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# Optimising policies to achieve agricultural transformation objectives: An application for Ethiopia

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# Optimising policies to achieve agricultural transformation objectives: an application for Ethiopia

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#### ABSTRACT

Policymakers seek objectives that can be conflicting under a budget constraint. Solving this problem requires a multi-criteria decisionmaking technique whereby equations of a dynamic computable general equilibrium model are constraints to a policy optimisation problem. We illustrate this approach in the framework of agricultural transformation objectives. Using data for Ethiopia we show the potential conflict between policy objectives and how policies are optimally determined to arrive at the best possible compromise. Should Ethiopian policymakers pursue increasing agri-food GDP, rural household welfare, or agri-food exports, for example, they will not necessarily observe strong trade-offs between these objectives. However, if they invest in different agricultural sectors to achieve such objectives, the way in which they finance the investment will result in macroeconomic trade-offs. Only when the new investment is mostly allocated to oilseeds and coffee will there be not only simultaneous but also maximised improvement in all three policy objectives.

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#### **KEYWORDS**

Computable general equilibrium; compromise programming; optimal policy design; economic development; agricultural transformation

#### 1. Introduction

In economic literature, the design of an optimal policy usually involves the assumption that the policymaker (also regarded as the social planner) maximises some social welfare function. Typically, this social welfare function is identified with the utility function of a representative consumer. However, it is difficult to determine in practice the social welfare function that would be maximised, because all individual preferences need to be aggregated. In reality, it is virtually impossible to combine the preferences of all members of a society in a single social preference relationship with reasonable properties (Arrow, 1963).

Another challenge is that, by pursuing several objectives at the same time, policymakers usually face particularly complex decision-making problems. For example, when seeking to achieve higher economic growth, a policymaker may also be aiming at ensuring that the new economic growth trickles down to the poor. Importantly, some

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of these objectives may be conflicting; for example, poverty reduction programmes may conflict with achieving fiscal consolidation. The challenge for the policymaker is then to prioritise multiple objectives and find optimal policies to pursue them, considering that these objectives are all important and interlinked, and are even sometimes in conflict, under an existing budget constraint. It is therefore important for policymakers to have tools that provide options for resolving their decision-making problem.

This paper proposes a tool for decision-making and explains how it works in practice in the context of agricultural transformation objectives in Ethiopia – although the tool can easily be applied to analyse other development processes. Developing countries – like Ethiopia – pursue different objectives to achieve agricultural transformation, in the realms of agricultural productivity, employment, productive linkages between agriculture and the rest of the economy, and market integration (Timmer, 1988). The process of agricultural transformation is also characterised by economy-wide and multi-sectoral interactions over time that may be affected by policy choices.

There is nowadays also consensus in scholarly and policy circles that agricultural transformation should be inclusive,<sup>1</sup> which adds complexity to decision making. In this case, policymakers will be transforming agriculture with inclusion only if they also achieve objectives such as rural poverty reduction, improved food security and nutrition for all, increased gender equality, and so forth. Policymakers thus face the challenging task of making the optimal policy choices to achieve a multiple set of objectives of inclusive agricultural transformation (IAT), while minimizing trade-offs between them.<sup>2</sup>

In this paper, we use multi-criteria decision making (MCDM) techniques, widely used in operations research/management science (OR/MS), to deal with situations of multiple conflicting objectives. Among the MCDM techniques, we focus on compromise programming (CP). In recent years, MCDM techniques have been applied to several economic problems in which it is not reasonable or operational to assume the existence of a single goal or objective.<sup>3</sup>

We apply MCDM techniques to demonstrate how a selection of optimal policies that enables IAT may be carried out. To that end, we also innovate and use a recursivedynamic, multisector computable general equilibrium (CGE) model, which was extended to incorporate MCDM elements in a dynamic setting. Policy instruments are optimally determined to achieve development objectives – thus moving away from the standard CGE modelling practice whereby policy instruments are exogenously determined. Furthermore, to show applications for IAT objectives, the proposed modelling approach was applied using a dataset for Ethiopia, a country that has not fully undergone agricultural transformation.

André, Cardenete, and Romero (2008), André and Cardenete (2009a, 2009b) and Cicowiez, Decaluwé, and Nabli (2017) have already combined the use of MCDM techniques and a CGE model in a static setting. Our paper provides several contributions to this

<sup>&</sup>lt;sup>1</sup>See, for example, Osabuohien (2020) for an in-depth discussion on the need for inclusive agricultural and rural development in the context of Africa. Focusing on Africa makes a lot of sense when it comes to the issue of agricultural transformation considering that, in sub-Saharan Africa only, industrialisation, the main driver of past transformations, is not occurring in most countries (FAO 2017).

<sup>&</sup>lt;sup>2</sup>There is also an increasing focus on the environmental sustainability of agricultural transformation within the limits of the available natural resources, which adds complexity. This important dimension is beyond the scope of this paper.

<sup>&</sup>lt;sup>3</sup>For textbook treatments, see Ballestero and Romero (1998), Romero and Rheman (2003), and André, Cardenete, and Romero (2010). For a review of applications of MCDM techniques, see Mardani et al. (2014) and Zavadska and Turskis (2011).

literature. First of all, we combine the use of MCDM techniques and a CGE model in a recursive-dynamic setting, which is necessary for two reasons. The decision-making problem in practice unfolds over time, implying also inter-temporal trade-offs, particularly in the context of IAT where the development problem is inherently dynamic. A dynamic setting is also needed to properly include government investment as a key policy instrument to pursue development objectives. Second, this paper shows a way for policymakers to optimise their policies to achieve development objectives over time, to which they may give different weights - based on several criteria, including political economy considerations, under their budget constraints. Third, the paper also contributes to the literature that applies MCDM techniques to economic problems and policies, specifically in the context of IAT where multiple objectives need to be pursued over time. Fourth, the previous literature that combines MCDM techniques with a CGE model has focused on the assessment of existing policies and how to improve them. On the other hand, in this paper we also use the approach to determine how to optimally design a new policy, such as the sectoral allocation of increased government investment. Fifth, we make a contribution to the policy design literature - of which a recent survey is found in Howlett and Mukherjee (2014) - by developing an empirical framework that can be used to provide empirical content and quantify the trade-offs involved in alternative policy mixes.

