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Abstract

We study the impact of climate change on migration by developing a real options model that rigorously formalizes the trade-off between migrating early and procrastinating to learn more about the government's implementation of an adaptation policy that can effectively moderate the consequences of climate change. The model delivers an unambiguous guide to estimation of the impact of climate change on the occurrence of natural disasters and of the latter on migration decisions within a structural empirical model where the distinct mediation roles of the option value of waiting components (migration cost, home income, quality of government) are specified in a principled way. Evidence from panel data on international bilateral migration flows supports the main predictions of the theory and points to the key mediating role of government.

JEL-Codes: C330, H310, O150, Q540.

Keywords: option value of waiting, climate change adaptation, international migration.

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1 Introduction

Earth's climate has experienced substantial variability over time. However, the increase in surface temperature during the past 50 years (global warming) has been an extraordinary regime shift that is deemed unlikely to be the result of the interaction of the natural processes that drove the evolution of Earth's living conditions during the previous climate eras (IPCC, 2023). Moreover, while during the recent decades warming has exceeded its trend throughout the planet, local temperature changes have differed considerably. The regions experiencing the most intense warming are increasingly facing natural hazards such as heatwaves, droughts, wildfires, floods, landslides, and storms, leading in turn to a number of dramatic socio-economic consequences: decreased crop yields and food production, lower agricultural employment and income, famine, malnutrition, depletion of water resources, spread of infectious diseases, losses and interruptions to business activities, and violence and armed conflict (UNDRR, 2024).

Amongst the possible adaptation responses to those climate-related risks, the recent years have seen a growing interest in the analysis of the links between global environmental change, extreme natural events, and human migration, also due to early sensational predictions in this sense (Myers, 2005; Stern, 2006). However, a substantial portion of the existing empirical research failed to find any significant evidence of an impact of climate change on migration, pointing to what has been termed the "immobility paradox" (Beine and Jeusette, 2021). In fact, adverse climatic developments tend in some instances to reduce rather than enhance mobility, in line with the concept of "trapped population" (Black et al., 2013), where liquidity constraints provoked or exacerbated by climatic shocks are responsible for people's inability to move.

During the past decade, a voluminous literature - reviewed by Berlemann and Steinhardt (2017), Cattaneo et al. (2019), Kaczan and Orgill-Meyer (2020), Beine and Jeusette (2021), Piguet (2022), and Moore and Wesselbaum (2024) - has investigated the impact of climate-related variables on migration using cross-country panel data. While a consensus seems to have emerged around some of the possible causes of the enormous variability in the estimates of the impact of climate on migration - including whether slow-onset versus fast-onset climate-related phenomena are employed, the frequency and length of the time-dimension of the panels, and the way migration itself is defined and measured

- we believe that the remaining profound indeterminacy around the way the influence of Earth's climate on human mobility ought to be specified empirically can in large part be attributed to the fact that the mechanism linking climate change, the realization of natural disasters, and the migration decision is rarely modelled in a rigorous way.[1]

Frequently, the primary manifestation of climate change (global warming, leading in turn to the slow-onset phenomena of progressive land degradation and rising sea levels) is muddled with the extreme weather realizations that result from the disruption to the pattern of moisture generation across the Earth's surface and the atmosphere that global warming provokes (heatwaves, floods, landslides, storms). As a result, the issue of the heterogeneous and to a large extent country-specific ways the former (warming) affects the latter (natural disasters) remains entirely unaddressed. In fact, while some attempts have been made to identify the mediating roles of origin countries' characteristics in explaining the different response of migration to climate change across the globe, including geographic position (latitude), level of GDP, share of agriculture, net irrigation rate, and state of conflict (Beine and Parsons, 2015, 2017; Coniglio and Pesce, 2015; Cai et al., 2016; Cattaneo and Peri, 2016; Dallmann and Millock, 2017; Aburn and Wesselbaum, 2019; Minehan and Wesselbaum, 2023), the role of government and its ability to put in place appropriate adaptation policies that can contain the disastrous effects of climate change and induce residents to delay migration has, to the best of our knowledge, never been systematically studied before.[2]

[1] In their broad review of the major findings on the impact of climatic conditions on human health, economic growth, social interactions, and demographic dynamics, Carleton and Hsiang (2016) concluded that "the wide-ranging climatic effects on migration are not well understood and remain an area of active investigation."

[2] Three related literatures study the mediating role of government policy in the presence of climate change, though with a different focus. First, research on the climate change-armed conflict nexus, surveyed by Burke et al. (2024), points to the ability of governments to reduce the risk of conflict that is usually associated with extreme climatic conditions through the expansion of income assistance and social protection programs targeted to poor households and communities. Second, Cattaneo et al. (2019) review the somewhat sparse, mostly country-specific studies that hypothesise that compensation payments, relief aid, and international development assistance can mitigate the consequences of climate-related episodes on migration, though none of those contributions relies on the pre-emptive adaptation mechanisms that we postulate and test here. Finally, several studies within the literature on the macroeconomic effects of disasters (reviewed by Kousky, 2014, Botzen et al., 2019, and Ferreira, 2024) have attempted to identify the factors that can mitigate those detrimental effects, finding that countries with better institutions (high democratic quality and good governance indicators) appear to be insulated against death from natural disasters (Kahn, 2005) and to be able to lessen their adverse consequences on economic growth (Noy, 2009; Felbermayr and Groschl, 2014).

This paper aims at contributing to the existing climate-migration literature by tackling this important modelling issue. From a theoretical viewpoint, we address the elusive mechanism linking climate change and migration by modelling the choice of residents in regions affected by climate change about either migrating to safe regions or waiting to learn more about the decisions of their governments with respect to the implementation of an adaptation policy that would make staying in future periods viable and safe. Since the migration decision entails fixed unrecoverable costs, is to a large extent irreversible, and is made in the presence of uncertainty about future gains from migration that is at least partially resolved by waiting, we rely on a real options framework (Dixit and Pindyck, 1994).

The idea of interpreting migration as an investment that is costly to undo and is made in an uncertain environment, where waiting to gather more information and keeping the option to migrate in the future has value, dates back to Burda (1995). However, only recently have scholars studying the link between climate change and migration decisions employed this modelling approach.[3] Mense (2018) extends the standard hedonic framework (no uncertainty and no relocation costs) by considering explicitly the role of uncertainty in the valuation of a slowly changing amenity (such as air quality) when there are positive migration costs, and shows that higher uncertainty pushes up the implicit price of the amenity by raising the option value of waiting and that small information shocks about the evolution of the quality of the amenity might not be enough to provoke outmigration because moving is costly and entails giving up the option to move at a later point in time. More recently, Braun (2023) models the impact of slow-onset climatic events such as temperature increase and sea level rise and argues that the immobility paradox can be explained by the observation that affected individuals postpone their migration responses to those events in the face of uncertainty and only migrate once the effects of climate change have exceeded certain thresholds.

Unlike those contributions, the option value of waiting model that we develop below has the unique feature of allowing residents to update in a Bayesian way their beliefs about the evolution of climate by observing the realizations of

[3] A related literature (reviewed in Ginbo et al., 2021) employs a real options framework to study investment in adaptation strategies (e.g., flood risk control infrastructures) in the presence of uncertainty about climate evolution, where the decision to invest is an option that can be used at the present time or delayed to a future period, when additional information will be available.

environmental shocks in their region and of encompassing the realistic possibility that they be hit by rapid-onset events that destroy their assets and "kill" their valuable option to migrate in the future. This implies that, similarly to Hsiang (2016) and Carleton et al. (2022), we view climate as affecting social outcomes both through a direct pathway (natural disasters exerting an impact on affected populations' wellbeing, e.g., the assets of households living in flooded villages) and through an indirect, informational one (households living in non-flooded villages learning about climate change through the observation of the frequency of flooding in the region). In addition, we allow the government to devise an adaptation policy to reduce vulnerability to climate change, and households to migrate selectively based on observed government decisions. This model adds to the comprehension of the climate-induced migration phenomenon in two ways.

First, it rigorously formalizes the fundamental trade-off in the decision to procrastinate migration: gathering more information about future adaptation policies, yet running the risk of being unable to exercise the migration option in the future. Interestingly, the "bad news principle" from the theory of investment under uncertainty (Bernanke, 1983) does not apply to this model: the risk of being hit by a trapping event while waiting and the residual chance of a disaster even in the presence of government's intervention imply that the value of the migration option is not independent of "good news" - i.e., the magnitude of the income gain when migration is not regrettable. This implies that all news matter here. In fact, we show that the bad news principle arises as a special case where waiting is not hazardous and public adaptation policies remove the chances of a disaster altogether.

