Assessing Impacts from Irrigation Expansion on Ethiopian Households

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Introduction

Ethiopia's agricultural sector is mainly based on rainfed agriculture, despite large water resources in form of river basins and groundwater potential. According to estimates, only 5% of the country's irrigable land has been equipped for irrigation so far (Gebremeskel Haile, 2015; Makombe et al., 2011). It is believed that irrigation development plays a crucial role to improve the country's food security situation through increasing annual cropping periods, make use of improved seeds and other inputs like chemical fertilizer, and stabilizing fluctuations of rain-dependent agricultural systems (Awulachew et al., 2010; Gebul, 2021). The latter is gaining special importance in the face of climate change and its induced fluctuations on rainfed agriculture (Gebreegziabher et al., 2016). Irrigation expansion has been a crucial part of agricultural development policies of the Ethiopian government, such as the two 'growth and transformation plans' (GTP I and GTP II) (MoFED, 2010; National Planning Commission, 2016), under which the number of small-, medium- and large-scale irrigation schemes has increased significantly in the past decades (Gebul, 2021; National Planning Commission, 2018). Despite its recognition to foster agricultural development and food security, economy-wide assessments of irrigation development in Ethiopia with implications for agricultural output and household incomes are scarcely researched.

In this study, Ethiopia's irrigation expansion is examined using a CGE model. The aim is to extend the agricultural production system in a country-wide CGE model by irrigation technology. In doing so, the model serves as a framework to investigate further irrigation expansion in Ethiopia and its impacts on agricultural production, household incomes, and ultimately, the country's food security situation. The country-wide analysis is regionally disaggregated to account for regional variations in agricultural production and technologies used. Also, special focus is put on small-scale irrigation development, as specified below. The CGE model serves as the link between water usage and irrigation possibilities on the production side, and changes in household incomes on the consumption side of the economy. Thus, helping to understand in which way households benefit from this type of infrastructure development. Due to the structure of the model and database used, impacts on the subnational level are examined.

Method

Modeling framework

The analysis employs the single-country CGE model STAGE (McDonald & Thierfelder, 2020), programmed in the General Algebraic Modelling System software (GAMS). The model is of neoclassical origin. The model encompasses linear and nonlinear behavioral relationships that determine the agents behavior. Domestic agents (households, enterprises, government, activities and investments) consume composite commodities, that are aggregates of domestically produced and imported commodities. The domestic and imported commodities are imperfect substitutes with a constant elasticity of substitution (CES). The ratio of domestically produced and imported commodities within a composite commodity are determined by their relative prices (Armington, 1969).

Domestic production is a multi-level production process. On the top level of each production activity, "value added" and aggregated commodity inputs are combined using CES or Leontief technologies. Value added comprises an aggregate of factor inputs, such as labor, land or capital, which can be substituted by CES technology on the second level of the production process. In this analysis, labor is defined as an aggregate of different labor types (skilled, semi-skilled and unskilled), which are combined on the third level of the production process. The aggregated commodity inputs are generated using Leontief technology on the second level. Here, the demands for commodity inputs are in fixed proportions relative to the aggregate commodity inputs of each activity.

Activities produce multiple commodities as output. Each activity adjusts its output mix in the response to changes in the relative prices of domestically produced commodities using Constant Elasticity of Transformation (CET) technologies, which reflect imperfect product transformation. The distribution of domestically produced commodities among domestic demand and exports is also governed by relative prices on these markets, using CET functions. For further information on the model please refer to the technical documentation of the STAGE model (McDonald & Thierfelder, 2020), which is available at: http://www.cgemod.org.uk/stg.html.

Model database

The model is calibrated using a Social Accounting Matrix (SAM) as database. The SAM provides representative model agents together with all respective transaction values between them. The agents provided are activities, commodities, production factors, households, enterprises, government, savings, investments and "rest of the world", which is a representative account for all foreign commodity in- and outflow. For this analysis, the most recent SAM for Ethiopia is applied, which was compiled by the Joint Research Center of the European Commission for the fiscal year of 2015/16. This features the so-called 'home production home consumption' (HPHC) issue, for which regionally disaggregated representative households are introduced in the agricultural activities accounts. The database thus allows depicting the two-sided economic behavior of households as consumers on the one hand, and producers of agricultural commodities, on the other hand, that constitutes an appropriate depiction for developing countries in which subsistence agriculture is common (Mengistu et al., 2019). This feature serves as the base to incorporate small-scale irrigation in the analysis.

