucially on the redistribution mechanism for reform revenues. In scenario 2 the government uses revenues directly to increase public spending. In scenarios 3 and 4 government spending remains mostly constant, as reform revenues are used to finance either cash transfer schemes or tax reductions.
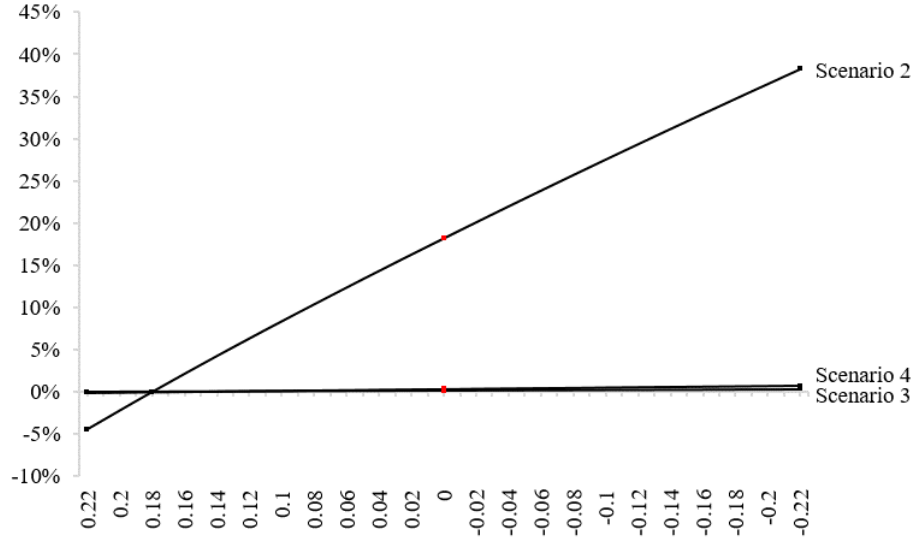

Figure 10: Change in government expenditure, relative to baseline expenditure, for different rates of subsidisation (baseline $s^e_{Petrol} = 0.18$).

9.6. Effect on output

Figure 11(a) presents the estimated change in output for all sectors considered in scenario 4. Full subsidy removal is estimated to result in a 10% reduction of the petrol sector, while increasing petrol taxes to 22% would reduce this sector even further to 20%. Estimated output changes are very similar in scenario 3, thus not reported separately.

Figure 11(b) shows further that the largest absolute growth would occur in the formal sector of the economy. This illustrates that FFS result in grave misallocation of resources in favour of the petrol and energy sectors, crowding out consumption from all other sectors.

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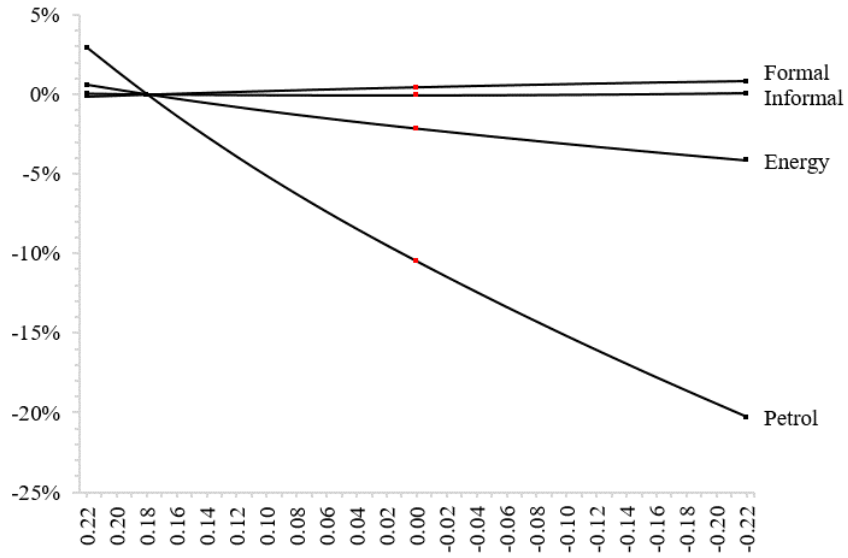
**(a)** Relative output change (%) for different subsidisation rates
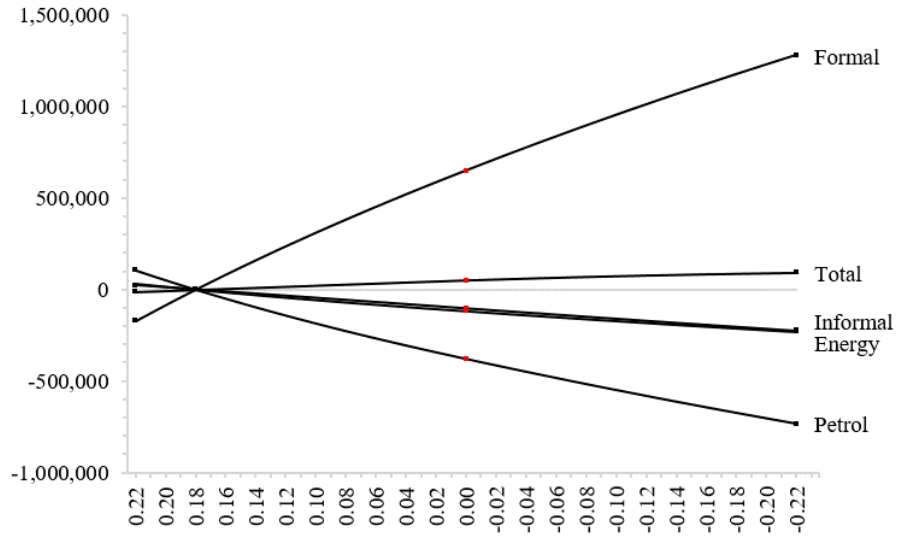
**(b)** Absolute output change (mil. Naira) for different subsidisation rates

Figure 11: Scenario 4: Relative and absolute change in output in different sectors. (a) presents the change relative to baseline output, while (b) presents absolute change in mil. Naira.

