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Gender and Distance in Domestic and International Environmental Migration

A structural gravity approach

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Abstract

The article provides cross-sectional evidence of domestic and international human migration associated with environmental shocks, with a specific emphasis on gender-specific heterogeneity and geographical distance. Both sudden and gradual environmental changes may influence the decision to migrate. However, the response is conditional to the cost and opportunity to move, which can vary based on gender and the distance between the location affected by the environmental shock and the hosting destination, within the country or internationally. Using the 5-year estimates of internal and international domestic migration flow disaggregated by sex, representative of the period 2005-2010, we estimate a structural gravity model and we find that migration can be influenced by environmental risks, as people may seek safer or more stable environments when their home regions are prone to disasters, albeit differently for each gender, both within a country and across borders.

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1 Introduction

In recent decades, the global climate crisis has garnered significant international attention among major institutions as well as a growing consensus on the need for an urgent response. As stated by the Secretary-General of the United Nations, the climate emergency exacerbates existing issues (such as economic inequality, the marginalization of vulnerable groups, reduced agricultural productivity, increased poverty, and food insecurity) and, then, contributes to social cohesion problems and conflicts. This environmental emergency also significantly affects the migration of populations, forcing an average of 21.5 million people to move due to natural disasters and climate emergencies over the last decade, according to the United Nations High Commissioner for Refugees (UNHCR, 2021).

The economic literature on migration recognizes the phenomenon as a complex interaction of various causes, including environmental factors. Recent reviews (Hoffmann et al., 2020; Beine and Jeusette, 2021; Cipollina, De Benedictis, and Scibè, 2023) show that climate change and natural disasters affect migration, but the impact varies across different contexts, with inconsistent effects in terms of direction and magnitude. Therefore, the relationship between environmental factors and migration is not always straightforward.

Given the topic's relevance and the need for evidence-based policies, the goal of this article is to provide a micro-level assessment of the intricate link between human mobility and environmental shocks¹. We specifically refer to “*environmental migration*,” which involves individuals or groups forced to leave their homes due to sudden or gradual environmental changes that adversely affect their lives, temporarily or permanently, in their country or abroad.² This working definition encompasses people who are displaced

¹ In our article, the term *environmental shocks* refers to changes in the environment that may result from climate change, as well as extreme environmental events, which may or may not be related to climate change, such as earthquakes, for example.

² See: Migration and the Environment (2007) MC/INF/288, available at https://www.iom.int/sites/g/files/tmzbd1486/files/jahia/webdav/shared/shared/mainsite/about_iom/en/

by natural disasters as well as those who choose to move because of progressively deteriorating environmental conditions.

To do that, we derive a theoretically-grounded gravity equation, consistent with the structural gravity model (Anderson, 2011), closely following Gröschl and Steinwachs (2017) in the introduction of environmental variables in the gravity setting. The analysis uses the “Sex-disaggregated 5-year internal and international interregional migration flow estimates” dataset, representative of the period 2005-2010, produced using microdata from the IPUMSI census and data on bilateral migrant stocks disaggregated by sex from UNDESA (Ceausu et al., 2021; Abel and Cohen, 2022).

This new data enables us to make two contributions to the existing literature:

- first, our analysis allows us to assess the *gender* responses to environmental shocks and to identify the vulnerabilities of male and female migrants across countries also in light of gender disparities;

- second, the inclusion of internal flows allows to address the *distance puzzle*, which in trade involves measuring the effects of distance on international trade versus its effects on domestic trade. In the context of migration, the inclusion of internal migration accounts for the effects of internal factors influencing international movements of migrants. Furthermore, it offers a more precise understanding of the factors driving international migration.

In summary, our analysis contributes to filling a gap in the existing scientific literature on environmental migration by providing evidence that supports the significant impact of environmental events on migration patterns, with a specific emphasis on gender-specific responses.

2 Literature review

2.1 Literature review on environmental migration

The literature on the effects of climate and natural disasters on migration finds evidence of a direct or indirect impact of environmental factors on migration patterns, either

internally or internationally, according to many specific historical and development-related factors (Barrios, Bertinelli, and Strobl, 2006; Gray and Mueller, 2012b; Gray and Mueller, 2012a; Marchiori, Maystadt, and Schumacher, 2012; Beine and Parsons, 2015; Drabo and Mbaye, 2015; Beine and Parsons, 2017; Braun, 2023; Berlemann and Tran, 2020). While climate change does play a role in migration, the impact varies significantly based on specific area characteristics (such as historical temperature and rainfall patterns) and individual factors (including gender, age, and rural/urban residence). This reveals non-linear relationships and diverse outcomes, as highlighted in UNHCR (2021) and Braun (2023).

Climate change primarily leads to internal migrations and urbanization rather than international displacements, as indicated by Gray and Mueller (2012a), Gray and Wise (2016), and Thiede, Gray, and Mueller (2016). Conversely, in macroeconomic studies, other authors show that natural disasters have a limited impact on international migration (Halliday, 2006; Naudé, 2010; Gray and Mueller, 2012b; Drabo and Mbaye, 2015; Koubi et al., 2016; Berlemann and Tran, 2020). Then, environmental shocks do not uniformly result in increased migration rates for all individuals; their influence on migration varies among different demographic groups.

Within the large empirical literature on environmental migration, our work is related to the growing literature estimating the factors influencing environmental migration using a gravity framework.

Even before the seminal contribution of Tinbergen (1962) on trade, the pioneer in using the gravity equation to model migration patterns is Ravenstein (1889) (see De Benedictis and Taglioni (2011) for a historical account). Gravity equations used to estimate migration flows have theoretical foundation based on micro models of choice and, in recent times, have been increasingly applied (Beine, Bertoli, and Fernández-Huertas Moraga, 2016; Beine, Docquier, and Özden, 2011; Bertoli and Moraga, 2013; Bertoli and Moraga, 2015; Grogger and Hanson, 2011), thanks to the increasing availability of dyadic data on bilateral stocks of migrants, often used to proxy flows of migration.

Most gravity models of migration rely on a Random Utility Maximization (RUM)

setup, based on the Roy-Borjas model (Roy, 1951; Borjas, 1987), to describe migration as a location decision choice of individuals in an origin i facing a set of destinations j with specific utilities and costs. By assuming an i.i.d. extreme value type I distribution (McFadden, 1973), the model estimates the probability that an individual will choose a specific destination j over any other potential destination while maximizing their utility (Beine, Bertoli, and Fernández-Huertas Moraga, 2016).

The first attempt to use gravity models for environmental migration is Afifi and Warner (2008), in which *naive* gravity equation is used to estimate a battery of 13 theory-established determinants and 13 environmental variables.³ While this approach provided insights into the influence of various factors on bilateral migration flows, the specification does not take into account what has been called in literature *multilateral resistance terms* (MR) (Bertoli and Moraga, 2013). These terms account for the impact of third destinations in influencing migration choices. The gravity literature emphasizes that the flow of individuals between two countries does not depend solely on the attractiveness of those two countries but also on how these two countries relate to the opportunities offered by other potential destinations. In the context of the trade literature, neglecting to consider alternative partners (destinations in the case of migration) has been regarded as a *gold medal mistake* in gravity specifications, resulting in biased estimates (Baldwin and Taglioni, 2006; De Benedictis and Taglioni, 2011). This limitation also affected the model developed by Alexeev, Good, and Reuveny (2011). However, their model introduces interaction terms between weather-related disasters and some of the canonical determinants, assuming that the impact of disasters might vary depending on a country's economic and political capacity to handle such impact.⁴

In assessing climate factors' impact on international migration to OECD countries, many influential contributions utilize RUM-based gravity models, focusing on wage differentials and migrant networks (Grogger and Hanson, 2011; Beine, Docquier, and Özden,

³ The definition of *naive* gravity is introduced in Head and Mayer (2014) to describe non-structural gravity equations, with the intent to point out potential bias for the negligence of structural parameters such as multilateral resistance terms.

