A 72H EXPLORATION OF THE CO-EVOLUTION OF FOOD INSECURITY AND INTERNATIONAL MIGRATION

COMPLEXITY72H

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ABSTRACT

Food insecurity, defined as the lack of physical or economic access to safe, nutritious and sufficient food, remains one of the main challenges of the 2030 Agenda for Sustainable Development. Food insecurity is a complex phenomenon, resulting from the interplay of environmental, socio-demographic, and political events. Previous work has shown the nexus between climate change, conflicts, migrations and food security at the households, however these relations are still largely unexplored at national scales. In this context, during the Complexity72h workshop, held at the Universidad Carlos III de Madrid in June 2024, we explore patterns for the co-evolution of food insecurity and international migration flows at the national scale, accounting also for remittances, as well as for changes in the economic, conflict, and climate situation. To this aim, we gathered data from several publicly available sources (Food and Agriculture Organization, World Bank, and UN Department of Economic and Social Affairs) and presented analyses between food insecurity and migrations, migrations and remittances, and remittances and food insecurity. Eventually, we present the idea of a model summarizing the previous evaluations to simulate the link underlying food insecurity and international migration flows. We argue that simulation investigating the food security-migration nexus may help develop effective polices to ensure food security across countries.

Keywords Food insecurity · International migration · Remittances

1 Introduction

Achieving food security (i.e., economic and physical access to sufficient, safe, and nutritious food for everyone everywhere FAO [1996]) is an ambitious target embedded in the Sustainable Development Goal 2 UN [2015]. Unfortunately, up to 2023, nearly 282 million people across 59 countries or territories experienced severe food insecurity and needed food assistance WFP Seminal papers investigate factors affecting people food security. Among these factors, low income and education, climate change, and conflicts feature as characteristics of food insecure households Allee et al. [2021], d'Errico et al. [2023], Smith et al. [2017a,b].

These drivers are also common to international migration phenomena Castelli [2018]. Food insecurity has been reported as a mediating factor of such drivers on migration Morales-Muñoz et al. [2020] and both its presence and inequality in regards to it are correlated to out migration Smith and Wesselbaum [2022]. In turn, migration impacts food insecurity both at destination and origin country in several ways. For example, being an immigrant in a country increases one's likelihood to be food insecure because usually immigrants are poorer than locals Smith et al. [2017a]. On the other hand, even though migration can lead to labour loss at the origin country, it also decreases the quantity of food required at household level Zezza et al. [2011]. Furthermore, international remittances sent by migrants account for a relevant fraction of several country's international investments, especially in low- and middle-income countries where their flows are larger than official development assistance Ratha et al. [2018]. In those cases, migration may lead to an increase of household income. This in turn improves food security through better food consumption and other indirect investments Zezza et al. [2011], Obi et al. [2020]. This has been analysed at state level, where total remittances are associated with total migration fluxes and the difference between origin and destination country income per capita Ratha et al. [2010].

In general, seminal works explore the relation between migration and food security focusing on household level data retrieved through surveys Allee et al. [2021], d'Errico et al. [2023], Smith et al. [2017a,b]. Against this background, we present preliminary analyses linking food security and international migration considering indicators at the national scale. In this way, we aim to enlarge the literature on food security and migration from a more general perspective, also considering the remittances migrants living abroad send to the home country as a factor affecting food insecurity. Our approach can pave the way for future analyses in this field that can lead to effective polices for ensuring food security across countries.

