Designing policies towards economic resilience and food security during turbulent times: an application to the Kenyan economy

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1. Introduction

The multiple crises over the last three years have determined large volatilities on the world commodity markets and have put in perspective the paradigm of economic development through globalization[1]. The impact of these crises are notably relevant for African countries, which suffer from high poverty rates and food insecurity on one hand and a high reliance on global markets for processed commodities on the other. Many governments in Africa are now looking into enhancing the resilience of their economies by boosting intra-African trade[2] and the domestic production of key commodities such as pharmaceuticals[3], fertilizer products[4] and food[5]. While these transformations could take time to produce results, fiscal intervention combined with international aid are the short run policy levers that can help economies partial shield themselves from the negative external events (Nechifor et al., 2021).

In the case of Kenya, while the latest world trade constraints coming from the Russian war in Ukraine have had fewer direct implications on imports of food, fertilizer and petroleum products, the economy was exposed to an increase in world commodity prices. To counter the negative effects on welfare, the government has sought to implement in 2022 a set of subsidies on petroleum products and fertilizers which, under budgetary constraints, had to be reconsidered[6] later on.

This research thus seeks to address the issue of optimal government policy in the context of global crises. It considers the post-COVID-19 realities in which economies especially in Africa are already more vulnerable given that their high public debt and a smaller fiscal space for intervention. The research aims to identify those policy levers that can create synergetic effects on a number of socio-economic objectives. It employs a newly developed framework (optCGE) for parsing the space of possible policy designs. The framework is based on artificial intelligence algorithms and embeds JRC DEMETRA, a detailed country-level CGE model for Kenya (Boulanger et al., 2020). OptCGE can consider multiple policy metrics such as GDP, government income, consumer prices or welfare with disaggregations for different household groups. Starting from these objectives, the framework uses

[1] https://blogs.worldbank.org/developmenttalk/how-war-ukraine-reshaping-world-trade-and-investment
[2] https://www.uneca.org/stories/boosting-africa%E2%80%99s-resilience-to-the-adverse-impact-of-the-ukraine-crisis
[3] https://pressroom.ifc.org/all/pages/PressDetail.aspx?ID=26493
[4] https://www.afdb.org/en/news-and-events/nigeria-fertilizer-project-raises-yields-by-over-50-showcases-successful-ppps-18933
[5] https://www.bloomberg.com/news/articles/2022-06-16/wheat-farming-drive-in-ethiopia-gathers-pace-as-shortages-bite
[6] https://www.reuters.com/world/africa/kenya-scraps-petrol-subsidy-after-president-warned-it-was-unsustainable-2022-09-15/

multi-objective evolutionary algorithms (MOEA) to construct a Pareto surface with those designs that are optimal (Figure 1). The 'decision variables' in Figure 1 are CGE model parameters or fixed variables that can define a policy implementation such as a blend of tax/subsidy rates, transfers to households or public spending on specific sectors. The framework goes well beyond sensitivity analysis exercises by adopting an agnostic view on policy design – the modeler can decide which policy levers to include as decision variables but does not formulate the set of magnitudes for the individual policy instruments. Furthermore, optCGE delivers all the points on the Pareto surface (each point defining a policy option combining several policy instruments) and allows for the analysis of trade-offs and synergies across policy objectives. The output can thus be employed in participatory modelling exercises for close to real-time modelling whereby the modelers and policy makers can parse together the space of solutions and can filter out those policy configurations that are undesirable or unacceptable. An implementation of a similar framework with an application to the Sustainable Development Goals in Egypt was done in Basheer et al. (2022). An interactive dashboard to filter options is provided together with this paper – the link to access it can be found at the end.