9.7. Effect on labour tax evasion

This section presents the estimated changes in tax evasion activities for different scenarios. As factor and production taxes remain unchanged in scenarios 2 and 3, tax evasion is not reduced significantly in most sectors (Figure 12). A notable exception is the petrol sector. A significant reduction in the size (i.e. output) of the petrol sector means that its tax burden decreases, and thus necessarily also the amount of evaded taxes. As this observation is valid for scenarios 2 and 3, only results for the latter are presented here (Figure 12). In scenario 4 reform revenues are used exclusively to reduce labour taxes in all sectors. Accordingly, Figure 12 shows a significant reduction in labour tax evasion throughout the economy.
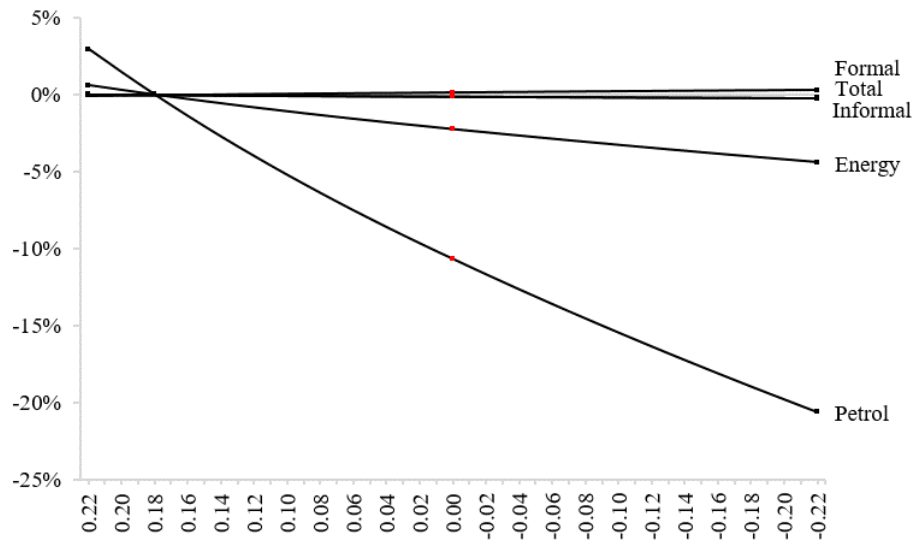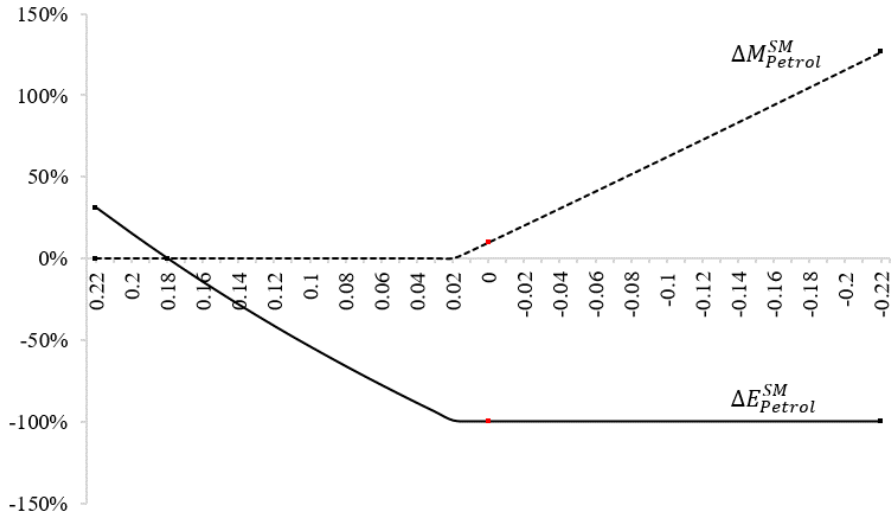

Figure 12: Scenario 3: Change in labour tax evasion for different subsidisation rates
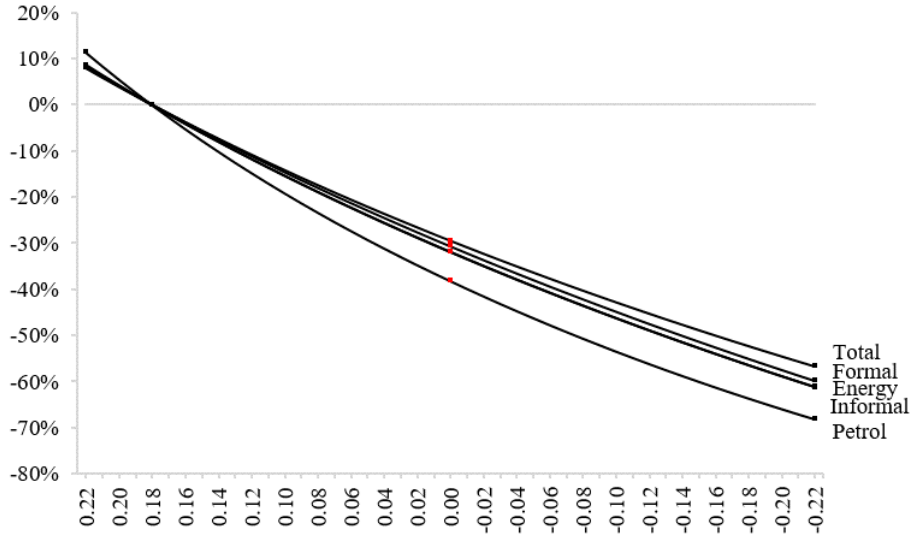
Figure 13: Scenario 4: Change in labour tax evasion for different subsidisation rates

9.8. Effect on fuel smuggling

This section presents the estimated changes in fuel smuggling as fuel subsidies are decreased and taxes increased (Figure 14).