⁴ Alexeev, Good, and Reuveny (2011) do so by including interactions with GDP per capita and foreign aid.

2011). Beine and Parsons (2015) use a gravity model to indirectly estimate the impact of wages on international migration, revealing different effects of gradual factors and environmental shocks based on country characteristics. An important feature of this contribution is to also include South-South migration, which has often been overlooked when studying only OECD destinations. The results indicate a non-significant impact of rainfall deficiency, while natural hazards show some stimulation of rural-urban mobility. MR terms in Beine and Parsons (2015) are not modeled in the theoretical framework, however, the authors argue that including destination time-varying fixed effects completely controls for inward MR terms, and the structure of a large panel has been proven to provide similar results to the estimation with the full set of theoretically-consistent origin-time fixed effects.⁵ In their 2017 follow-up paper (Beine and Parsons, 2017), the authors refine their strategy, introducing a richer set of fixed effects and excluding explicit origin-specific variables. The revised results demonstrate different responses conditioned by income levels and highlight the emergence of financial constraints in poorer countries, where climate shocks have a greater influence on financial constraints than on the desire to move. Natural disasters discourage emigration but especially encourage it towards neighboring countries and, for middle-income origins, discourage emigration and promote emigration towards former colonizing countries.

The first attempt to apply a structural approach to gravity models of migration is introduced in a seminal contribution by Anderson (2011). Gröschl (2012) adapts the structural model in general equilibrium proposed by Anderson, introducing aggregated disasters at origin and destination. The frequency of disasters at origin and destination are introduced in the utility maximization function of an individual, to obtain a tractable gravity equation that takes into account MR terms (derived from a Taylor expansion à la Baier and Bergstrand (2009)). Conditional models and a set of robustness checks account for various sources of heterogeneity and obtain evidence of migration being considered as an adaptation strategy to climate change, particularly evident in the case of middle-

⁵ The empirical model is estimated with a maximum Pseudo-Poisson probability according to Silva and Tenreyro (2006), an estimation strategy that allows taking into account a large number of zeros in the dependent variable.

income countries affected by weather-related events rather than geophysical disasters.

2.2 Literature review on gender migration

Our work is also related to the scant literature focusing on how gender-related factors impact migration patterns. In the context of environmental migration, gender plays a crucial role, similar to other forms of migration. Indeed, the vulnerabilities, experiences, needs, and priorities of environmental migrants differ depending on the contrasting roles, responsibilities, access to information and resources, education, physical security, and employment opportunities available to women and men (IOM, [2014](#); IOM, [2021](#)).

Recently, the literature on gender and migration has shed some light on the complex and gender-specific nature of migration experiences and outcomes. The study of gender has taken on a pivotal role in many areas of applied economics (Croson and Gneezy, [2009](#); Alesina, Giuliano, and Nunn, [2013](#); Grogger and Hanson, [2011](#); Duflo, [2012](#); Li, [2021](#)), in the field of migration, the literature emphasizes the importance of understanding and addressing challenges and opportunities faced by migrant women and the need for policies and interventions that respond to their specific needs (Pedraza, [1991](#)). Similar to men, women may migrate for better job opportunities, to reunite with family members, or to escape conflict or persecution in their home country. However, women may experience discrimination or exploitation in the workplace or encounter added obstacles in accessing education, healthcare, or other services in certain countries, thus making migration to countries with greater gender equity a more feasible option. Moreover, the literature on gender and migration highlights the importance of intersectionality (Anthias, [2012](#); Bastia, [2014](#); Domaas, [2021](#)), which examines how gender interacts with other social identities such as race, ethnicity, or nationality. For example, women from marginalized communities may face additional challenges and barriers during the migration process.

The influence of environmental changes on migration flows varies among different demographic groups. In the research conducted by Thiede, Gray, and Mueller ([2016](#)), their focus was on internal migrations within seven major Latin American countries. They observed that climatic changes, particularly variations in temperatures, play a role in

promoting migration rather than confining populations to their original areas. However, it's important to note that the overall impact of these climatic changes varies significantly due to specific area characteristics, such as historical temperature and rainfall patterns, as well as individual factors like gender, age, and whether people reside in rural or urban areas (Gray and Wise, 2016). A study conducted by Ruysen and Sara (2018) explores the link between perceptions of gender discrimination and the intention to emigrate, with a particular focus on differences between men and women. The study highlights that women, and to a lesser extent men, are more likely to declare the intention to emigrate if they perceive that women are not treated with respect. However, the authors note that neither men nor women are more likely to initiate preparations to move abroad in response to perceived hostility towards women. This suggests that, despite the perception of discrimination, migratory behaviors do not change significantly. Other factors, such as economic growth, could influence perceptions of discrimination beyond the institutional quality of a country and could also be causes of migration. Neumayer and Plümper (2021) find that the absence of economic, social and cultural rights for women in countries of origin may contribute to the gender gap in migration to Germany. However, it is noted that an increase in economic rights in the country of origin is associated with greater female migration. Recently, a study by Gutmann, Marchal, and Simsek (2023) examined the effects of differences in rights (i.e., institutional quality) between two populations in the same country on the differences in their propensity to emigrate, focusing on the gender migration gap. The authors find that greater equality in economic and political rights exacerbates the gender migration gap. The result is consistent across middle- and high-income countries. However, in low-income countries of origin, improving gender equality narrows the gap, as it provides women with the financial means to emigrate. The study addresses issues of endogeneity and contributes to the literature on female migration and the impact of institutions on migration. The authors suggest that strengthening individual rights in low-income countries could inadvertently increase emigration rates, and policymakers should be prepared for these side effects.

We take stocks of these contributions in building a simple RUM model and in

structuring the empirical analysis.

3 Theoretical model

The model draws on Anderson (2011) structural model and closely follows Gröschl and Steinwachs (2017) in the introduction of environmental variables in the gravity setting.

Based on the gender migration model by Gutmann, Marchal, and Simsek (2023), the model starts from an individual $g = f, m$ (for female and male) born in country i who decides whether to migrate to another country j in the set of possible destinations $k = 1, \dots, D$ or stay in the origin country i . The decision derives from utility maximisation that takes into account expected income at the destination (as in standard canonical migration literature), the costs of moving to another country and the evaluation of the level of *risk* in the country of origin and potentially in the destination. Additionally, individuals have their preferences toward migration, unobservable for the econometrician. Individuals also have a certain degree of risk aversion that affects their decision. In simple terms, individual of each gender g decides to migrate if $(w_{gj}/C_{gij}R_j)\varepsilon_{gij} > w_{gi}/R_i$, where w_{gj} is the gender-specific deterministic component (or gross utility) derived from living in the country j , w_{gi} is the gender-specific income at origin, C_{gij} are the gender-specific costs of migrating from i to j (with $C_{gii} = 0$), R_j and R_i are the random environmental shocks respectively at destination and origin. Assuming the expected utility as a logarithmic constant relative risk aversion function,⁶ in which the parameter σ captures a measure of elasticity of substitution that can be also interpreted as a risk aversion parameter, utility can be expressed as:

$$u_{gij} = (1 - \sigma)\ln w_{gj} - (1 - \sigma)\ln C_{gij} - (1 - \sigma)\ln R_j - (1 - \sigma)\ln w_{gi} + (1 - \sigma)\ln R_i + \varepsilon_{gij} \quad (1)$$

Following the assumptions in McFadden (1973) and McFadden (1984) on the unobservable term ε_{gij} (i.i.d. extreme value type I), individuals can be aggregated up to a representative

⁶ The specification of the utility function has been used also in Gröschl and Steinwachs (2017), from which the choice is drawn. However, this particular utility function produces similar tractable gravity equations as canonical RUM model (Gröschl and Steinwachs, 2017).