Second, the model clarifies for the first time the distinct roles played by the determinants of the option value of waiting in the timing of the migration decision, namely: a) the mediating role of government through the implementation of effective adaptation policies in the relationship between climate change (warming) and the realization of natural disasters;[4] b) the mediating role of the migration cost and of the home income differential in the relationship between the exposure of a region to those disastrous events and the ultimate decision about whether to exercise the migration option. As a result, our theory delivers an unambiguous guide to estimation of the impact of climate change on the oc-

[4] Amongst the constraints to the implementation of effective adaptation policies, IPCC (2023) lists "lack of political commitment," "low uptake of adaptation science," "low sense of urgency," "limited institutional capacity," "insufficient financing, and a lack of political frameworks and incentives for finance" (pp. 61-62).

currence of natural disasters and of the latter on migration within a structural two-equation empirical model where the mediation roles of the components of the option value of waiting are specified in a principled way.

Guided by the theory, we perform an empirical analysis on a large panel dataset of bilateral migration flows through three decades (Aburn and Wesselbaum, 2019; Minehan and Wesselbaum, 2023), merging the original dataset with an index of corruption and government effectiveness in origin countries to proxy the quality of government. First, the reduced-form evidence provides a consistent picture of increasing temperatures having a positive impact on international migration, with the quality of government in origin countries being estimated to have a large and significant role in moderating that impact. Second, the estimation of a two-equation structural model reveals that while temperature generally raises the frequency of natural disasters, the disaster-generating effect of warming is offset by the presence of high quality governments. In turn, a higher frequency of disasters is estimated to provoke an increase in migration that is less pronounced if either the level of income or the cost of migrating from origin countries is high.

The rest of the paper is organised as follows. Section **2** develops the theoretical model, section **3** discusses the components of the option value of waiting, section **4** is devoted to the empirical analysis, and section **5** concludes.

2 The model

2.1 Framework

Consider an economy composed of two regions, each of which is initially inhabited by n individuals. Mobility between the two regions is costly. Let one of the regions - region r - be at risk of natural disasters that destroy residents' assets, provoke a fall in their incomes, and trap them there, while the other - region s - is climatically safe. Due to climate change, the disastrous events in region r get increasingly likely, though people (and their government) only learn about those developments through signals they receive over time.

The economy lasts three periods, that we label, for reasons that will become obvious below, the age of innocence, the age of awareness, and the age of government. In each period, region r can experience either of two states of the world: a high-risk state, where each resident of the l localities of region r (districts or cities) is hit by a catastrophic event (such as a flood or a storm) with probability $\overline{\pi} > 0$, and a low-risk state, where each resident is hit with probability $\underline{\pi} < \overline{\pi}$. Region r's residents cannot observe the current state of the world. By contrast, the safe region s is unaffected by climate change and so the probability that a resident is hit by a disaster is always 0.

If no disaster occurs, a resident of region r earns income $Y + \Delta_r$, where Y is the regular income that one can earn both in the risky and in the safe region, while Δ_r is the income that is earned only if he stays in the home region, which can be related to own markets and customers or location-specific human capital. In case of a disaster, a resident's income falls to 0 in the current as well as in all future periods. The loss of income provoked by the disaster creates a liquidity constraint preventing migration to the safe region in the current as well as in all future periods, making those residents the "trapped population." Therefore, people may want to move to the safe place before being hit by the disastrous event. The decision to migrate, however, entails giving up Δ_r and suffering a fixed one-off migration cost $F > 0$. A resident makes the migration decision by maximizing the expected lifetime income net of the migration cost given the information that he has at the beginning of periods 1 and 2. To analyze the effect of the awareness of risk on residents' migration/waiting decisions, we will focus on the population that does not migrate in period 0.

At the beginning of period 0, region r's residents are unaware of the consequences of climate change on the likelihood of natural disasters, and hold a prior belief that the high-risk state (low-risk state) occurs with probability p_0 $(1 - p_0)$. As a result, the *ex ante* probability that a resident of region r is hit by a natural disaster in period 0 is:

$$\phi_0 = p_0\overline{\pi} + (1 - p_0)\underline{\pi}. \tag{1}$$

Suppose that, during period 0, e_0 of the l localities in region r are hit by disasters, an information that is public for all residents. Therefore, at the beginning of period 1, residents update their beliefs about the risk of a disaster. Based on a Bayesian updating process, the probability of the high-risk state of the world given the information (e_0, l) is:

$$p_1 = \Pr\left(\pi = \overline{\pi} | e_0, l\right) = \frac{\Pr\left(e_0, l | \pi = \overline{\pi}\right) p_0}{\Pr\left(e_0, l | \pi = \overline{\pi}\right) p_0 + \Pr\left(e_0, l | \pi = \underline{\pi}\right)\left(1 - p_0\right)}, \tag{2}$$

where $\Pr(e_0, l|\pi) = \binom{l}{e_0} \left(\pi\right)^{e_0} \left(1 - \pi\right)^{l - e_0}$. As a result, the belief in the probability that a resident in region r is hit by a disaster at the beginning of period

1 is:

$$\phi_1 = p_1\overline{\pi} + (1 - p_1)\underline{\pi}. \tag{3}$$

Upon updating their beliefs, region r's residents consider whether to move to region s or to wait and postpone their decision to period 2. Since the migration decision is assumed to be irreversible, residents need to form expectations about the likelihood of their region being in the high-risk state in period 2 too.

During period 1, the government of region r can devise an adaptation policy to reduce future vulnerability to climate change.[5] We assume that there are two types of government: a foresighted government (the good type) that is concerned about the future adverse effects of climate change and actually implements such adaptation policies, and a myopic government (the bad type) that only cares about its short-run political rent and takes no action in response to climate change. Residents cannot observe the type of government nor whether it adopts any policy until period 2. However, it is commonly believed that the government is of the bad (good) type with probability γ $(1 - \gamma)$.[6]

We assume that the policy implemented by the good government in period 1 will effectively reduce the number of disasters such that $e_2 \to 0$ in period 2 (while the policy cannot eliminate the risk and turn it into a safe region). By contrast, the bad government takes no action in period 1, and we assume that

[5] According to the United Nations Office for Disaster Risk Reduction, vulnerability to natural disasters relates to physical (poor design and construction of buildings, unregulated land use planning), social (inequality, marginalisation, exclusion), economic (dependence on single industries, lack of insurance), and environmental (poor environmental management, overconsumption of natural resources) factors (UNDRR, 2024). As a result, effective adaptation policies include structural measures like investments in flood risk control infrastructures (such as dikes and levees), water storage improvements, resource-saving technologies, construction of irrigation systems, reforestation, wetlands restoration, upstream forest management, urban greening, and non-structural measures like early warning systems and financial or technical support to switch to climate-change-resistant crops (IPCC, 2023).

[6] Although we do not explicitly model the choice of government here and take this γ as exogenously given, it can be regarded as the reduced form of the following game. Consider the situation where the government can allocate a budget of B to spending on the adaptation policy M and the political rent R. The government's objective function is $R + \delta_\theta \rho(M) = B - M + \delta_\theta \rho(M)$, where δ_θ is the discount factor for the government of type $\theta \in \{g, b\}$, and $\rho(M)$ is the reputational gain in the future, where $\rho(0) = 0, \rho' > 0$ and $\rho'' < 0$, which means that the adaptation policy can provide the government with a gain in its reputation or winning the reelection from being perceived as the "good" type. Assume that $\delta_b < \delta_g$, which means that the good (type g) government is more foresighted than the bad (type b) one. It is easy to see that the optimal spending M^* satisfies $\rho'(M^*) = 1/\delta_\theta$ and is thus increasing in δ_θ. In other words, the more foresighted a government is, the more it will spend on the adaptation policy. Moreover, $M^* \to 0$ if $\delta_B \to 0$, which means that the myopic type spends nothing since it does not care about its reputation or reelection at all. Therefore, there is a separating equilibrium where the good type chooses to spend $M^* > 0$ while the bad type chooses $M^* = 0$.

climate keeps on deteriorating so that $e_2 \to l$, i.e., almost every locality is hit by a disaster in period 2.

At the beginning of period 2, since residents can observe whether the government intervenes or not, they can infer its type. If the government does not intervene, people will infer that it is of the bad type, and so region r will almost surely end up being in a high-risk state ($\Pr(\pi = \overline{\pi}) \to 1$), as long as the number of localities l is large. On the other hand, if the government intervenes, people will infer that it is of the good type, and the economy will be in a low-risk state almost surely ($\Pr(\pi = \overline{\pi}) \to 0$).[7] As a result, at the beginning of period 2, the belief about the probability of the high-risk state is:

$$p_2 \to \begin{cases} 1 & \text{if no intervention is made,} \\ 0 & \text{if intervention is made.} \end{cases} \tag{4}$$

From the perspective of period 1, the *ex ante* probability of being hit by a natural disaster during period 2 is:

$$\phi_2 = \gamma\overline{\pi} + (1-\gamma)\underline{\pi}. \tag{5}$$

There is a trade-off in the migration decision: postponing the decision until period 2 allows residents to observe whether the adaptation policy is actually in place or not, that is, whether region r in period 2 is in a high-risk or a low-risk state. However, they also encounter the risk of being "trapped" when it is too late to exercise the migration option.