The paper contains four more sections. Section 2 briefly presents the MCDM analysis with a focus on compromise programming and describes how the MCDM might be used to select optimal policies in the context of a recursive-dynamic, multisector CGE model. Section 3 illustrates how the modelling approach works in practice, by developing an application related to IAT in the context of Ethiopia. Finally, Section 4 highlights our main conclusions and future possible extensions to the modelling approach.

# 2. Modelling approach

MCDM techniques are useful to solve decision-making problems in which the decision variables (hereafter also referred to as *the policy instruments*) are chosen optimally or, in other words, are defined according to different conflicting criteria (hereafter also referred to as *the policy objectives*). In practice, they aim to obtain solutions that are at least optimal or Pareto efficient, in the sense that further improvement in any policy objective can only be achieved by worsening the value of at least one other policy objective.<sup>4</sup> Naturally, the concept of Pareto optimality leads to the concept of trade-offs among policy objectives; that is, the opportunity cost of one policy objective in terms of another policy objective.

Among the various MCDM techniques, we specifically use the compromise programming (CP) proposed by Yu (1973) and Zeleny (1973, 1974), and combine it with a CGE model, in order to represent optimal policymaking and obtain the so-called efficient policies to achieve IAT objectives in Ethiopia.<sup>5</sup> In CP, the first step is to identify an ideal or utopian solution (or point) that is only a point of reference for the policymaker. Then, CP realistically assumes that the policymaker (i.e., the decision maker) seeks a solution as close as possible to the ideal solution. To achieve "proximity" to this ideal solution,

<sup>&</sup>lt;sup>4</sup>A policy objective can be a "more is better" objective (such as increasing economic growth) or "less is better" objective (such as reducing poverty). In the first case the aim is to maximise the value of the policy objective, in the second to minimise it.

<sup>&</sup>lt;sup>5</sup>For details on alternative MCDM techniques, see André et al. (2010).

a distance function is introduced. Thus, the concept of distance is used as a proxy measure for human preferences rather than being treated in its geometric sense.<sup>6</sup> CP is underpinned by the axiom of choice that assumes that alternatives closer to the ideal one, are preferred to alternatives that are distant from the ideal one. In other words, the rationale of human choice is to be as close as possible to the ideal.

In short, in the CP setting, the policymaker cares about several conflicting policy objectives and must set the available policy instruments to find an optimal compromise among all of them. To do so, it is necessary to calculate distances between each solution and the ideal solution. In practice, the implementation of this approach requires a modelling tool featuring the following elements: (a) determination of relevant policy objectives as measured by specific macroeconomic, sectoral, or distributive (e.g., poverty) variables; (b) determination of policy instruments and the feasible range for those policy instruments (e.g., tax rates are allowed to deviate, for example, only  $\pm$  10 percentage points from their current value); (c) a structural model that includes behavioural functions for economic agents (i.e., producers and consumers) that allows calculating the wolle of policy objectives as a function of policy instruments; (d) a dataset to calibrate the modelling tool; and (e) a multi-criteria technique to be applied in order to solve the decision problem. In this paper, (a) and (b) are framed in the context of IAT objectives and alternative policy instruments to achieve them; for (c) we use a recursive-dynamic CGE model; for (d) we use a recent social accounting matrix and other data for Ethiopia; and, for (e) we use CP as defined above.

More precisely, our modelling approach comprises a recursive-dynamic CGE model designed for country-level analysis of medium- and long-run development policies, on top of which we add an optimisation problem.<sup>7</sup> It is not the purpose of this paper to describe this CGE model in detail, for which the reader can refer to Supplementary material A. As noted in the introduction, some literature has already combined the use of MCDM techniques and a CGE model in a static setting. We are rather integrating MCDM techniques and a CGE model in a dynamic setting where the government could either be myopic as consumers and producers or forward-looking. The dynamic setting is preferred for three reasons. First, it allows us to examine the decision-making problem over time and inter-temporal trade-offs if any. Second, government investment becomes a policy instrument that affects capital accumulation and productivity over time. Third, government investment needs to be financed and depending on the financing source, it may also lead to public debt accumulation over time. To that end, our modelling approach includes

<sup>&</sup>lt;sup>6</sup>In CP, a generalisation of the Euclidean distance known as the Minkowski distance of order p (p-norm distance) is used.

Mathematically, the family of distance measures that we use below is derived from  $L_p(x, y) = \left[\sum_{i=1}^{n} |x_i - y_i|^p\right]^{\frac{1}{p}}$ , where

a different distance measure is obtained for each value of the parameter *p*. In the equation for  $L_p$ , as *p* increases, more weight is given to the largest deviation. In fact, when  $p = \infty$ , the distance  $L_p$  is given exclusively by the largest deviation. In other words, the parameter *p* weights the deviations according to their magnitudes. In this paper, the  $L_p$  metrics are used to calculate distances between solutions belonging to an efficient set and an ideal (or utopian) solution. Interestingly, the use of the distance concept as a proxy measure for the policymaker's preferences makes the compromise programming approach a sound practical method to select the best compromise (or optimal) solution from the efficient ones (Romero & Rheman, 2003).

<sup>&</sup>lt;sup>7</sup>Excluding the policy optimisation problem, our CGE model draws heavily from what is proposed in Cicowiez and Lofgren (2017), which in turn is related to the CGE model documented in Lofgren, Cicowiez, and Diaz-Bonilla (2013). It contains both neoclassical and structuralist features.

a forward-looking government with alternative financial mechanisms and a relatively detailed disaggregation of government spending, not only recurrent spending – as is the case in most CGE models – but also capital spending in different sectors.

