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Optimal allocation of agriculture's public budget can improve transformation and healthy diets access in Ethiopia

Marco V. Sánchez [a,*], Martín Cicowiez [b]

[a] *Agrifood Economics Division, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, Rome 00153, Italy*

[b] *Agrifood Economics Division, FAO and Lecturer and Researcher, Universidad Nacional de La Plata, La Plata, Argentina*

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Abstract

Agriculture is under transformation in sub-Saharan Africa where millions still do not have access to a healthy diet. Policy makers in this region should find ways to accelerate agricultural transformation while increasing access to healthy diets. Optimizing agriculture's public budget stands out as a handy option. By combining a dynamic computable general equilibrium model and a multi-criteria decision-making technique, and applying them in the context of Ethiopia, this paper points to an important trade-off that policy makers should keep in mind. An optimal allocation of agriculture's public budget aimed at increasing agri-food output, creating off-farm jobs and reducing rural poverty, which are agricultural transformation objectives, will help to reduce the cost of a healthy diet, allowing around 2 million more Ethiopians to afford it. This number could even be higher should policy makers allocate the budget optimally aiming at only lowering the cost of a healthy diet, but at the cost of reducing household income and slowing down transformation.

JEL classifications: C61; C68; E61; O18

Keywords: Computable general equilibrium; Optimal policy design; Economic development; Agricultural transformation; Nutrition

* Corresponding author.
E-mail address: marco.sanchezcantillo@fao.org (M.V. Sánchez).

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1. Introduction

Agricultural transformation entails four consecutive phases: (i) a rise in agricultural productivity per worker resulting in a surplus of labor, expenditures and savings; (ii) the tapping of such surplus (e.g. through taxation and factor flows) to enable development in non-agricultural sectors through better integration of factor and product markets between the rural and non-rural sectors; (iii) the progressive integration of agriculture into the broader economy, via improved infrastructure and market-equilibrium linkages; and (iv) the establishment of agriculture's role in an industrialized economy (Timmer, 1988). There is consensus in scholarly and policy circles that agricultural transformation should be inclusive (Osabuohien, 2020).

In sub-Saharan Africa, policy makers are finding it challenging to achieve agricultural transformation results, not only in the realms of agricultural productivity growth, agricultural and national economic growth and employment, and food industry development, but also in terms of poverty, hunger, food insecurity and malnutrition reduction. In this region, agriculture still represents a significant share of total output and employment and is a source of livelihoods and food for millions. Industrialization is not yet occurring in most countries (FAO, 2017). At the outset of the 2010s, only a few sub-Saharan African countries had showed to be, at least potentially, on the long-term path of economic transformation (Letiche, 2010). In 2020, 85.5% of sub-Saharan Africans did not have sufficient income to cover the cost of a healthy diet, a percentage that is significantly above that of any other region in the world (FAO et al., 2022).

A healthy diet provides adequate calories and micronutrients and a diverse intake of safe foods from several different food groups (FAO et al., 2020). However, the production of some foods in these food groups may not be among the high priorities of ongoing inclusive agricultural transformation (IAT) strategies. Many sub-Saharan African countries are still highly reliant on the production of one crop for national food security, which largely determines the total caloric intake of the rural population (Heumesser & Kray, 2019). Hence, a key question is: What are potential ways of transforming agriculture in sub-Saharan Africa that also contribute to making healthy diets more available and affordable? We argue that countries in this region will not only require an expansion in the supply of the nutritious foods that constitute healthy diets, but also an increase in people's incomes and a behavioral shift in consumption – with the latter aspect being beyond the scope of this paper.

A supply expansion that benefits people's income will require stepping up investments with increased cost-effectiveness. Very few sub-Saharan African countries have met the Maputo target of allocating at least 10% of their national budget to food and agriculture, under the Comprehensive Africa Agriculture Development Programme (CAADP) (Pernechele et al., 2021). However, we argue that optimizing public budgets in agriculture is needed before the low level of public spending is addressed. That is to say, intra-sectoral reallocations will be needed to accelerate progress towards IAT objectives, while making healthy diets more affordable. Matchaya (2020) had already recommended, in the context of Southern African countries, that policy makers should improve intra-sectoral allocations, targeting areas and crops that are more effective in creating sectoral growth, based on evidence from a cointegration analysis. In the case of our paper, following the principles of Pareto optimality, a public budget becomes optimal when policy makers reach a compromise to reallocate it in a unique way, whereby it is not possible to improve in at least one policy objective without worsening any of the other policy objectives—while considering the workings of the whole economy.

IAT is typically aimed at increasing agri-food output, creating rural off-farm jobs, and reducing rural poverty. Some of these IAT objectives may conflict with other objectives; for example, rural poverty reduction programs of an agricultural transformation strategy may conflict with fiscal consolidation. Adding the objective of increasing access to healthy diets makes the policy maker problem more complex. For example, if agricultural transformation results in increased agri-food output but agriculture continues to be predominantly cereal-based, then the nutritious foods that make up healthy diets may remain costly, unless these foods are imported more cheaply. The key issue for policy makers is to find the optimal policy mix that, at a given budget constraint, allows them to achieve a compromise for making progress towards several important objectives, while minimizing trade-offs. This paper addresses this policy making dilemma in the context of Ethiopia.

The aforementioned four consecutive phases of agricultural transformation, as defined by Timmer (1988), entail economy-wide and multi-sectoral interactions that are affected by policy choices. For this reason, we follow the policy optimization modeling approach proposed in Sánchez and Cicowiez (2022), whereby a dynamic computable general equilibrium (CGE) model is combined with compromise programming (CP). The latter is a multi-criteria decision-making (MCDM) technique that allows us to deal with a situation of multiple objectives, some of which could be conflicting. Combining a CGE model and MCDM techniques had originally been proposed by André et al. (2008) using a static CGE model, rather than a dynamic one. CGE models are considered the workhorse models of policy analysis focusing on economy-wide effects induced by exogenous economic shocks or policy interventions (De Melo, 1988; Dixon & Jorgenson, 2013; Shoven & Whalley, 1992). MCDM techniques are widely used in operations research/management science and in recent years they have been applied to solve several economic problems in which it is not reasonable or operational to assume the existence of a single goal or objective.