In summary, the game proceeds in the following three stages:

Period 0: At the beginning of this period, all players hold a commonly prior belief that a resident of region r is hit by a disaster with probability ϕ_0. A resident in region r then decides whether to migrate to the safe region or to stay in the home region. During this period, there are e_0 among l localities where a disaster occurs.

Period 1: At the beginning of this period, players update their belief about the risk of disaster to ϕ_1 after observing e_0. A resident in region r who has

[7] Note that when $e \to l$, $\Pr(e, l|\pi = \overline{\pi}) \to (\overline{\pi})^l$ and $\Pr(e, l|\pi = \underline{\pi}) \to (\underline{\pi})^l$. Then by using equation (2), $\Pr(\pi = \overline{\pi}|e, l) = \frac{(\overline{\pi})^l p}{(\overline{\pi})^l p + (\underline{\pi})^l (1-p)} \to 1$ when l is large since $\overline{\pi} > \underline{\pi}$, i.e., the true state is almost surely to be of high-risk ($\pi = \overline{\pi}$) under a bad government regardless of the prior belief p. Similarly, when $e \to 0$, $\Pr(e, l|\pi = \overline{\pi}) \to (1-\overline{\pi})^l$ and $\Pr(e, l|\pi = \underline{\pi}) \to (1-\underline{\pi})^l$, and so $\Pr(\pi = \overline{\pi}|e, l) = \frac{(1-\overline{\pi})^l p}{(1-\overline{\pi})^l p + (1-\underline{\pi})^l (1-p)} \to 0$ when l is large, i.e., the true state is almost surely to be of low-risk ($\pi = \underline{\pi}$) under a good government.

not been hit by a disaster decides whether or not to migrate. The good government then decides to intervene with an adaptation policy during this period, while the bad government takes no action.

Period 2: After observing the government action, residents can infer its type and update the belief to ϕ_2. Then a resident in region r who has not been hit by a disaster decides whether to migrate or to stay. The good government's adaptation policy then takes effect.

2.2 The subgame perfect Nash equilibirum

In this section, we analyze the subgame perfect Nash equilibrium of this game, and so we apply backward induction to solve the problem.

2.2.1 Period 2: The age of government

Given the policy choice made by the government during period 1, region r will end up being either in a high-risk or in a low-risk state. If the government is of the good type, a resident of region r that has not been hit by a disaster during period 1 obtains a period 2 payoff

$$(1-\underline{\pi})(Y+\Delta_r)$$

if he keeps staying in region r, and

$$Y-F$$

if he decides to migrate to region s. Then, he will stay in region r in period 2 if

$$F \geq \underline{\pi}(Y+\Delta_r)-\Delta_r \equiv \underline{F}_2. \tag{6}$$

To maintain an interesting discussion, we focus on the case where $\underline{F}_2 > 0$ or equivalently, $\underline{\pi} > \frac{\Delta_r}{Y+\Delta_r}$.

On the other hand, if the government is bad and does not intervene, each resident obtains a period 2 payoff

$$(1-\overline{\pi})(Y+\Delta_r)$$

if he keeps staying in region r, and

$$Y-F$$

if he migrates to region s. Then, he will stay in region r if

$$F \geq \overline{\pi}(Y + \Delta_r) - \Delta_r \equiv \overline{F}_2. \tag{7}$$

Apparently, $\overline{F}_2 > \underline{F}_2$ since $\overline{\pi} > \underline{\pi}$. Thus, we summarize the resident's migration decision in period 2:

Lemma 1. *If a resident of region r has not been hit by a disaster during period 1, his migration decision in period 2 is the following:*

(1) If $F \geq \overline{F}_2$, then he will keep staying in region r in period 2 regardless of the government's policy.

(2) If $\underline{F}_2 < F < \overline{F}_2$, then he will keep staying in region r in period 2 if the government intervenes and migrate to region s if the government does not intervene.

(3) If $F \leq \underline{F}_2$, then he will migrate to region s in period 2 regardless of the government's policy.

The result is intuitive: when the migration cost is sufficiently high (low), every resident would like to stay (migrate). In either case, the government adaptation policy has no effect. When the migration cost is moderate, the government policy does matter: an adaptation policy that effectively moderates the negative consequences of climate change can indeed keep residents in the home region.

2.2.2 Period 1: The age of awareness

At the beginning of period 1, residents hold the beliefs of ϕ_1 for the probability of being hit by a disaster in period 1 and ϕ_2 for the expected probability of the same event in period 2. Based on these beliefs, a resident in region r who has not been hit by a disaster during period 0 decides whether or not to migrate to region s. According to Lemma 1, there are three cases to consider:

Case 1: $F \geq \overline{\pi}(Y + \Delta_r) - \Delta_r = \overline{F}_2$.

In this case, residents will stay in region r in period 2 regardless of the government's policy. Then in period 1, if a resident stays in region r, he obtains:

$$(1 - \phi_1)\left(1 + \frac{1 - \phi_2}{1 + i}\right)(Y + \Delta_r),$$

where $\phi_2 = \gamma\overline{\pi} + (1-\gamma)\underline{\pi}$. If he instead migrates, he obtains:

$$Y - F + \frac{1}{1+i}Y.$$

Thus, he will stay in region r in this period if

$$F \geq \left(\phi_1 + \frac{\phi_1 + \phi_2(1-\phi_1)}{1+i}\right) Y - (1-\phi_1)\left(1 + \frac{1-\phi_2}{1+i}\right)\Delta_r \equiv \widehat{F}_1(\gamma). \quad (8)$$

Note that $\widehat{F}_1(\gamma)$ is an increasing function of γ, which means that when it is more likely that the government is of the bad type, the threshold in the migration cost for a resident to keep staying in the home region will be higher, i.e., he is more willing to migrate.

$\widehat{F}_1(\gamma)$ can be larger or smaller than $\overline{F}_2$; however, since Case 1 occurs only when $F \geq \overline{F}_2$, it means that if $\widehat{F}_1(\gamma) > \overline{F}_2$, residents with $F \geq \widehat{F}_1(\gamma)$ will stay in both periods 1 and 2, and those with $\overline{F}_2 \leq F < \widehat{F}_1(\gamma)$ will migrate to the safe region in period 1.[8] On the other hand, if $\widehat{F}_1 \leq \overline{F}_2$, then all residents in this regime will stay in region r in periods 1 and 2. In other words, there is no migration in either period when $F \geq \max[\widehat{F}_1(\gamma), \overline{F}_2]$, and migration takes place in period 1 when $\overline{F}_2 \leq F < \widehat{F}_1(\gamma)$, regardless of the government's policy.

<u>Case 2</u>: $\underline{F}_2 < F < \overline{F}_2$.

In this case, a resident will keep staying in region r in period 2 if the government intervenes and migrate to region s if the government does not intervene. That is, the government's policy *does affect* residents' behavior. Then, if he stays in region r in period 1, the expected payoff starting from period 1 is:

$$(1-\phi_1)\left\{(Y+\Delta_r) + \frac{1}{1+i}\left[\gamma(Y-F) + (1-\gamma)(1-\underline{\pi})(Y+\Delta_r)\right]\right\},$$

while if he instead migrates, he again obtains:

$$Y - F + \frac{1}{1+i}Y.$$

Thus, he will stay in region r in this period if

$$\begin{aligned} F \geq \left(1 - \frac{\gamma(1-\phi_1)}{1+i}\right)^{-1} &\left\{\left[\phi_1 + \frac{\phi_1 + (1-\gamma)(1-\phi_1)\underline{\pi}}{1+i}\right] Y \right. \\ &\left. -(1-\phi_1)\left[1 + \frac{(1-\gamma)(1-\underline{\pi})}{1+i}\right]\Delta_r\right\} \equiv \widetilde{F}_1(\gamma). \end{aligned} \quad (9)$$

[8] In the latter case, the decision-making in period 2 is off the equilibrium path.

$\widetilde{F}_1(\gamma)$ is also an increasing function of γ, which means that a resident is more likely to move if the government intervenes with a lower probability. $\widetilde{F}_1(\gamma)$ can be larger or smaller than $\overline{F}_2$. Based on a similar reasoning as in Case 1, when $\underline{F}_2 \leq F \leq \min[\widetilde{F}_1(\gamma), \overline{F}_2]$, residents will migrate to region s in period 1, while if $\widetilde{F}_1(\gamma) \leq F \leq \overline{F}_2$, residents will stay in their home place in period 1 and keep staying in the next period if and only if the government intervenes.

<u>Case 3</u>: $F \leq \underline{F}_2$.