Figure 14: Percentage change in petrol smuggled out of (ΔE_{Petrol}^{SM}) or into (ΔM_{Petrol}^{SM}) Nigeria in scenario 2.

Note that smuggling is positive for the baseline subsidisation rate, i.e. fuel is being smuggled out of the country. As the subsidy is reduced, and eventually turned into an energy tax, the energy price differential between domestic

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and foreign fuel is reversed. Without measures to prevent smuggling, in-bound smuggling takes place, thus undermining the energy tax. It should be noted 20that smuggling is not necessarily zero when the subsidisation (or tax) rate s^e_{Petrol} is zero; the smuggling quantity depends not only on s^e_{Petrol}, but also on the ratio between prices p^e_j and p^q_j (see equations 7 and 8).

Figure 15 presents the total value of fuel subsidy leakage (or fuel tax undermining) due to smuggling. Out-bound smuggling implies that fuel subsidies provided by the home government are smuggled (i.e. leaked) out of the country. In-bound smuggling implies that domestic energy taxes are being evaded, as cheaper un-taxed fuel is smuggled in, thus reducing the government's fuel tax revenue.

Moreover, Figure 16 presents the losses associated with both outbound and inbound smuggling activities (e.g. due to transport costs).
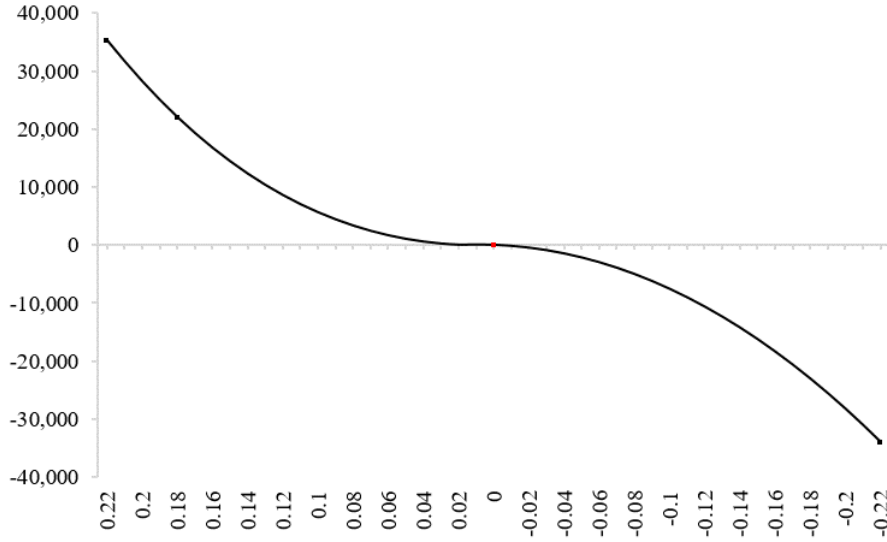
Figure 15: Total net subsidy value smuggled out (for $s^e_{Petrol} > 0$), or fuel tax undermined through inbound smuggling (for $s^e_{Petrol} < 0$). In mil Naira.
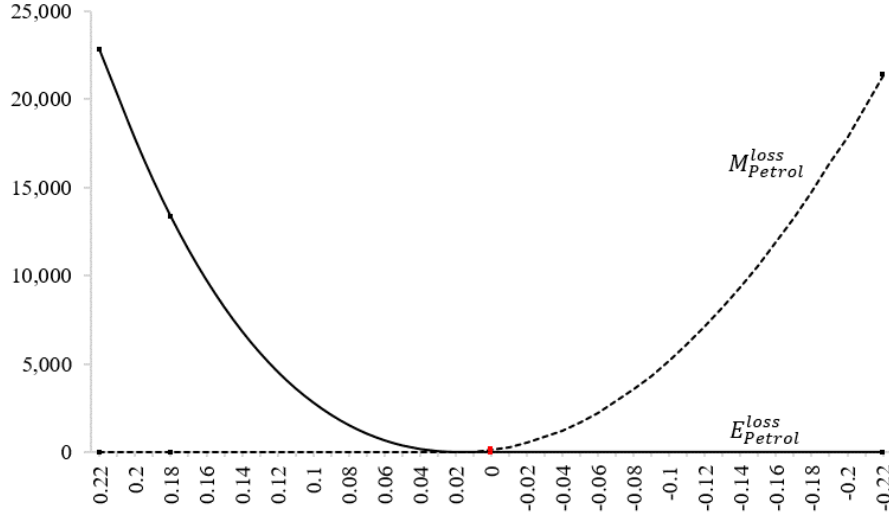
Figure 16: Total losses due to outbound (E^{loss}) and inbound smuggling (M^{loss}).

*9.9. Fiscal efficiency and social welfare: the role of tax evasion and smuggling*

Figure 17 presents the social welfare cost of reform, which is used to evaluate double dividend style reforms (see Section 8.1) – i.e. scenario 4. For reference the figure presents welfare costs for a counter-factual simulation which omits tax evasion and smuggling (line (a) in Figure 17), and the model which takes these illicit activities into account (b).