The recursive-dynamic CGE model is made up of a set of simultaneous linear and non-linear equations that are solved one period at a time, and then each within-period solution is linked up over time through dynamic variables. It is economy-wide in the sense that it provides a comprehensive and consistent view of an economy, including the linkages among production sectors and the incomes they generate, households, the government (its budget and fiscal policies), and the rest of the world (balance of payments). It is an appropriate tool for analysing IAT issues as it captures, in an integrated framework, key indicators such as, *inter alia*, capital accumulation, technological change, productivity growth, sectoral and national output and employment growth, backward and forward linkages across sectors, and differences between sectors in terms of household preferences for what they produce and their links to international trade and the domestic economy.

In each period for which the recursive-dynamic CGE model is solved, the different agents (producers, households, government, and the country in its dealings with the outside world) are subject to budget constraints: their receipts and spending are fully accounted for and must balance out (as they must in the real world). For example, households, while setting aside a part of their incomes to pay direct taxes and save, allocate the remaining part to their consumption with a utility-maximising composition. In turn, producers maximise their profits by choosing the optimal quantities of labour, capital and natural resources. For the country, the real exchange rate adjusts to ensure that the external accounts are in balance; other options, including adjustments in foreign reserves or borrowing are possible, but may not work in the long run - simply because foreign debt cannot rise forever. Wages and rents, as well as prices, play the crucial role of clearing markets for factors and commodities (goods and services), respectively. For commodities that are traded internationally (exported and/or imported), domestic prices are influenced by exogenous international prices. Thus, we are applying the modelling framework to countries - such as Ethiopia - considered as small in world markets as they do not influence the import and export prices they face.

Over time, economic growth in this recursive-dynamic CGE framework is determined by changes in factor employment and total factor productivity (TFP) which create the links between within-period solutions. Accumulation of capital stocks is endogenously generated by the model, depending on investment and depreciation. For labour and natural resources, the growth in employable stocks is exogenous to the model. The unemployment rate for labour is endogenous. TFP growth is made up of two components, one that responds positively to growth in government infrastructure capital stocks and one that, unless otherwise noted, is exogenous.

In this paper, instead of solving a CGE model as a system of simultaneous equations, as typically done, we solve an optimisation problem in which the CGE model equations act as constraints to the policy optimisation problem. Specifically, the optimisation problem we solve is

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$$\min L_p = \left(\sum_{t \in T} \frac{1}{(1+\rho)^t} \left( \sum_{i1 \in I1}^{\sum} wt_i^p \left( \frac{XOBJ_{i,t}^* - XOBJ_{i,t}}{XOBJ_{i,t}^* - XOBJ_{i,t}} \right)^p + \sum_{i2 \in I2} wt_i^p \left( \frac{XOBJ_{i,t} - XOBJ_{i,t}}{XOBJ_{i,t} - XOBJ_{i,t}^*} \right)^p \right) \right)^{\frac{1}{p}}$$
(1)

subject to

$$xinst_{j,t}^{min} \leq XINST_{j,t} \leq xinst_{j,t}^{max}$$

$$F(XOBJ_t, XINST_t, X_t, z_t, \sigma_t, \delta_t) = 0$$

where,

*i*1 and *i*2 are elements in the sets *I*1 and *I*2 of "more is better" and "less is better" policy objectives, respectively;

*j* are elements in the set *J* of policy instruments;

 $\rho$  is the discount factor for the policymaker;

*wt<sub>i</sub>* is the weight given to the divergence between objective *i* and its ideal value; that is, it measures the relative importance of objective *i* in a given decision situation;

*p* 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 (as further explained below);

 $XOBJ_{i,t}$  is the *i*-th policy objective that is an endogenous variable in the CGE model;  $XOBJ_i^*$  is the ideal value for objective *i*;

 $XOBJ_{i*}$  is the anti-ideal (or nadir) point for objective *i*;

 $XINST_{j,t}$  is the *j*-th policy instrument that is an endogenous variable in the CGE model; and,

the second set of constraints,  $F(\cdot) = 0$ , represents the CGE model as a square system of non-linear equations that satisfies the property of homogeneity of degree zero in prices. The  $F(\cdot)$  vector function depends on the CGE model's endogenous variables (i.e.,  $XOBJ_t$ ,  $XINST_t$  and  $X_t$ ), exogenous variables  $z_t$ , behavioural parameters  $\sigma_t$ , and calibration parameters  $\delta_t$ .

By construction, the normalised distances are bounded between 0 and 1. Thus, the ideal (anti-ideal) solution is achieved for an objective when the distance is 0 (1). Consequently, the normalised distances measure the percentage of achievement of one objective with respect to its ideal value. The normalisation of the distance is necessary for practical reasons. Units of measurement may differ depending on the policy objectives (e.g., percent for the poverty rate vs. number of workers for employment). Therefore, to avoid a meaningless summation, the units of measurement for the various policy objectives must be normalised. In addition, if the absolute values for the achievement levels of the several objectives are different (e.g., two target values might be very different even when both policy objectives are measured using the same units, such as household per capita consumption and overall GDP), then the normalisation of the distances is necessary to avoid solutions biased towards those objectives that can achieve larger values.

In equation (1), the best compromise solution is the alternative with the lowest value for  $L_p$  because it is the nearest solution to the ideal solution. Obviously, the best compromise solution can change according to the values of the parameter p and the weights  $wt_i$  that are chosen – ideally by the policymaker, adding political economy considerations. The

parameter p is a real number in the interval  $[1, \infty]$  and acts as a weight attached to the deviations according to their magnitudes. Similarly,  $wt_i$  are the weights for various deviations capturing the relative importance given – by the policymaker – to each 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  $p = \infty$ . More specifically, Yu (1973) shows that, with two objectives, the compromise set is contained within the solutions obtained for  $L_1$  and  $L_\infty$ . In turn, Freimer and You (1976) demonstrate that, for problems with more than two objectives, the CP solutions for  $L_1$  and  $L_\infty$  do not necessarily define the compromise set. However, Blasco, Cuchillo-Ibáñez, Morón, and Romero (1999) shows that such outcome is unlikely. In Section 3, p = 2 and we consider alternative weighting schemes for Ethiopia. In practice, p = 2 offers a balance between (a) maximizing the overall achievement of all the policy objectives in set I (p = 1), and (b) maximizing the balance among all policy objectives in set I ( $p = \infty$ ).