In this case, a resident will migrate to the safe region in period 2 regardless of the government's policy. If he stays in region r in period 1, the expected payoff starting from period 1 is

$$(1-\phi_1)\left[(Y+\Delta_r)+\frac{1}{1+i}(Y-F)\right].$$

Thus, he will stay in region r in period 1 if

$$F \geq \frac{\phi_1[(1+\frac{1}{1+i})Y+\Delta_r]-\Delta_r}{1-\frac{1-\phi_1}{1+i}} > \underline{F}_2 = \underline{\pi}(Y+\Delta_r)-\Delta_r. \tag{10}$$

The second inequality in (10) is due to the fact that $1 > \overline{\pi} \geq \phi_1 \geq \underline{\pi} > 0$. Since Case 3 occurs when $F \leq \underline{F}_2$, (10) implies that, in this regime, the residents of region r will always migrate in period 1.

2.2.3 Period 0: The age of innocence

Given the strategies adopted by residents and the government in periods 1 and 2, there are five possible situations to consider at the beginning of period 0: (a) A resident stays in region r for all three periods regardless of the policy; (b) a resident stays in region r in periods 0 and 1 but migrates to region s in period 2 regardless of the policy; (c) a resident stays in region r in periods 0 and 1, while he stays in region r in period 2 if and only if the government intervenes; (d) a resident stays in region r in period 0 but migrates to region s since period 1; and (e) a resident migrates to s since period 0.

In order to maintain an interesting discussion, we focus on the case where not all residents decide to migrate in period 0. In order for case (a) to be supported as an equilibrium, the payoff from staying for all three periods:

$$(Y+\Delta_r)\left[\sum_{t=0}^{2}\left(\frac{1}{1+i}\right)^t(1-\phi_0)^{t+1}\right]$$

should be larger than the payoff from migrating in period 0:

$$Y - F + Y \left[\sum_{t=1}^{2} \left(\frac{1}{1+i} \right)^t \right].$$

That is, it requires:

$$\begin{aligned} F > Y & \left[\sum_{t=0}^{2} \left(\frac{1}{1+i} \right)^t - \sum_{t=0}^{2} \left(\frac{1}{1+i} \right)^t (1-\phi_0)^{t+1} \right] \\ & - \Delta_r \left[\sum_{t=0}^{2} \left(\frac{1}{1+i} \right)^t (1-\phi_0)^{t+1} \right] \equiv F_0. \end{aligned} \tag{11}$$

We will assume that condition (11) - and the other ones for situations (b), (c), and (d), all of which have thresholds that are captured by F_0 - hold, and that $F_0 < \underline{F}_2$, so that we can focus on the population for whom it is optimal to stay in region r at the beginning of period 0. This is the case as long as the prior belief ϕ_0 is not too large (i.e., region r is still relatively safe at the age of innocence).

The following proposition summarizes the equilibrium outcome:

Proposition 1. *Suppose that ϕ_0 is sufficiently small such that $F_0 < \underline{F}_2$. Then there is a $\gamma^* = \max\left\{0, \frac{[(1+i)(\overline{\pi}-\phi_1)-\phi_1-(1-\phi_1)\underline{\pi}](Y+\Delta_r)+\Delta_r}{(1-\phi_1)(\overline{\pi}-\underline{\pi})(Y+\Delta_r)}\right\}$ such that for a resident who stays in region r during period 0 (i.e., $F > F_0$):*

(1) When $\gamma^* = 0$:

(i) If $F \geq \widehat{F}_1(\gamma)$, then he will stay in region r for all three periods regardless of the government's policy.

(ii) If $F_0 \leq F \leq \widehat{F}_1(\gamma)$, then he will migrate to region s in period 1 regardless of the government's policy.

(2) When $\gamma^* > 0$:

(i) If $F \geq \max[\widehat{F}_1(\gamma), \overline{F}_2]$, then he will stay in region r for all three periods regardless of the government's policy.

(ii) If $F_0 \leq F \leq \min[\widehat{F}_1(\gamma), \widetilde{F}_1(\gamma)]$, then he will migrate to region s in period 1 regardless of the government's policy.

(iii) If $\widetilde{F}_1(\gamma) \leq F \leq \overline{F}_2$, then he will stay in region r in period 1 and keep staying in the home region in period 2 if and only if the government intervenes. This case occurs only if $\gamma < \gamma^*$.

Proof. See the Appendix. □

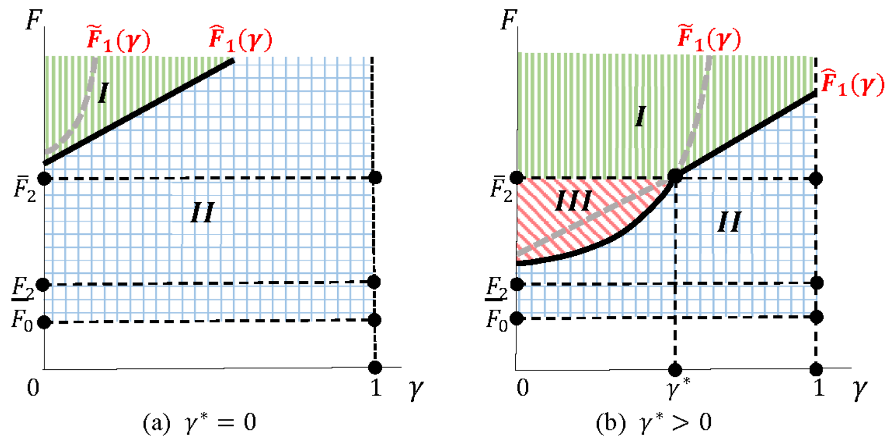

Figure 1 The equilibrium migration patterns

We use Figure 1 to illustrate the residents' migration patterns in the equilibrium as proposed in Proposition 1. γ^* is the threshold value of γ for the regime where the government's policy affects the resident's migration decision - Case 2 in period 1 - can be supportable as an equilibrium. If $\gamma^* = 0$, then the resident's payoff if he stays in the home region in period 1 under Case 2 is always lower than the payoff from migration, and so it cannot be supported as an equilibrium. Then, only two cases are possible: when the migration cost is sufficiently high, residents are trapped in the risky region in both periods 1 and 2 (i.e., Regime I), while if the migration cost is relatively low, residents will migrate to the safe region in period 1 (i.e., Regime II). In particular, $\gamma^* = 0$ occurs when $\phi_1 \to \overline{\pi}$, which can be due to, for example, $e_0 \to l$, which means that the number of disasters occurring in period 0 is so large that residents believe that region r is already in a high-risk state. In this case, they tend to migrate immediately if the migration cost is not too high because the loss of being hit outweighs the gain of staying for one more period and waiting for the good government's policy. By contrast, the residents whose migration cost is too high are trapped and unable to move in either period. Therefore, the government's policy has no impact on the migration decision.

Alternatively, when $\gamma^* > 0$, the government's adaptation policy can have an impact on the migration decision in the regime $\widetilde{F}_1(\gamma) \leq F \leq \overline{F}_2$ (i.e., Regime III). This situation occurs when $\phi_1 \to \underline{\pi}$, indicating that region r is relatively low-risk, and $\overline{\pi} - \underline{\pi}$ is sufficiently large, meaning that the government's policy can make a lot of difference, and so it is worthwhile to stay for one more period and wait for new information to come in. In this case, a resident whose migration cost is moderate will stay in region r in period 1 and will keep staying in the home region in the next period if and only if the government intervenes.

3 Discussion: The option value of waiting

We are particularly interested in the case of Regime III, where residents' migration decisions are policy-dependent. There is a tradeoff in determining the timing of migration: postponing the decision to period 2 allows residents to reduce uncertainty and to make their decision contingent on the government's type. However, procrastination also means that they face the risk of being trapped in the home locality.

To see this tradeoff more clearly, note that, in the policy-dependent regime, the net benefit of staying in period 1 (i.e., the expected payoff of staying minus that of migrating), or the "option value of waiting," is:

$$\begin{aligned} w = &\left[1 - \frac{\gamma(1-\phi_1)}{1+i}\right] F - \left[\phi_1 + \frac{\phi_1 + (1-\gamma)(1-\phi_1)\underline{\pi}}{1+i}\right] Y \\ &+ \ (1-\phi_1)\left[1 + \frac{(1-\gamma)(1-\underline{\pi})}{1+i}\right] \Delta_r. \end{aligned} \tag{12}$$

Equation (12) shows that w is: (a) increasing in the migration cost (F); (b) decreasing in the regular income earned in either region (Y); (c) increasing in the excess income earned by staying in the home locality (Δ_r); (d) decreasing in the probability of the bad government (γ), as long as $\underline{\pi}$ is low.

(a), (b) and (c) are intuitive: residents tend to postpone migration if the migration cost is high, the income earned in the safe region is low, and the income surplus earned in the home region is high. As for (d), a smaller $\underline{\pi}$ indicates that a disaster is very unlikely to occur in period 2 if the government is of the good type. This implies that the government's intervening policy can be very effective, and so waiting is worthwhile.