2 Materials and Methods

In this article we employ three main publicly available datasets coming from different sources: the Food and Agriculture Organization of United Nations (FAO), the World Bank Group (WBG), and the United Nation Population Division (UNPD). We use FAO data to obtain national food insecurity indicators (FAO [2023]). In particular, we obtain the 3-year average percentage of country population affected by *severe food insecurity*. Moreover, from this dataset, we also obtain other annual national indicators: Temperature Change on Land, Gross Domestic Product per capita (GDP), and Political Stability, quantified by the *Political Stability and Absence of Violence/Terrorism Index* ([FAO, 2024, 2022a]). Temperature Change on Land measures annual mean temperature change with respect to a baseline temperature measured during the 1951–198 period, while the Political Stability index measures "perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism" (Daniel Kaufmann [2023]). This index gives each country's score in units of a standard normal distribution, ranging from -2.5 to 2.5. Furthermore, we obtain yearly *received remittances* from the WBG data, containing compensation and money transfers between countries converted in current USD (Group [2023]), along with each country's income group label (low income, lower-middle income, upper-middle income, and high income) as assigned by the WBG in 2019. Finally, from the UNPD, we obtain open data on international migration ([United Nations and Affairs, 2015, Division, 2020]), i.e. estimates of the international migrant stock for the mid-point (1 July) for each available year.

To ensure consistency throughout the study and to be able to compare each yearly indicator (temperature change, GDP, political stability, etc.) with food insecurity, we computed the 3-year averages for all yearly indicators along with the total outgoing migration estimate for each considered country, calculated as the estimated total number of people that migrated from each country for the mid-point of a given year. At the same time, when combining the datasets, we considered the ISO3 codes for each considered country as used by the FAO and by the WBG ([FAO, 2022b, Group, 2010]) and filtered the dataset to consider only countries that had available GDP data. The data pipeline followed to obtain the dataset for this study is illustrated in Fig. 1.

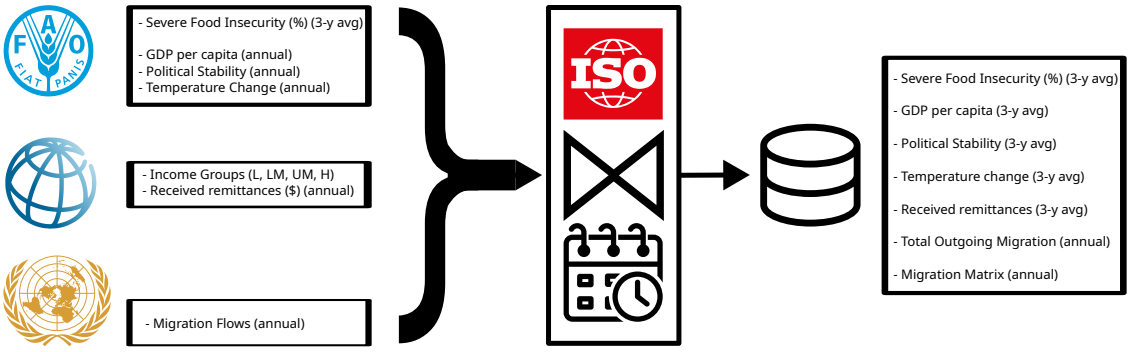

Figure 1: **Data cleaning and aggregation flow**. Data from FAO, WBG, and UNPD are combined by means of their ISO3 country codes and made consistent by computing 3-year averages from annual indicators. To produce this figure, we employed Creative Commons icons from TheNounProject by the authors Rikas Dzihab and New icon.

3 Results

Within the Complexity 72h workshop, we provided a preliminary analysis of the complex nexus between food security and migrations. The initial analysis here presented is organized in three macro-steps linking: (i) food security and migration flows, (ii) migrations and remittances, and (ii) the combination of the standard drivers of food security (i.e., national income, climate change, and political stability) with remittances to investigate food security. The following subsections present the initial outcomes. Fig. 2 qualitatively represents the three macro-steps.