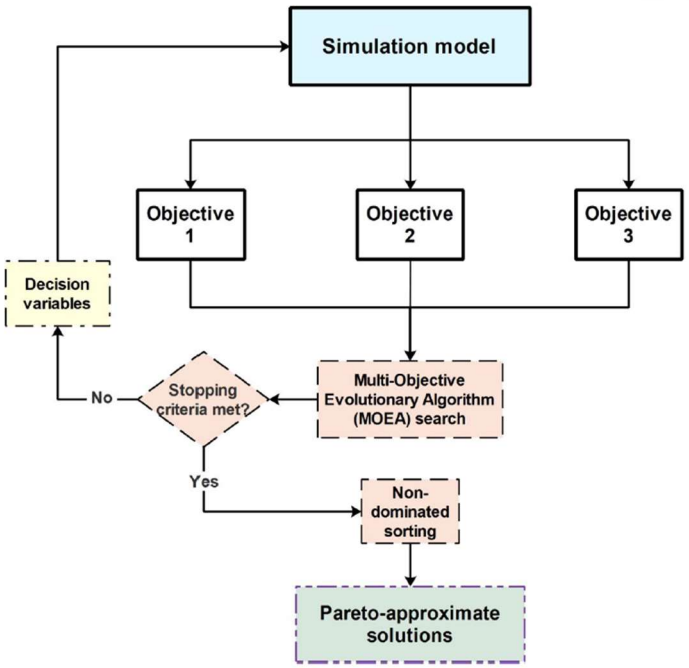


Figure 1 – Overview of optCGE. The simulation model is the DEMETRA country-level CGE model for Kenya. The decision variables are the policy instruments implemented in the CGE model.

2. Case study

The Russian invasion, combined with the sanctions imposed to the Russian and Belorussian economies, determined considerable supply constraints across major commodity markets. Directly, the war led to a reduction in export capacity (reduced port access for Ukraine, Russia and Belarus), to lower energy production and exports by Russia, to a contraction of available productive land and labour force for agriculture in Ukraine and to lower access to finance and technology for ongoing production in sanctioned countries. Indirectly, other countries, under concerns for their own security of supply, imposed temporary bans on key commodities like wheat, fertilizer and oilseeds.

In the case of Kenya, the imports bill is dominated by petroleum products (16% of imports, mostly sourced from the Middle East), followed by wheat (2% of imports, of which a third coming from

Russian and Ukraine), palm oil (2% of imports, mostly sourced from South-East Asia). Fertilizers represent 0.8% of total imports, with only a tenth of that sourced from Russia. Also, fertilizers use in agriculture is low, capturing only 1-2% of crop production costs (Mainar Causapé et al., 2018). Therefore, at a first glance, Kenya has some direct exposure to trade constraints from Ukraine and Russia for wheat and to a smaller extent for fertilizers. A priori, the bulk of the war's negative effects of the Kenya is therefore through the increase in world commodity price given the reshuffling of international trade and the trade restrictions imposed on Russia, Ukraine and Belarus.

The subsidies the Kenyan government adopted in 2022 had to later be withdrawn due fiscal constraints. Prior to 2022, Kenya's public debt, measured as a share of GDP, had steadily increased with a steep expansion of commercial borrowing both domestically and internationally. In 2020, in the context of the COVID-19 pandemic, Kenya's debt carrying capacity and the risk of debt distress were downgraded by the IMF from strong to medium and from moderate to high respectively. While the reduction in borrowing in 2022 has allowed for a reduction in debt as percentage of GDP to 60% (from 61.4% in 2021, (NTEP, 2023a)) the burden of debt servicing payments has continued to increase reaching 5.3% of GDP, or almost 30% of government revenue in 2022. Going forward, the government has aimed to rely on concessional and semi-concessional borrowing for external borrowing and on longer maturity debt on the domestic markets to reduce overall interest rates and debt servicing payments. In the medium run, the fiscal deficit is targeted to reduce from 6.2% to 3.6% of GDP, with tax revenues to increase from 17.3% to over 18% of GDP by FY2026/27 (NTEP, 2023b). This highlights the increase in the tax base (such as the reduction of the VAT collection gap) as an important avenue. The public debt is also targeted to reduce to 52.5% by FY2026/27 hinting at lower overall government borrowing.

Prior to the COVID-19 pandemic, the food poverty incidence in Kenya was already high with 1 in 3 people not reaching the minimum 2,250 kilocalories/day as per their expenditures on food ((KNBS, 2018). Food poverty was higher in rural areas where 35.8% of the population (10.4 million individuals) were living below the food poverty line, compared to 25.1% in urban and semi-urban areas. COVID-19 may have determined a further fall in these numbers, with an estimated decrease in the number of food sufficient households by 1.3% nationally (Nechifor et al., 2021). For 2022, due to the prolonged draught and the increase in world food prices, the IPC projected a 900 thousand increase in the number of people facing high levels of acute food insecurity in Kenya's ASAL counties (IPC reference), which cover 38% of Kenya's population.