In the conventional option value of waiting model, only bad news matters in the calculation of the value of waiting - the *bad news principle* (Bernanke, 1983). This is due to the fact that procrastination allows the investor to learn about the state of the world in the future period and only invest in favorable conditions, so that the high returns in the good state of the world will accrue in period 2 both when investing early and when postponing investment to the next period. In case of bad news in period 2, postponing the decision allows to avoid the negative consequences of the bad state of the world by not investing.

The same principle applies to migration set-ups where the act of migration involves up-front irreversible fixed costs, future rewards of migration are uncertain - high wages abroad in good states of the world (good news) versus low wages abroad in bad states of the world (bad news) - and procrastination is an option (Burda, 1995): since waiting does not foreclose migration in the next period, early migrants can profit from future realizations of good states, so that the value of the migration option is independent of the wage gain in the good state of the world, while indeed migration does not take place if conditions in the future period turn out to be unfavorable.

In our model, however, unlike the Burda (1995) one, uncertainty is present in all periods. The inherent uncertainty of period 1 (the possibility that a disaster during period 1 prevents migration in period 2), joint with the residual uncertainty in period 2 (the government's adaptation policy does not rule out with certainty the chance of a disaster) imply that *all* news matters here.

To make our point clearly, we split (12) into two parts, thus disentangling the two mutually exclusive cases that can possibly arise. First, from the point of view of early migrants, a "good news" is the circumstance where a disaster occurs in the home locality in period 1, indicating that early migration was a good choice - which is equivalent to a high-income realization in the location of destination in the Burda (1995) framework. If a resident migrates in period 1, he secures incomes $(Y - F, Y)$ in periods 1 and 2, which is higher than $(0, 0)$ if he had not migrated and was hit by a disaster. In this case, what happens in the home locality in period 2 is irrelevant. Thus, the option value of waiting related to the good news income gain (which occurs with probability ϕ_1 from period 1's perspective) is:

$$w^G = -(Y - F) - \frac{1}{1+i}Y. \tag{13}$$

Note that $w^G < 0$ since $F < \overline{F}_2$ in this regime.

On the other hand, the "bad news" for early migrants is the case when no disaster occurs in the home locality in period 1. Early migration yields income Y in both periods 1 and 2, while postponing the decision to period 2 allows the resident to earn $Y + \Delta_r$ in period 1 and $\gamma(Y - F) + (1 - \gamma)(1 - \underline{\pi})(Y + \Delta_r)$ in period 2. Thus, the option value of waiting related to the bad news income gain (which occurs with probability $1-\phi_1$ from period 1's perspective) is:

$$w^B = Y + \Delta_r - (Y - F) + \frac{1}{1+i}\Big\{ [\gamma(Y-F) + (1-\gamma)(1-\underline{\pi})(Y+\Delta_r)] - Y \Big\}. \tag{14}$$

It is easy to check that

$$w = \phi_1 w^G + (1-\phi_1) w^B.$$

That is, the value of the migration option is not independent of the "good news" income gain. In particular, $w^G < 0$, and if $w > 0$, then $w^B > 0$. Intuitively, when early migration is a good choice (good news), the value of waiting is reduced; and if waiting is optimal, the bad news income gain will provide more incentives to wait. Therefore, all news matter, unless $p_1 = 0$ (people believe that the region is always in the low-risk state) and $\underline{\pi} = 0$ (the risk of a disaster is completely eliminated in the low-risk state) such that $\phi_1 = 0$ (waiting during period 1 is not hazardous), in which case the bad news principle is back.

4 Empirical analysis

4.1 Specification

We test the main predictions of our theoretical model on a panel dataset of international migration flows between 198 origin countries and 16 OECD destination countries between 1985 and 2015 (Aburn and Wesselbaum, 2019; Minehan and Wesselbaum, 2023). We merge that dataset with an index of corruption in origin countries to capture the key mediator of the climate-migration relationship predicted by our model - the quality of government as the fundamental determinant of the implementation of an effective policy of adaptation to climate change. All variables employed in the analysis are discussed in section **4.2** below. Summary statistics are in table A.1 in Appendix 3.

Since, as in Cattaneo and Peri (2016), we first aim at estimating the reduced-form impact of the slow-onset climate change process on the decision to migrate from affected countries, we transform the original yearly bilateral dataset built by Aburn and Wesselbaum (2019) into 10-years averages of bilateral migration flows (1986-1995, 1996-2005, 2006-2015), and use the logarithm of the dyadic decadal average migration flows to destination countries as the dependent variable. Moreover, as in Cattaneo and Peri (2016), Beine and Parsons (2017) and most of the empirical literature on climate change and migration (Berlemann and Steinhardt, 2017), we only consider migration from non-OECD countries because those countries are likely to be the most severely affected by climate change. The list of origin and destination countries is provided in Appendix 2. For comparison, Appendix 3 (tables A.2 and A.3) reports estimates of the baseline reduced-form specification on the original Aburn and Wesselbaum (2019) yearly dyadic dataset both when OECD countries are included in the pool of origin countries and when they are not. We briefly discuss those results below.

The main equation we estimate - equation (15) - lets the logarithm of average migration flows from country o to country d in decade t depend on temperature in origin country o and its interactions with the determinants of the option value of waiting suggested by the theoretical model - equation (12) - and detailed in equation (16) below. Moreover, equation (15) includes a dyadic fixed effect (f_{od}), decade effects (h_t), and an idiosyncratic shock ($\varepsilon_{od,t}$):

$$\ln(mig_{od,t}) = \beta_1 temp_{o,t} + \sum_j \beta_j \left[D_o(\mathrm{j}) \times temp_{o,t}\right] + f_{od} + h_t + \varepsilon_{od,t}, \qquad (15)$$

where the time-invariant indicators $D_o(j)$ are generated by:

$$\begin{aligned} D_o(\text{good}) &= (1|\text{quality of government is high}), \\ D_o(\text{rich}) &= (1|\text{per capita income is high}), \\ D_o(\text{far}) &= (1|\text{migration cost is high}). \end{aligned} \qquad (16)$$

According to the theoretical model, the origin country's features in (16) (that we take here as time-invariant) act as *mediators* to induce residents in those countries to postpone migration in the face of climate change relative to residents in countries not sharing those features (low government quality, low income, low migration cost), that are instead predicted to move early as a result of climate change. In section **4.4** we formally test the distinct mediation roles played by those variables as predicted by the theoretical model.

Following Cattaneo and Peri (2016), we employ a parsimonious specification that does not include any additional controls - such as decade-varying demographic structure - that are likely to be themselves affected by climate change. This way, we capture the total effect of climate change on migration - both the direct one and the potential indirect effects occurring through changes of other endogenously determined variables (Berlemann and Steinhardt, 2017).

Finally, the dyadic fixed effect f_{od} in (15) that might be correlated with the interacted temperature terms and might thus produce a bias in our estimates is removed by taking deviations from dyadic means.

4.2 Variables

The dependent variable is constructed from the 2015 Revision of the United Nations' Population Division and from OECD data (Aburn and Wesselbaum, 2019). The data include regular, permanent migration flows and exclude illegal immigration. Hence, it likely underestimates true migration flows.

Origin countries' temperatures are measured by the average monthly temperature (in degrees Celsius) provided by the World Bank Climate Change Knowledge Portal, and averaged across each decade. Variations in temperature are considered the main drivers of the negative effects of climate change on the economy (Dell et al., 2009, 2014) and typically turn out to be the main climate-related determinants of international migration (Auffhammer et al., 2013; Berlemann and Steinhardt, 2017; Kaczan and Orgill-Meyer, 2020; Beine and Jeusette, 2021).

Data on GDP at origin are from the World Bank. GDP per capita is measured at constant 2010 U.S. dollars. The *rich* country indicator equals 1 if the average per capita GDP during the third decade is above the sample median GDP.

The *far* indicator proxying the cost of moving out of a country equals 1 if the origin-destination distance is above the sample median distance (high migration cost). Between-countries distance variables come from the GeoDist dataset from CEPII (Mayer and Zignago, 2011).

Finally, the quality of government is proxied by the Corruption Perceptions Index computed by Transparency International. While the index has been available from 1995, the early waves covered a limited number of countries (41 in 1995). In addition, given the extremely limited variability in the ranking of countries over time, we employ the average country index over the third decade. In our main specification (estimates in tables 1 and 2), we build a sort of "absolute" indicator of quality of government in the sense that it equals 1 if the corruption perceptions index of a country is above the median index of all the countries for which it is available, including OECD countries. The worldwide index has a median value of 3.2 (average value at about 4) on a 0 to 10 scale. In this specification, $\frac{2}{3}$ of the non-OECD origin countries that we use in the analysis are assigned to the low quality of government group.