# 3. Results for Ethiopia

The first and second growth and transformation plans (GTP) of Ethiopia outlined the vision for a transformed agricultural sector aimed at increasing productivity of strategic crops, together with specialisation, diversification and commercialisation. Clear signs of agricultural transformation in this country are a declining share of agriculture in GDP (National Bank of Ethiopia, 2020; National Planning Commission, 2018), increased labour productivity between 2004 and the 2014/15 (National Planning Commission, 2016), movement of rural labour away from agriculture (National Planning Commission, 2018 and World Bank<sup>8</sup> data), and a reduction in poverty and food insecurity (National Planning Commission, 2018). However, challenges persist. Agriculture is predominantly cereal-based and relies on a household-based and subsistence-oriented system. Rural off-farm employment creation remains below expected targets (National Planning Commission, 2018). Productivity growth is still below its potential because of under-developed input supply systems, poor incentives, and predominance of rain-fed farming systems, moisture stress and eroded soils, and low levels of mechanisation. Rural poverty continues to be more severe than urban poverty (UNDP 2018).

The basic accounting structure and much of the data required to apply the dynamic MCDM-CGE modelling approach (or to calibrate it) to Ethiopia's context, particularly to obtain its base-year solution, is derived from a social accounting matrix (SAM) for the year 2015/2016, which is documented in Mengistu et al. (2019). Thus, 2016 is the base-year situation in our recursive-dynamic setting for Ethiopia's application. We adapted this SAM to include an unconventional treatment of financial flows and a relatively detailed disaggregation of government spending (recurrent and capital) in agri-food sectors.<sup>9</sup> In our application, the Ethiopian SAM singles out 28 activities and commodities (of which 11 are

<sup>&</sup>lt;sup>8</sup>World Bank's Indicators of Employment in agriculture (% of total employment) (modelled ILO estimate). Available at https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS (accessed 25 February 2021).

<sup>&</sup>lt;sup>9</sup>More specifically, the SAM in Mengistu et al. (2019) was extended to single out (a) foreign borrowing by the government and the private sector, (b) domestic borrowing by the government, and (c) government and private investments. Besides, we separated foreign borrowing by the government from current transfers from the rest of the world to the government. Finally, and based on a supply and use table for Ethiopia for the year 2011, we changed the cost structure of the meat and dairy sectors in order to consider cattle and raw milk as their intermediate inputs, respectively.

agricultural and 3 are food related), 4 factors of production (labour, land, private capital, and government capital), 5 institutions (rural and urban households, enterprises, government, and rest of the world), and auxiliary accounts for trade and transport margins and indirect and direct taxes. Our CGE model also relies on complementary data on base-year employment and unemployment, factor stocks, and elasticities to calibrate the base-year solution. For the solution overtime, we use data for capital depreciation rate, labour supply, and population projections from different sources.<sup>10</sup>

A practical way to show how the policy optimisation works in our dynamic setting, is to use (the sectoral composition of) government investment as the policy instrument. On the one hand, using investment as policy instrument will have a Keynesian effect (i.e., it boosts final demand), even in the first year of the policy optimisation period. On the other hand, using investment as a policy instrument might also have a Ricardian effect; that is, given the resulting increase in the capital stock, the model allows assuming that sector specific TFP increases.

In this application of the proposed approach, we assume that the Ethiopian government pursues, as IAT policy objectives, increasing (a) agri-food GDP,<sup>11</sup> (b) rural household consumption per capita, and (c) agri-food exports. The sectoral composition of government investment is considered as a policy variable, so we assume that the share of (new) investment made in the different sectors is endogenously determined on a period-byperiod basis. This allows us to also assess the impact of increasing government investment and allocating it among the different agricultural sectors - which in our Ethiopian dataset are crops and livestock. Moreover, we assume that overall government investment increases by 15%. In other words, since government investment in agricultural sectors will be increasing to achieve one or more (but up to three) policy objectives, the government must optimally select the agricultural sectors to allocate this additional investment. It is also assumed that the marginal product of the additional government investment in agricultural sectors is 0.15, irrespective of the targeted sector (i.e., for every Ethiopian Birr the government invests in agricultural sectors, TFP increases by 0.15 cents of Ethiopian Birr in those sectors). In the literature, estimates for the marginal product of public capital vary widely but values in the range of 0.15–0.60 were estimated for a wide range of country categories (Dessus & Herrera, 2000; Gupta, Kangur, Papageorgiou, & Wane, 2014; Lowe, Papageorgiou, & Perez-Sebastian, 2019). Mathematically, the CP problem can be written as

$$\min OBJ = \sum_{t' \in T} \frac{1}{(1+\rho)^{t'}} \left[ \begin{pmatrix} wt_{RGDPTRG} \cdot \left(\frac{RGDPTRG_{t'}^* - RGDPTRG_{t'}}{RGDPTRG_{t'}^* - RGDPTRG_{t'}}\right)^p \\ + wt_{QHPCTRG} \cdot \left(\frac{QHPCTRG_{t'}^* - QHPCTRG_{t'}}{QHPCTRG_{t'}^* - QHPCTRG_{t'}}\right)^p \\ + wt_{QETTRG} \cdot \left(\frac{QETTRG_{t'}^* - QETTRG_{t'}}{QETTRG_{t'}^* - QETTRG_{t'}}\right)^p \end{pmatrix}^{\frac{1}{p}} \right]$$
(2)

subject to

<sup>&</sup>lt;sup>10</sup>For capital depreciation rates, we follow Agénor, Bayraktar, and El Aynaoui (2008) and assume 5.0% and 2.5% for private and public capital, respectively. For unemployment and underemployment, we use the estimates from the ILOSTAT database (accessed 25 February 2021): 2.2% and 25.8%, respectively. For projections of the population, split into multiple age groups, we use the 2019 UN World Population Prospects dataset. The complete dataset for Ethiopia is available upon request to the authors.