In addition to shedding light on how to balance out agricultural transformation and healthy diets access through an optimal budget in agriculture, this paper also contributes to the emerging literature on repurposing public support to food and agriculture. Worldwide, this support has been estimated to account for almost USD 630 billion per year on average over 2013–2018 (FAO et al., 2022). Several recent studies have recommended redirecting or "repurposing" some of these public resources towards investments and incentives that encourage increased productivity, sustainable production practices and healthy dietary choices (Ding et al., 2021; FAO et al., 2022; FAO, UNDP et al., 2021; Gautam et al., 2022). However, there is a lack of country-specific studies in this literature.

The remainder of the paper includes four more sections. To provide context, Section 2 briefly describes Ethiopia's agricultural transformation and nutrition agendas and their persisting challenges. Section 3 describes the policy optimization modeling framework used to determine optimal ways to allocate Ethiopia's public budget in agriculture to accelerate IAT and make healthy diets more affordable. Section 4 provides an analysis of optimal domestic public budget scenarios that can allow Ethiopia to get better results in transforming agriculture with inclusion. Finally, Section 4 discusses the implications of the results and Section 5 concludes.

2. Agricultural transformation and nutrition in Ethiopia

Ethiopia has invested significantly to transform agriculture. Between 2004 and 2018, it exhibited the highest annual average growth rate of public expenditure on food and agriculture relative to 12 other sub-Saharan African countries. Even so, Ethiopia is among the countries that in the late-2010 s had not yet met the 10% of total public spending to agriculture target defined by the African Union's Maputo Declaration (Pernechele et al., 2021). Current public expenditures in Ethiopia's agriculture also need to be allocated optimally to accelerate IAT.

Clear signs of agricultural transformation in Ethiopia include, inter alia: a declining share of agriculture in total employment and gross domestic product (GDP) (NBE, 2020; NPC, 2018); increased labor productivity in agriculture (NPC, 2016); a more intensive use of modern inputs and increased efficiency (Bachewe, 2012; Bachewe et al., 2018); movement of rural labor away from agriculture (NPC, 2018); and a reduction in poverty and food insecurity (NPC, 2018).

The other side of the story is that Ethiopia's agriculture is still predominantly cereal-based and relies on household-based and subsistence-oriented systems. Rural off-farm employment creation remains off target (NPC, 2018). Productivity growth is still below its potential because of underdeveloped input supply systems, poor incentives, and the predominance of rain-fed farming systems, moisture stress and eroded soils, and low levels of mechanization. Technical change in the production of major crops (i.e. teff, maize, barley, wheat and sorghum) has increased with better use of available technology, but improving efficiency and technology adoption are still critically needed to boost output levels (Meja et al., 2021). Rural poverty also continues to be high (UNDP, 2018).

In 2018–2020, on an annual average basis, 18.2 million Ethiopians experienced hunger and 56.3% of them were moderately or severely food insecure (FAO, ECA et al., 2021). In 2020, the cost of a healthy diet was lower in Ethiopia than in sub-Saharan Africa (USD 3.37 vs USD 3.44 per person per day). However, because incomes are low relative to such cost, 86.8% of Ethiopians (99.7 million) could not afford a healthy diet in 2020, compared with 85% in sub-Saharan Africa, or 79.9% in Africa (FAO et al., 2022).

Since 2012, the nutrition challenges have prompted Ethiopia's government to join global initiatives that commit to eradicate hunger and prevent all forms of malnutrition. The main commitments in such initiatives have been reflected in national policy documents and plans, and the scaling up of nutrition programs have clearly made a tremendous contribution to reducing undernutrition. However, Ethiopians' income and livelihoods will have to improve to make healthy diets more affordable and more boldly address nutrition challenges. We argue that optimally reallocating the public budget in agriculture across different budget lines can play a fundamental role in this direction.

3. Method and data

In the MCDM-CGE policy optimization modeling framework applied here for Ethiopia, policy instruments are optimally determined to make progress towards IAT objectives. This means we are moving away from the standard CGE modeling practice whereby policy instruments are exogenously determined. We identify synergies and potential conflicts (i.e. trade-offs) in pursuing three IAT objectives: maximizing agri-food GDP,[1] maximizing off-farm rural employment relative to on-farm rural employment (for simplification, hereafter, maximizing rural off-farm employment), and minimizing rural poverty. We are also including the objective of minimizing the cost of a healthy diet,[2] which is not typically seen as an outcome of IAT. Ultimately, a compromise that helps improve on all four objectives is reached, which is a novelty of the approach.

[1] Agri-food GDP comprises the value added from crops, livestock, fishery, forestry, and the food processing industry.

[2] Sánchez and Cicowiez (2022) do not consider this objective or that of maximizing rural off-farm employment.

3.1. Policy optimization modeling approach

In terms of theoretical pedigree, our CGE model can be characterized as a recursive-dynamic extension of standard comparative-static single-country CGE models for developing countries in the tradition of Dervis et al. (1982), Robinson (1989), and Lofgren et al. (2002). In recent years, models belonging to this class have been widely used in applied development policy research. We also use an unconventional treatment of financial flows and a relatively detailed disaggregation of government spending (recurrent and investment) and its financing, following Cicowiez and Lofgren (2017) and their application for agriculture in Sánchez and Cicowiez (2022) and Sánchez, Cicowiez, and Ortega Díaz (2022).

Some features of the CGE model are worth noting. Over time, economic growth is driven by changes in factor use and total factor productivity (TFP). The accumulation of capital stocks is endogenously generated by the model, depending on investment and depreciation. For other factors, the growth in employable stocks is exogenous to the model, i.e. the supplies in each time period are projected exogenously. For labor, the projections reflect the evolution of the population at labor-force age and labor-force participation rates. For natural resources, the projections are closely linked to production projections. The unemployment rate for labor is endogenous. TFP growth is made up of two components, one that responds positively to growth in selected government expenditures (e.g. infrastructure), as further explained below, and one that is exogenous.[3]

Following a relatively simple microsimulation model and using household survey data, we compare household per capita consumption generated by the CGE model with: (i) the cost of a healthy diet to calculate the share and number of the population that cannot afford a healthy diet, and (ii) a poverty line to calculate poverty. To that end, the microsimulation model is linked to the CGE model through household consumption and commodity prices.[4]

Instead of solving Ethiopia's CGE model as a system of simultaneous equations, as typically done, we solve an optimization problem whereby the CGE model equations are constraints to a policy optimization problem. The Ethiopian policy maker has policy objectives and resorts to policy instruments to pursue them. The first step in CP is to identify an ideal or utopian solution (or point) in which each of the policy objectives is individually optimized (Yu, 1973; Zeleny, 1974). This ideal solution is only a point of reference for the policy maker. Subsequently, it is assumed that the policy maker sets the available policy instruments in such a way that all policy objectives are simultaneously optimized while their values are as close as possible to their ideal solution. A distance function measures the distance from the ideal solution to any set of values for the policy objectives. The concept of distance is not used in its geometric sense but as a proxy measure for the policy maker's preferences.