3. Methods

3.1. Framework setup

The application of the optCGE framework to this case study involves the embedding of JRC DEMETRA as simulation model. The CGE model is specifically designed to analyse policies and shocks in a developing context, comprising a detailed account of subsistence consumption through the Home Production for Home Consumption (HPHC) specification. Other features of the model involve the user capability to modify the production and utility functions without altering the model code by using external Excel spreadsheets. In this regard, for the present application, the utility function was defined through a two-level LES-CES functional form whereby basic commodities are bundled at the bottom level as CES nests of functional groups (grains, other food, manufacturing, energy and services) which are then combined at the top level as LES components. The production was also modified from the typical formulation to enable a better representation of fertilizer effects in crop production by adding fertilizer as a direct substitute to the value added nest.

DEMETRA was calibrated using the 2016 SAM for Kenya which comprises 53 marketed commodities, 18 home commodities, 40 productive activities and 22 households groups. The household groups are divided into income quintiles for the two largest urban areas, Nairobi (NA) and Mombasa (MO), and into urban and rural areas for the 6 agro-ecological zones in Kenya (High Rainfall – HR, Semi-arid North - MN, Semi-arid South - MS, Coast - CO, Arid North - AN, Arid South – AS).

OptCGE is developed in Python and employs the Python GAMS API to pass model shocks and retrieve results efficiently from GAMS. Although the framework allows for dynamic recursive simulations, for the sake of simplicity in highlighting the functioning of the MOEAs, the application was limited to a static comparative setup.

With many possibilities to design potential policies for the case study, three classes of instruments were considered as MOEA 'decision variables', summing up as 115 parameters in the DEMETRA model, namely:

1. Sales subsidies/taxes applied to all marketed commodities with allowed changes from the base rate in the range of:
   - -12.6% to 0% for petroleum products
   - -11% to 0% for fertilizers
   - -4% to +1% for trade services and transportation
   - -1% to +1% increase for all other commodities
2. Output subsidies/taxes applied to all activities with allowed changes from the base rates in the range of -1% and +1%
3. Additional government transfers to households, not exceeding a third of the initial transfer values and not more than 5bn KSh per household group.

The MOEA application constructs a Pareto surface approximation defined by six policy objectives: **GDP**, **CPI**, **Food CPI** (as a measure of food security), **Government revenues**, **Welfare** (measured as the Equivalent Variation) and **GINI Welfare** (as a measure of inequality).

In addition to the MOEA evaluations of best policy designs, once the stopping criteria was met (the stagnation in the MOEA hypervolume increase), a Random Forest (RF) machine learning regression was employed to identify the policy instruments with the highest impact on each objective.

3.2. Base case definition

The implications of changes in world commodity prices and in the global economic outlook due to the war are determined using the DEMETRA model calibrated to the Kenyan economy. The World Bank Commodity Outlook is the reference for commodity price forecasts. Comparing the pre-war forecasts for 2022 (October issue) with the April 2022 forecasts, there was an increase in world prices of 35% for fuels, 75% for fertilizers, 43% for wheat, 30% for maize and 30% for vegetable oils.

To evaluate the effectiveness of the 2022 Kenyan government intervention from the angle of the objectives defining the MOEA search, the base response is also included and discussed in relation to effects of the three price shock categories (fossil fuels, fertilizers and crops). The base case for policy intervention are the measures already announced by the Kenyan government in 2022 to counter the price inflation which consisted in fuel subsidies (100 billion KSh or 800 million EUR[7]) and fertilizer

[7] https://www.kenyanews.go.ke/national-treasury-to-progressively-eliminate-fuel-subsidy/

subsidies (5.7 billion KSh or 45 million EUR[8]). The ad valorem equivalent of these amounts for 2022 are -12.6% and -11% for fuels and fertilizers respectively.