individual and derive the probability that individual of each gender g living in the country i will move to the country j over all other alternatives $k \in D$ that maximises his utility as:

$$P(u_{gij}) = Pr[u_{gij} = \max_k u_{gik}] = \frac{e^{u_{gij}}}{\sum_k^D e^{u_{gik}}} \quad (2)$$

Assuming that the aggregated level of discrete choice represents the probability of migration flows from i to j , flows can be represented as the share of the native population multiplied by the probability of migration of the representative individual:

$$M_{gij} = P(u_{gij})N_{gi} \quad (3)$$

where N_{gi} is the total population originating from i for each g . Following Gröschl and Steinwachs (2017), we build a cost-risk measure combining the components of shock and costs in the utility function, $\theta_{ij} = C_{ij}R_j/R_i$, which can be decomposed at any moment. Thus, Equation 3 can be rewritten as:

$$M_{gij} = \frac{(w_{gj}/\theta_{ij})^{1-\sigma}}{\sum_k (w_{gk}/\theta_{ik})^{1-\sigma}} N_{gi} \quad (4)$$

Taking $\Omega_{gi} = \sum_k^D (w_{gk}/\theta_{ik})^{1-\sigma}$ and defining the market clearing condition $N_{gj} = \sum_i M_{gij}$,⁷ meaning that labour demand at destination equals the labour force supplied to j from all origins i (including j itself), Equation 4 can be rewritten as:

$$N_{gj} = w_{gj}^{1-\sigma} \sum_i \frac{\theta_{ij}^{1-\sigma}}{\Omega_{gi}} N_{gi} \quad (5)$$

from which the equilibrium wage at the destination is derived:

$$w_{gj}^{1-\sigma} = \frac{N_{gj}}{\sum_i \theta_{ij}^{1-\sigma} / \Omega_{gi}} N_{gi} \quad (6)$$

with $\Omega_{gj} = \sum_i \frac{\theta_{ij}^{1-\sigma}}{\Omega_{gi}} \frac{N_{gi}}{N}$ the equilibrium wage is $w_{gj}^{1-\sigma} = \frac{N_{gj}}{\Omega_{gj}N}$.

⁷ Assuming a rigid labour demand at destination (Bertoli and Moraga, 2017).

These steps yield the formulation of a tractable gravity equation:

$$M_{gij} = \frac{N_{gi}N_{gj}}{N_g} \left(\frac{\theta_{ij}}{\bar{\Omega}_{gi}\bar{\Omega}_{gj}} \right)^{\sigma-1} \quad (7)$$

where the inward migration friction (multilateral resistance term) is

$$\bar{\Omega}_{gj} = \left[\sum_i \frac{\theta_{ij}^{1-\sigma}}{\Omega_{gi}} \frac{N_{gi}}{N_g} \right]^{1/(1-\sigma)} \quad (8)$$

and the outward migration friction is

$$\bar{\Omega}_{gi} = \left[\sum_j \frac{\theta_{ij}^{1-\sigma}}{\Omega_{gj}} \frac{N_{gj}}{N_g} \right]^{1/(1-\sigma)} \quad (9)$$

In Equation 7 the first part represents a frictionless migration by gender h , in other words, it is the probability of finding migrants originating in i of gender h in the country j proportional to their share of the world population (note: $M_{gij}/L_{gj} = N_{gi}/N_g$). The second term of Equation 7 contains important theoretical parameters: $\bar{\Omega}_j$ is the inward multilateral resistance term (IMRT) as specified in Equation 8. It is analogous to IMRTs defined in trade literature, which can be interpreted in the case of migration as the barriers for all migrants to destination j irrespective of their origin. The IMRT aggregates all the barriers to *immigration* from a hypothetical origin world to destination j . $\bar{\Omega}_i$ is the outward multilateral resistance term (OMRT) as specified in Equation 9. Similarly to the other, it can be interpreted as the barriers for all migrants from origin i to migrate irrespective of their destination. The OMRT aggregates all outward barriers to *emigration* to a hypothetical destination world. IMRT and OMRT are general equilibrium concepts because their solution in the simultaneous system involves every bilateral migration cost in the world.

To make the impact of random shocks visible in the gravity equation of migration, we decompose θ_{ij} following Gröschl and Steinwachs (2017):

$$M_{gij} = \frac{N_{gi}N_{gj}}{N_g} \left(\frac{\chi_{ij}}{\bar{\Omega}_{gi}\bar{\Omega}_{gj}} \right)^{1-\sigma} \left(\frac{R_i}{R_j} \right)^{1-\sigma} \quad (10)$$

Equation 10 predicts that flows are expected to decrease for higher migration costs (χ_{ij}) and for larger the random shock in the destination country (R_j), and to increase for larger the shock in the origin (R_i).

4 Empirical specification

To perform our empirical analysis, we built a dataset including internal migration flows and bilateral data on international migration flows of 117 countries over the period 2005-2010. Since, migrations are not homogeneous through time and tend to come in waves, our model does not take into account the time dimension and only considers cross-sectional observations referred to the five-year period, for which data are available.

A well-known problem prompted by bilateral data is the presence of a consistent number of zeros. Indeed, in our sample, the percentage of non-linked dyads ij of countries is 54 percent. A strategy to deal with the presence of zeros, proposed by Silva and Tenreyro (2006) and suggested in recent empirical analyses (Yotov et al., 2016), is to estimate the gravity model Equation 10 in multiplicative form using a PPML estimator:

$$M_{gij} = \exp[\alpha + \beta \text{GRAVITY}_{ij} + \gamma_g + \delta_1 \ln(R_i) - \delta_2 \ln(R_j)] \times \epsilon_i. \quad (11)$$

The dependent variable M_{gij} refers to both internal and international migration of individuals of gender g from country i to the country j over the period 2005-2010, the vector of bilateral costs, GRAVITY_{ij} , is composed by well-recognized covariates canonically introduced in the gravity literature, as the logarithm of the weighted distance between country i and j ; the logarithm of the origin and destination nominal GDP; a dummy for shared border between i and j ; a dummy for common official language between i and j ; a dummy for colonial ties between i and j ; and finally, a dummy for common religion between i and j . For all gravity controls, we take the average value over the period 2005-2010. The dummy γ_g distinguishes the migration flow by gender g . For natural disasters controls, R_i and R_j , we take the frequency (count of events that occurred in the area) of environmental shocks with a one-year lag (over the period 2004-2009), focusing on fast-onset events, which

can be also defined as natural hazards or extreme events, such as: *biological* (animal accident; epidemic; insect infestation); *climatological* (droughts or wildfires); *geophysical* (earthquakes, mass movements, volcanic eruptions), *hydrological* (floods and landslides); *meteorological* (extreme temperature, storms - cyclones, typhoons, hurricanes, tropical storms, tornadoes).

The inclusion of domestic data is crucial for estimating a structural gravity model. The structural gravity model allows a comprehensive view of migration patterns, and including internal migration data provides essential insights into the overall movement of populations. In trade literature, the use of domestic trade flows in gravity estimations is a well-established practice (Yotov et al., 2016). Various influential studies have employed domestic trade data to measure the impact of international borders and assess the ‘home bias’ in trade (Yotov, 2022). Indeed, the inclusion of domestic migration data in the gravity model for migration bears similarities to the rationale behind incorporating intra-national trade data in structural gravity estimations. Analogous to the reasons for trade, there are several compelling arguments supporting the incorporation of internal migration flows into the gravity model for migration.

Firstly, mirroring gravity theory in trade, individuals often choose among and move to domestic as well as foreign locations. Just as consumers select both domestic and foreign varieties in trade, migrants may decide between locations within their home country and those in other countries. Including domestic migration in the model ensures consistency with this fundamental aspect of migration behavior.

Secondly, the inclusion of intra-national migration contributes to the theoretically consistent identification of the effects of various factors. In the trade context, understanding the impact of bilateral trade policies is crucial, and similarly, in migration, policies or other shocks affecting movement within a country are important to consider.