Government recurrent and investment expenditures in priority areas defined below are the instruments that the Ethiopian policy maker uses to pursue the four IAT objectives in this paper. Mathematically, the optimization problem is as follows:

[3] Supplementary material A presents a complete mathematical statement of the recursive-dynamic CGE model and is available upon request to the authors.

[4] Supplementary material B explains these extensions in detail and is available upon request to the authors.

$$\min L_p = \left(\sum_{t \in T} \frac{1}{(1+\rho)^t} \left(wt^p_{RGDPTRG} \left(\frac{rgdptrg^*_t - RGDPTRG_t}{rgdptrg^*_t - rgdptrg_{t*}} \right)^p + wt^p_{QHPCTRG} \left(\frac{qhpctrg^*_t - QHPCTRG_t}{qhpctrg^*_t - qhpctrg_{t*}} \right)^p + wt^p_{QLABAGRNAGR} \left(\frac{qlabagrnagr^*_t - QLABAGRNAGR_t}{qlabagrnagr^*_t - qlabagrnagr_{t*}} \right)^p + wt^p_{RATZDIETCPI} \left(\frac{RATZDIETCPI_t - ratzdietcpi^*_t}{ratzdietcpi_{t*} - ratzdietcpi^*_t} \right)^p \right) \right)^{\frac{1}{p}}$$

subject to the following endogenously determined policy instruments to pursue the objectives:

$$invg^{\min}_{fcap,t} \leq INVG_{fcap,t} \leq invg^{\max}_{fcap,t}$$

$$qg^{\min}_{c,t} \leq QG_{c,t} \leq qg^{\max}_{c,t}$$

$$tq^{\min}_{c,t} \leq TQ_{c,t} \leq tq^{\max}_{c,t}$$

and also subject to all the recursive-dynamic CGE model equations.

where,

$t \in T$: set of time periods.

L_p: distance measure between a given solution and the ideal (and unattainable) solution.

p: parameter that determines the relevance of the mean divergence between objectives and their ideal values vis-à-vis the distribution of divergences between each objective and its ideal value.

ρ: discount factor for the policy maker.

$RGDPTRG_t$: agri-food GDP.

$QHPCTRG_t$: rural household consumption per capita (i.e. our proxy for rural poverty).

$QLABAGRNAGR_t$: ratio between rural off-farm and on-farm employment (i.e. our proxy for rural off-farm employment).

$RATZDIETCPI_t$: the cost of a healthy diet relative to the consumer price index (CPI).

$rgdptrg^*_t$ and $rgdptrg_{t*}$: ideal and anti-ideal values for agri-food GDP; the ideal value is obtained by setting $wt_{RGDPTRG} = 1$ and $wt_{QHPCTRG} = wt_{QLABAGRNAGR} = wt_{RATZDIETCPI} = 0$; the anti-ideal value is obtained as the minimum value for $RGDPTRG_t$ that results from solving the problem above with $wt_{RGDPTRG} = 0$ and only one of the other three policy objectives with a weight equal to 1 (i.e., $wt_{QHPCTRG} = 1$, $wt_{QLABAGRNAGR} = 1$, or $wt_{RATZDIETCPI} = 1$); a similar method is used to calculate the ideal and anti-ideal values of the other three policy objectives.

$qhpctrg^*_t$ and $qhpctrg_{t*}$: ideal and anti-ideal values for rural household consumption per capita.

$qlabagrnagr^*_t$ and $qlabagrnagr_{t*}$: ideal and anti-ideal values for ratio between rural off-farm and on-farm employment.

$ratzdietcpi^*_t$ and $ratzdietcpi_{t*}$: ideal and anti-ideal values for the cost of a healthy diet relative to the CPI.

$wt_{RGDPTRG}$, $wt_{QHPCTRG}$, $wt_{QLABAGRNAGR}$, and $wt_{RATZDIETCPI}$: weights attached to each of the four policy objectives.

$INVG_{fcap,t}$: government investment in priority area $fcap$ (i.e. irrigation, mechanization, rural roads, and rural electrification).

$invg^{\min}_{fcap,t}$ and $invg^{\max}_{fcap,t}$: lower and upper bounds for government investment in priority area $fcap$.

$QG_{c,t}$: government recurrent spending in priority area c (i.e. research and development, extension services, improved seeds, and fertilizers).

$qg_{c,t}^{min}$ and $qg_{c,t}^{max}$: lower and upper bounds for government recurrent spending in priority area c.

$TQ_{c,t}$: tax (or subsidy) rate on commodity c; where c only applies to fertilizers.

$tq_{c,t}^{min}$ and $tq_{c,t}^{max}$: lower and upper bounds for tax (or subsidy) rate on commodity c.

Technically, a general characterization of the dynamic CGE model is given by the following nonlinear continuously differentiable function

$$X_t = F(X_t, X_{t-1}, Y_t, Z_t)$$

$$t = 1, \ldots, T$$

that defines a set of structural equations for n contemporaneous endogenous variables, represented by the n-element vector X_t. The model F is a function of X_t (i.e. not a reduced form) as well as of lagged values of the endogenous variables X_{t-1}, which reflect the structural dynamics of the model. The vector Y_t denotes a set of m contemporaneous endogenous variables which are assumed to be the policy instruments (i.e. they are controllable by the policy maker).[5] The last argument of the model's functional specification, Z_t, is a k-element vector which represents exogenous variables that are outside the control of the policy maker. Naturally, the policy objectives and policy instruments in the optimization problem mathematically stated above are contained in X_t and Y_t, respectively.