<sup>&</sup>lt;sup>11</sup>In what follows, agri-food GDP (or agri-food exports) comprises the value added (or the sales to the rest of the world) from crops, livestock, fishery and forestry and the food processing industry.

$$ISCAL_{fcapg,t} = 1.15 \cdot ISCAL_{fcapg,t}^{0}$$

$$0 \leq DMTFP_{a,fcapg,t} \leq 1$$

all the CGE model equations

where,

*wt*<sup>*p*</sup><sub>*RGDPTRG*</sub>: weight of agri-food GDP in the objective function;

 $wt_{QHPCTRG}$ : weight of rural household consumption per capita in the objective function;

*wt*<sub>QETTRG</sub>: weight of agri-food exports in the objective function;

*p*: as define above;

 $\rho=$  0.035: for illustrative purposes, the discount rate for the policy maker is assumed equal to 3.5%;

*RGDPTRG*: agri-food GDP;

*RGDPTRG*<sup>\*</sup>: ideal value for agri-food GDP;

*RGDPTRG*<sub>\*</sub>: anti-ideal value for agri-food GDP;

QHPCTRG: rural household consumption per capita;

*QHPCTRG*<sup>\*</sup>: ideal value for rural household consumption per capita;

*QHPCTRG*<sub>\*</sub>: anti-ideal value for rural household consumption per capita;

QETTRG: agri-food exports;

*QETTRG*<sup>\*</sup>: ideal value for agri-food exports;

*QETTRG*<sub>\*</sub>: anti-ideal value for agri-food exports;

*ISCAL*<sub>*fcapg,t*</sub>: investment scaling factor (for gross fixed capital formation)<sup>12</sup>;

 $DMTFP_{a,fcapg,t}$ : change in mapping – TFP in activity *a* affected by capital stock *f* (with relative value indicating strength of effect). To simplify,  $DMTFP_{a,fcapg,t}$  as a policy instrument determines the share of the overall increase in government investment that is channelled to the different agricultural sectors. In other words, it determines what sectors benefit the most from the TFP boost promoted by the increase in government investment.

In equation (2), *RGDPTRG*, *QHPCTRG*, and *QETTRG* are the achieved (endogenous) values associated with policy objectives that Ethiopia is pursuing in practice and each of them is normalised by subtracting from the ideal value and dividing by the difference between the ideal and the anti-ideal values.<sup>13</sup> Then, by construction, each ratio in equation (2) is bounded between 0 (i.e., when the objective is equal to the ideal) and 1 (i.e., when the objective is equal to the anti-ideal). As explained, this normalisation eliminates units of measurement and allows the summation in equation (2) to be economically meaningful. The weights  $wt_{RGDPTRG}$ ,  $wt_{QHPCTRG}$ , and  $wt_{QETTRG}$  are preference parameters that help us represent, on the basis of information and/or actual policy dialogue, or alternatively just our own assumption as done for the purposes of this paper, how concerned the policymaker is about each policy objective. Interestingly, 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 base situation.

<sup>&</sup>lt;sup>12</sup>In the model, government GFCF is calculated as  $DKGOV_t = dkgovb_t \cdot ISCAL_{gov,t}$ , where  $DKGOV_t$  is government GFCF,  $dkgovb_t$  is exogenous government GFCF, and  $ISCAL_{gov,t}$  is a scaling factor for government GFCF. For details, see Supplementary Material A.

<sup>&</sup>lt;sup>13</sup>Note that all three policy objectives are of the "more is better" variety.

In Appendix A, we consider changes in the parameter p to test the sensitivity of the results to prioritizing policy effectiveness (i.e., minimizing the average distance to the ideal point) versus policy equity (i.e., minimizing the maximum distance to the ideal point) among the policy objectives. Specifically, we consider the cases where p = 1 and  $p = \infty$  as a result of which the optimal solution respectively minimizes the average disagreement or minimizes the maximum disagreement.

In this application for Ethiopia, we run the model from 2016 to 2025. Thus, starting from the base-year, 2016 and up to 2025, we generate a base scenario characterised by a business-as-usual assumption. To facilitate the presentation and the analysis, the base scenario assumptions are kept as simple and transparent as possible. Most importantly, it is assumed that (a) the GDP growth rate is exogenous, drawing on IMF data (IMF, 2019) – as opposed to non-base scenarios where the GDP growth rate is invariably endogenous; (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,<sup>14</sup> including all receipt and spending items in the government budget. Then, we generate two optimal policy scenarios which, for the period 2016 to 2019, do not deviate from the base scenario. Hence, the optimisation period is 2020-2025. In the first optimal policy scenario, the macroeconomic closure<sup>15</sup> is the following: the government balance clears through endogenous government domestic borrowing, the saving behaviour of households and enterprises does not change (that is, their savings rates are exogenous), but real private investment is endogenous to ensure aggregate private savings net of domestic government borrowing match private investment, and the current account balance is fixed (in foreign currency; which is also the negative of foreign savings), which is ensured through a flexible real exchange rate. The second optimal policy scenario only differs from the first one in one aspect; that is, it considers the case in which the government balance clears through endogenous government foreign borrowing in order to assess the sensitivity of our results to the choice of financing of the new government investment.

To compute the ideal and anti-ideal values, the following three single-objective optimisation problems must be solved:

Firstly, to compute *RGDPTRG*\*,

#### max RGDPTRG

subject to the same constraints as above. Secondly, to compute *QHPCTRG*<sup>\*</sup>,

#### max QHPCTRG

subject to the same constraints as above. Thirdly, to compute *QETTRG*<sup>\*</sup>,

#### max QETTRG

subject to the same constraints as above.

<sup>&</sup>lt;sup>14</sup>These exclude transfers originating from domestic non-government institutions, which are assumed to be an exogenous share of the institution's income providing the transfer.

<sup>&</sup>lt;sup>15</sup>At the macro level, our CGE model – like any other CGE model – requires the specification of equilibrating mechanisms (or "closures") for three macroeconomic balances: government, savings-investment, and the balance of payments.

Moreover, the anti-ideal values for the three policy objectives are also obtained from solving the same three optimisation problems.

Next, the values for  $RGDPTRG^*$ ,  $RGDPTRG_*$ ,  $QHPCTRG^*$ ,  $QHPCTRG_*$ ,  $QETTRG^*$ , and  $QETTRG_*$  are used to compute the so-called payoff matrix (Table 1), which assumes values 0 or 1 for the weights in equation (2).