Out of the 94 commodities in the SAM, 52 are agricultural commodities. This includes major cereals (e.g. teff, maize, wheat), cash crops (e.g. sugar cane, oilseeds, coffee, cotton), pulses, oilseeds, livestock and animal products (e.g. cattle, poultry, dairy products). 23 agricultural commodities are depicted as marketed as well as own-consumed produce. Economic production is divided into 61 activities, of which 24 represent the agricultural sector. A distinctive feature are 11 regional household activities for each administrative region of Ethiopia. These activities produce the own-consumed together with marketed agricultural commodities, by which the "home-consumption-home-production" feature is illustrated. All other activities represent nation-wide production. The remaining agricultural activities are divided into cropping and livestock activities. Cropping activities produce multiple commodities, such as food and cash crops production, whereas for livestock activities, each commodity has a representative activity producing it. Production factors are capital and labor. Capital is divided into land, livestock and non-agricultural capital. For each administrative region in the SAM, labor is separated into skilled, semi-skilled and unskilled, which totals in 33 different labor accounts. Household accounts are distinguished by the administrative region and whether they represent rural population, urban population, or population living in small towns. For some regions, not all population types are represented (e.g. for Addis Ababa only one representative household for urban population exists). Altogether, there are 28 different household accounts in the SAM.

Data on irrigation

Irrigation is incorporated into the production technology of the CGE model by disaggregating agricultural activities into irrigated and non-irrigated activities. Precise data on the proportion of irrigated and rainfed production at the regional level in Ethiopia is scarce. This information, however, is necessary to be able to disaggregate the regionally specified household activities in agricultural production. The Spatial Production Allocation Model (SPAM) from the International Food Policy Research Institute (IFPRI) provides plausible estimates on different production technologies for various crops at a 5 arcmin spatial resolution. In a matching and calibration process, data from different sources and at different special scales were combined. Sources include national statistical offices, ministries of agriculture, surveys and international databases, such as FAOSTAT. SPAM data can then be aggregated at a national and even two sub-national levels. In the case of Ethiopia, these are administrative regions and zones. The most recent SPAM data for Africa South of the Sahara refers to the year 2017, was first published in 2020 and is publicly available (IFPRI, 2020). The dataset contains the physical area, harvested area, production quantity, value of production and yield for 42 different crops. Four different cropping technologies are distinguished. Irrigated farming refers to area equipped with full or partial irrigation. This is usually combined with high level of inputs and advanced management techniques (e.g. soil conservation). Rainfed farming is divided into high-input farming, low-input farming and subsistence farming. Rainfed subsistence farming is defined as mostly for personal consumption and low-input (Yu et al., 2020).

According to the SPAM data, 42.8% of total agricultural production in Ethiopia can be assigned to rainfed high-input, 34.7% to rainfed low-input and 18.1% to rainfed subsistence production. Only 4.5% is irrigated. The share of irrigated agricultural production varies considerably across regions. In Harari and Dire Dawa, for instance, 26.2% and 16.1% are irrigated, respectively, whereas for most other regions, irrigation makes up only 4-8% of total agricultural production (IFPRI, 2020).

SAM disaggregation

Irrigation was incorporated into the model by disaggregating each agricultural cropping activity into two: irrigated and rainfed.

For each Ethiopian administrative region in the SPAM data, the irrigated share of the total regional agricultural production is calculated. Here, the variable “production quantity” was applied. Each regional agricultural household activity in the SAM is then disaggregated into rainfed and irrigated according to the SPAM data. The administrative region of Addis Ababa in the SAM is not represented in the SPAM data. According to the SAM, however, its regional household activity only accounts for 0.7% of the total supply of all regional household activities. Consequently, we take the share of the entire agricultural production in Ethiopia according to the spam data as a proxy for this regions. The four nationwide primary agricultural cropping activities, afood (food crops), acash (cash crops), acoff (coffee), and acrop (crops nec) are also disaggregated into rainfed and irrigated production. For these activities, the same irrigation share as Addis Ababa was used in disaggregating. The disaggregation according to the irrigated and rainfed shares explained above is applied to the rows (output-side) and columns (input side) of the SAM. The calculated shares of irrigated and rainfed agriculture are displayed in table 1 below.