The best compromise solution to the optimization problem is the nearest solution to the infeasible ideal solution (i.e. the alternative with the lowest value for L_p) (Zeleny, 1973). In other words, the ideal solution (or point) represents the joint location of the individual maximum values of all the policy objectives. Therefore, arriving at a compromise solution can be viewed as minimizing the policy maker's regret for not obtaining the ideal solution. Because units of measurement may differ depending on the policy objectives (e.g. percent for the poverty rate vs number of workers for employment), we normalize the units of measurement for the various policy objectives to avoid a meaningless summation.[6]

Naturally, arriving at a compromise solution depends on the values of the parameter p and the weights wt_i (where i refers to an element in the set of policy objectives) that are chosen – ideally by the policy maker.[7] The parameter p is a real number in the interval $[1, \infty]$ that acts as a weight attached to the deviations from the ideal solution according to their magnitudes. In turn, wt_i are the weights for various deviations capturing the relative importance given to each policy objective. It is possible to generate different compromise solutions for different sets of values for p and wt_i. However, the literature has showed that, in most applications, the compromise set is bounded by the solutions obtained when $p = 1$ and $p = \infty$. In Section 4, we set $p = 2$ and consider alternative weighting schemes representing different scenarios. In practice, $p = 2$ offers a balance between (a) maximizing the overall achievement of all the policy objectives ($p = 1$), and (b) maximizing the balance among all policy objectives ($p = \infty$).[8]

[5] In a typical CGE model application, the elements of Y_t are generally considered as exogenous variables.

[6] Due to the normalization, all policy objectives take values between 0 (ideal) and 1 (anti-ideal).

[7] Gómez-Limón and Atance (2004) argue that social preferences may also be considered in weighting policy objectives.

[8] Supplementary material C is available from the authors upon request. Its first section shows results for solutions obtained when $p = 1$ and $p = \infty$, which help understand how sensitive the results are to changes in this parameter. The alternative solutions do not differ significantly when we consider such alternative metrics for the distance function.

The weights $wt_{RGDPTRG}$, $wt_{QHPCTRG}$, $wt_{QLABAGRNAGR}$, and $wt_{RATZDIETCPI}$ are preference parameters that help us represent, on the basis of information or actual policy dialogue, how concerned the policy maker is about each policy objective. This CP procedure ensures that the solution found is efficient, but it does not guarantee that all the policy objectives improve with respect to the initial (base) situation.

3.2. Data

The basic accounting structure and much of the Ethiopian data required to calibrate the MCDM-CGE policy optimization modeling framework is derived from a social accounting matrix (SAM) for 2015/2016. We started from the SAM documented in Mengistu et al. (2019) and extended it to include selected financial flows (i.e. government domestic and foreign borrowing and non-government foreign borrowing) and a relatively detailed disaggregation of government spending (recurrent and investment) as follows: for recurrent spending, research and development (R&D) by commodity, extension services by commodity, improved seeds by commodity, fertilizer, and cash transfers; and for investment spending, mechanization by commodity, rural roads, rural electrification, and irrigation by commodity. The extent to which these types of government spending will affect TFP in agricultural production is given by the value of an elasticity as follows: for improved seeds, 0.116 (Gebeyehu, 2016); for fertilizers, 0.231 (Teka & Lee, 2019); for irrigation, 0.102 (Makombe et al., 2007); for extension, 0.263 (Benin, 2006); for rural roads, 0.110 (Mogues & Benin, 2012); and for R&D, 0.066 (Benin, 2006). The values for elasticities for trade, production, and consumption were defined on the basis of the literature and author assessments, drawing on a combination of econometric evidence and experience from similar country applications.[9]

For the solution over time, we use data for capital depreciation rates, labor supply, and population projections from different sources. For capital depreciation rates, we use 5.0% and 2.5% for private and public capital, respectively, following Agénor et al. (2008). For unemployment and underemployment, we use the estimates from the ILO ILOSTAT database (accessed on February 25, 2021): 2.2% and 25.8%, respectively. For projections of the population by age groups, we use the 2022 UN World Population Prospects dataset. Finally, the results for poverty and affordability of a healthy diet are calculated using the 2018/2019 Ethiopia Socioeconomic Survey.

To estimate the affordability of a healthy diet, we use the least-cost healthy diet, which represents the minimum cost of purchasing a healthy diet that satisfies dietary recommendations from food-based dietary guidelines (FBDG), at a given place and time, following Herforth et al. (2022). The diet is estimated using average food group amounts recommended across FBDG, which are scaled to meet a consistent dietary energy intake target (i.e. 2330 kcal). The food groups are six: fats; fruit; legumes, nuts, and seeds; animal source foods; starchy staples; and vegetables.[10]

[9] These elasticities are part of the dataset used to calibrate the MCDM-CGE policy optimization modeling framework, which is available from the authors upon request. Supplementary material C is also available from the authors upon request. Its second section shows a systematic analysis to assess the sensitivity of the results presented in Section 4 of this paper to the various model elasticities. In terms of the direction of the changes for the key indicators associated with the policy objectives shown in Section 4, the results are robust to relatively large changes in the elasticities.

[10] Protein-rich foods in a healthy diet include legumes, nuts, and seeds, as well as animal source foods such as dairy meat, fish, and eggs.

Table 1
Least-cost healthy diet in Ethiopia, 2017.

ICP name and total	FBDG food group	(a) Price per kcal of food (ETB)*	(b) Energy per gram of food	(c) Recommended grams of selected food item per day per person	(d) Total kcal of a healthy diet (≈2329 kcal per day)**	(e) Price per day (ETB)***
Palm oil, WKB****	Fats	0.01	8.84	33.03	292.00	1.57
Banana, short finger length	Fruit	0.03	0.89	88.76	79.00	2.49
Fresh mangoes	Fruit	0.05	0.60	131.67	79.00	4.03
Spotted beans	Legumes, nuts, and seeds	0.01	3.47	82.71	287.00	2.20
Fresh small sardines	Animal source foods	0.02	1.31	110.69	145.00	2.96
Red Snapper (AFR)****	Animal source foods	0.03	1.44	100.69	145.00	4.28
Maize grains, white	Starchy staples	0.00	3.65	160.55	586.00	1.54
Wheat flour, not self-rising, BL****	Starchy staples	0.00	3.64	160.99	586.00	2.27
Fresh onions	Vegetables	0.04	0.40	108.33	43.33	1.53
Fresh cabbage, green	Vegetables	0.04	0.25	173.33	43.33	1.75
Fresh carrots	Vegetables	0.05	0.41	105.69	43.33	2.20
Total (where applicable)					2329.00	26.82

Notes: * Based on 2017 ICP prices. ** (d) = (b) x (c). *** Cost of the least-cost healthy diet in Ethiopia based on 2017 ICP prices. (e) = (a) x (d). **** WKB: Well-known brand; AFR: African Red Snapper; BL: selected cheapest flour is brand-less. *Source:* Authors based on the application of the method proposed in Herforth et al. (2022) using FAO data.