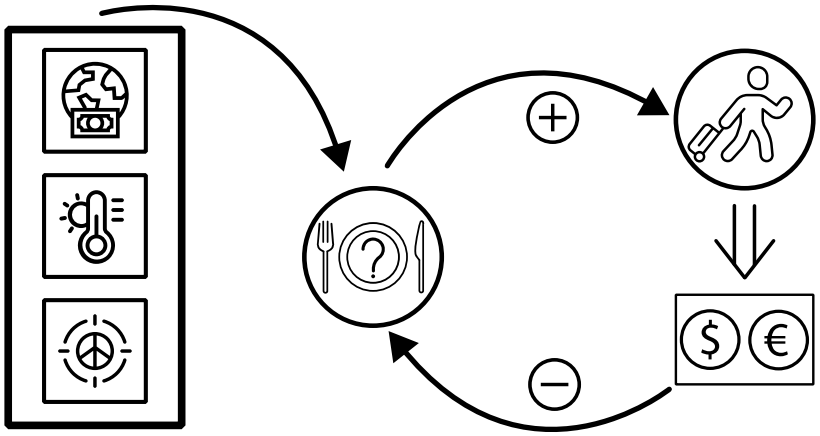

Figure 2: **Schematic representation of the proposed framework to investigate the co-evolution of food insecurity and international migration**. Food insecurity can drive individuals to leave their home country. Once people reach more secure countries, they tend to send remittances to relatives who remained in their home country, which can help them reduce their food insecurity. Finally, we propose to estimate changes in food insecurity in the origin country considering the known drivers of food insecurity (i.e., economic situation, conflict, and climate) as well as the positive effect of remittances (mediating the impact of outgoing migration). To produce this Figure, we employed Creative Commons icons from TheNounProject by the authors: Sergey Novosyolov, Moch Rizki Eko Waluyo, UNKNOWN, bsd studio, Geni Alando, and yuni sarah.

3.1 Food security and international migration

In general, people may decide to leave their home country when the food security situation is worsening. Thus, we assume that relative changes in total out-going migration from a country in the future might positively correlated with relative changes in the current food insecurity situation in that country, as suggested by Smith and Wesselbaum [2022]. We empirically explored this association in our data as shown in Fig. 3. Qualitatively, we notice that numerous countries are in the first and third quadrants. Countries in the first quadrant have recorded a relative increment in food insecurity and a relative increment in future migration rate. Conversely, where food insecurity decreases, migration out-fluxes in the next years decrease as well (countries in the third quadrant).

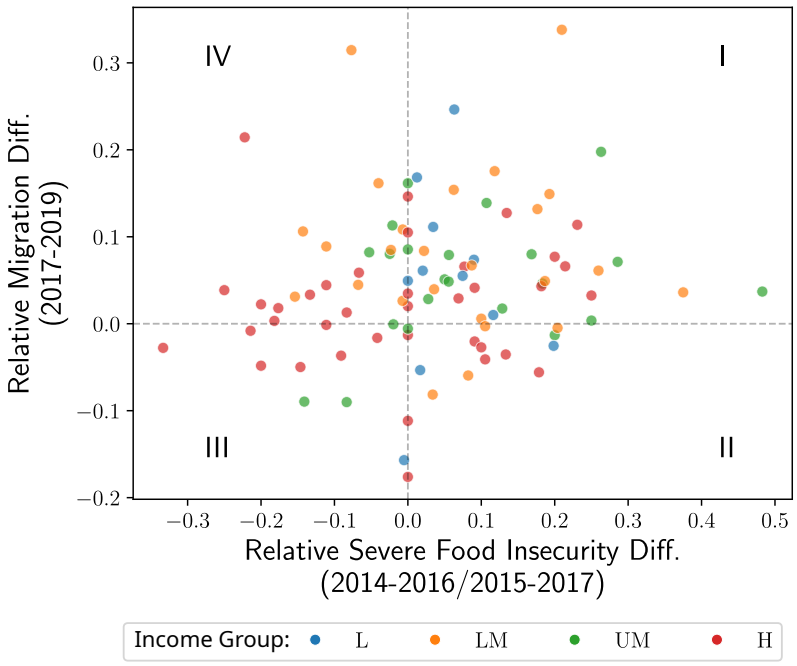

Figure 3: **Relative changes in future total outgoing migration in function of relative changes in the origin country food insecurity situation**. Each point represents a country and is coloured by its income group, Low (L), Lower-Middle (LM), Upper-Middle (UM), High (H).