For comparison, Appendix 3 reports the corresponding estimation results when: a) the quality of government binary index is built with reference to the median corruption index in the actual non-OECD sample used in the analysis (tables A.4 and A.5). In this case, the Corruption Perceptions Index takes on the median value of 2.8 (average value at about 3), with half of the countries in the sample being assigned to the low quality of government group by construction; b) we employ the government effectiveness index from the World Bank Worldwide Governance Indicators (tables A.6 and A.7). The index is meant to capture "perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" (Kaufmann et al., 2010). It is constructed from a large number of distinct sources including regional development banks and civil society initiatives and ranges between -2.5 and 2.5. We define the government of a country in the sample of non-OECD countries as low effectiveness if its index is below the sample median value of -0.5 (average 2006-2015). Appendix 2 shows how the origin countries in the sample fare with respect to those three ways of proxying the quality of their governments. A comparison of tables 1 and 2 with the Appendix tables A.4 to A.7 shows that the results are remarkably similar.

4.3 Results

The results of estimation of the reduced-form equation (15) are reported in table 1, using the sample of non-OECD origin countries for which migration, temperature, and proxies of the determinants of the option value of waiting are available (5,030 observations). The reduced-form evidence provides a consistent picture of increasing temperatures having a positive impact on international migration only from the countries where the quality of government is low. The basic specification in column 1 returns an estimate of β_1 of 0.35 (s.e. $= 0.06$). This means that a temperature increase of a quarter of a degree Celsius - the average decadal rise of temperature across the origin countries in the sample - is predicted to raise migration by almost 10%. However, column 2 shows that the positive impact of temperature on migration is largely offset by a counteracting negative impact arising from the interaction of temperature with the high quality of government dummy. In countries ruled by good governments, the estimated impact of temperature on migration is 0.15 (s.e. $= 0.10$), about $\frac{1}{3}$ of the estimated impact of temperature on migration in countries ruled by bad governments ($\beta_1 = 0.43$; s.e. $= 0.07$), and is not significantly different from zero. On the other hand, columns 3 and 4 show that the estimate of β_1 is unaffected when including the interactions with the proxies of the other two components of the option value of waiting (origin countries' wealth and distance), that are not estimated to play a significant mediation role with respect to climate change.

Estimation of equation (15) on the original Aburn and Wesselbaum (2019) yearly dyadic panel dataset (tables A.2 and A.3 in Appendix 3) returns evidence that is in line with the decadal data. As could be expected, the estimated response of migration to temperature is smaller when using yearly data (capturing a short-term response of migration to temperature shocks) and when OECD countries (that are arguably less vulnerable to climate change) are included in the pool of origin countries. Moreover, the results confirm the significant role played by the quality of government in moderating the impact of temperature on migration.

Table 1 Reduced-form: temperature and migration

	(1)	(2)	(3)	(4)
	ln(migration)			
temperature	0.350***	0.428***	0.418***	0.477***
	(0.064)	(0.075)	(0.085)	(0.102)
temperature × D(good)		-0.281***	-0.281***	-0.277***
		(0.109)	(0.109)	(0.108)
temperature × D(rich)			0.027	0.012
			(0.107)	(0.109)
temperature × D(far)				-0.135
				(0.106)
observations	5,030			

Notes: Standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

4.4 Mechanism

According to the theoretical model, a region that is affected by climate change inexorably ends up in a high-risk state of the world where the likelihood of the occurrence of a disaster is $\pi = \overline{\pi}$, unless a (good) government intervenes with an adaptation policy that keeps the region in a low-risk state of the world ($\pi = \underline{\pi}$) - equation (5). As a result, the key role of the quality of government that emerges from the model is its mediation of the relationship between climate change and the frequency of disasters:

$$\boxed{\begin{array}{c}\text{climate change}\\ [\textit{temperature}]\end{array}} \quad \underset{\left(\begin{array}{c}\text{quality of government}\\ [\textit{corruption/effectiveness index}]\end{array}\right)}{\Longrightarrow} \quad \boxed{\begin{array}{c}\text{state of the world}\\ [\textit{disastrous events}]\end{array}}$$

where, in empirical terms, climate change is captured by the evolution of temperature, the state of the world by the number of disasters, and the quality of government by the index of government corruption or of policy effectiveness.

Second, the model predicts that, as a result of the occurence of disasters that convey residents information about the state of the world of the region where they live (high risk versus low risk), residents who are not trapped decide to move if the benefits of doing so outweigh the costs in terms of foregone income at home (Δ_r) and migration expenses (F) - equations (6) and (7). The link between the realization of disasters and the migration decision envisaged in our theoretical moel can be represented as follows:

$$\boxed{\begin{array}{c}\text{state of the world}\\ [\textit{disastrous events}]\end{array}} \quad \underset{\left(\begin{array}{c}\text{home income}\\ [\textit{per capita GDP}]\\ \text{migration cost}\\ [\textit{distance}]\end{array}\right)}{\Longrightarrow} \quad \boxed{\begin{array}{c}\text{outmigration}\\ [\textit{bilateral flows}]\end{array}}$$

As a result, a structural test of our model relies on estimation of the following two-equations system:

$$\begin{aligned}
\ln(mig_{od,t}) &= \alpha_1 \ln(events_{o,t}) + \alpha_{rich} \left[D_o(\text{rich}) \times \ln(events_{o,t})\right] \\
&\quad + \alpha_{far} \left[D_o(\text{far}) \times \ln(events_{o,t})\right] + \xi_{od,t}, \qquad (17) \\
\ln(events_{o,t}) &= \lambda_1 temp_{o,t} + \lambda_{good} \left[D_o(\text{good}) \times temp_{o,t}\right] + \omega_{od,t},
\end{aligned}$$

where $events_{o,t}$ measures the number of disastrous events in origin country o in decade t, and $\xi_{od,t}$ and $\omega_{od,t}$ include country-pair and decade effects.

We proxy the state of the world in a country by the (log of the) total number of natural disasters occurred during a decade. We use data from the Global Database for Comprehensive Disaster Data (EM-DAT) that includes events with at least 10 deaths (persons confirmed as dead and persons missing and presumed dead), or 100 affected individuals (injured, left homeless, or requiring immediate assistance in terms of basic survival needs), or with a request for national or international assistance. Of all included events, we consider those classified as climatological (drought, wildfire), hydrological (flood, landslide), and meteorological (heatwave, storm). While most of those events can admittedly be considered beyond the control of governments irrespective of their quality and integrity - and as such can be considered as natural *hazards* - our hypothesis is that proper adaptation policies can prevent the transformation of those extreme natural conditions caused by climate change - *hazards* - into catastrophic outcomes for the population - *disasters* (Dey and Lewis, 2021; UNDRR, 2024).

Table 2 Temperature, disasters, and migration

	(1)	(2)	(3)
		ln(migration)	
ln(events)	2.846**	0.870***	1.469***
	(1.069)	(0.235)	(0.345)
ln(events) × D(rich)			-0.380**
			(0.195)
ln(events) × D(far)			-0.356*
			(0.193)
		ln(events)	
temperature	0.123***	0.311***	0.265***
	(0.042)	(0.043)	(0.045)
temperature × D(good)		-0.437***	-0.421***
		(0.077)	(0.070)
observations		5,030	

Notes: Standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

The system of equations (17) is estimated by three-stage least squares and the results are reported in table 2. First, temperature is estimated to have a positive and highly statistically significant impact on the frequency of disasters. According to the estimate of λ_1 in column (1), lower panel, an increase in temperature by a quarter of a degree Celsius in a decade raises the number of disasters by around 3% across the sample. However, when allowing for a role of the quality of government in column (2), the estimated coefficient on temperature interacted with the high quality of government dummy ($\lambda_{good} = -0.44$; s.e. =

0.08) suggests that the disastrous effects of increasing temperatures ($\lambda_1 = 0.31$; s.e. $= 0.04$) are entirely offset in the presence of good quality governments, arguably because of the effective adaptation policies they are able to put in place.

In turn, the upper panel of table 2 suggests that a higher frequency of disasters generally leads to an increase in migration, compatibly with the belief update transmission mechanism envisaged in the theoretical model. However, the estimated coefficients on the interaction terms suggest that the migration response is significantly lower if either the income in the origin country is high ($\alpha_{rich} = -0.38$; s.e. $= 0.19$) or if the cost of migration is high ($\alpha_{far} = -0.36$; s.e. $= 0.19$).

Finally, we should note that the estimated elasticity of migration α_1 in (17) is the net effect of the direct and belief effects of the realization of disasters, with the direct effect lowering the ability to migrate and the belief effect raising the willingness to migrate. As a result, we can conclude that the belief update pathway prevails on the direct forced immobility one, but we are unable to quantify the latter by using macro data at the country level. Observations at lower levels of aggregation or micro data (Letta et al., 2024) would be ideally required to discriminate between households that decide to delay migration relative to those that are forced to do so.