The results show that taking into account illicit activities lowers the estimated welfare costs of full FFS removal (i.e. $s^e_{Petrol} = 0$) by 34% relative to the counter-factual simulation (omitting tax evasion and smuggling). When fuel taxes are further increased to 22% (i.e. $s^e_{Petrol} = -0.22$), taking into account illicit activities lowers the welfare cost by 36% relative to the counter-factual. Figure 18 summarises these results: In the simulated range for the subsidisation rate, the effect of tax evasion and smuggling reduces welfare costs by between 34% to 42%. The larger portion of this difference is due to the tax evasion effect (accounting for 69% to 86% of the welfare cost reduction).

Overall, these results highlight that accounting for illicit activities, such as tax evasion and fuel smuggling, can make a crucial difference when determining the costs and benefits of FFS reform. Omitting these aspects may cause studies to significantly under-estimate the benefits (or over-estimate the costs) of FFS reform.
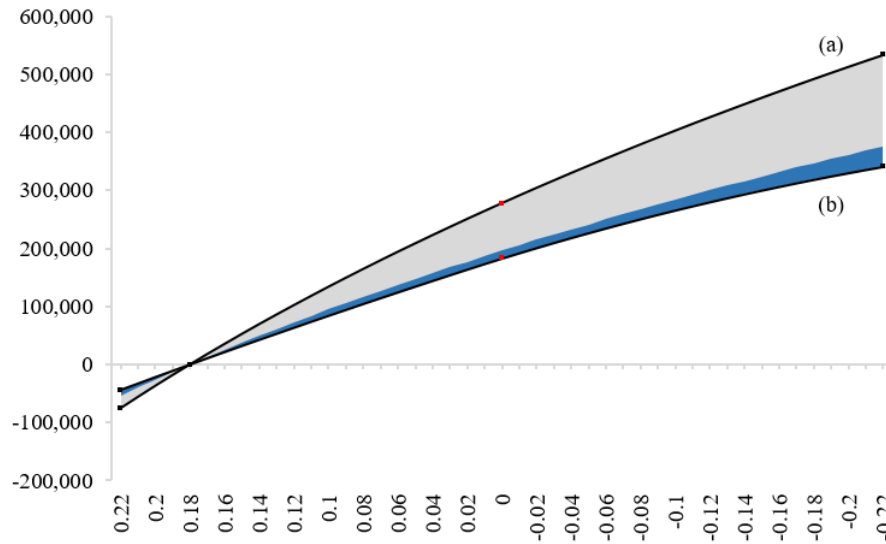
Figure 17: Scenario 4: Welfare cost of FFS reform (a) without, (b) and with tax evasion and smuggling taken into account (in mil N) for different subsidisation rates. The reduction of welfare costs due to tax evasion effects (grey) is larger than the reduction due to smuggling effects (blue).
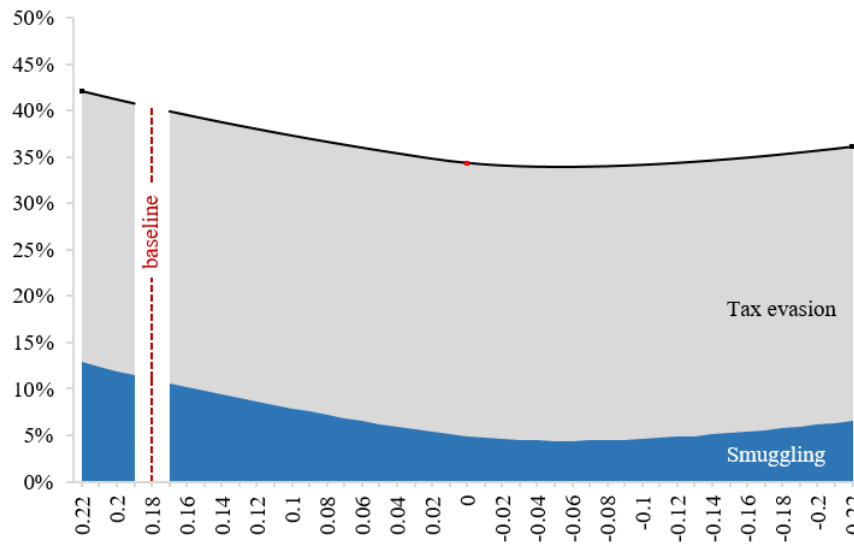
Figure 18: Scenario 4: Percentage reduction of welfare cost of FFS reform when illicit activities are taken into account (relative to counter-factual scenario). The tax evasion effect (grey) accounts for a larger share of the reduction than the smuggling effect (blue).

10. Sensitivity and robustness

This section provides the results from sensitivity analyses around parameters that may influence the key results: In particular it considers variations of + and – 25% around the elasticities of substitution (σ_i) and transformation (ψ_i), the parameter r in the smuggler's loss function, and parameters $N_{h,j}^f$ and N_j^z in the tax evasion loss functions.

10.1. The elasticities of substitution and transformation

To test the sensitivity of sectoral output estimates to variation in elasticity values, low and high value cases for the elasticities of substitution and transformation are considered. The elasticity of substitution in the CES production function is given by σ_i (Equation 40, where $\eta_i = (\sigma_i - 1)/\sigma_i$, with $\eta_i \leq 1$). The elasticity of transformation in the CET production function is given by ψ_i (Equation 43, where $\phi_i = (\psi_i + 1)/\psi_i$, with $\phi_i \leq 1$). The low case is defined as a 25% reduction of the elasticity value compared to the base run calibration (see Section 6); the high case is defined as a 25% increase over the base run value.