3.2 Migration and remittances

Better earning opportunities are one of the drivers of migration. This allows migrants to contribute to the livelihood strategies of their households through *remittances*, i.e. the money they send to the household Zezza et al. [2011]. With the upsurge of international migration, remittances have expanded dramatically and are linked to economic development and poverty reduction Zezza et al. [2011]. They are also seen as a significant capital flow to developing countries. Ratha et al. [2010].

We use a simplified version of the model for estimating bilateral remittances suggested in Ratha and Shaw [2007]. The model assumes Remittance flow between countries to be affected by three factors: the migrant stocks in different destination countries, incomes of migrants in the different destination countries, and to some extent incomes in the source country. The average remittance sent by a migrant from country i in destination country j is modelled as a function of the per capita income of the origin country and the destination country

$$r_{ij} = f(Y_i, Y_j) = \begin{cases} Y_i, & \text{if } Y_j < Y_i; \\ Y_j, & \text{if } Y_j \geq Y_i. \end{cases} \tag{1}$$

Here, Y_i is the average per capita GDP of the origin country and Y_j is the average per capita GDP of the destination country. The rationale is that the migration occurs in the expectation of earning a higher level of income for the dependent household than what the migrant would earn in their home country. So, it is assumed that the average remittance by an individual is at least as much as the per capita income of the home country, even when the individual migrates to a lower-income country.

The total amount of remittances received by country i is

$$\overline{R_i} = \sum_j r_{ij} M_{ij}, \tag{2}$$

where M_{ij} is the migration vector between country i and different destination countries j.

In Ratha and Shaw [2007], they propose the relation between the level of remittance (r_{ij}) and per capita income of origin and destination countries (Y_i, Y_j) to have an exponential parameter β. But we assume a simplification with

$\beta = 1$, which gives us equation 1. In contrast to the use of average per capita GNI for Y_i and Y_j, we use the average per capita GDP, for the consistency of variables across our results about food insecurity and migration data.

We use equations 1 and 2 to estimate the remittance values for all origin countries using migration and average GDP data. Then, we compare the calculated remittances $\overline{R_i}$ with actual remittance data R_i for the period 2017-2019.