5 Conclusions

Global surface temperature in the first two decades of the 21^{st} century (2001–2020) has been about 1°C higher than during the second half of the 19^{th} century and its increase in the past 50 years has been higher than in any other 50-year period over the last 2000 years (IPCC, 2023). In turn, climate change has been affecting the frequency and intensity of natural hazards like heatwaves, droughts, and tropical cyclones, provoking damages and increasingly irreversible losses in terrestrial, freshwater, and coastal ecosystems, and being responsible for sea level rises, desertification, and land degradation, with falls in productivity in climate-exposed sectors of the economy such as agriculture, forestry, fishery, and tourism. A potential response of the people living in the regions that are most exposed and vulnerable to those climatic phenomena is migration.

Exposure and vulnerability to the extreme events generated by climate change, though, vary dramatically from one place to another, not only because of geographic, economic, and social factors, but also depending on the policies that are actually put in place to mitigate their impact. The objective of this paper has been to answer the question of whether the quality of government - and in particular its ability to put in place effective policies of adaptation to climate change - can explain the heterogeneous responses of migration to climate change across the countries that are most severely affected by it.

To do so, we have first modelled the impact of climate change on migration within a real options framework, where people update their beliefs about the evolution of climate by observing the realizations of environmental shocks in their region, and where postponing the migration decision to learn about the response of government to climate change can - depending on the existing exposure to risk, the cost of migration, and the risk-reducing effectiveness of adaptation policies - be a valuable option. Interestingly, the "bad news principle" from the theory of investment under uncertainty does not apply to this model: the risk of being hit by a trapping event while waiting and the residual chance of a disaster even in the presence of government's intervention with an adaptation policy imply that the value of the migration option is not independent of "good news" - i.e., the magnitude of the income gain when migration is not regrettable - so that all news matters. In fact, we show that the bad news principle arises as a special case where waiting is not hazardous and public adaptation policies remove the chances of a disaster altogether.

Besides formalizing the trade-off in the decision to procrastinate (gathering more information about future adaptation policies and thus being able to migrate selectively, yet running the risk of being unable to exercise the migration option in the future), a further contribution of this paper is to identify the variables that affect the option value of waiting (the fixed cost of migration, the home income level, and the quality of government) and to clarify their distinct roles in the transmission mechanism from climate change to the migration decision.

Guided by the theory, we have tested the model's main predictions on a large panel dataset of bilateral migration flows (Aburn and Wesselbaum, 2019; Minehan and Wesselbaum, 2023), merging the original dataset with an index of corruption in origin countries to proxy the quality of government. First, the reduced-form evidence provides a consistent picture of increasing temperatures having a positive impact on international migration, with the quality of government in origin countries playing a significant role in moderating that impact. Second, estimation of a two-equation structural model reveals that while temperature generally raises the frequency of natural disasters, the disaster-generating effect of warming is entirely offset in the presence of good quality governments. In turn, a higher frequency of disasters is estimated to provoke an increase in migration that is less pronounced if either the level of income or if the cost of migrating from the origin countries is high.

This paper represents just a first step in the exploration of the role of the quality of government in origin countries in mediating the impact of climate change on migration, and several interesting dimensions of this highly policy-relevant topic remain unexplored. Amongst the questions that this paper does not formally address, the endogenous determination of the quality of government definitely seems an interesting long-run issue that would be worth analyzing in future work both theoretically and empirically - particularly in consideration of the potential influence of the very process of climate change on the evolution of the composition of the population and of the quality of institutions in origin countries. Relatedly, future work could fruitfully search for empirical evidence of association between competing indicators of the quality of the governance of a country - related to broad dimensions such as democratic participation, decentralization, and political stability - and the size, variety, and effectiveness of structural and non-structural policies of adaptation to climate change.

Appendix 1

Proof of Proposition 1. We first show a useful lemma:

Lemma 2. *There is a $\widehat{\gamma}$, where $\widetilde{F}_1(\widehat{\gamma}) = \widehat{F}_1(\widehat{\gamma}) = \overline{F}_2$, satisfying that $\widetilde{F}_1(\gamma) > \widehat{F}_1(\gamma) > \overline{F}_2$ if $\gamma > \widehat{\gamma}$ and $\widetilde{F}_1(\gamma) < \widehat{F}_1(\gamma) < \overline{F}_2$ if $\gamma < \widehat{\gamma}$.*

Proof. As mentioned in the context, when $F \geq \overline{F}_2$ (i.e., Case 1), the expected payoff if a resident stays in region r in period 1 is:

$$(1-\phi_1)\left(1+\frac{1-\phi_2}{1+i}\right)(Y+\Delta_r), \tag{18}$$

and when $\underline{F}_2 < F < \overline{F}_2$ (i.e., Case 2), the resident's expected payoff if he stays in period 1 is:

$$(1-\phi_1)\left\{(Y+\Delta_r)+\frac{1}{1+i}\left[\gamma(Y-F)+(1-\gamma)(1-\underline{\pi})(Y+\Delta_r)\right]\right\}. \tag{19}$$

On the other hand, if the resident instead chooses to migrate, he obtains:

$$Y-F+\frac{1}{1+i}Y. \tag{20}$$

We observe several properties: (a) (18) is independent of F and both (19) and (20) are decreasing in F. (b) Given the same γ, (18) = (19) at $F = \overline{F}_2$, and (18) > (<) (19) if F < (>) $\overline{F}_2$. (c) Both (18) and (19) are decreasing in γ as long as $F > \underline{F}_2$.

Recall that the thresholds $\widehat{F}_1(\gamma)$ and $\widetilde{F}_1(\gamma)$ are obtained by equating (18) and (19) to the same payoff (20), respectively. Then, if $F = \widetilde{F}_1(\gamma) = \overline{F}_2$ for some γ, it must be the case that $\widetilde{F}_1(\gamma) = \widehat{F}_1(\gamma) = \overline{F}_2$. We denote this γ by $\widehat{\gamma}$. Morevoer, if $F = \widetilde{F}_1(\gamma) > \overline{F}_2$ for some γ, since (18) > (19) and (20) is decreasing in F, in order to maintain (18) = (20), it must be the case where $\widehat{F}_1(\gamma) < \widetilde{F}_1(\gamma)$. It follows that $\widetilde{F}_1(\gamma) > \widehat{F}_1(\gamma) > \overline{F}_2$. By the analogous reasoning, if $F = \widetilde{F}_1(\gamma) < \overline{F}_2$ for some γ, it must be the case where $\widetilde{F}_1(\gamma) < \widehat{F}_1(\gamma) < \overline{F}_2$.

According to (8) and (9), both $\widehat{F}_1(\gamma)$ and $\widetilde{F}_1(\gamma)$ are increasing in γ. Therefore, we conclude that $\widetilde{F}_1(\gamma) > \widehat{F}_1(\gamma) > \overline{F}_2$ if $\gamma > \widehat{\gamma}$ and $\widetilde{F}_1(\gamma) < \widehat{F}_1(\gamma) < \overline{F}_2$ if $\gamma < \widehat{\gamma}$. □

Now we can show this Proposition. By solving $\widetilde{F}_1(\widehat{\gamma}) = \widehat{F}_1(\widehat{\gamma}) = \overline{F}_2$, we find that:

$$\widehat{\gamma} = \frac{[(1+i)(\overline{\pi}-\phi_1)-\phi_1-(1-\phi_1)\underline{\pi}](Y+\Delta_r)+\Delta_r}{(1-\phi_1)(\overline{\pi}-\underline{\pi})(Y+\Delta_r)}. \tag{21}$$

It is possible that $\widehat{\gamma} < 0$ (e.g., when $\phi_1 \to \overline{\pi}$), which is, however, not feasible since $\gamma \in [0, 1]$. In this case, $\gamma^* = 0$ and so $\widetilde{F}_1(\gamma) > \widehat{F}_1(\gamma) > \overline{F}_2$ for all γ. However, recall that $\widetilde{F}_1$ is an active threshold only when $F_0 \leq F \leq \overline{F}_2$ (i.e., Case 2). This means that, given $F > \overline{F}_2$, the resident's payoff if he in the home region in period 1 under Case 2 - (19) - is always lower than the payoff from migration - (20) - since the threshold that makes these two payoffs equal is outside the possible range. Therefore, the active threshold is $\widehat{F}_1(\gamma)$, and so the resident will stay for all three periods if $F \geq \widehat{F}_1(\gamma)$, and migrate to region s in period 1 if $F_0 \leq F \leq \widehat{F}_1(\gamma)$, regardless of the government's policy.