Table 1: Irrigated and rainfed shares applied to agricultural activities:

	share irrigated	Rainfed (1-share irrigated)
Afar	80.5%	19.5%
Amhara	4.4%	95.6%
Benishangul Gumuz	0.6%	99.4%
Dire Dawa	16.1%	83.9%
Gambella	0.0%	100.0%
Harari	26.2%	73.8%
Oromia	4.5%	95.5%
SNNP	4.0%	96.0%
Somali	7.7%	92.3%
Tigray	5.9%	94.1%
Addis Ababa, afood, acash, acoff, acrop	4.5%	95.5%

Source: IFPRI (2020)

Irrigation production technology is in need of advanced technical equipment and management techniques, which is reflected in its input structure. Machinery and higher skilled labor are needed to operate irrigation systems. Furthermore, irrigation is often combined with water conservation measures and other agricultural inputs, such as fertilizers. The variation in input structure (intermediate commodity inputs and input factors) is accounted for in disaggregating the SAM columns (which reflect the input-side of economic activities).

Scenarios

Together with a reference scenario, 4 additional scenarios are considered. The scenarios are used to depict a gradual increase in irrigation expansion in Ethiopia via shifting rainfed production towards irrigated production. Two scenarios constitute an increase in irrigated production by 50% and 100%, respectively. The other two scenarios portray the same percentage increases in irrigated production, however with double the input costs of irrigation expansion.

The scenarios are used to investigated, how irrigation expansion impacts agricultural output and ultimately Ethiopian households in different regions. Special focus is put on household income and consumption.

References

Armington, P. S. (1969). A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers*, *16*(1), 159–178. www.jstor.org/stable/3866403

Awulachew, S. B., Erkossa, T., & Namara, R. E. (2010). Irrigation potential in Ethiopia Constraints and opportunities for enhancing the system. *International Water Management Institute: Addis Ababa, Ethiopia*.

Gebreegziabher, Z., Stage, J., Mekonnen, A., & Alemu, A. (2016). Climate change and the Ethiopian economy: A CGE analysis. *Environment and Development Economics*, *21*(2), 205–225. https://doi.org/10.1017/S1355770X15000170

Gebremeskel Haile, G. (2015). Irrigation in Ethiopia, a Review. *Journal of Environment and Earth Science*, *5*(15), 141–147. https://www.cabdirect.org/cabdirect/abstract/20153373120

Gebul, M. A. (2021). Trend, status, and challenges of irrigation development in Ethiopia—A review. *Sustainability*, *13*(10), 5646. https://doi.org/10.3390/su13105646

IFPRI. (2020). *Spatially-Disaggregated Crop Production Statistics Data in Africa South of the Sahara for 2017*. Harvard Dataverse, V3. https://doi.org/10.7910/DVN/FSSKBW

Makombe, G., Namara, R., Hagos, F., Awulachew, S. B., Ayana, M., & Bossio, D. (2011). *A comparative analysis of the technical efficiency of rain-fed and smallholder irrigation in Ethiopia* (IWMI Working Paper 143). https://doi.org/10.5337/2011.202

McDonald, S., & Thierfelder, K. (2020). *A Standard Applied General Equilibrium Model: Technical Documentation - STAGE_3 Version*. http://www.cgemod.org.uk/stg.html

Mengistu, A., Woldeyes, F., Dessie, E., Ayalew, Z., Yeshineh, A., Mainar Causapé, A. J., & Ferrari, E. (2019). Ethiopia Social Accounting Matrix 2015/16. *Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12389-7*. https://doi.org/10.2760/974668

MoFED. (2010). *Growth and Transformation Plan: 2010/11-2014/15. Volume I: Main Text*. Ministry of Finance and Economic Development (MoFED), Addis Ababa, Ethiopia

National Planning Commission. (2016). *Growth and transformation plan II (GTP II)—(2015/16-2019/ 20)*. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia

National Planning Commission. (2018). *The Second Growth and Transformation Plan (GTP II) Midterm Review Report.* Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia

Yu, Q., You, L., Wood-Sichra, U., Ru, Y., Joglekar, A. K. B., Fritz, S., Xiong, W., Lu, M., Wu, W., & Yang, P. (2020). A cultivated planet in 2010-Part 2: The global gridded agricultural-production maps. *Earth System Science Data*, *12*(4), 3545–3572. https://doi.org/10.5194/essd-12-3545-2020