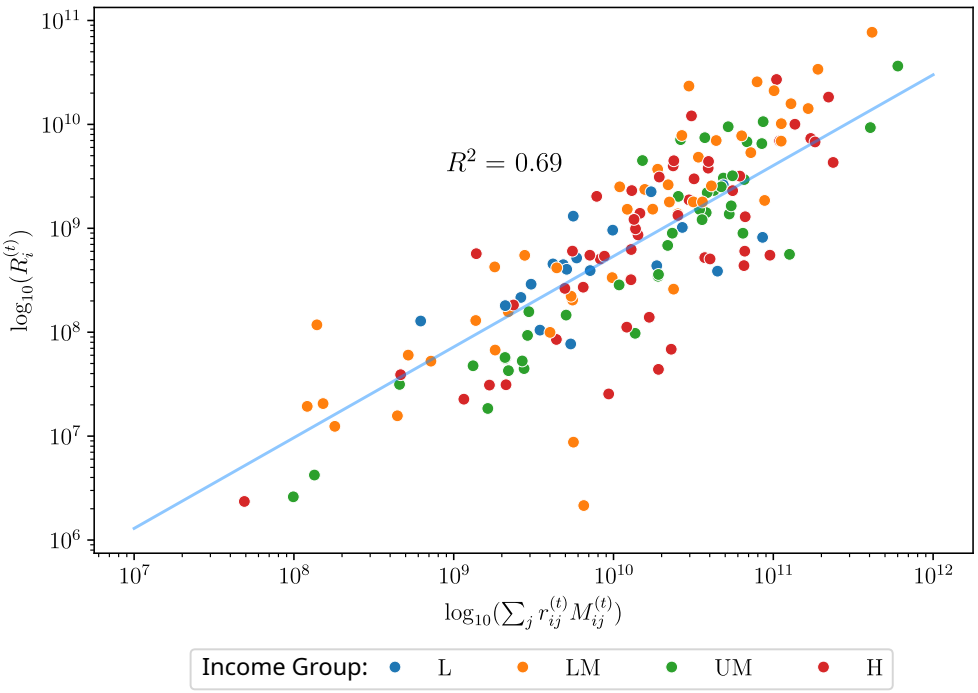

Figure 4: **Relationship between the observed received average remittances of each country for the 2017-2019 period and the estimated average remittances for the same time period**. Each point represents a country and is coloured by the its income group, Low (L), Lower-Middle (LM), Upper-Middle (UM), High (H).

In Figure 4 we observe a linear relation on the log-log scale for the calculated vs observed remittances plot with a slope value of $\gamma \simeq 0.87$. This implies a modification to equation 2, which takes a form

$$R_i^{(t)} = \left(\sum_j r_{ij}^{(t)} M_{ij}^{(t)} \right)^{\gamma} \tag{3}$$

with $\gamma = 0.8731$. This validates the assumptions of the model by Ratha and Shaw [2007] and gives a modified relation between remittance received by origin country and the migrant stock from that country. This relation can be used in modeling remittance from migrants to further explore its effect on food insecurity.

3.3 Remittances and other drivers of food insecurity

Food security is dependent on a combination of drivers related to availability, access and utilization Morales-Muñoz et al. [2020]. We categorise the drivers into forces related to the political stability of the country, the effect of climate change, and the conditions of the national economy. Naturally, agricultural production is tied to environmental change. Conflicts, related to political instability, diminish investments in agricultural technology and the capability of the state to provide infrastructure for food storage, distribution and access. Drought and other climate shocks are aggravated by conflict, which further complicates the impacts on food security and livelihood. The status of a national economy is subject to a multitude of other forces, including climate and internal politics, inequality, and population pressures. The levels of the national economy have a feedback effect on food insecurity. In section 3.2, we discuss the effects of remittance on poverty reduction and economic development, which could be linked to food insecurity.

We decompose the evolution of food insecurity into two components: migration, modulated by the function $G(R)$ through the dummy variable of remittance $R(M)$, and internal factors related to economic well-being in the home

country (GDP per-capita, e), climate change (estimated using soil temperature variation, T), and political stability (s,Daniel Kaufmann [2023]). In section 3.2, We identify that $G(R)$ takes the form of a logarithmic function, and so we can write the relative change of the food insecurity on a state level as,

$$\frac{f_i^{t+\Delta t} - f_i^t}{f_i^t} = \alpha + \beta \log_{10}\left(\frac{R_i^t}{R_i^{t-\Delta t}}\right) + \gamma \frac{s_i^t - s_i^{t-\Delta t}}{s_i^{t-\Delta t}} + \zeta(T_i^t - T_i^{t-\Delta t}) + \eta \frac{e_i^t - e_i^{t-\Delta t}}{e_i^{t-\Delta t}}. \tag{4}$$

We estimate the coefficients of equation 4 through multi-linear regression, using the method of ordinary least squares. The value of each independent variable at time t is calculated from the data using a three-year rolling-average. Regression is performed using data from the yearly period 2014-2016, with Δt corresponding to a one-year shift in the period start and end year.