4. Results

4.1. Base case results

The model runs of the external shocks taken alone show significant macroeconomic effects – see Figure 2a for all commodity price increases combined. Government revenues would have been particularly effected even without the responses, with a 3.2% decrease. At the same time, Figure 2b indicates that the largest contributor to the negative effects at a macro level is the increase in fossil fuel prices with crop prices coming second but impacting the food CPI the most.

The base government response had an overall positive effect on economic outcomes but a strong recovery was not achieved. Figure 2c shows that the subsidies applied to fossil fuels had the highest contribution (they are nevertheless much more significant) with recovery potential of a 0.4% and 1% increase for GDP and welfare, plus a 0.5% reduction in CPI. The trade-offs of this measures are a 0.5% increase in the food CPI (highlighting a potential degradation of food security through a lower food affordability), an increase in inequality through a higher GINI index, and a substantial decrease in government revenues of -4.8%. Fertilizer subsidies did not have a visible impact on the six objectives, as fertilizer inputs in the base case are quite low. Of the six objectives, only government revenues see a noticeable negative effect of -0.25%. Overall, the government base response leads therefore to an improvement in 3 of the 6 objectives in the MOEA application, with the other three seeing a deterioration.

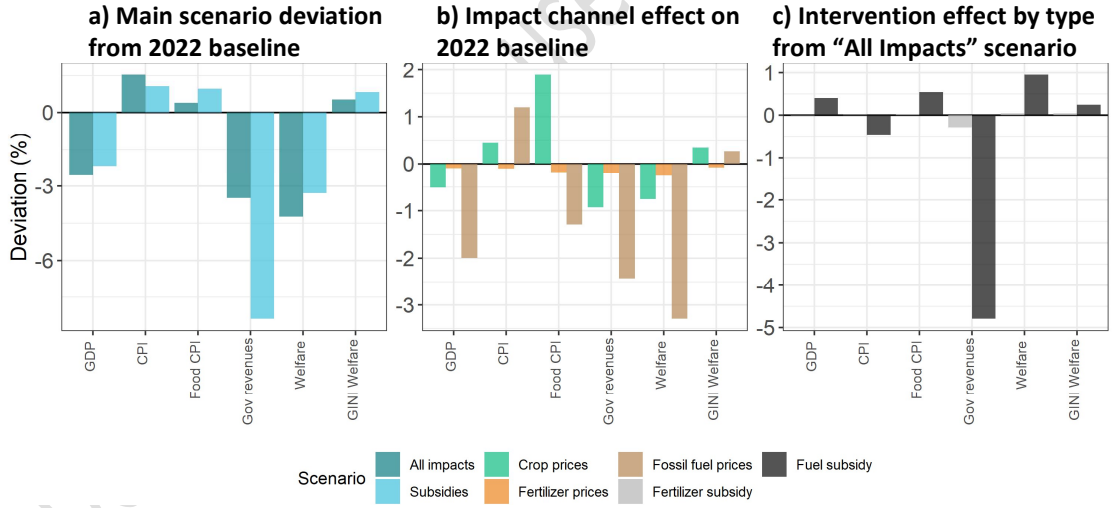


Figure 2 - Macroeconomic effects by impacts channel and policy measure in 2022 – base case