Third, solving the *distance puzzle* in trade means studying how distance affects international trade versus its impact on domestic trade. Likewise, analysis that includes migration allows for an in-depth investigation of how distance influences migration patterns within and between countries.

The domestic flow in our analysis enables the identification of the effects of environmental shocks on international migration flows versus affected destinations, in the presence of importer and exporter fixed effects. This is because such environmental shocks apply only to international flows, while the fixed effects are defined for both international and intra-national observations.

However, with country-fixed effects, a variety of potentially interesting determinants can no longer be identified and estimated in a gravity equation, as those will be absorbed by them (Head and Mayer, 2014). To inflate our specification including a set of dummies for origin and destination countries, we introduce a bilateral measure to capture the impact of differences in natural disaster occurrence between i and j . We take the *Helpman similarity index* expressed as:

$$H_{ij} = 1 - \left(\frac{R_i}{R_i + R_j} \right)^2 - \left(\frac{R_j}{R_i + R_j} \right)^2 \quad (12)$$

When two countries have similar levels of environmental risks, the value of this index is high. In contrast, when two countries have dissimilar levels of environmental risks, the value of this index is low. We expect that people migrating in response to an environmental shock in the home country moves to another country under the condition $R_i \geq R_j$. To distinguish the cases in which the similarity index takes on the same value, whether the origin or destination country has experienced more shocks, and to emphasize the condition $R_i \geq R_j$, we multiply the *Helpman similarity index* for the variable that measures the natural disasters in country j . Therefore, we estimate the following equation:

$$M_{gij} = \exp[\gamma_i + \gamma_j + \gamma_g + \beta \text{GRAVITY}_{ij} - \delta_1 (H_{ij} \times R_j)] \times \epsilon_i \quad (13)$$

The inclusion of fixed effects for origin γ_i and destination γ_j countries enable us to control for any other observable or unobservable characteristics, as well as missing or imperfectly measured variables. The term $(H_{ij} \times R_j)$ relies on the assumption that our variable of interest affects only international flows allowing us to identify the effects of

random environmental shocks on migration flows across borders, in addition to geography, while distinguishing between internal and international flows. Indeed, the estimated coefficient of this term indicates whether international migration occurs between countries with similar risk levels or between different risk levels.

Our strategy is motivated by two reasons. Firstly, the aim is to investigate whether flows occur between countries with different levels of environmental risk. The underlying assumption is that people from highly risky countries may decide to migrate to countries with a lower level of risk to minimise both the hazards and not-hazard-related risks. Conversely, it may also predict that people move between equally or similarly risky countries: this might happen in a variety of cases, for example following sudden outbreaks of natural hazards or conflicts, or because of restrictive entry policies in wealthier (and less risky) countries. Thus, the term $(H_{ij} \times R_j)$ tests the hypothesis that the international migration to countries with similar random shocks is lower.

Furthermore, we interact the dummy of gender, γ_g , with the shocks to investigate the differential response of men and women to environmental shocks. The second reason that led to this choice is also motivated by the fact that considering risk at origin and destination separately would make them enter the equation as country-specific covariates. This would create a problem with a theory-consistent estimation: in fact, a structural gravity equation must be estimated including fixed effects which allows for controlling multilateral resistance terms, which are essential theoretical tools to take into account alternative destinations. Introducing a bilateral index, resulting from the combination of values of risks at both sides of the flow, allows us to obtain correct estimates of gravity. However, it implies the impossibility of investigating the directions and role of country-specific levels of risk in the determination of flows.

Another potential issue is represented by the interdependence of countries. Dyadic observations typically violate the assumptions of independence of observations, so that it is impossible to rely on the assumption of i.i.d. stochastic term. One solution is to use the robust standard errors, but they may not be sufficient to correct. At the country-pair level, may exist some clustering. Therefore, errors are clustered by symmetric country-

pairs (De Benedictis and Taglioni, 2011).

5 Data

To perform the empirical analysis of the theoretical model presented above, we used the “Sex-disaggregated 5-year internal and international Interregional migration flow estimates” (Ceausu et al., 2021) dataset representative of the 2005-2010 period, produced using IPUMSI census microdata (collected during the 2000 and 2010 round of censuses) and UNDESA sex-disaggregated bilateral migrant stock data (2017 Revision).⁸

The dataset provides estimates on internal and international migration using *interregional* migration flows, defined as the migration flows between sub-national administrative units located within the same country. Data are disaggregated by gender, g , for each unit of observation.

The methodology of the estimates in the dataset follows the definition of internal migrants as all the individuals that reside in a different administrative unit of the same country compared to their usual residence. Similarly, international migrants are those who reside in an administrative unit of another country compared to their country of origin. The estimates represent 5-year migration flows spanning from 2005 to 2010.

Our analysis exploits the dataset at a national level, by aggregating administrative regions at a country level. The aggregation results in a 121×121 matrix of dyadic flows by gender g from a country of origin i to a country of destination j (M_{gij}), allowing j to correspond to i (loop) to account for internal migration (M_{gii}). The motivation comes from the novel opportunity provided by this dataset to use internal migration flows to measure the impact of natural disasters on overall migration. Including internal flows allows control for all forms of migration, not limiting to cross-border flows. This results in including the probability that in the case of those events, migration might likely occur within a country and people might move or be displaced in nearby regions. As already highlighted by the literature (Beine and Parsons, 2017), hazard- or climate-

⁸ This work was produced as a collaboration between WorldPop, Flowminder and the Asian Demographic Research Institute (ADRI). See also Abel and Cohen (2022).

related migration likely occurs at a regional level, between neighbouring countries, or within the same country, especially in light of the sudden unpredictable feature of some of the events. In line with previous findings, the present analysis will also find evidence of this reaction. It is important to point out that, unlike several previous analyses, the data hereby used contain measures of flows of migration. Due to data unavailability, data on stocks have often been used in studies requiring dyadic observations, with the non-negligible difference that stocks of migrants describe the cumulative presence of foreign-born in a country, while flows can capture the number of people moving from a place to another in the specific time window considered (actual *emigration* and *immigration*).

Migration data have been merged with data on natural disasters. The most reliable and complete dataset for natural disasters is the Emergency Events Database (www.public.emdat.be),⁹ compiled by the Centre for Research on the Epidemiology of Disasters (CRED),¹⁰ which contains 22,000 mass disasters from 1900 to the present day. Observations have been grouped to match the time window in Ceausu et al.’s dataset, aggregating the number of disasters by type (as shown in Table 1) and by the total number. In this way, we obtained a measure of the frequency of hazards by country for the 5-year period. Occurrence and frequency of natural hazards are the most common tools used by the literature to relate disasters to migration determinants.

⁹ Access date: May 23th, 2023.

¹⁰ CRED is part of the School of Public Health of the Université Catholique de Louvain (UCL). CRED launched the EM-DAT in 1988, with the support of the World Health Organization and the Belgian government. EM-DAT is compiled from various sources, according to their rank in terms of reliability: UN agencies (OCHA, WHO, WMO, FAO, etc.), national governments, US agencies (NOAA, USGS, etc.), inter-governmental organisations (World Bank) and insurance companies. www.emdat.be.