σ_i; ϕ_i		Base run	Low case		High case	
Petrol	$s_{Petrol}^e = 0.22$	3,736,698	3,728,096	*-0.23%*	3,744,630	*0.21%*
	$s_{Petrol}^e = 0$	3,252,824	3,288,715	*1.10%*	3,217,423	*-1.09%*
	$s_{Petrol}^e = -0.22$	2,898,255	2,970,800	*2.50%*	2,827,282	*-2.45%*
Energy	$s_{Petrol}^e = 0.22$	5,870,983	5,870,212	*-0.01%*	5,873,555	*0.04%*
	$s_{Petrol}^e = 0$	5,720,992	5,735,723	*0.26%*	5,709,553	*-0.20%*
	$s_{Petrol}^e = -0.22$	5,607,641	5,635,414	*0.50%*	5,584,303	*-0.42%*
Formal	$s_{Petrol}^e = 0.22$	142,209,300	142,341,800	*0.09%*	142,257,400	*0.03%*
	$s_{Petrol}^e = 0$	143,031,500	143,116,800	*0.06%*	143,157,200	*0.09%*
	$s_{Petrol}^e = -0.22$	143,661,100	143,701,300	*0.03%*	143,849,000	*0.13%*
Informal	$s_{Petrol}^e = 0.22$	114,992,600	115,065,200	*0.06%*	115,144,100	*0.13%*
	$s_{Petrol}^e = 0$	114,866,800	114,996,800	*0.11%*	115,004,900	*0.12%*
	$s_{Petrol}^e = -0.22$	114,745,200	114,924,800	*0.16%*	114,868,500	*0.11%*

Table 2: Sensitivity of sectoral output to variation in the elasticities of substitution (σ_i) and transformation (ψ_i). Absolute values represent the total value of output (in mil Naira) for each sector in each case. Percentage values represent the deviation of the low and high case estimates from the base run results.

Table 2 shows that the variation in elasticities has minimal impact on the estimates. In addition, Figure 19 demonstrates that also the social welfare cost of reform is robust to variation in the elasticities.
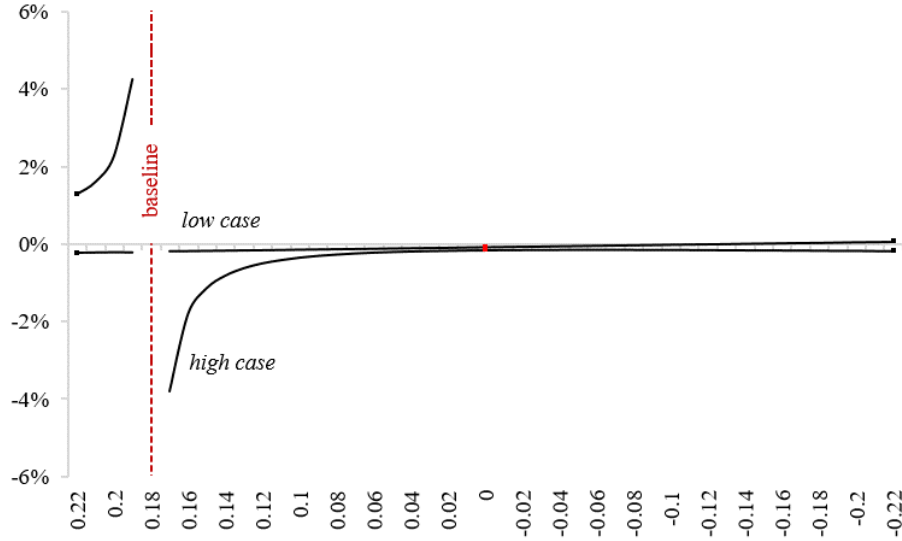
Figure 19: Sensitivity to variation in σ_i and ψ_i: Percentage deviation of the social welfare cost of reform from the base run estimation. Note that illicit activities are taken into account in both cases.

10.2. Parameter r in the smuggling function

The smuggler is modelled to maximise their profits, by choosing the inbound and outbound smuggling quantities (E_j^{SM} and M_j^{SM}). His optimisation problem is constrained by the cost of smuggling (e.g. transportation costs, bribes), which primarily depends on the smuggled quantity, as well as parameters r and A_j^{SM}. In the base run analysis the parameter value is set at $r = 2$, which assumes linear smuggling behaviour.

This section demonstrates the sensitivity of smuggling estimates and the overall results to a variation in parameter r. It presents model results for a low value case of r (25% lower than the base run value), and a high value case (25% higher). Note that the parameter A_j^{SM} is calibrated on the basis of r, thus no separate sensitivity analysis is required (Section 6.3). Table 3 presents the deviation of the estimated smuggling quantities for these low and high value cases of r.

The percentage deviations in Table 3 appear large, in particular for subsidisation rates close to zero. However, it should be noted that the absolute values are small in all cases. This is illustrated by Figure 20, which demonstrates that the variation in r mainly affects the curvature of the smuggling estimates. In both the low and high cases of r the smuggling quantity can be below or above the base run estimate, depending on the value of s_{Petrol}^e.