The least-cost healthy diet in Ethiopia cost 26.82 Ethiopian birr (ETB) in 2017 (Table 1). The food items that provide protein (e.g., fish and some fruits) are relatively more costly than the other foods that make up the healthy diet. In turn, protein from animal source foods is more cheaply available from fish (i.e. fresh small sardines and African Red Snapper) rather than meat, such as from beef which is an important sector in Ethiopia. The food items in the least-cost healthy diet (Table 1) are linked to commodities in the CGE model and the cost of the diet changes as the prices of the foods it comprises change within the CGE model.

4. Simulation results

4.1. Base scenario

Our base or business-as-usual scenario starts from 2016 (i.e. the base-year for which the MCDM-CGE policy optimization modeling framework was calibrated) and extends up to 2025. It assumes that (a) the GDP growth rate is exogenous; (b) all international (export and import) prices are constant in real terms; and (c) drawing on the SAM data, most payments made by institutions (i.e. households, enterprises, and the government) are kept constant as GDP shares, including all receipt and spending items in the government budget. The base-year composition of the public budget for agriculture remains unchanged.

Table 2
Values for rural consumption per capita and variables associated with the policy objectives in the base scenario.

Item	Agri-food GDP	Rural consumption per capita	Rural off-farm (vs on-farm) employment	Cost of the least-cost healthy diet	Rural poverty
	Billion ETB	ETB	Ratio	Ratio	%
2020	700.16	8653.27	0.58	1.00	24.12
2025	836.92	10,093.41	0.61	1.07	18.00
Percentage change 2025–2020	19.53	16.64	5.55	7.07	–25.36

Source: Authors' calculations.

The following closure rules are used in the base scenario aiming at mimicking an unchanged economic policy environment: (a) the government balance clears through government foreign borrowing; (b) the saving behavior of households and enterprises does not change (i.e. savings rates are exogenous), but real investment adjusts endogenously to ensure aggregate private savings net of lending to the government match aggregate private investment; and (c) a flexible real exchange rate equilibrates the current account of the balance of payments by influencing export and import quantities at fixed world prices. The assumption of a flexible real exchange rate rules out the use of an increase in foreign borrowing to finance a current account deficit.

Based on IMF (2022), GDP growth is projected at an annual rate of 6.1% up to 2025. Table 2 shows the base-scenario values for the variables associated with the four policy objectives (and rural household per capita consumption which is used to calculate rural poverty) for the years 2020 and 2025 (and their percentage change). Given that private consumption growth exceeds population growth, aggregate household welfare is increasing. Rural poverty is decreasing and rural off-farm employment is increasing relative to rural on-farm employment due to different sectoral growth rates. Slow growth of land supplies and low-income elasticities of demand result in lower growth for agriculture. The price of agri-food products increases relative to the price of non-agri-food products and such change in relative prices also makes the relative cost of the least-cost healthy diet slightly more expensive. However, given the increase in household per capita consumption, there is a decrease in the population share that cannot afford the least-cost healthy diet (i.e. from 78.8% in 2020 to 77.1% in 2025).

4.2. Policy scenarios

We generate policy scenarios that deviate from the base scenario as a result of alternative optimal allocations of the same domestic public budget in agriculture from 2023 to 2025, which allow to improve in one or more objectives. In these policy scenarios, GDP is now invariably endogenous while assumptions with regard to closure rules and world prices remain unchanged.

To develop the policy scenarios, we solve the policy optimization problem identified in Section 3 following two stages. Firstly, we compute the ideal and anti-ideal values of the four variables associated with the four policy objectives. To that end, we solve four single-objective optimization problems. To simplify, Table 3 shows the so-called payoff matrix applied to our policy objectives in 2025. The second row shows the values of the variables associated with the four policy objectives, when only agri-food GDP growth is maximized while the other three policy objectives are not part of the optimization problem. For instance, if Ethiopian policy

Table 3
Agri-food GDP, rural poverty, rural off-farm employment and cost of healthy diet in Ethiopia in the base and payoff matrix, 2025.

Item	Agri-food GDP Billion ETB	Rural poverty %	Rural off-farm (vs on-farm) employment Ratio	Cost of the least-cost healthy diet Ratio
Base scenario	836.92	18.00	0.610	1.0670
Maximizing agri-food GDP	**843.33**	17.75	0.617	1.0400
Minimizing rural poverty	842.86	**17.72**	0.616	1.0394
Maximizing rural off-farm employment	842.03	<u>17.90</u>	**0.618**	<u>1.0404</u>
Minimizing the cost of the healthy diet	<u>839.45</u>	17.84	<u>0.611</u>	**1.0247**

Note: Bold and underlined figures represent ideal and anti-ideal values for each policy objective, respectively. *Source:* Authors' calculations.

makers are only concerned about increasing agri-food GDP, thus giving a weight equal to 1 to this policy objective (and weights equal to 0 to the other three policy objectives), they could optimally set the available policy instruments (government recurrent and investment spending) and attain an agri-food GDP that is 0.8% larger than in the base scenario (i.e. the percent change from 836.9 in the base scenario to 843.3 in the ideal situation; see Table 3). The same logic applies to the other policy objectives.

For the four single-objective optimization problems, the values in the main diagonal of the payoff matrix show the best attainable results when only one policy objective is considered. Ethiopian policy makers thus face some degree of conflict, as it would not be possible for them to obtain the maximum for the four policy objectives simultaneously. There are no trade-offs, though, as targeting only one policy objective does not have a negative impact on any of the other objectives. Instead, synergies are actually seen. For instance, optimizing to pursue any IAT policy objective reduces the relative cost of the least-cost healthy diet. If the Ethiopian policy maker only cares about minimizing the cost of the least-cost healthy diet, agri-food GDP and rural poverty would also move in the right direction. However, in this last case, IAT outcomes are not as good as when each IAT objective is individually the priority. Interestingly, the ratio between rural off-farm employment and rural on-farm employment barely changes.