The first row of the payoff matrix (Table 1) shows the values for the three policy objectives when only agri-food GDP growth is maximised – and raising rural household consumption per capita and increasing agri-food exports are not part of the optimisation problem. The second row shows the values for the three policy objectives when rural household consumption per capita is maximised – without optimising for higher agri-food GDP growth and higher agri-food exports. The third row shows the values for the three policy objectives when agri-food exports are maximised – without optimising for raising rural household consumption per capita and increasing agri-food GDP growth. For instance, if Ethiopian policymakers are only concerned about increasing agri-food GDP, thus giving a weight equal to 1 to this objective (and weights equal to 0 to the other two objectives), they could optimally set the available policy instruments and attain an agrifood GDP percent deviation relative to the base in 2025 of 3.3% (i.e., the percent change from 763.7 in the base scenario to 788.6 in the ideal situation; see Table 1).<sup>16</sup>

The payoff matrix also points to Ethiopian policymakers facing some degree of conflict, as it would not be possible for them to obtain the maximum for the three policy objectives simultaneously. In other words, the values in the main diagonal of the payoff matrix show the best attainable results when only one policy objective is considered. The values for *RGDPTRG* and *QHPCTRG* tend to move in unison, but in conflict with the value for *QETTRG*. Naturally, this conflict is an essential element to have a genuine multi-criteria – in this case, three-criteria – decision-making problem. Thus, since it is impossible to achieve the optimal value for all three policy objectives at the same time, Ethiopian policymakers would have to establish some compromise between them.

Table 2 shows additional results together with a weighting scheme that gives equal weights to the three policy objectives we are considering (see last column). In all cases, it is assumed that government investment increases by 15%. In addition, we also show results for rural poverty – endogenously generated by the model, which essentially follow the results for rural household consumption per capita. The lower part of the table shows the

Scenario	RGDPTRG(billion Birr)	QHPCTRG(Birr per capita)	QETTRG(billion Birr)
Base	763.70	10,515.25	64.88
Payoff matrix max RGDPTRG (agri-food GDP)	788.60	10,609.68	79.78
max QHPCTRG (rural household consumption per capita)	788.22	10,620.30	85.53
max QETTRG (agri-food exports)	787.80	10,615.05	87.10

**Table 1.** Agri-food GDP, rural household consumption per capita and agri-food exports in Ethiopia in the base and payoff matrix for the last simulation year of first optimal policy scenario.

Note: In this and below, bold and underlined figures represent ideal and anti-ideal values for each policy objective, respectively. Source: Authors' calculations.

<sup>16</sup>Payoff matrices were similar for all simulation years, hence not presented here.

		Weights				
		RGDPTRG = 1.00	RGDPTRG = 0.00	RGDPTRG = 0.00	RGDPTRG = 0.33	
		QHPCTRG = 0.00	QHPCTRG = 1.00	QHPCTRG = 0.00	QHPCTRG = 0.33	
	Base	QETTRG = 0.00	QETTRG = 0.00	QETTRG = 1.00	QETTRG = 0.33	
Policy objective/instrument	(1)	(2)	(3)	(4)	(5)	
RGDPTRG – agri-food GDP	763.70	788.60	788.22	787.80	788.42	
(billion Birr)						
QHPCTRG – rural household	10,515.25	10,609.68	10,620.30	10,615.05	10,620.13	
consumption per capita						
(Birr per capita)						
QETTRG – agri-food exports	64.88	79.78	85.53	87.10	86.04	
(billion Birr)						
Rural poverty rate (%)	16.55	16.24	16.21	16.23	16.21	
Government investment						
share (%)						
Teff	8.82	1.59	2.11	2.12	2.18	
Barley	3.12	0.56	0.74	0.75	0.77	
Wheat	6.79	29.53	1.62	1.63	3.05	
Maize	9.92	1.78	2.37	2.38	2.45	
Oilseeds	2.97	20.80	27.66	27.78	28.61	
Fruits	1.18	0.21	0.28	0.28	0.29	
Coffee	4.90	34.34	45.67	45.87	47.25	
Other crops	42.69	7.67	14.86	10.24	10.55	
Flowers	0.46	0.08	0.11	4.35	0.11	
Cattle	4.92	0.88	1.17	1.18	1.21	
Other livestock	14.22	2.55	3.40	3.41	3.51	
Total	100.00	100	100	100	100	

**Table 2.** Simulation results for Ethiopia with alternative weighting schemes for prioritising agri-food GDP, rural household consumption per capita, and agri-food exports in the last simulation year of first optimal policy scenario.

Note: In this table and Table 4, the rural poverty rate is presented for illustration purposes. Strictly speaking, the rural poverty rate is not a policy objective in the application. However, it is calculated by the CGE model based on the results for the rural household consumption per capita. Source: Authors' calculations.

composition of the additional government investment by sector of allocation. As we can see, the results vary between scenarios. For example, the share of government investment for wheat increases when the Ethiopian policymakers' objective is to increase agri-food GDP, but falls in the other cases. The share of government investment for flowers increases when their objective is to promote agri-food exports, but falls in the other cases – more generally, in column (4), investment is directed to the most export-oriented crops. The cases of oilseeds and coffee are interesting because all the weighting schemes show increases in investment to promote them. In other words, these are sectors that would make it possible for Ethiopian policymakers to obtain gains in all three policy objectives both individually and simultaneously. In all cases, given that the funding for the increase in government investment comes from domestic borrowing, private investment declines strongly with a negative impact on GDP growth (not shown here).

Figure 1 shows the share of government investment in agriculture that is allocated to the different sectors under the assumption that Ethiopian policymakers would give equal weights to all three policy objectives. It shows that investment allocation changes only slightly during the policy optimisation period 2020–2025.



Figure 1. Sectoral allocation of government investment in agriculture under the assumption that Ethiopian policymakers assign equal weights to all policy objectives (%). Source: Authors' calculations.