Dep. Variable:	$(f_i^{t+\Delta t} - f_i^t)/f_i^t$	**Model:**	Ordinary Least Squares
R-squared:	0.236	**Adj. R-squared:**	0.201
F-statistic:	6.720	**Prob (F-statistic):**	9.24e-05
BIC:	-86.81	**AIC:**	-99.42
Log-Likelihood:	54.709		

	coefficient	**std err**	**t**	**P> |t|**	**[0.025**	**0.975]**
α	0.4436	0.143	3.112	0.003	0.160	0.727
$(e_i^t - e_i^{t-\Delta t})/e_i^{t-\Delta t}$	-1.2307	0.658	-1.871	0.065	-2.538	0.076
$(s_i^t - s_i^{t-\Delta t})/s_i^{t-\Delta t}$	0.0450	0.020	2.265	0.026	0.006	0.085
$\log(R_i^t/R_i^{t-\Delta t})$	-0.2103	0.132	-1.598	0.114	-0.472	0.051
$T_i^t - T_i^{t-\Delta t}$	-0.1230	0.033	-3.746	0.000	-0.188	-0.058

Table 1: **OLS regression results** linking relative changes in remittances and in other known food insecurity drives (i.e., economic situation, conflict, and climate) with future relative changes in food insecurity levels.

3.4 Exploring an integrated model for the co-evolution of food insecurity and international migration

In light of the preliminary analyses performed in this workshop, we argue there is room to develop a mechanistic model to address the food security-migration nexus. In this direction, we propose a preliminary model for the co-evolution of food insecurity and international migration which combines the three investigations described above to obtain an analytical framework linking food insecurity, migrations, and remittances in accordance to the diagram presented in figure 1. Despite further analyses being required, developing a conceptual framework of this kind could be useful to study the possible evolution of future migration fluxes, remittances, and food insecurity at the national scale.

In this context, we considered the impact of food insecurity on international migration (in terms of country's total outgoing migration) preliminary as a linear function of the following form:

$$\frac{m_i^{t+\Delta t} - m_i^t}{m_i^t} = \alpha + \beta \frac{f_i^t - f_i^{t-\Delta t}}{f_i^{t-\Delta t}} \tag{5}$$

where m_i^t is total number of people from country i living abroad at time t, f_i^t is food insecurity of country i at time t, and α and β are parameters to be estimated from the data (fitting the available data, we get $\alpha = 0.0436$ and $\beta = 0.0846$).

Once the total number of people deciding to migrate out of a country is determined, we make the assumption that the profile of the destination countries is kept unchanged throughout the period of the time further considered. Figure 5 shows an empirical validation of this hypothesis in our data. This allows us to consider the transition matrix introduced in section 3.2.

As presented in section 3.2, the initial study linking international migration and remittances showed that the relation between the two could be described by equation 3. Based on this, we estimated the total remittances R_i^t received by a country i at each time t through equation 3 and using the parameter γ obtained from the fitting of the data.

Eventually, food security can be updated considering remittances, political stability, soil temperature variation, and national per-capita GDP following equation 4. The five paramters fitted to the data were used in the model.

The preliminary model developed considers the relationships discussed above and described in figure 1. This was initialized with country level data on food insecurity and total migration from 2016 to 2019, for the same times relative. We used the data available on GDP per capita, temperature change and political instability both for the initializing period of 2016 to 2019 and the simulation period. Due to the time constraints of the workshop under which this work was performed, we leave the analysis of simulations estimating changes in food security and migration flows up to 2023 for the future. Following preliminary simulations and their analysis, we will extend this to different altered scenarios where the impact of temperature changes and economic shocks will be consider