Table 1: Classification of natural hazards

Category	Definition [variable]	Type of hazard
Geophysical	Hazard originating from solid earth [H_Geo]	Earthquake Mass movement (rock fall, landslide) Volcanic activity.
Meteorological	Hazard caused by short-lived extreme weather and atmospheric conditions that last from minutes to days [H_Meteo]	Storm (tropical and extra-tropical storm, convective storm) Extreme temperature (cold wave, heat wave, severe winter) Fog
Hydrological	Hazard caused by the occurrence, movement, and distribution of water [H_Hydro]	Flood Landslide (wet) Wave action
Climatological	Hazard caused by atmospheric processes ranging from intra-seasonal to multi-decadal climate variability [H_Clima]	Drought Glacial lake Wildfire
Biological	Hazard caused by other causes, such as exposure to toxic substances, vector-borne diseases carried by living organisms [H_Bio]	Animal accident Epidemics Insect infection

Note: Classification made within the framework of the EM-DAT (*Emergency Events Database*) developed by the Centre for Research on the Epidemiology of Disasters (CRED). <https://www.emdat.be>

The model presented takes into account a set of additional variables that enter the model to explain the determinants of flows. Gravity equations traditionally include geographical and cultural linkages. The empirical literature has extensively tested the negative effect of distance and the positive effect of being a neighbouring country to determine the direction of flows. The model introduces also three measures of dyadic cultural linkages between origins and destinations: colonial history, sharing the same language and the same religion exert additional effect to determine bilateral flows (Beine, Bertoli, and Fernández-Huertas Moraga, 2016). The additional gravitational variables (*Distance*, *Contiguity*, *Language*, *Colony* and *Common religion*) are taken from CEPII's Gravity Dataset.¹¹

To test the hypothesis that women living in countries with higher gender inequality may face more challenges and limitations in terms of accessing education, employment, and other opportunities, and then migrate less we collected data on the Gender Inequality Index (GII) by country from UNDP (2022).¹²

The **GII** is a composite metric of gender inequality that combines measures on

¹¹ Centre d'Etudes Prospectives et d'Informations Internationales, http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=8.

¹² Available at <https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII>.

reproductive health, empowerment, and the labour market. A lower GII value indicates a smaller gap between women and men, while a higher value suggests increased inequality. In our analysis we split the sample (using the median) by the value of GII, the female population with at least some secondary education, % ages 25 and older (F_EDU) and the female labour force participation rate, % ages 15 and older (F_LFP).

In Appendix A, we provide descriptive statistics of the main variables in our dataset used in the empirical analysis.

6 Discussion of Results

A first attempt to include risk measures to estimate the impact of environmental events on migration flows is made through a *naïve* gravity equation without including fixed effects, as a preliminary estimation to investigate the direction of the impact. Results show that controls for disasters at origin, i , are always positive and statistically significant as expected, meaning that at higher environmental shocks correspond higher incentives to migrate; while coefficients of disasters at destination, j , are negative implying that with higher environmental shocks at destination retaining people to choose a specific country as destination (see showed Table B1 in Appendix B).

Our baseline model, Equation (13), is estimated including the *Helpman similarity index*, as defined in Equation (12), and country-fixed effects to control for missing and/or imperfectly measured variables. For a better understanding of female migration patterns, we add the dummy `INTL_female` equal to one for international flows of females, and zero otherwise, and the dummy `INTRA_female` equal to one for domestic movements of females, and zero otherwise. This allows us to capture the differing migration preferences and decisions between women and men, internally and internationally. The results, shown in Table 2, provide robust insights into the impact of environmental shocks.¹³

First of all, the signs of the covariates of the traditional gravity variables are in line with what is generally expected in the literature. Distance consistently exhibits

¹³ The controls for disasters are the frequency of hazards by country in the previous period. A robustness analysis of lags used for the disasters is in Appendix C.

a negative and statistically significant coefficient, indicating that as distance increases, flows tend to decrease. Contiguity of countries enhances the probability of flows (as observed in Columns 2-6), and the positive coefficients of the language dummy and the religious proximity suggests that people are more likely to move towards regions that share the same language and religion (even if coefficients are not statistically significant). Additionally, the positive coefficients of colonial links imply that historical ties play a significant role in determining international migration flows.

Table 2: Helpman similarity index

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(\text{Distance}_{ij})$	-2.724*** (0.122)	-2.590*** (0.101)	-2.571*** (0.101)	-2.573*** (0.102)	-2.597*** (0.102)	-2.553*** (0.101)
Contiguity_{ij}	-0.047 (0.158)	0.050 (0.165)	0.077 (0.164)	0.074 (0.164)	0.061 (0.162)	0.102 (0.164)
Language_{ij}	0.113 (0.210)	0.064 (0.199)	0.071 (0.199)	0.080 (0.200)	0.092 (0.201)	0.068 (0.200)
Colony_{ij}	1.114*** (0.258)	1.176*** (0.274)	1.148*** (0.278)	1.097*** (0.261)	1.114*** (0.268)	1.154*** (0.301)
$\text{Common religion}_{ij}$	0.271 (0.219)	0.087 (0.218)	0.059 (0.217)	0.055 (0.217)	0.006 (0.216)	0.065 (0.217)
INTRA_female	-0.090*** (0.027)	-0.093*** (0.027)	-0.094*** (0.027)	-0.094*** (0.027)	-0.094*** (0.027)	-0.094*** (0.027)
INTL_female	-0.567*** (0.086)	-0.488*** (0.081)	-0.486*** (0.082)	-0.489*** (0.082)	-0.487*** (0.082)	-0.489*** (0.083)
$H_{ij} \times R_j$	-0.305*** (0.097)					
$\text{INTL_female}*(H_{ij} \times R_j)$	0.100*** (0.030)					
$H_Bio_{ij} \times R_j$		-0.125*** (0.022)				
$\text{INTL_female}*(H_Bio_{ij} \times R_j)$		0.018** (0.008)				
$H_Clima_{ij} \times R_j$			-0.131*** (0.023)			
$\text{INTL_female}*(H_Clima_{ij} \times R_j)$			0.018** (0.008)			
$H_Geo_{ij} \times R_j$				-0.132*** (0.023)		
$\text{INTL_female}*(H_Geo_{ij} \times R_j)$				0.019** (0.008)		
$H_Hydro_{ij} \times R_j$					-0.153*** (0.029)	
$\text{INTL_female}*(H_Hydro_{ij} \times R_j)$					0.022** (0.010)	

H_Meteo _{ij}						-0.151*** (0.025)
INTL_female*(H_Meteo _{ij} × R _j)						0.021** (0.010)
Constant	31.283*** (0.764)	30.461*** (0.634)	30.344*** (0.632)	30.355*** (0.637)	30.501*** (0.639)	30.232*** (0.634)
Observations	25,312	25,312	25,312	25,312	25,312	25,312
R ²	0.967	0.968	0.968	0.968	0.968	0.968
Country <i>i</i> and <i>j</i> fixed effects	yes	yes	yes	yes	yes	yes

Note: The dependent variable is the domestic and international migration flow by gender *g* from country *i* to country *j* over the period 2005-2010. Helpman indexes are lagged 1 year (period 2004-2009). Robust standard errors clustered by country pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Country fixed effects are included (unreported).

Turning to our variable of interest, the results reported in Table 2 show that women tend to migrate less than men, both within their own country and across international borders. Notably, the coefficient of the dummy variable `INTRA_female` indicates the internal movement of females as a proportion of the total male flows (excluding international female flows), while the coefficient of the dummy variable `INTL_female` denotes the proportion of international female migration in relation to the overall migration of males, excluding internal female migration.

The lowest negative and statistically significant coefficient of the `INTL_female` dummy variable suggests that women migrate less internationally. This is likely due to various factors that make it more difficult for women to migrate abroad.

In the extreme case of the highest value of $(H_{ij} \times R_j)$, both the source and destination countries experience equivalent environmental shocks. Conversely, in the opposite scenario where the index equals 0, country *i* and country *j* have vastly different levels of exposure to environmental shocks (in the most extreme scenario, one country is highly susceptible to environmental hazards while the other faces no risk at all), leading to greater migration flows between countries with different levels of exposure to environmental hazards.

The variable $(H_{ij} \times R_j)$ in Column (1) of Table 2 refers to the occurrence of any disasters without distinguishing by type. In the other Columns, variables for specific disasters are added.

When considering all disasters (Column 1), $(H_{ij} \times R_j)$ shows a negative and statistically

significant coefficient (-0.305). This result confirms the idea that people in countries differing in vulnerability to environmental shocks are more inclined to migrate. In other words, individuals are more likely to migrate when their home country significantly differs from their destination country in terms of environmental vulnerability.