#### 3.1. Macroeconomic trade-offs of government investment financing

A body of CGE modelling literature also points to the different trade-offs that emerge when policymakers pursue development objectives, depending on the source of financing of the government budget.<sup>17</sup> Our modelling framework captures this possibility and, in order to show it in the context of Ethiopia, we developed a variant of the previous optimal policy scenario, by simply switching the clearing variable for the government budget from domestic borrowing (which is now exogenous) to foreign borrowing (which is now endogenous). Ethiopian policymakers will clearly see different results if they alternatively finance the new government investment using foreign borrowing (Tables 3 and 4).

As expected, due to the absence of the crowding-out of private investment that domestic borrowing was causing in the first optimal policy scenario, Ethiopian policy-makers would see more favourable overall results when they finance new investment using foreign borrowing. In other words, we see larger improvements relative to the base scenario for two of the three IAT policy objectives we are considering. On the other hand, a new macroeconomic trade-off emerges with foreign borrowing as agri-food exports are lower relative to the scenario with domestic borrowing as the inflow of foreign exchange results in a real exchange rate appreciation that penalises export competitiveness (compare the values of the last column in Tables 1 and 3). Interestingly, the allocation of the new government investment across sectors is similar irrespective of two financing mechanisms considered here.

An advantage of the dynamic setting is that public debt can be traced over time, in scenarios where the policymaker finances government investments with domestic or foreign borrowing. In both cases, pursing the IAT objectives entails public debt accumulation under the assumption that this is not being repaid over the time frame 2016 to 2025 (Table 5).

<sup>&</sup>lt;sup>17</sup>See, for instance, several country applications in Sánchez and Cicowiez (2014), Sánchez and Vos (2013) and Sánchez, Vos, Ganuza, Lofgren, and Díaz-Bonilla (2010).

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Scenario	RGDPTRG(billion Birr)	QHPCTRG(Birr per capita)	QETTRG(billion Birr)
Base Payoff matrix	763.70	10,515.25	64.88
max RGDPTRG (agri-food GDP)	793.24	10,879.77	76.38
max QHPCTRG (rural household consumption per capita)	793.08	10,895.25	83.21
max QETTRG (agri-food exports)	792.49	10,890.71	83.97

**Table 3.** Agri-food GDP, rural household consumption per capita and agri-food exports in Ethiopia in the base and payoff matrix for the last simulation year of second optimal policy scenario.

Source: Authors' calculations.

**Table 4.** Simulation results for Ethiopia with alternative weighting schemes for prioritising agri-food GDP, rural household consumption per capita, and agri-food exports in the last simulation year of second optimal policy scenario.

		Weights				
		RGDPTRG = 1.00	RGDPTRG = 0.00	RGDPTRG = 0.00	RGDPTRG = 0.33	
		QHPCTRG = 0.00	QHPCTRG = 1.00	QHPCTRG = 0.00	QHPCTRG = 0.33	
	Base	QETTRG = 0.00	QETTRG = 0.00	QETTRG = 1.00	QETTRG = 0.33	
Policy objective/instrument	(1)	(2)	(3)	(4)	(5)	
RGDPTRG – agri-food GDP (billion Birr)	763.70	793.24	793.08	792.49	793.10	
QHPCTRG – rural household	10,515.25	10,879.77	10,895.25	10,890.71	10,895.03	
consumption per capita						
QETTRG – agri-food exports	64.88	76.38	83.21	83.97	82.95	
(billion Birr)						
Rural poverty rate (%)	16.55	15.41	15.36	15.37	15.36	
Government investment						
share (%)						
Teff	8.82	1.57	2.21	2.12	2.19	
Barley	3.12	0.55	0.78	0.75	0.77	
Wheat	6.79	30.77	1.70	1.63	2.84	
Maize	9.92	1.76	2.49	2.38	2.46	
Oilseeds	2.97	20.60	29.01	27.78	28.68	
Fruits	1.18	0.21	0.30	0.28	0.29	
Coffee	4.90	33.45	47.90	45.87	47.35	
Other crops	42.69	7.59	10.70	10.24	10.57	
Flowers	0.46	0.08	0.12	4.35	0.12	
Cattle	4.92	0.87	1.23	1.18	1.22	
Other livestock	14.22	2.53	3.56	3.41	3.52	
Total	100.00	100	100	100	100	

Source: Authors' calculations.

Ethiopia's government debt builds up more when domestic borrowing is used compared to foreign borrowing, which happens for two reasons. The first is that the domestic interest rate is higher than the foreign interest rate. The other reason is GDP increases less when using domestic borrowing to finance the increase in government investment – due to the crowding-out of private investment. This information can prove crucial for Ethiopia's policymakers as an additional criterion to assess the macroeconomic feasibility (i.e., the public debt sustain-ability aspect) of their policy optimisation to achieve development objectives.

**Table 5.** Government debt/GDP ratio in Ethiopia with alternative weighting schemes for prioritising agri-food GDP, rural household consumption per capita, and agri-food exports in the last simulation year of the two optimal policy scenarios (percentage points deviation with respect to the base scenario).

	Weights					
	RGDPFCTRG = 1.00	RGDPFCTRG = 0.00	RGDPFCTRG = 0.00	RGDPFCTRG = 0.33		
	QHPCTRG = 0.00	QHPCTRG = 1.00	QHPCTRG = 0.00	QHPCTRG = 0.33		
Financing mechanism	QETTRG = 0.00	QETTRG = 0.00	QETTRG = 1.00	QETTRG = 0.33		
Optimal policy scenario with domestic borrowing	7.91	7.69	7.57	7.60		
Optimal policy scenario with foreign borrowing	5.26	4.94	4.92	4.95		

Source: Authors' calculations.

#### 4. Discussion

Policymakers simultaneously pursue several objectives, some of which are even in conflict, and their budgets are typically too limited to achieve all of them simultaneously, particularly in developing countries and even more so during the current economic recession context in the face of the COVID-19 pandemic. Budgets are limited but a recovery and further development are also needed.