Secondly, we developed the public budget optimization scenarios whereby we apply different weighting schemes to the optimization problem introduced in Section 3. Specifically, we consider three scenarios:

- Minimizing the cost of the least-cost healthy diet (i.e. $wt_{RGDPTRG} = 0$, $wt_{QHPCTRG} = 0$, $wt_{QLABAGRNAGR} = 0$, and $wt_{RATZDIETCPI} = 1$); this scenario corresponds to the last column in the payoff matrix (see Table 3)
- Optimizing for pursuing the three IAT objectives: maximizing agri-food GDP, maximizing rural off-farm employment relative to on-farm employment, and minimizing rural poverty (i.e. $wt_{RGDPTRG} = 1/3$, $wt_{QHPCTRG} = 1/3$, $wt_{QLABAGRNAGR} = 1/3$, and $wt_{RATZDIETCPI} = 0$)
- Optimizing for pursuing all four objectives above (i.e. $wt_{RGDPTRG} = 1/4$, $wt_{QHPCTRG} = 1/4$, $wt_{QLABAGRNAGR} = 1/4$, and $wt_{RATZDIETCPI} = 1/4$)

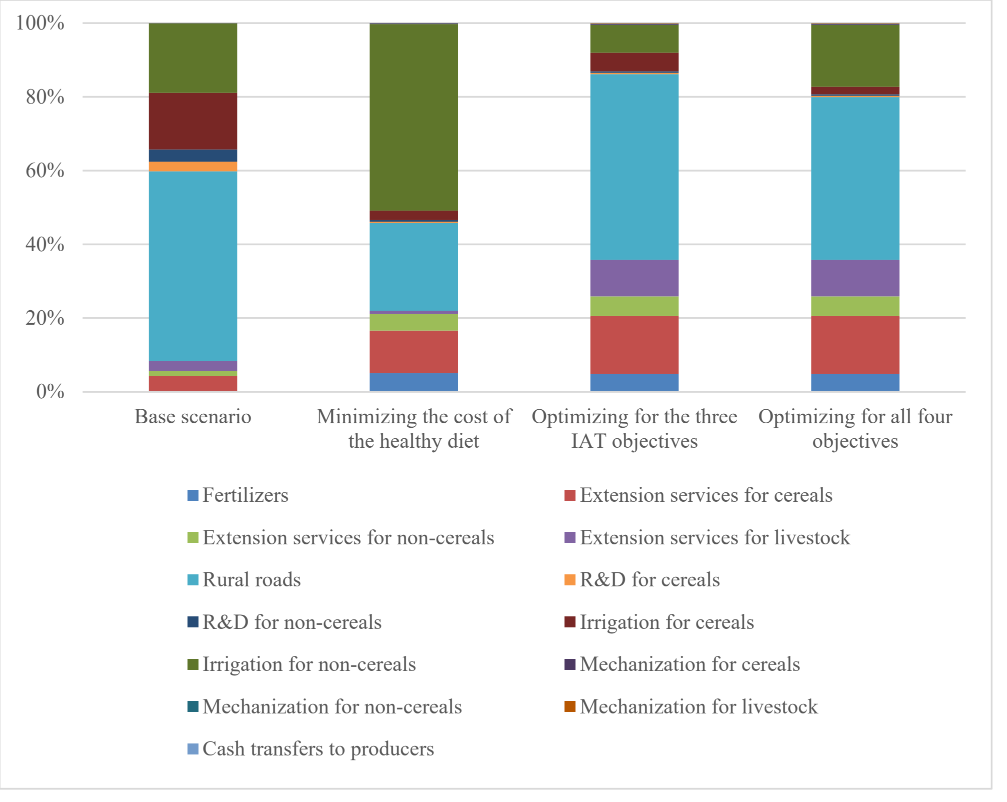

Fig. 1. Public budget allocation by type of spending in the base and budget optimization scenarios, 2025.
Source: Authors' calculations.

In these three public budget optimization scenarios, agriculture's public budget provides the policy instruments (i.e. the categories of expenditures introduced before, defined by priority areas such as fertilizers, extension services, rural roads, R&D, irrigation, and mechanization, and by commodity). Moreover, these policy instruments are bounded and even if this is the case, the three public budget optimization scenarios are budget neutral.[11]

Optimizing to prioritize a policy objective alone or in combination with other policy objectives results in a reallocation of Ethiopia's public budget in agriculture, as shown for 2025 in Figs. 1 and 2.[12]

[11] The bounds for policy instruments would ideally be defined in consultation with government experts. For this paper's scenarios, we have made the choice that public investments across agriculture can decrease (increase) up to 85% (400%) relative to their base-year values. Government consumption, which is used to model the provision of extension services, can decrease (increase) up to 50% (100%) relative to its base-year value. For taxes and subsidies, the lower and upper bounds are –15% and 15%, respectively, but in our Ethiopian application only the subsidy on fertilizers is being considered as a policy instrument as far as taxes/subsidies are concerned.

[12] In Fig. 1, to facilitate the presentation, agricultural commodities in the CGE model are grouped into cereals, non-cereals, and livestock. In Fig. 2, we show results for all the individual agricultural commodities in the CGE model and some of these commodities are used to define the least-cost healthy diet (i.e. wheat, maize, oilseeds, vegetables, fruits, and pulses).