To test the sensitivity of the estimated social welfare cost of FFS reform, Figure

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r		Base run	Low case		High case	
	s^e_{Petrol}=0.22	160,376	212,556	*+32.54%*	145,940	*-9.00%*
Value of smuggling	s^e_{Petrol}=0.1	55,919	25,869	*-53.74%*	72,264	*+29.23%*
outbound (+)	s^e_{Petrol}=0	-12,048	-1,203	*-90.02%*	-27,116	*+125.06%*
and inbound (-)	s^e_{Petrol}=-0.1	-76,158	-48,018	*-36.95%*	-94,089	*+23.54%*
	s^e_{Petrol} =-0.22	-154,739	-197,849	*+27.86%*	-135,590	*-12.38%*

Table 3: Sensitivity analysis for smuggling parameter r. Absolute values represent the total value of smuggled fuel (in mil Naira) in each case. Percentage values represent the deviation of the low and high case estimates from the base run results.
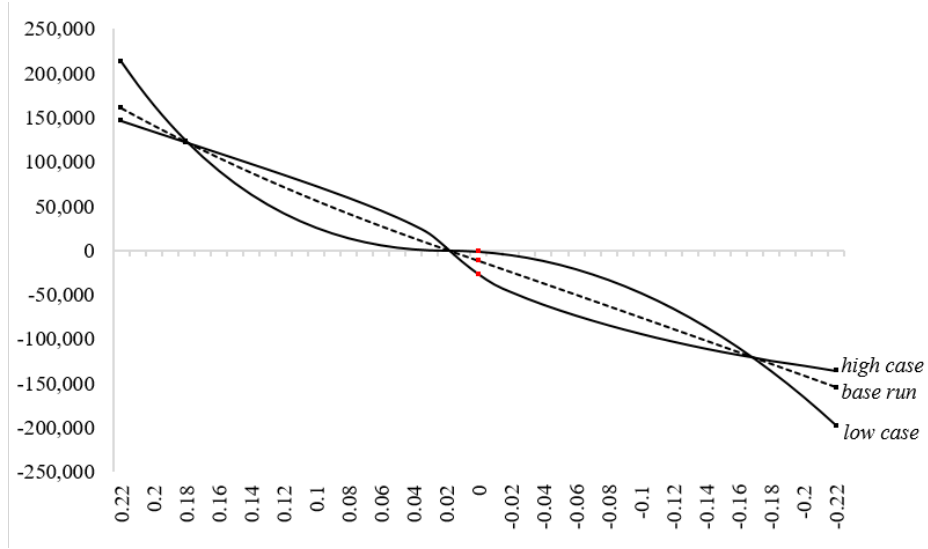

Figure 20: Sensitivity to variation in r: Estimated change in the outbound (+) and inbound (-) smuggling estimates (in mil Naira) at different subsidisation rates s^e_{Petrol}.

21 presents the difference between the welfare costs in the illicit activities model and the counter-factual (Section 9.9). Both the low and high cases highlight that the variation in parameter r has no impact on the overall conclusion that illicit activities (in this case smuggling) can play a key role in determining the welfare cost of FFS reform. In both cases the welfare cost is about 40% lower when illicit activities are considered.
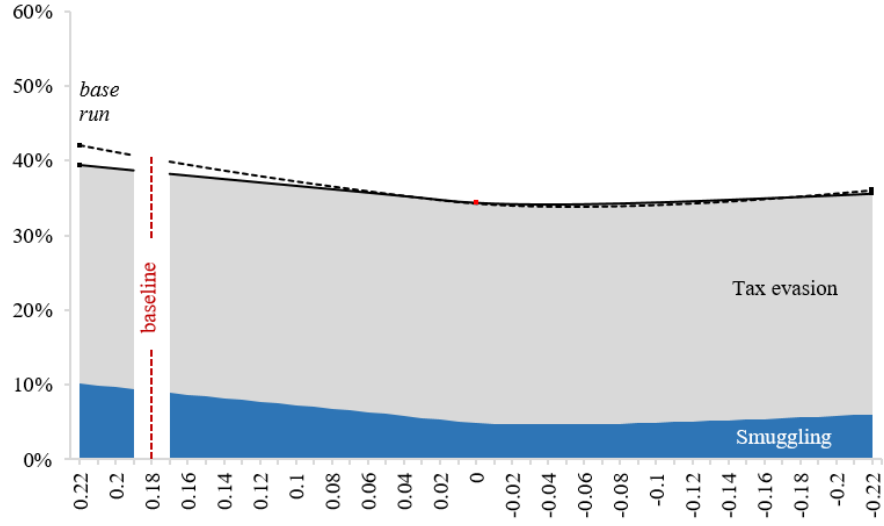
(a) Low case
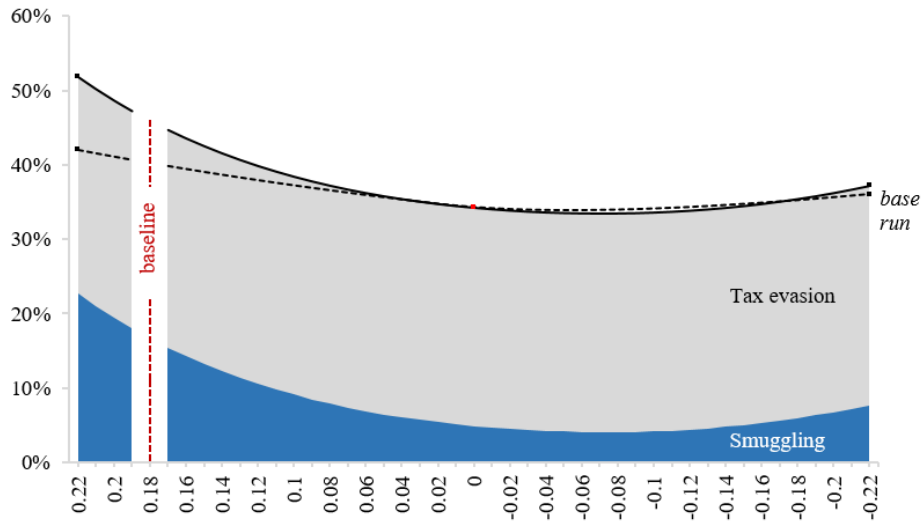
(b) High case

Figure 21: The percentage difference between social welfare costs of FFS reform in the model considering illicit activities, and a counter-factual (see Section 9.9). Due to the lesser contribution of smuggling to this difference, the variation in r has little effect on the overall conclusions.