On the other hand, if $\widehat{\gamma} > 0$, then $\gamma^* = \widehat{\gamma}$ and the case $\widetilde{F}_1(\gamma) < \widehat{F}_1(\gamma) < \overline{F}_2$ occurs when $\gamma < \widehat{\gamma}$. In this case, since $\widehat{F}_1(\gamma)$ is active only when $F \geq \overline{F}_2$ (i.e., Case 1), the only active threshold is $\widetilde{F}_1(\gamma)$, and so the resident will stay for all three periods when $F \geq \overline{F}_2$, migrate to region s in period 1 when $F_0 \leq F < \widetilde{F}_1(\gamma)$, and stay in the home region both in periods 1 and 2 if and only if the government intervenes when $\widetilde{F}_1(\gamma) \leq F \leq \overline{F}_2$. By contrast, if $\gamma > \widehat{\gamma}$, it is similar to the previous case where $\widetilde{F}_1(\gamma) > \widehat{F}_1(\gamma) > \overline{F}_2$. That is, a resident will stay for all three periods if $F \geq \widehat{F}_1(\gamma)$, and migrate to region s in period 1 if $F_0 \leq F \leq \widehat{F}_1(\gamma)$, regardless of the government's policy. This proves the Proposition. □

Appendix 2

List of (origin, *destination*) countries. Origin countries: [1]: high quality of government relative to worldwide median index of corruption (Transparency International); [2]: high quality of government relative to non-OECD origin countries' sample median index of corruption (Transparency International); [3]: high quality of government relative to non-OECD origin countries' sample median index of government effectiveness (World Bank).

Afghanistan, Albania[2,3], Algeria[2,3], Angola, Argentina[2,3], Armenia[2,3], *Australia*, *Austria*, Azerbaijan, Bangladesh, Barbados[1,2,3], Belarus, *Belgium*, Belize[1,2,3], Benin, Bhutan[1,2,3], Bolivia, Bosnia and Herzegovina[2], Botswana[1,2,3], Brazil[1,2,3], Bulgaria[1,2,3], Burkina Faso[1,2], Burundi, Cambodia, Cameroon, *Canada*, Cape Verde[1,2,3], Central African Republic, Chad, China[1,2,3], Colombia[1,2,3], Comoros, Congo, Costa Rica[1,2,3], Cote d'Ivoire, Croatia[1,2,3], Cuba[1,2,3], Cyprus[1,2,3], *Denmark*, Djibouti[2], Dominica[1,2,3], Dominican Republic[2], Ecuador, Egypt[2,3], El Salvador[1,2,3], Eritrea, Eswatini (Swaziland)[2,3], Ethiopia, Fiji[1,2], *Finland*, Gabon[2], Gambia, Georgia[1,2,3], *Germany*, Ghana[1,2,3], Grenada[1,2,3], Guatemala, Guinea, Guinea-Bissau, Guyana[3], Haiti, Honduras, India[1,2,3], Indonesia[3], Iran[3], Iraq, *Italy*, Jamaica[1,2,3], Jordan[1,2,3], Kazakhstan[3], Kenya, Kiribati[2], Kyrgyzstan, Laos, Latvia[1,2,3], Lebanon[2,3], Lesotho[1,2,3], Liberia, Libya, Lithuania[1,2,3], Madagascar[2], Malawi, Malaysia[1,2,3], Maldives[3], Mali, Mauritania, Mauritius[1,2,3], Moldova[2], Mongolia[2], Morocco[1,2,3], Mozambique, Myanmar, Namibia[1,2,3], Nepal, *Netherlands*, *New Zealand*, Nicaragua, Niger, Nigeria, North Macedonia[2,3], *Norway*, Oman[1,2,3], Pakistan, Panama[1,2,3], Papua New Guinea, Paraguay, Peru[1,2,3], Philippines[3], Russia[3], Rwanda[2,3], Samoa[1,2,3], Saudi Arabia[1,2,3], Senegal[1,2,3], Seychelles[1,2,3], Sierra Leone, Solomon Islands, South Africa[1,2,3], *Spain*, Sri Lanka[2,3], St. Lucia[1,2,3], St. Vincent and the Grenadines[1,2,3], Sudan, *Sweden*, *Switzerland*, Tajikistan, Tanzania[2], Thailand[1,2,3], Togo, Tonga[3], Trinidad and Tobago[1,2,3], Tunisia[1,2,3], Uganda, Ukraine, *United Kingdom*, *United States of America*, Uruguay[1,2,3], Vanuatu[2,3], Venezuela, Vietnam[3], Yemen, Zambia, Zimbabwe.

Appendix 3

Table A.1 Descriptive statistics (decadal dyadic data; no OECD countries)

	obs.	mean	std.dev.	min	max
ln(migration)	5,030	3.99	2.54	0	11.25
ln(events)	5,030	2.07	1.15	0	5.52
temperature (° Celsius)	5,030	21.39	7.05	-5.70	29.05
index of corruption (0-10)	5,030	3.15	1.14	1.56	6.98
index of effectiveness (-2.5,+2.5)	5,030	-0.43	0.64	-1.70	1.37
GDP per capita (US$)	5,030	2,254	1,292	63	4,649
distance (km)	5,030	7,972	4,020	271	18,953

Table A.2 Reduced-form (yearly dyadic): full sample

	(1)	(2)	(3)	(4)
		ln(migration)		
temperature	0.092***	0.255***	0.351***	0.348***
	(0.014)	(0.026)	(0.033)	(0.038)
temperature × D(good)		-0.283***	-0.267***	-0.266***
		(0.037)	(0.038)	(0.038)
temperature × D(rich)			-0.179***	-0.163***
			(0.037)	(0.037)
temperature × D(far)				-0.045
				(0.038)
observations	83,197	78,827	77,900	76,769

Notes: Standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

Table A.3 Reduced-form (yearly dyadic): no OECD countries

	(1)	(2)	(3)	(4)
		ln(migration)		
temperature	0.169***	0.234***	0.243***	0.264***
	(0.019)	(0.026)	(0.036)	(0.042)
temperature × D(good)		-0.174***	-0.173***	-0.172***
		(0.048)	(0.049)	(0.049)
temperature × D(rich)			-0.005	0.016
			(0.047)	(0.047)
temperature × D(far)				-0.111**
				(0.047)
observations	66,663	62,293	61,366	60,235

Notes: Standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

Table A.4 Reduced-form (decadal dyadic): quality of government #2

	(1)	(2)	(3)	(4)
		ln(migration)		
temperature	0.350^{***}	0.622^{***}	0.631^{***}	0.667^{***}
	(0.064)	(0.091)	(0.104)	(0.115)
temperature × D(good)		-0.510^{***}	-0.511^{***}	-0.503^{***}
		(0.104)	(0.106)	(0.107)
temperature × D(rich)			-0.022	-0.031
			(0.107)	(0.109)
temperature × D(far)				-0.091
				(0.105)
observations		5,030		

Notes: Quality of government indicator = 1 (good) if index of corruption (Transparency International) is larger than the non-OECD sample median; standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

Table A.5 Temperature, disasters, and migration: quality of government #2

	(1)	(2)	(3)
		ln(migration)	
ln(events)	2.846^{**}	1.070^{***}	1.646^{***}
	(1.069)	(0.215)	(0.382)
ln(events) × D(rich)			-0.393^{*}
			(0.214)
ln(events) × D(far)			-0.339
			(0.212)
		ln(events)	
temperature	0.123^{***}	0.474^{***}	0.422^{***}
	(0.042)	(0.058)	(0.061)
temperature × D(good)		-0.530^{***}	-0.517^{***}
		(0.070)	(0.062)
observations		5,030	

Notes: Quality of government indicator = 1 (good) if index of corruption (Transparency International) is larger than the non-OECD sample median; standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

Table A.6 Reduced-form (decadal dyadic): quality of government #3

	(1)	(2)	(3)	(4)
		ln(migration)		
temperature	0.350***	0.591***	0.618***	0.701***
	(0.064)	(0.086)	(0.100)	(0.114)
temperature × D(good)		-0.509***	-0.519***	-0.528***
		(0.104)	(0.105)	(0.105)
temperature × D(rich)			-0.062	-0.083
			(0.108)	(0.109)
temperature × D(far)				-0.174*
				(0.105)
observations		5,030		

Notes: Quality of government indicator = 1 (good) if index of government effectiveness (World Bank) is larger than the non-OECD sample median; standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

Table A.7 Temperature, disasters, and migration: quality of government #3

	(1)	(2)	(3)
		ln(migration)	
ln(events)	2.846**	0.920***	1.369***
	(1.069)	(0.177)	(0.312)
ln(events) × D(rich)			-0.291*
			(0.176)
ln(events) × D(far)			-0.255
			(0.175)
		ln(events)	
temperature	0.123***	0.483***	0.438***
	(0.042)	(0.045)	(0.047)
temperature × D(good)		-0.618***	-0.599***
		(0.065)	(0.060)
observations		5,030	

Notes: Quality of government indicator = 1 (good) if index of government effectiveness (World Bank) is larger than the non-OECD sample median; standard errors clustered by country dyad; ***: p value < 0.01; **: p value < 0.05; *: p value < 0.10.

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