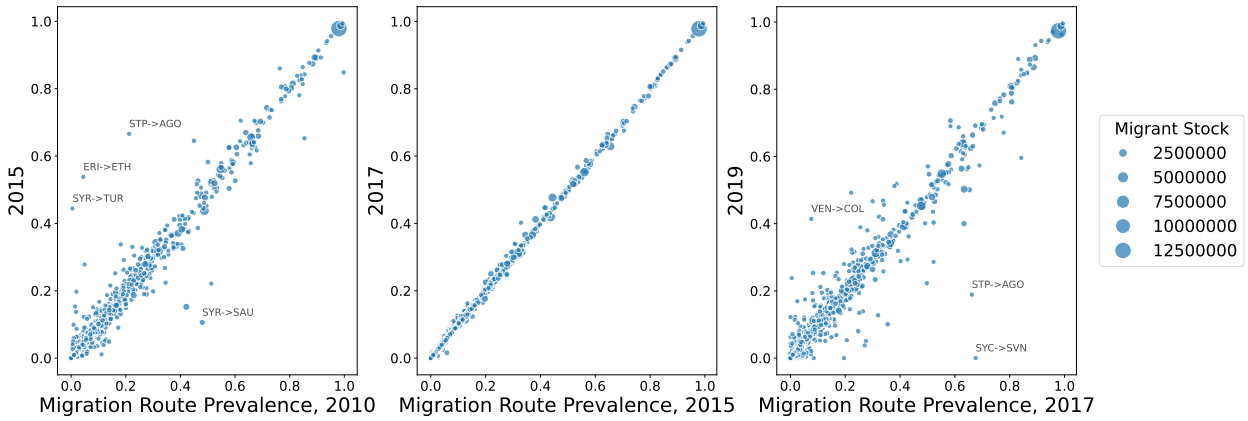

Figure 5: Migration route prevalence is the migrant stock that is in one country as a proportion of the total migrant stock existing worldwide from the origin country. By comparing migration route prevalence at a time t with a time $t + \Delta t$, we may observe variation in destination choice over time. All three time period comparisons display strong correlation between the two time periods, this motivates our assumption that the likelihood of destination choice can be assumed to be static over time.

4 Discussion

During the Complexity 72h workshop, we performed a qualitative analysis on the links between food insecurity and international migration. In this preliminary study, we observed a general positive trend between the changes in food insecurity and out-going migration flows, thus motivating one side of our model's logic. The other part of the model assumes that migrants living abroad send remittances back home. On this side, we proposed a preliminary approach to estimate the remittances that migrants send to the origin country. The method indicates that 69% of the variance in the remittance data is accounted for by migration, so providing initial evidence to support the model.

The initial analysis presented in this report presents some limitations and room for improvements. These lie both with the data and the model itself.

Using data from three different sources presents challenges in matching time period coverage between them. Migration stock data is available every 5 years from 1990 to 2015, as well as for 2017 and 2019; while food insecurity data is available as aggregates of three consecutive years starting for the period 2014-16 and updated every year; and socioeconomic data for income groups, received remittances, GDP per capita, and political stability is available every year for the whole time period. Further complication arises from inconsistent collection for countries between the three sources and naming convention inconsistencies for countries themselves - index keys to match between sources were implemented to achieve consistent results, but the impact of missing countries was not explored due to time constraints of the workshop. Future data collection by international agencies will provide more complete data records that would increase confidence in our evaluations.

Modelling limitations arise from restricting the scope to the evolution of remittances and food insecurity and lack of data to evaluate the results. In an attempt to uncover the relationships among the considered variables, we performed trend analyses to explore linear relationships between food insecurity and migration flows, migration and remittances, and how remittances, climate chance, economic situation, and political instability may affect food insecurity. Higher order relationships were not considered. No evaluation of the model is presented due to the limited time of the workshop and data. Therefore this work does not intend to provide results, rather a preliminary data exploration and conceptual formalization to model this significant problem.

Future development on this exploration will build robustness and confidence in the framework and output. Alternative data sources may be a source of longer time span and improved internal consistency of each country's indicators. Future modelling work will develop more complex analytical frameworks to deepen investigation into the relationships amongst the underlying variables, also considering possible effects of several control variables.

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References

FAO. Report of the world food summit, 1996. URL `https://www.fao.org/4/w3548e/w3548e00.htm`. accessed 26-06-2024.

UN. Transforming our world: The 2030 agenda for sustainable development. *New York: United Nations, Department of Economic and Social Affairs*, 1:41, 2015.

WFP. Global report on food crises 2024.