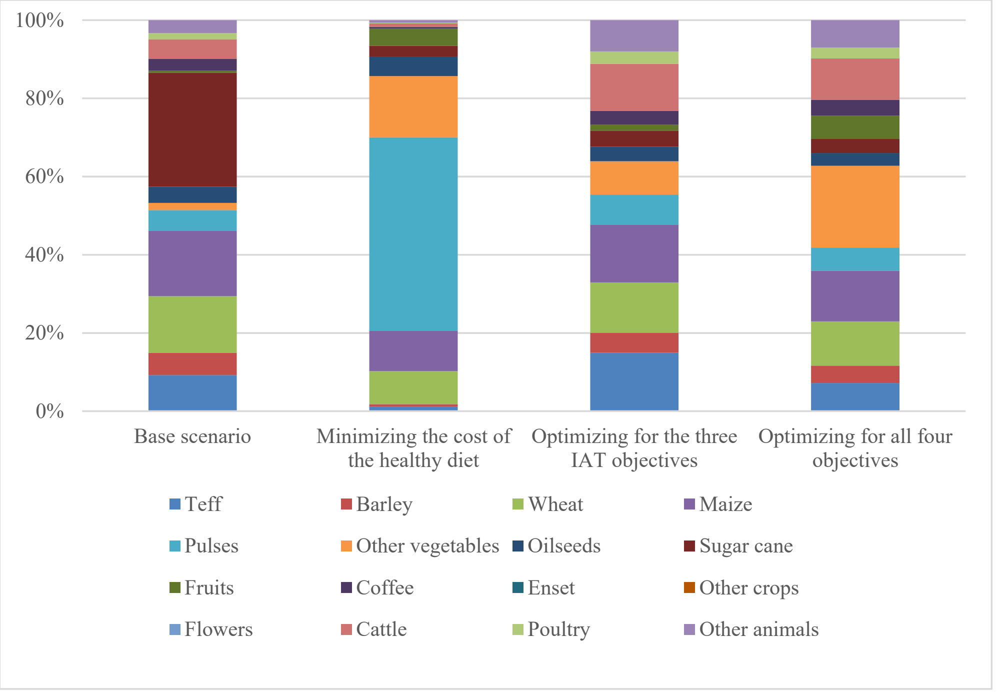

Fig. 2. Public budget allocation by commodity in the base and budget optimization scenarios, 2025.
Source: Authors' calculations.

When the budget optimization is only for IAT objectives, extension services in both cereals and livestock farming, as well as fertilizers though to a lower extent, have to be prioritized at the cost of other budget lines, notably irrigation for cereals (i.e. teff, barley, wheat, and maize). When the budget optimization also includes minimizing the cost of the least-cost healthy diet, it becomes necessary to step up the budget in irrigation, for example, notably because there will be more production and consumption of nutritious foods, such as fruits and vegetables which are relatively more water intensive. More budget also needs to be allocated to the production of pulses, and less to cereals and sugar cane. The share of irrigation expenditures within the budget increases significantly if the budget optimization is only for minimizing the cost of the least-cost healthy diet, at the cost of other expenditures that are important in the current budget allocation, such as those for rural roads and even irrigation for cereals.[13] In the three budget optimization scenarios, the share of the budget allocated to R&D is quite reduced because, in the short timeframe considered, spending in some of the other priority areas has a relatively larger impact on TFP – at the given elasticities values. In these three scenarios, the alternative optimal public budget reallocations are better solutions because they allow for improving the outcomes

[13] While water is a constraint for irrigation in certain parts of Ethiopia, the water availability in the country would allow to irrigate approximately 5.3 million ha (Bekele Awulachew & Ayana, 2011). Our scenarios would not result in unsustainable water withdrawals not only because there is not a binding water resource constraint, but also because public expenditure in irrigation diminishes for cereals and sugar cane.

Fig. 3. Value of the outcome variables associated with the policy objectives in the budget optimization scenarios, 2025 (% change relative to the base scenario).
Source: Authors' calculations.

associated with all four objectives (Fig. 3). This suggests that Ethiopia's government could achieve better IAT results if it optimally repurposes its budget in agriculture.

The most significant improvement – relative to the base scenario – is seen in the reduction of the cost of the least-cost healthy diet, irrespective of the scenario. Hence, the current budget in agriculture is suboptimal for ensuring that the nutritious foods that make up the least-cost healthy diet can be produced and offered at a lower cost to more Ethiopians. No matter the scenario, the increase in the supply of the nutritious foods that make up the least-cost healthy diet and the resulting reduction in the cost of this diet, will result in more household consumption of pulses, vegetables, and fruits – relative to total household consumption (Fig. 4). This could improve nutrition outcomes in the future. Notwithstanding these potential benefits, there are also potential trade-offs to consider.

If the current budget is optimized only to reduce the cost of the least-cost healthy diet without pursing IAT objectives, the government gives up the possibility of, with the same budget, achieving a higher agri-food GDP growth, more rural off-farm employment creation, and more rural poverty reduction. There is improvement in all four objectives if the current budget is optimally repurposed to pursue only the three IAT objectives without optimizing to minimize the cost of the least-cost healthy diet (Fig. 3).

5. Policy implications

Ethiopian policy makers can repurpose the public budget in agriculture to reduce the cost (and increase the affordability) of healthy diets, but this will imply some degree of specialization towards the production of the foods that make up these diets. For example, if their objective were to reduce the cost of the least-cost healthy diet, as analyzed in this paper, the

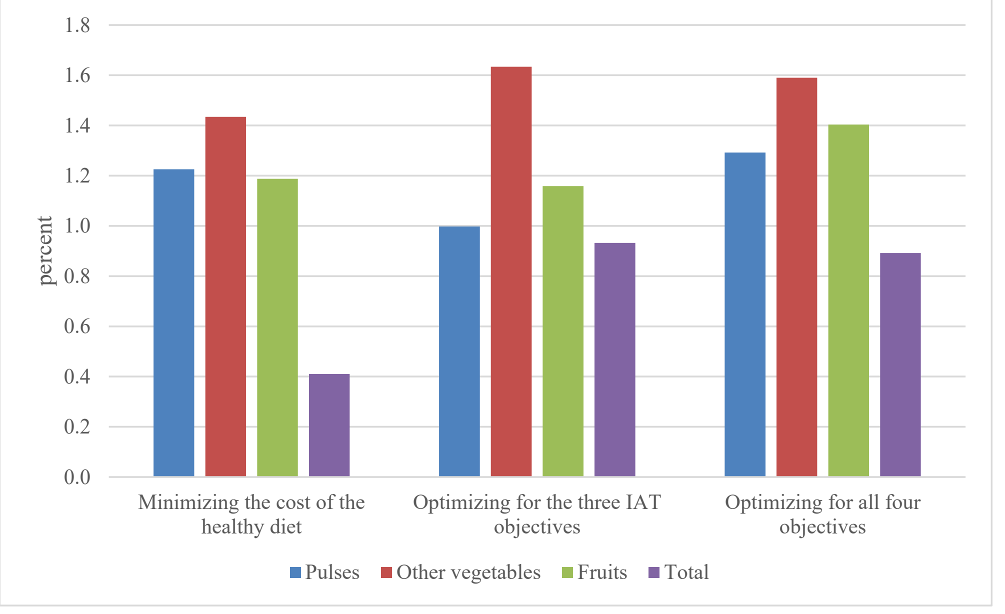

Fig. 4. Household consumption by selected food items and total in budget optimization scenarios, 2025 (% change relative to the base scenario).*Note:* Total includes the consumption of all foods, in addition to pulses, vegetables and fruits, as well as non-food commodities.
Source: Authors' calculations.

production of fish, which is the protein food in this diet (see Table 1), would have to be promoted at the cost of producing fewer of other protein foods such as beef (see Fig. 2).[14] The production of pulses, fruits and vegetables would also increase at the cost of some production of cereals and sugar cane. This of course would affect the country's production structure and generate job losses in labor-intensive agricultural sectors that would be receiving less budget support, all of which would affect household consumption and income per capita and increase rural poverty.