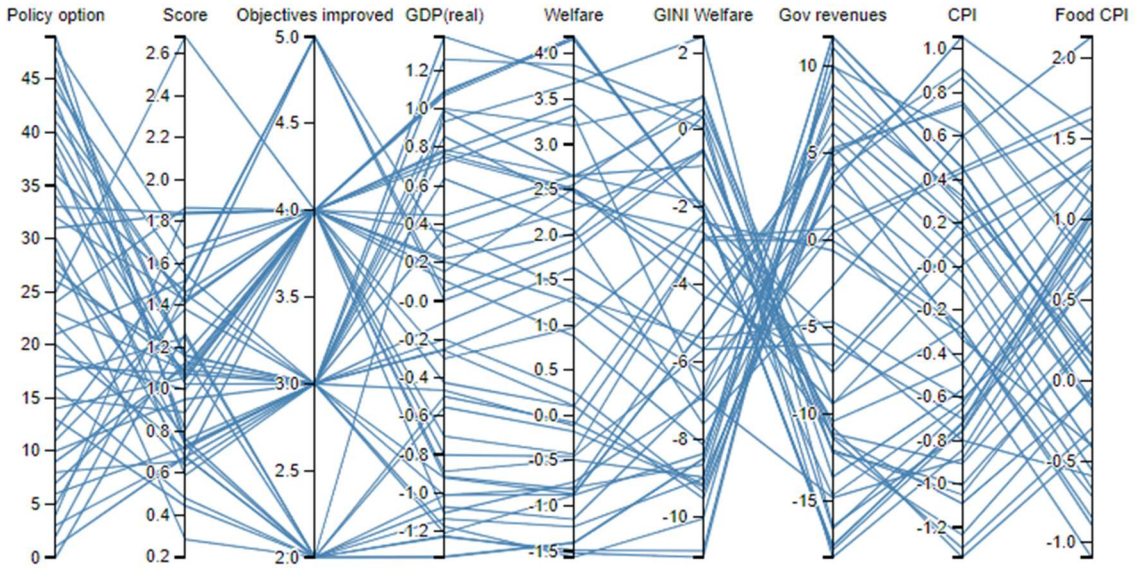
4.2. Alternative policy designs using optCGE

The MOEA balances several policy objectives showing the policy designs that minimize the trade-offs and enhance synergies across different policy domains. Following 15 000 evaluations by the

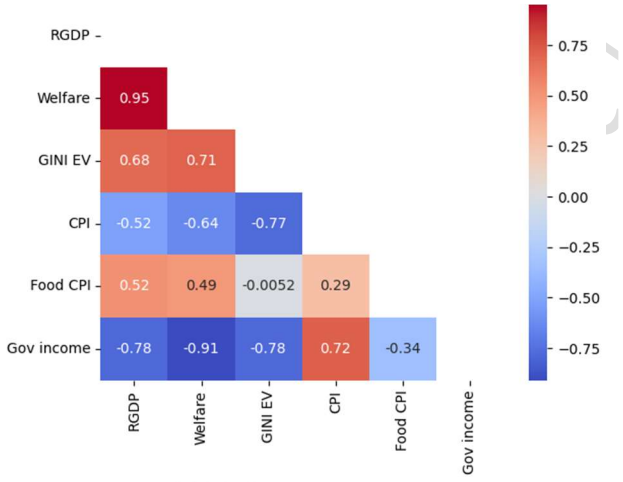
[8] https://www.capitalfm.co.ke/business/2022/04/cost-of-fertilizer-to-reduce-by-half-as-govt-announces-sh5-7bn-subsidy/

algorithm, 50 policy options[9] were delivered. These can be depicted through a parallel axes plot covering the six objectives and some additional metrics to facilitate the design selection (Figure 3a).

a) MOEA design outcomes across the six policy objectives



b) objective correlation matrix



c) objective outcomes in relation to total number of objectives improved

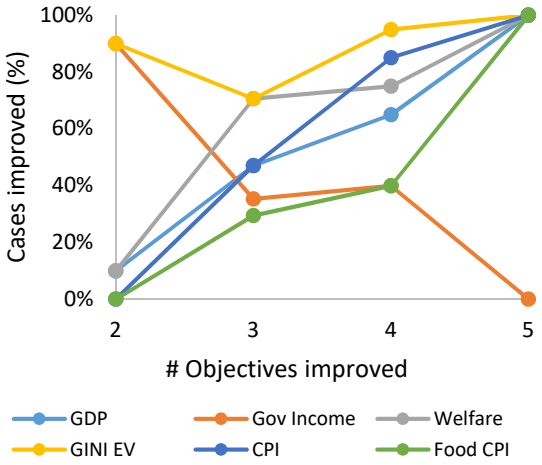


Figure 3 – MOEA objective details on the Pareto surface approximation

One additional metric is the number of objectives that are improved relative to no government intervention. From section 4.1, we obtained that government base measures improved 3 objectives. Through the MOEA policy definition, we obtained 3 designs with 5 objectives improved (all at the expense of government income), 20 designs with 4 objectives, 17 designs with 3 objectives, and 10 designs with 2 objectives (mostly improving government income and GINI welfare).