Examining specific events, this result holds across all types of events, especially for *Hydrological* and *Meteorological* disasters, where coefficients are higher (in absolute terms) and equal to -0.153 and -0.151, respectively.

An interesting finding is that the interaction terms between the Helpman indices and the *gender* dummy variable for females are always positive and statistically significant. This indicates that the gap in international migration between males and females decreases by 0.100 in countries with similar environmental risk levels. Therefore, the responsiveness in seeking safer or more stable environments is more similar between genders.

This pattern is observed for all kinds of events. However, motivations for migration can vary depending on the type of environmental event. For example, the decision to migrate in response to a biological event might be driven by health concerns, while migration in response to climatological events could be motivated by factors such as resource scarcity or changing agricultural conditions. Consequently, biological events like pandemics can disrupt healthcare systems and economies, potentially impacting women and men more equally. On the other hand, climatological events, as well as hydrological or meteorological events, might affect agriculture and livelihoods, and these impacts could be less gender-specific.

These findings raise questions about the underlying factors contributing to this trend, which may involve gender-specific vulnerabilities or preferences in response to environmental risks.

To better understand female migration patterns and their responses to environmental shocks, we divided the sample based on the income levels of the countries of origin. Column 1 of Table 3 shows the result of the interacted model that includes the interaction term between the dummy `INTL_female` and the dummy `High_income` equal to 1 for migrants from high-income countries, and zero otherwise, while Columns 2-3 show the

results of the sample split by income.¹⁴

The results reported in Table 3 indicate that women tend to migrate less than men, both internally and internationally, regardless of the income level of the origin countries, even if the dummy `INTRA_female` is not statistically significant in the sample of migrants from low-income countries (Column 2).

Table 3: Results by income levels in origin countries

	(1) Interacted model	(2) Low income countries	(3) High income countries
<code>INTRA_female</code>	-0.091*** (0.027)	-0.075 (0.047)	-0.108*** (0.032)
<code>INTL_female</code>	-0.610*** (0.109)	-0.581*** (0.120)	-0.494*** (0.100)
$(H_{ij} \times R_j)$	-0.327*** (0.118)	-0.203* (0.118)	-0.339*** (0.102)
<code>INTL_female*(H_{ij} × R_j)</code>	0.120*** (0.039)	0.106*** (0.041)	0.032 (0.048)
<code>INTL_female*High_income</code>	0.174 (0.195)		
$(H_{ij} \times R_j)*High_income$	0.125 (0.135)		
<code>INTL_female*(H_{ij} × R_j)*High_income</code>	-0.114* (0.064)		
<code>Constant</code>	31.390*** (0.788)	32.538*** (1.425)	34.859*** (0.841)
Observations	25,312	15,904	9,408
Pseudo R^2	0.967	0.966	0.988
Country fixed effects	yes	yes	yes
Gravity controls as in Table 2	yes	yes	yes

Note: The dependent variable is the domestic and international migration flow by gender g from country i to country j over the period 2005-2010. Helpman indexes are lagged 1 year (period 2004-2009). Country-fixed effects and gravity controls are included (unreported). Robust standard errors clustered by country-pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Country groups are defined according to income levels from the World Bank classification. The sample *Low income countries* includes lower middle income countries and low income countries. The sample *High income countries* includes upper middle income countries and high-income countries.

When examining migration patterns between groups of countries categorized by

¹⁴ Gravity controls are incorporated in the estimations but are not presented in the Table due to space constraints. Nevertheless, the coefficients remain robust, and the complete tables are available from the authors upon request.

income levels (Columns 2 and 3),

Looking at the response to the environmental events (the coefficient of the variable $(H_{ij} \times R_j)$), we find a lower statistical significance in the case of migration from developing countries, which represents a greater proportion of our sample. On the other hand, the coefficient of the interaction with the gender dummy is consistently positive and statistically significant in columns 1 and 2. This implies that women appear to exhibit different patterns of migration behavior in response to environmental events compared to men, this is particularly true in developing countries. However, in developed countries, in contrast to developing countries, the response of women to the environmental shock is statistically significant only at the 10% level of confidence (see coefficient of the interaction `INTL_female*(Hij × Rj)*High_income`). This difference may be because, in developed countries, women's decisions regarding relocation are influenced by factors such as career considerations and financial independence. Therefore, there is no reason to expect different responses between men and women to a natural disaster.

To verify whether and how gender inequality in the origin country affects our results, we interact the dummy `INTL_female` with various measures of gender inequality, such as the Gender Inequality Index (`GII`), the female population with at least some secondary education (`F_EDU`), and the female labor force participation rate (`F_LFP`). The results in Table 4 show that gender inequality can affect female migration in various ways.

When considering the `GII` in origin countries (Column 1), the interaction term between the dummy variable `INTL_female` and the `GII` index is positive and statistically significant (1.095). This suggests that the international migration of women increases in countries with higher gender inequality. In such nations, women may encounter fewer economic opportunities and limited access to education and employment. Migration can be seen as a strategy to pursue better prospects and escape constraints imposed by gender-based discrimination. Moving to another country not only provides them with opportunities for better jobs but also allows them to seek environments where they perceive a higher level of personal safety and equal treatment.

Table 4: Sample spits based on measures of gender inequality in origin countries

	(1) GII _i	(2) F_EDU _i	(3) F_LFP _i
INTRA_female	-0.100*** (0.026)	-0.092*** (0.027)	-0.091*** (0.027)
INTL_female	-1.228*** (0.332)	-0.325** (0.140)	-0.130 (0.202)
(H _{ij} × R _j)	-0.784*** (0.265)	-0.388*** (0.137)	-0.004 (0.172)
INTL_female*(H _{ij} × R _j)	0.370** (0.172)	0.037 (0.051)	-0.054 (0.080)
INTL_female*GII	1.095** (0.546)		
(H _{ij} × R _j)*GII	0.716 (0.475)		
INTL_female*(H _{ij} × R _j)*GII	-0.434* (0.254)		
INTL_female×F_EDU		-0.008** (0.003)	
(H _{ij} × R _j)*F_EDU		0.003 (0.003)	
INTL_female*(H _{ij} × R _j)*F_EDU		0.002 (0.001)	
INTL_female×F_LFP			-0.010** (0.004)
(H _{ij} × R _j)*F_LFP			-0.008** (0.004)
INTL_female*(H _{ij} × R _j)*F_LFP			0.004 (0.003)
Constant	30.821*** (0.690)	31.392*** (0.783)	30.865*** (0.749)
N	22,176	22,400	24,864
pseudo R ²	0.969	0.967	0.968
Country fixed effects	yes	yes	yes
Gravity controls as in Table 2	yes	yes	yes

Note: The dependent variable is the domestic and international migration flow by gender g from country i to country j over the period 2005-2010. Helpman indexes are lagged 1 year (period 2004-2009). Country-fixed effects and gravity controls are included (unreported). Robust standard errors clustered by country-pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

However, in countries with a higher GII, the presence of a natural disaster exacerbates conditions for women. The coefficient of the interaction (INTL_female*(H_{ij} × R_j)*GII) is equal to -0.434, indicating a significant negative impact. This implies that the presence of a natural disaster intensifies constraints on women, making migration more challenging

for them in these circumstances.

When we consider the level of female education (Column 2), the interaction term between the dummy variable `INTL_female` and the female population with at least some secondary qualifications (`F_EDU`) is negative and statistically significant (-0.008). This suggests that education can empower women by influencing their decision-making processes. Such empowerment could lead to greater opportunities and the ability to make choices other than migration. However, levels of female education do not seem to limit economic opportunities for females, implying it might not necessarily shield them from economic vulnerabilities, especially in the context of natural disasters. Indeed, there is no discernible difference in the migration trend between women and men as a consequence of a natural disaster; thus, regardless of education levels, both genders exhibit similar migration patterns in response to natural disasters.