10.3. Tax evasion parameters $N_{h,j}^f$ and N_j^z

As part of its optimisation problem, the firm chooses the optimal level of factor and production tax evasion (see equations 11 and 16). Besides the effective tax rates ($\tau_{h,j}^f$ and τ_j^z), the choice of the optimal evasion rate is determined by the parameters $N_{h,j}^f$ and N_j^z, which characterise the cost of evasion activities (equations 1 and 2). The values of $N_{h,j}^f$ and N_j^z in the base run calibration range between 8.01 and 9.02; thus the elasticities of tax evasion with respect to the tax rate (expressed as $1/N_j$) are between 0.11 and 0.13. These values are in line with the elasticities used by Liu (2013).

As before, the low case considers 25% lower values for $N_{h,j}^f$ and N_j^z, while the high case considers 25% higher values. Note that the parameters $A_{h,j}^f$ and A_j^z are calibrated on the basis of $N_{h,j}^f$ and N_j^z (Section 6.2). Thus no separate sensitivity analysis is required for these. Table 4 reports the sensitivity of tax evasion estimates with respect to variation in parameters $N_{h,j}^f$ and N_j^z.

| $N_{h,j}^f$		Base run	Low case		High case	
Total	$s_{Petrol}^e = 0.22$	2,416,237	2,343,597	*-3.01%*	2,463,199	*+1.94%*
factor tax	$s_{Petrol}^e = 0$	1,577,961	1,494,444	*-5.29%*	1,631,069	*+3.37%*
evasion	$s_{Petrol}^e = -0.22$	966,775	895,413	*-7.38%*	1,012,810	*+4.76%*
N_j^z		Base run	Low case		High case	
Total	$s_{Petrol}^e = 0.22$	2,078,998	2,078,724	*-0.01%*	2,079,238	*+0.01%*
production tax	$s_{Petrol}^e = 0$	1,978,902	1,977,739	*-0.06%*	1,979,653	*+0.04%*
evasion	$s_{Petrol}^e = -0.22$	1,906,655	1,905,962	*-0.04%*	1,907,141	*+0.03%*

Table 4: Deviation from the base run estimates for low and high value cases for the tax evasion parameters $N_{h,j}^f$ and N_j^z.

Figure 22 shows that the variation in parameters $N_{h,j}^f$ and N_j^z notably influences the level of tax evasion taking place, thus the associated evasion losses. However, note that base run parameter values for illicit activities have been chosen conservatively; i.e. the base run is likely to underestimate the role of tax evasion.

With respect to the social welfare cost of FFS reform, the difference between the illicit activities model and the counter-factual remains large regardless of the value of $N_{h,j}^f$ and N_j^z. In the high value case, the social welfare cost of reform is nearly 50% lower in the illicit activities model compared to the counter-factual. Even in the low value case, the welfare cost is at least 30% lower compared to the counter-factual. Thus, the overall conclusion remains unchanged that illicit activities play a significant role in determining the welfare costs of reform.
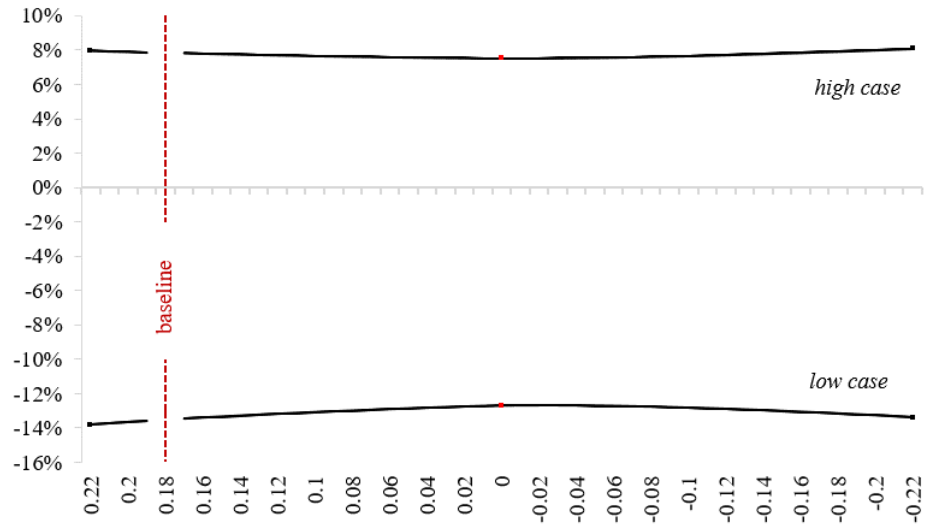
Figure 22: Percentage deviation of the social welfare cost of FFS reform to a variation in parameters $N_{h,j}^{f}$ and N_{j}^{z} from the base run estimate (see Section 9.9); presented for different subsidisation rates along the horizontal axis.
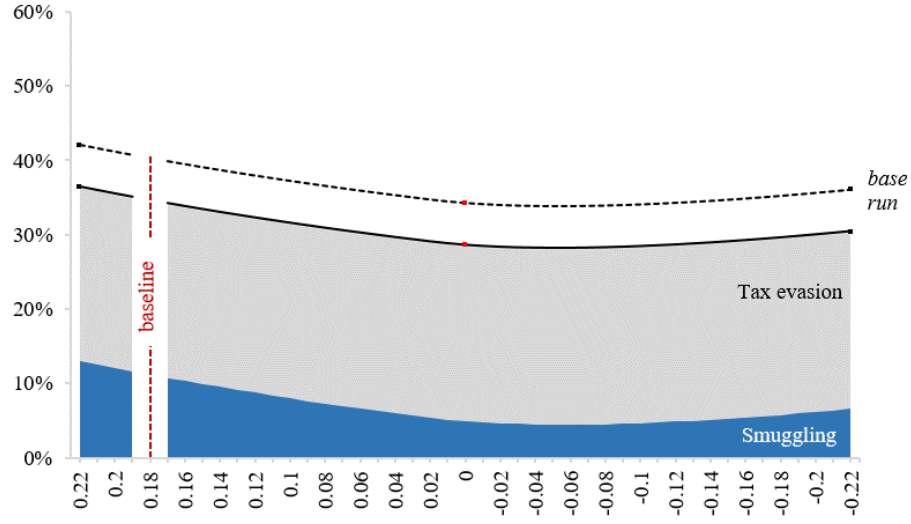
(a) Low case
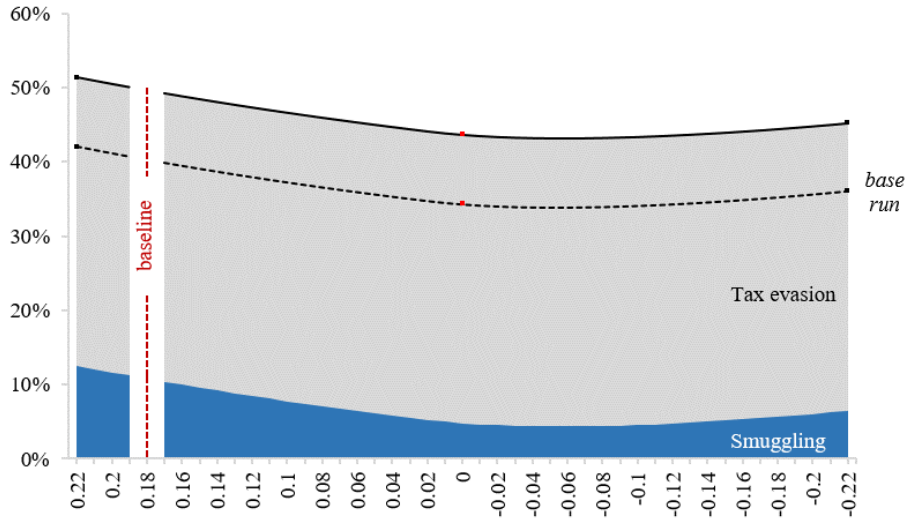
(b) High case