Another metric is a score adding up the percentage change improvements across the six objectives[10]. The government base response has a base score of 0.2 (an overall positive impact). All the designs

[9] The number of designs is determined by the algorithms used. In this case, the MOEA employed is NSGA-II.

delivered by the MOEA have a better score (min score 0.28, max score 2.68) indicating a superiority of all points on the Pareto surface approximation. Nevertheless, it should be noted that the score used was not part of MOEA evaluation, as it was not included in the MOEA objectives list.

The MOEA thus delivers options that can improve objectives above the MOEA baseline levels (the 'All impacts' scenario from section 4.1) by maximizing GDP (+1.4% in Policy option 11[11]), welfare (+4.2% Policy option 4), government income (+11.7% Policy option 3) or minimizing GINI welfare (-11.1% Policy option 0), CPI (-1.3% Policy option 5), food CPI (-0.5% Policy option 9). Figure 3a also highlights the use of a key policy instrument (fuel subsidies) whereby the Pareto surface is concentrated either in high subsidy values (close to the maximum allowed in the definition of the MOEA application) or towards zero values (the minimum allowed).

Figure 3b shows the objective correlation matrix across the 50 policy options. The strongest negative correlation is obtained between welfare and government income, hinting at the capacity to improve welfare through subsidies. The strongest positive correlation is between GDP and welfare. At the same time, there is a positive correlation between welfare and GINI welfare (welfare expansion increases inequality) and a negative correlation between CPI and inequality (lower prices decrease inequality). Among all objectives, Food CPI exhibits the lowest correlation coefficients. In particular, there is a lack of correlation between Food CPI and GINI welfare and a low positive correlation between Food CPI and CPI. These results highlight a wider space to balance this objective against the other ones.

Figure 3c gives an overview on which objectives are more likely to be sacrifice as the overall number of objectives is improved. In this regard, the improvement in government income is traded off as the number of objectives improved increases. Also, at 3 and 4 objectives improved, food CPI is also more likely to be traded-off relative to the remaining four objectives (RGDP, CPI, Welfare and GINI welfare). Overall, the objective that is most likely to be improved is GINI welfare (43/50 options) followed by welfare (31/50 options), while food CPI is the least likely to be improved (16/50 options).

Moving on to the analysis of instruments, the RF regression was trained on the entire population of policy designs (corresponding to 15 000 DEMETRA model runs required to meet the stop criteria) to determine a feature importance score to each of the 115 instruments. The regression shows a high concentration of influence of 10 of the 115 MOEA decision variables (policy parameters in the DEMETRA model) – Figure 4a. The highest influence on GDP outcomes are the sales tax of petroleum and the output tax of trade services. For welfare, the sales tax on transportation is also important. The GINI welfare is, however, driven by government transfers in the lower three income quintiles in Mombasa. For prices, the sales tax on transportation, trade services and fuels and vegetable oils take up all the influence, with a residual left to the output tax on construction.

The correlation heatmap of these instruments in relation to the objectives highlight the direction in which these have an influence – Figure 4b. The sales taxes have a negative impact on GDP (hence high subsidies on fuels and trade services lead to positive GDP outcomes), welfare and GINI welfare. The correlation is more mixed in relation to aggregate prices, with a positive correlation with general CPI (the strongest correlation obtained for vegetable oil, transportation and trade services) and a negative correlation between food CPI and the fuels sales tax (consistent with the results from the

[10] In this case, the improvements in four objectives (GDP, Welfare, CPI and Food CPI) are given a weight of 1 while that of the other two objectives (Gov Income and GINI Welfare) are given a weight of 0.2.