If we examine female employment levels (Column 3), as one might expect, women in countries with higher female labor force participation migrate less internationally; the interaction term `INTL_female × F_LFP` is negative and statistically significant (-0.010). The negative sign of the coefficient of the interaction term $(H_{ij} \times R_j) * F_LFP$, which is equal to -0.008, indicates that the presence of a natural disaster is associated with lower international migration flows in countries with higher rates of female participation in the workforce. Therefore, in countries where women are actively engaged in the workforce, individuals as a whole may be more resilient after a natural disaster and consequently migrate less internationally.

Moreover, greater female participation in the workforce makes women less vulnerable to the economic impacts of natural disasters.

The interaction coefficient (`INTL_female * (Hij × Rj) * F_LFP`) is positive and statistically significant (0.004), even if not statistically significant, implying that in the presence of a natural disaster, the gap between female and male migration flows tends to be smaller in countries where women face higher rates of labor force participation.

The breakdown of the sample based on the regions of origin of migrants (Table 5) reveals statistically significant differences in the migration flows of females compared

to males across most regions. The gap in international migration is more prominent in countries of the South Asia region and Sub-Saharan Africa, indicating that gender disparities in migration are heightened in these areas, likely due to regional socio-cultural factors, economic opportunities, or political stability.

Examining the migrants' response to environmental shocks, the estimated coefficients of the variable $(H_{ij} \times R_j)$ suggest that individuals from the Middle East, Africa (both North and Sub-Saharan), and South Asia are more responsive to such shocks. Hence, environmental factors play a role in migration decisions in these regions. However, a negative and statistically significant gap between genders is observed in South Asia and Sub-Saharan Africa, indicating a more pronounced response of females to environmental disasters in these specific regions.

Table 5: Sample splits by Regions of origin

	(1) East Asia & Pacific	(2) Latin Amer. & Caribbean	(3) Middle East & North Africa	(4) South Asia	(5) Sub-Saharan Africa
INTRA_female	-0.078** (0.039)	-0.009 (0.016)	-0.268*** (0.082)	-0.197*** (0.042)	-0.080 (0.061)
INTL_female	-0.264 (0.235)	-0.160** (0.064)	-0.236** (0.114)	-0.768*** (0.141)	-0.475*** (0.100)
$(H_{ij} \times R_j)$	-0.540** (0.245)	-0.144 (0.163)	-1.197*** (0.265)	-0.633*** (0.134)	-1.553*** (0.191)
INTL_female*($H_{ij} \times R_j$)	0.103 (0.119)	0.033 (0.028)	-0.461*** (0.175)	0.109*** (0.029)	0.186* (0.096)
Constant	34.539*** (1.795)	35.462*** (1.609)	28.756*** (1.647)	25.404*** (3.223)	25.801*** (0.893)
Observations	3,636	4,850	2,328	1,302	8,772
Pseudo R^2	0.987	0.989	0.957	0.980	0.969
Country fixed effects	yes	yes	yes	yes	yes
Gravity controls as in Table 2	yes	yes	yes	yes	yes

Note: The dependent variable is the domestic and international migration flow by gender g from country i to country j over the period 2005-2010. Helpman indexes are lagged 1 year (period 2004 -2009). Country fixed effects and gravity controls are included (unreported). Robust standard errors clustered by country pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample for Europe and Central Asia omitted for a few number of observations.

7 Conclusions

The article employs a structural gravity model to analyze migration patterns in response to environmental changes. The analysis incorporates both internal and international migration flows, allowing for better control of the *multilateral resistance terms* in a gravity model, enhancing the model’s theoretical coherence and providing a more nuanced understanding of migration dynamics.

The findings reveal that women tend to migrate less than men, both internally and internationally, potentially influenced by various factors that make it more difficult for them to move. Environmental shocks, especially hydrological and meteorological disasters, significantly impact migration flows. In particular, the analysis finds a negative correlation between the Helpman similarity index and migration, indicating that individuals migrate more when their country of origin differs significantly from their country of destination in terms of vulnerability. environmental.

An interesting finding is the negative interaction between the Helpman indices and the gender dummy, equal to 1 for women, which suggests that the gap between men and women is lower in movements towards countries with similar levels of risk.

When the analysis is extended by dividing the sample based on the income levels of the countries of origin, the results show that disparities between male and female migration are less pronounced in high-income countries. Women in high-income countries show a slightly higher propensity for international migration compared to women in low-income countries.

To assess the impact of gender inequality in countries of origin, the analysis considers the Gender Inequality Index (GII), the female education (F_EDU), and the female labor force participation rate (F_LFP). The results indicate that gender inequality influences female migration differently from male migration. Specifically, the positive and statistically significant interaction between `INTL_female` and `GII` suggests that female migration increases in countries with higher gender inequality. This implies that women may migrate to escape limitations in economic opportunities, education, and employment imposed by gender-based discrimination, seeking better prospects and improved conditions in

other countries. Both education and employment appear to empower women, influencing migration decisions. When considering female education, a negative and statistically significant interaction between the dummy variable `INTL_female` and the female population with at least some secondary qualifications, `F_EDU` suggests that education empowers women, potentially offering alternatives to migration. However, education doesn't seem to shield females from economic vulnerabilities during natural disasters.

Examining female employment levels, higher female labor force participation is associated with lower international migration, indicating increased resilience after natural disasters. Higher female workforce participation also reduces vulnerability to the economic impacts of such disasters.

Examining regional variations in migration patterns, the analysis reveals that the Middle East and North Africa, as well as South Asia, exhibit higher gender disparities in migration, likely influenced by socio-cultural factors, economic opportunities, or political stability. Analyzing responses to environmental shocks, individuals from the Middle East, North Africa, and South Asia are more responsive to such shocks, indicating the role of environmental factors in migration decisions. However, a negative and statistically significant gender gap in the Middle East and North Africa suggests gender differences in this specific region.

This study fills a gap in the literature on environmental migration, emphasizing the importance of addressing gender inequality. Our findings underscore the need for policymakers to consider these gender dynamics, providing valuable insights not only for migration policies but also for environmental protection policies.

Competing Interests

The authors declare that there are no competing interests.

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APPENDIX

A Dataset

Table A1 Descriptive statistics of the whole sample

Variables	Obs	Mean	Std. Dev.	Min	Max
Migration _{ij}	25,312	6,005	169,644	0	16,800,000
ln(Distance _{ij})	25,312	8.78	0.84	2.94	9.89
Contiguity _{ij}	25,312	0.02	0.16	0.00	1.00
ln(GDP _i)	25,312	16.42	2.09	12.01	22.11
ln(GDP _j)	25,312	16.45	2.08	12.01	22.11
Language _{ij}	25,312	0.20	0.40	0.00	1.00
Colony _{ij}	25,312	0.00	0.02	0.00	1.00
Common religion _{ij}	25,312	0.14	0.34	0.00	1.00
Gender (Female=1)	25,312	0.50	0.50	0.00	1.00
INTL	25,312	0.99	0.09	0.00	1.00
Disasters _i	25,312	2.56	3.99	0.00	26.00
Disasters _j	25,312	2.58	4.00	0.00	26.00
Biological _i	25,312	0.35	0.65	0.00	3.00
Biological _j	25,312	0.36	0.65	0.00	3.00
Climatological _i	25,312	0.13	0.36	0.00	2.00
Climatological _j	25,312	0.13	0.37	0.00	2.00
Geological _i	25,312	0.19	0.62	0.00	5.00
Geological _j	25,312	0.19	0.62	0.00	5.00
Hydrological _i	25,312	1.31	1.98	0.00	12.00
Hydrological _j	25,312	1.32	1.98	0.00	12.00
Metereological _i	25,312	0.58	1.80	0.00	14.00
Metereological _j	25,312	0.58	1.81	0.00	14.00
H-Disasters _{ij}	25,312	0.29	0.28	0.00	1.00
H-Biological _{ij}	25,312	0.94	0.14	0.00	1.00
H-Climatological _{ij}	25,312	0.98	0.08	0.00	1.00
H-Geological _{ij}	25,312	0.96	0.16	0.00	1.00
H-Hydrological _{ij}	25,312	0.71	0.30	0.00	1.00
H-Meteorological _{ij}	25,312	0.94	0.13	0.00	1.00
GII _i	22,176	0.55	0.13	0.14	0.81
F-EDU _i	22,400	33.42	24.82	1.64	99.88
F-LFP _i	24,864	51.11	19.19	10.42	87.34