The diminishing marginal productivity of public investments across sectors is also worth noting. When budget support is relatively increased for the selected number of nutritious foods that make up the least-cost healthy diet, then the diminishing marginal returns of such support will appear earlier (or are stronger), compared to the situation where budget support covers a larger number of sectors to achieve the broader IAT objectives. This is the case because increasing government spending to support a given agricultural product will boost its production and, consequently and ceteris paribus, decrease its price. Then, given the usual assumptions in production and consumption (i.e. decreasing marginal productivity and utility), the marginal impact of an increase in government spending to promote a given agricultural product will be

[14] We are not considering potential cultural restrictions in the optimization problem. The cultural role beef plays in Ethiopia cannot be denied, but it is also true that fish can provide the same protein intake at a cheaper cost to the Ethiopian consumer. The least-cost healthy diet is also defined at national level, meaning our analysis may be omitting different compositions of this diet at subnational level.

Table 4
Number of individuals that are employed, with income below the (national) poverty line and cannot afford a healthy diet in budget optimization scenarios, 2025 (change relative to the base scenario).

	Minimizing the cost of the healthy diet	Optimizing for the three IAT objectives	Optimizing for all four objectives
Employment (number of employed individuals)	183,838	458,353	439,464
Poverty (number of individuals below the national poverty line)	–206,257	–413,369	–395,461
Affordability (number of individuals that cannot afford the least-cost diet)	–2369,850	–1890,210	–2289,231

Source: Authors' calculations.

positive but diminishing. In other words, the demand conditions impose a limit to the amount of government promotion that the production of a given agricultural product can receive.

Furthermore, sectors are different not only in terms of how public expenditures affect them and their labor intensity, but also in terms of how they are integrated with the different markets and other sectors. Generally, we observe that the nutritious foods that make up the least-cost healthy diet tend to be: (i) more oriented to the domestic market and (ii) less productively linked with downstream processing and other non-agricultural sectors' economic activity. In the first case, the demand curve of these nutritious foods is relatively more vertical than that of other foods (i.e. they are exported relatively less and/or compete less with imports, with both possibilities increasing the slope of the demand curve given that Ethiopia is a price taker in world markets). For instance, the budget allocated in Ethiopia to an export-oriented sector such as oilseeds (i.e. a sector that exports 71.0% of its production) decreases when we move from optimizing the budget to pursue the three IAT objectives to optimizing the budget to pursue not only these objectives but also that of reducing the cost of the least-cost healthy diet. In turn, the ratio between exports and output for three key components of the least-cost healthy diet is much lower, i.e. 1.8% for vegetables, 2.0% for fruits and 9.3% for pulses. In the second case, due to its smaller input-output linkages, the sectors producing nutritious foods drive other sectors' productive activity relatively less than sectors such as sugar cane, wheat and cattle do.

The benefits and trade-offs of pursuing IAT objectives along with the objective of reducing the cost of the least-cost healthy diet, versus the situation where the latter objective is excluded from the optimization of the budget, can be deducted from Table 4. The main relative benefit is in terms of increasing the affordability of healthy diets for almost 400,000 Ethiopians. However, this would come at the cost of not only slowing down agri-food GDP growth but also of losing the opportunity of creating almost 19,000 jobs and lifting almost 18,000 people out of poverty. To improve on all four policy objectives simultaneously in the best possible manner, Ethiopian policy makers' compromise should be to repurpose the budget spent in agriculture for pursuing only IAT objectives. Even in this case would almost 2 million more Ethiopians be able to afford the least-cost healthy diet by 2025, using the same public resources.

6. Conclusion

Ethiopian policy makers may find it reasonable to compromise along the lines suggested in this paper. By reallocating the public budget optimally to pursue agricultural transformation objectives (e.g. increasing the budget of extension services in both cereals and livestock farming, as well as fertilizers though to a lower extent, relative to other budget lines, notably irrigation for cereals), not only will these policy makers secure stronger economic growth and faster and more inclusive agricultural transformation, but they will also ensure more access to healthy diets. Such compromise results in more value for the same public money, i.e. more agri-food GDP growth, new off-farm jobs created in rural areas, more people lifted out of poverty, and healthy diets becoming affordable to millions. Furthermore, increased consumption of pulses, vegetables and fruits will likely improve nutrition outcomes in the long-term.

The agricultural transformation and nutrition agendas must not be seen separately. Reallocating the budget only to explicitly reduce the cost of healthy diets would provide the best results in terms of increasing the number of Ethiopians that could afford such diets. Yet, this would come at the cost of slowing down agricultural transformation. This is mostly due to the effects that would be seen if agriculture suddenly were to specialize in the production of the selected number of nutritious foods that make up healthy diets. This would penalize some agricultural subsectors that are traditionally generators of employment and are supportive of livelihoods in Ethiopia, certainly including staples' production, cattle farming, and so forth.

The cost of the least-cost healthy diet in Ethiopia was lower than in sub-Saharan Africa in 2020, but due to how low people's incomes were relative to such cost, almost 100 million Ethiopians could not afford such a diet in 2020. For nutrition policies and programs to address malnutrition more effectively in Ethiopia, improving people's incomes and livelihoods is urgently needed, particularly in rural areas where poverty is higher. Inclusive agricultural transformation should be among the answers to address nutrition problems in Ethiopia, but this will depend on the coherence between the policies (i.e. the public budgets) allocated to implement the two agendas.

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