[11] Accessible through the dedicated interactive dashboard

base government response). As expected, government income is positively correlated with sales tax on fuels and transportation.

a) Feature relative importance **b) Correlation coefficients**

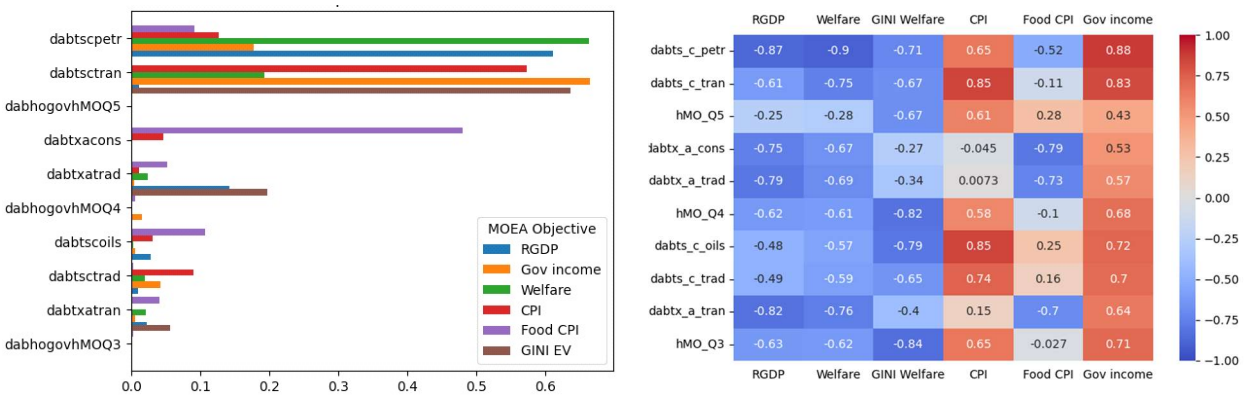


Figure 4 – MOEA top ranked instruments as resulting from RF ranking

Model parameter notation: 'dabts' = change in sales tax, 'dabtx' = change in output tax, 'dabhgov' = change in household transfers

The output tax on trade services has a strong negative correlation with GDP. Interestingly, together with the output tax on construction and trade services, these have a negative correlation with the food CPI, but lack any correlation with general CPI.

Finally, household transfers have a negative correlation with GINI welfare and a positive correlation with the CPI (but a lack of strong correlation with the food CPI) and government income (as transfers enter the expenditure side of the government balance). These results combined with the feature importance ranking for the GINI welfare highlight the need for having income quintiles in the SAM household disaggregation, these being available only for Nairobi and Mombasa in the present application, and not for the other regions in Kenya.

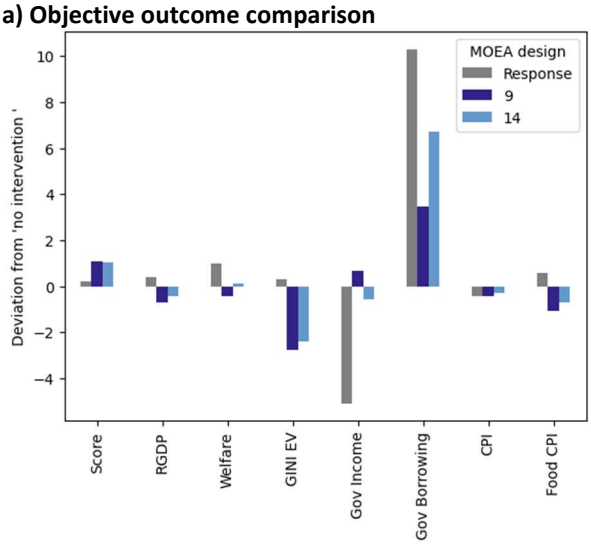
4.2. Selected designs based on food security and welfare objectives

Among the 50 policy options, the choice of one can be determined by multiple criteria (through a single objective such as GDP or a synthetic metric such as the Score presented in Figure 3a). In the following, we select the design that improves the food security metric food CPI the most (option 9). This option also decreases CPI and inequality and improves government income. However, this is accompanied by a decrease in aggregate welfare, driven by a marked decrease for certain household groups (Figure 3b), namely High Rainfal urban and rural, and Nairobi Q1, despite an increase for other groups (Coast rural, Nairobi Q2, Semiarid North and Mombasa Q4).