B Gravity Model

Table B1 Results for different types of natural disasters

	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(\text{Distance}_{ij})$	-1.476*** (0.082)	-1.508*** (0.126)	-1.488*** (0.093)	-1.488*** (0.106)	-1.520*** (0.071)	-1.498*** (0.092)
Contiguity_{ij}	0.605*** (0.177)	0.212 (0.252)	0.339* (0.199)	0.191 (0.225)	0.595*** (0.178)	0.436** (0.194)
$\ln(\text{GDP}_i)$	0.243*** (0.079)	0.556*** (0.090)	0.379*** (0.082)	0.466*** (0.065)	0.174** (0.082)	0.372*** (0.069)
$\ln(\text{GDP}_j)$	0.773*** (0.062)	0.657*** (0.089)	0.737*** (0.078)	0.702*** (0.096)	0.783*** (0.053)	0.741*** (0.083)
Language_{ij}	-0.659*** (0.187)	-0.582*** (0.211)	-0.645*** (0.187)	-0.663*** (0.194)	-0.627*** (0.189)	-0.666*** (0.190)
Colony_{ij}	0.626 (0.475)	0.875* (0.505)	0.486 (0.363)	0.837 (0.524)	0.563 (0.493)	0.655* (0.371)
$\text{Common religion}_{ij}$	-0.942*** (0.231)	-0.880*** (0.230)	-1.066*** (0.219)	-0.949*** (0.213)	-0.942*** (0.225)	-1.072*** (0.228)
Gender (Female=1)	-0.154*** (0.035)	-0.140*** (0.030)	-0.150*** (0.033)	-0.152*** (0.027)	-0.160*** (0.036)	-0.152*** (0.030)
Disasters_i	0.071*** (0.023)					
$\text{Gender} \times \text{Disasters}_i$	0.003** (0.001)					
Disasters_j	-0.165*** (0.047)					
$\text{Gender} \times \text{Disasters}_j$	-0.021 (0.017)					
Biological_i		0.570*** (0.205)				
$\text{Gender} \times \text{Biological}_i$		0.006 (0.034)				
Biological_j		-0.925*** (0.242)				
$\text{Gender} \times \text{Biological}_j$		-0.036 (0.049)				
Climatological_i			0.598* (0.328)			
$\text{Gender} \times \text{Climatological}_i$			0.021 (0.022)			
Climatological_j			-1.285*** (0.242)			
$\text{Gender} \times \text{Climatological}_j$			-0.038 (0.050)			
Geological_i				0.257** (0.119)		
$\text{Gender} \times \text{Geological}_i$				0.029** (0.014)		
Geological_j				-0.985*** (0.264)		
$\text{Gender} \times \text{Geological}_j$				-0.273** (0.127)		
Hydrological_i					0.195***	

					(0.054)	
Gender $\times$ Hydrological $_i$					0.007**	
					(0.003)	
Hydrological $_j$					-0.311***	
					(0.066)	
Gender $\times$ Hydrological $_j$					-0.039*	
					(0.024)	
Meteorological $_i$						0.111**
						(0.050)
Gender $\times$ Meteorological $_i$						0.005*
						(0.003)
Meteorological $_j$						-0.278***
						(0.068)
Gender $\times$ Meteorological $_j$						-0.020
						(0.017)
Constant	2.287	-1.038	0.611	-0.249	3.523*	0.772
	(1.934)	(2.916)	(2.101)	(2.428)	(1.880)	(2.065)
Observations	25,312	25,312	25,312	25,312	25,312	25,312
R^2	0.810	0.775	0.786	0.779	0.818	0.789
Country fixed effects	no	no	no	no	no	no

Robust standard errors clustered by country-pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Controls for disasters are lagged 1 year (period 2004-2009).

The variable *Disasters* in column (1) of Table B1 refers to the occurrence of any disasters without distinguish by type. In the other columns, variables for specific disasters are added. Controls for disasters at origin, i , are always positive, as expected, even though the statistically significant varies across type of disasters. This implies that higher environmental shocks correspond to higher incentives to migrate. The interaction term between the variable *disasters* at home and the gender *female* is also positive, suggesting that women tend to move more when a domestic disaster occurs.

Meanwhile, coefficients of disasters at destination, j , are negative, implying that higher environmental shocks at the destination discourage people from choosing a specific country as their destination. The interaction term between the variable *disasters* at the destination and the gender *female* is negative, indicating that are more reluctant to move to countries with a higher frequency of natural disasters.

For the origin country, the highest coefficient is estimated for *Climatological* events (0.598), such as more frequent and intense droughts or wildfires, which can have significant impacts on migration patterns. In contrast, the lowest coefficient is estimated for *Meteorological* events (0.111), such as more frequent and intense storms or extreme temperatures. On the other side, when looking at the frequency of the environmental events in destination countries, migrants are less inclined to arrive in areas with higher occurrence of *Climatological* and *Geological* events.

C Robustness

Table C1 Robustness Analysis of Lag Selection for Disaster Events

	H-Disasters lagged 2 years (2003-2008)	H-Disasters lagged 3 years (2002-2007)	H-Disasters lagged 4 years (2001-2006)	H-Disasters lagged 5 years (2000-2005)
$\ln(\text{Distance}_{ij})$	-2.627*** (0.119)	-2.725*** (0.115)	-2.752*** (0.113)	-2.750*** (0.121)
Contiguity_{ij}	0.008 (0.163)	-0.030 (0.166)	-0.079 (0.166)	-0.137 (0.157)
Language_{ij}	0.156 (0.209)	0.187 (0.204)	0.199 (0.210)	0.178 (0.208)
Colony_{ij}	1.176*** (0.256)	1.156*** (0.268)	1.132*** (0.263)	1.171*** (0.254)
$\text{Common religion}_{ij}$	0.213 (0.216)	0.224 (0.222)	0.269 (0.229)	0.322 (0.219)
INTRA_female	-0.095*** (0.027)	-0.092*** (0.027)	-0.091*** (0.027)	-0.092*** (0.027)
INTL_female	-0.606*** (0.087)	-0.552*** (0.079)	-0.543*** (0.075)	-0.582*** (0.083)
$(H_{ij} \times R_j)$	-0.431*** (0.096)	-0.236*** (0.049)	-0.210*** (0.046)	-0.031*** (0.010)
$\text{INTL_female} * (H_{ij} \times R_j)$	0.157*** (0.044)	0.073*** (0.023)	0.067*** (0.019)	0.013*** (0.004)
Constant	30.952*** (0.784)	31.102*** (0.779)	31.369*** (0.771)	30.846*** (0.826)
Observations	25,312	25,312	25,312	25,312
R^2	0.968	0.968	0.968	0.967
Country fixed effects	yes	yes	yes	yes

Note: The dependent variable is the domestic and international migration flow by gender g from country i to country j over the period 2005-2010. Robust standard errors clustered by country-pairs in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Country fixed effects are included (unreported).

The robustness of the results, tested through the utilization of lagged values of the variable $(H_{ij} \times R_j)$, is based in the intuitive argument that dependent and independent variables cannot fully adjust within a single year. The coefficients of the variable $(H_{ij} \times R_j)$, shown in Table C1, are consistently negative and statistically significant. Notably, the magnitude shows a decreasing trend. The interaction with the dummy variable *gender* is consistently positive and statistically significance.