In this paper, we have described a modelling tool that, using inclusive agricultural transformation objectives in the context of Ethiopia to demonstrate its usefulness, can assist in informing policymakers on alternative ways of resolving their decision-making problem over time. Instead of solving a CGE model as a system of simultaneous equations, as typically done, we propose an optimisation problem in which the model equations act as constraints to it. Using data for Ethiopia, our application has shown: (i) how Ethiopian policymakers could optimally determine policy instruments to achieve IAT objectives related to agri-food GDP, rural household consumption per capita (welfare), and agrifood exports – thus moving away from the standard CGE modelling practice of using exogenous policy instruments, and (ii) the potential macroeconomic trade-offs that these policymakers may encounter when using alternative government budget financing sources.

We find that, should Ethiopian policymakers pursue increasing agri-food GDP, rural household consumption per capita, or agri-food exports, for example, they would not necessarily observe strong trade-offs between these objectives. However, should they direct public investment to different agricultural sectors – as the policy instrument – to achieve those objectives, the way in which they finance the investment will have macroeconomic trade-offs. In addition, the results show that an increase in government investment should be mostly allocated to oilseeds and coffee to simultaneously maximise the improvement in all three policy objectives. A sector like flowers should only be promoted when agri-food exports receive a relatively large weight in the policymaker's optimisation problem.

Of course, Ethiopia faces a number of challenges to achieve IAT not considered here. Thus, a step going forward will be to develop a full application of the modelling approach to find the optimal policy mix for a larger number of IAT objectives in Ethiopia – or any other developing country. Ideally, this new application will be informed by dialogue with real world policymakers in order to define with them the weights they would like to assign to their policy objectives in light with their country development priorities, political economy considerations, and the space they believe they have for using policy instruments when pursuing their objectives.

Going forward, it will also be an interesting exercise to consider the potentially more serious conflict and trade-offs that emerge for the policymaker when pursuing agricultural development objectives *vis-à-vis* objectives for other sectors, such as education, nutrition, health, energy, among others.

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## **Appendix A: Alternative distance metrics**

In this appendix, we consider alternative distance functions  $L_{\infty}$  as discussed in Section 2. Specifically, instead of varying the weights attached to the different policy objectives, here we vary the value of the parameter p in equation (5). That is to say, we show results for p = 1 and  $p = \infty$ , which are added to those for p = 2 presented in the paper. In all cases, we assume that the weights for the different policy objectives are the same.

If p = 1, the optimisation problem in equation (5) can be written as

$$\min OBJ = \sum_{t' \in T} \frac{1}{\left(1 + \rho\right)^{t'}} \left[ \begin{pmatrix} wt_{RGDPTRG} \cdot \left(\frac{RGDPTRG_{t'} - RGDPTRG_{t'}}{RGDPTRG_{t'} - RGDPTRG_{t'}}\right) \\ + wt_{QHPCTRG} \cdot \left(\frac{QHPCTRG_{t'} - QHPCTRG_{t'}}{QHPCTRG_{t'} - QHPCTRG_{t'}}\right) \\ + wt_{QETTRG} \cdot \left(\frac{QETTRG_{t'} - QETTRG_{t'}}{QETTRG_{t'} - QETTRG_{t'}}\right) \end{pmatrix} \right]$$
(A1)

subject to

$$ISCAL_{fcapg,t} = 1.15 \cdot ISCAL_{fcapg,t}^{0}$$
  
 $0 \le DMTFP_{a,fcapg,t} \le 1$ 

and all the CGE model equations

If  $p = \infty$ , the optimisation problem in equation (5) can be written as

$$\min OBJ = \sum_{t' \in T} \frac{1}{\left(1 + \rho\right)^{t'}} DEV_t \tag{A2}$$

subject to

$$\begin{aligned} \frac{RGDPTRG_{t'}^{*} - RGDPTRG_{t'}}{RGDPTRG_{t'}^{*} - RGDPTRG_{t'*}} - DEV_{t} &\leq 0\\ \\ \frac{QHPCTRG_{t'}^{*} - QHPCTRG_{t'*}}{QHPCTRG_{t'}^{*} - QHPCTRG_{t'*}} - DEV_{t} &\leq 0\\ \\ \frac{QETTRG_{t'}^{*} - QETTRG_{t'}}{QETTRG_{t'}^{*} - QETTRG_{t'*}} - DEV_{t} &\leq 0\\ \\ ISCAL_{fcapg,t} &= 1.15 \cdot ISCAL_{fcapg,t}^{0}\\ \\ 0 &\leq DMTFP_{a,fcapg,t} \leq 1 \end{aligned}$$

and all the CGE model equations.

Table A1 show the best (compromise) policy mixes for the second optimal policy scenario discussed in the paper. Generally speaking, we found that the alternative solutions do not differ significantly when we consider alternative metrics for the distance function used to assess the difference between the ideal point and the optimal policy mixes. As expected, we see that the normalised total distance between the base scenario and the optimal solution is shortest when p = 1 or longest when  $p = \infty$ . On the one hand, when p = 1 the mean achievement of all the policy objectives is maximised. To that end, the rural household consumption per capita objective is fully achieved, while the other two objectives are partially achieved. On the other hand, when  $p = \infty$ , all the objectives show more balanced improvements. In fact, agri-food GDP and agri-food exports show the same normalised distance from their ideal values.

Table A1. Simulation results for Ethiopia with equal weighting scheme and alternative values for parameter p for prioritising agri-food GDP, rural household consumption per capita, and agri-food exports in the last simulation year of second optimal policy scenario.

	base	L <sub>1</sub>	$L_2$	L∞
Item				
RGDPTRG – agri-food GDP (billion Birr)	763.70	793.08	793.10	793.11
QHPCTRG – rural household consumption per capita (Birr per capita)	10,515.25	10,895.25	10,895.03	10,894.48
QETTRG – agri-food exports (billion Birr)	64.88	83.21	82.95	82.65
Normalised distance				
Total		0.1027	0.1112	0.1323
RGDPTRG – agri-food GDP (billion Birr)		0.2084	0.1850	0.1738
QHPCTRG – rural household consumption per capita (Birr per capita)		0.0000	0.0140	0.0492
QETTRG – agri-food exports (billion Birr)		0.0999	0.1347	0.1738

Source: Authors' calculations.