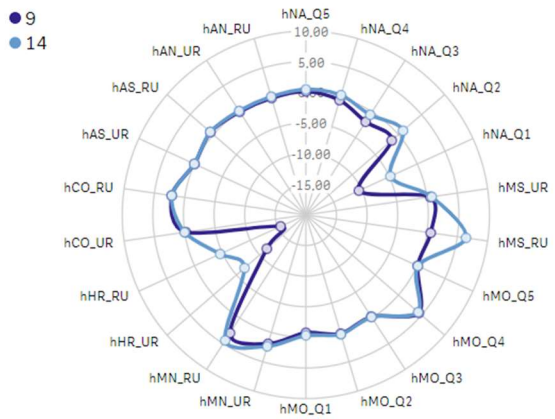
Policy option 9 involves a reduction in the sales tax for several food and agricultural commodities (exceptions are sugar, tobacco, 'other crops') and for trade services (but not for transport services). This option also does not involve an important subsidy for fertilizers or for fuels. The reduction in sales tax rates are accompanied by an increase in output taxes of corresponding activities (e.g. sugar and tea production) highlighting a shift of the tax burden from consumers to producers. As a consequence, total sales tax revenues decrease by 8.8% (34 bn KSh) while output tax revenues increase by 27% (52 bn KSh) and, combined, drive an overall increase of government income of 0.7% (10 bn KSh). At the same time, this option implies a more important increase in government transfers to households for specific households groups in the rural areas (Semi-Arid South, Coast, Semi-Arid North), and in Mombasa (particularly Q4) and Nairobi (particularly Q2). Compared to the

base response, option 9 ensures a more even recovery by removing some of the welfare gains in better-off household groups (Nairobi Q1-Q3, High Rainfall both rural and urban).

a) Objective outcome comparison



b) Welfare change by household group (bn KSh)



c) Option design details

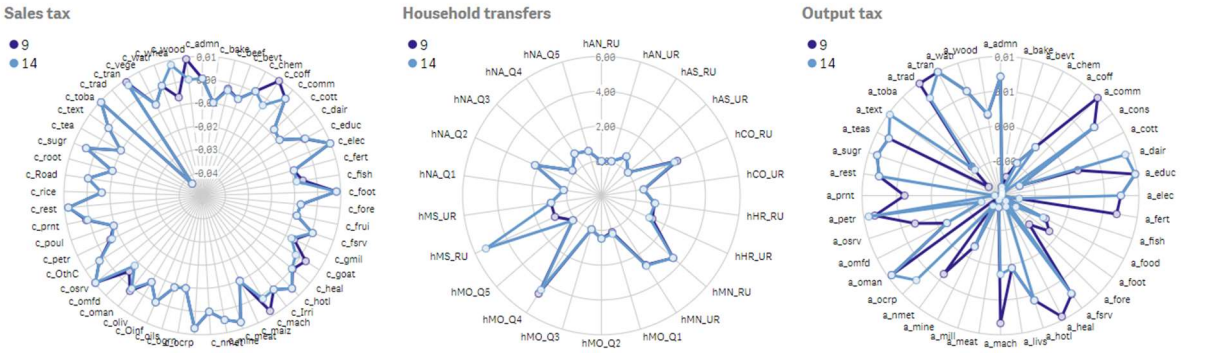


Figure 5 – Policy options towards increased food security

Given the negative impacts of this policy on GDP and aggregate welfare, stakeholders could be interested in identifying similar options but with some improvements in these two important policy objectives. In this regard, using the Euclidean distances to determine the similarities between the 50 policy option vectors, option 14 was also selected for comparison as the closest alternative. Indeed this option, delivers lower improvements in foodCPI and inequality reduction (however still significant in relation to the base government response). Nevertheless, it provides better outcomes for GDP and CPI. Welfare is also improved (tough lower than the government response), as the negative impacts on specific household groups are diminished relative to option 9 – Figure 4b.

The differences between the two options in terms of the policy instruments used are not significant in terms of sales tax changes (for instance, an increase for wheat and a decrease for coffee, wood products, machinery and other manufacturing). Option 14 also includes an increase in output tax for some sectors (textiles, 'other crops') and a decrease in some other manufacturing and services (printing, health, communications, 'other services'). In terms of household transfers, this alternative option increases the values only for the Semi-arid South rural households while marginally decreasing those of other groups (Mombasa Q4, High Rainfall urban). Nevertheless, this option leads

to improved welfare results at an aggregate level and a reduced inequality compare to the base government response.

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