Andrew Allee, Lee R Lynd, and Vikrant Vaze. Cross-national analysis of food security drivers: Comparing results based on the food insecurity experience scale and global food security index. *Food Security*, 13(5):1245–1261, 2021.

Marco d'Errico, Jeanne Pinay, Ellestina Jumbe, and Anh Hong Luu. Drivers and stressors of resilience to food insecurity: evidence from 35 countries. *Food Security*, 15(5):1161–1183, 2023.

Michael D Smith, Woubet Kassa, and Paul Winters. Assessing food insecurity in latin america and the caribbean using fao's food insecurity experience scale. *Food policy*, 71:48–61, 2017a.

Michael D Smith, Matthew P Rabbitt, and Alisha Coleman-Jensen. Who are the world's food insecure? new evidence from the food and agriculture organization's food insecurity experience scale. *World Development*, 93:402–412, 2017b.

Francesco Castelli. Drivers of migration: why do people move? *Journal of travel medicine*, 25(1):tay040, 2018.

Héctor Morales-Muñoz, Srijna Jha, Michelle Bonatti, Henryk Alff, Sabine Kurtenbach, and Stefan Sieber. Exploring connections—environmental change, food security and violence as drivers of migration—a critical review of research. *Sustainability*, 12(14):5702, 2020.

Michael D Smith and Dennis Wesselbaum. Food insecurity and international migration flows. *International Migration Review*, 56(2):615–635, 2022.

Alberto Zezza, Calogero Carletto, Benjamin Davis, and Paul Winters. Assessing the impact of migration on food and nutrition security. *Food Policy*, 36(1):1–6, 2011.

Dilip Ratha, Supriyo De, Sonia Plaza, Kirsten Schuettler, William Shaw, Hanspeter Wyss, and Soonhwa Yi. Migration and remittances: Recent developments and outlook. 2018.

Chinedu Obi, Fabio Bartolini, and Marijke D'Haese. International migration, remittance and food security during food crises: the case study of nigeria. *Food Security*, 12(1):207–220, 2020.

D Ratha, S Mohapatra, and A Silwal. Outlook for remittance flows 2010–11, migration and development brief 12. *Migration and Remittance Team Development Prospects Group, World Bank*, 2010.

FAO. Suite of food security indicators, 2023. URL `https://www.fao.org/faostat/en/#data/FS`. [Accessed 26-06-2024].

FAO. Temperature change on land, 2024. URL `https://www.fao.org/faostat/en/#data/ET`. [Accessed 26-06-2024].

FAO. Annual population, 2022a. URL `https://www.fao.org/faostat/en/#data/OA`. [Accessed 26-06-2024].

Aart Kraay Daniel Kaufmann. Worldwide governance indicators, 2023 update, 2023. URL `www.govindicators.org`. [Accessed on 10/19/2023].

World Bank Group. Personal remittances, received (current us dollars), 2023. URL `https://data.worldbank.org/indicator/BX.TRF.PWKR.CD.DT`. [Accessed 26-06-2024].

Department of Economic United Nations and Social Affairs. Trends in international migrant stock: The 2015 revision., 2015. URL https://www.un.org/en/development/desa/population/migration/data/estimates2/estimates15.asp.

UN Population Division. International migrant stock, 2020. [Accessed 26-06-2024].

FAO. Iso 3 code list (global, region, country), 2022b. URL https://data.apps.fao.org/catalog/dataset/iso-3-code-list-global-region-country. [Accessed 26-06-2024].

World Bank Group. Country codes, 2010. URL https://wits.worldbank.org/WITS/wits/WITSHELP/Content/Codes/Country_Codes.htm. [Accessed 26-06-2024].

TheNounProject. Noun Project: Free Icons & Stock Photos for Everything — thenounproject.com. https://thenounproject.com/. [Accessed 27-06-2024].

Dilip Ratha and William Shaw. South-south migration and remittances. *World Bank Working Paper*, 05 2007. doi:10.1596/978-0-8213-7072-8.