Figure 23: The percentage difference between social welfare costs of FFS reform in the illicit activities model and a counter-factual (see Section 9.9). (a) presents the estimate for $N_{h,j}^{f}$ and N_{j}^{z} taking values 25% lower than in the base run (25% higher in (b)).

11. Conclusion

It is widely accepted that FFS incentivise rampant fuel smuggling to neighbouring countries, meaning that a significant fraction of FFS benefits leaks out of the country. In addition, labour taxes not only distort incentives to work, but are associated with high evasion rates and incentivise informal economic activity.

This study makes the case that such illicit activities can play a key role in determining the welfare costs and benefits of fiscal reform, in particular FFS reform. It develops a CGE model for Nigeria to study the impact of FFS reform – and energy taxes – on key economic parameters, including consumption, income distribution, tax incidence, and fiscal efficiency. Throughout this analysis, the study examines the role of tax evasion and fuel smuggling, and shows that these factors can substantially strengthen the argument in favour of subsidy removal.

First, the study confirms several key observations made by the existing literature on FFS reform and energy taxation:

- FFS are highly regressive, with the bottom income quintile receiving 1% of total FFS payments and the top income quintile 75%.

- Removing FFS without compensation measures results in significant disposable income shocks to households across all income levels.

- Removing FFS and redistributing revenues using uniform cash transfers has a strong progressive (i.e. pro-poor) distributional effect. This progressive distribution becomes even more pronounced when FFS are replaced by fuel taxes.

- Removing FFS and using revenues to cut pre-existing labour taxes reduces fiscal distortions and the associated welfare losses.

- Removing FFS causes significant structural shifts in consumption bundles, with overall petrol consumption decreasing by over 19%. The simulated fuel tax can extend this reduction to over 35%. In turn, households increase their formal market consumption accordingly.

In addition, by considering the role of illicit activities, this study shows that conventional analyses may be overlooking a significant part of the picture:

- Regardless of the method of revenue redistribution, reducing subsidies diminishes the incentives for fuel smuggling, and hence the welfare losses associated with it. The reduction of these welfare losses must be considered when evaluating FFS reforms.

- In the case when revenues of FFS reform are redistributed using cash transfers, avoided smuggling means that the cash transfer scheme is disbursing the same aggregate benefit to the population as in the FFS scheme, but at a lower cost.

- Reducing FFS and using revenues to lower pre-existing labour tax rates not only mitigates labour market distortions, but reduces tax evasion; i.e. the government can earn the same level of tax revenues, while charging lower tax rates.

- A conservative estimate for Nigeria is that taking into account illicit activities can lower the welfare cost of FFS reform by up to 40%. The tax evasion effect accounts for (on average) 75% of this difference, with smuggling effects accounting for the remainder.

- The above mentioned benefits of FFS removal (i.e. in terms of income distribution, consumption, fiscal efficiency) can be increased when subsidies are not only removed, but replaced by fuel taxes. Such fuel taxes may reverse the direction of smuggling activities, though this is not enough to undermine the overall benefits.

Even though tax evasion tends to be particularly high in developing countries – large informal sectors are symptomatic for this – the "tax evasion effect" has not been studied before in the context of FFS reform. Similarly, despite being a frequently cited side-effect of FFS, smuggling has also received virtually no attention in the literature so far. This study demonstrates that such illicit activities can make a significant difference to the argument in favour of FFS reform; and should be considered when designing and implementing such reforms.

Acknowledgements

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