ALMA MATER STUDIORUM
UNIVERSITY OF BOLOGNA

SCHOOL OF SCIENCE

Laurea Magistrale in Analisi e Gestione dell'Ambiente
Curriculum in Water and Coastal Management

Climate Change and Human Migration: Managing the Cascade Effects Initiated by Natural Disasters

Thesis in: Environmental Economics And Risk Management In Coastal Policy

Supervisor:
Paolo F. Ricci, PhD, LLM

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List of Abbreviations

Administrative Appeals Office	AAO
African Union	AU
Area of Freedom, Security and Justice	AFSJ
Bayesian Expected Loss	BEL
Board of Immigration Appeals	BIA
Carbon Dioxide	CO2
Climate Resilient Development	CRD
Conference of the Parties	COP
Department of Homeland Security	DHS
European Union	EU
Immigration and Nationality Act	INA
Intergovernmental Panel on Climate Change	IPCC
Internally Displaced Persons	IDP
International Organization for Migration	IOM
Non-Governmental Organization	NGO
Office of the Chief Administrative Hearing Officer	OCAHO
Office of the Chief Immigration Judge	OCIJ
Regional Conference on Migration	RCM
Sea Level Rise	SLR
South American Conference of Migration	SACM
Sustainable Development Goals	SDGs
Task Force on Displacement	TFD
The Bureau of Population, Refugees and Migration	PRM
Treaty on the Functioning of the European Union	TFEU
United Nations	UN
United Nations Framework Convention on Climate Change	UNFCCC
United Nations High Commissioner For Refugees	UNHCR
United States	US
United States Citizenship and Immigration Services	USCIS
United States Customs and Border Protection	CBP
United States Immigration and Customs Enforcement	ICE
United States Dollar	USD
World War Two	WWII

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Abstract

The potential links between climate change, human migration and conflict have been receiving an increasing amount of attention since the turn of the century. Up-to-date reports that address the most recent understanding of climate change and environmental hazards indicate that humans have undeniably contributed to the rising global temperature and will continue to do so if lower pollution thresholds are not maintained. While this enacts a multitude of physical, biological, chemical, and societal changes, it is imperative to analyze and address the impact of climate change on human migration trends. Human migrants face several types of problems ranging from environmental issues related to climate change (sea-level rise, more frequent and intense storms and floods, drought, wildfires, etc.), to conflicts from physical migration into neighboring towns, cities, regions, or countries. These types of physical migration that are climate change driven, which can be referred to as "adaptation migration" can be capable of snowballing from a human-to-environment issue into a human-to-human conflict; usually involving some type of violence or political discrimination/persecution. The aim of this study is to analyze how climate change is impacting human migration trends, the possible percolating effects that can result from human migration, and how these factors have influenced and will continue to influence governments and governance in the coastal area. The information in this report will be able to provide a greater understanding of adaptation migration through the use of differential equations, how these trends can be modeled, and how Game Theory can be used as a strategic tool for policymakers moving forward.

Introduction

Links between climate change, human migration, and conflict have been receiving an increasing amount of attention. Recent reports (Martel et al., 2018; Van Oldenborgh et al., 2018; Bevacqua et al., 2019; Burrell et al., 2020; Knutson et al., 2020; Ortiz-Bobea et al., 2021; Perkins-Kirkpatrick et al., 2022) that address the present understanding of climate change and environmental hazards find that humans have undeniably contributed to the rising global temperature and will continue to do so unless much lower emissions of energy trapping gases that contribute to raising regional and interregional air and water temperatures are minimized. These cause dangerous consequences for all as well as physical, biological, chemical, and societal changes. Our work concerns the policy-science basis for the rational assessments of the impact of climate change on human migration and its uncertain, multiple, consequences and trends. We are not concerned with private decisions; rather, we focus on public decisions and how those decisions can benefit from formal methods to account for uncertainty, feedbacks, lagged effects, and other aspects of changing information and knowledge flows. This area of research seems to be somewhat neglected (Piguet et al., 2018); yet, climate changes can force migrations and can result in consequences that range from minor border disturbances to war. Humans can be forced to become migrants when they face the effects of climate change, such as SLR, more frequent and intense storms, floods, extreme droughts, and more frequent wildfires. Climate change can be expected to drive mass physical migrations. The effect of changes in migratory patterns caused by climate change may initially be slow-moving; however, one or more tipping points may suddenly arise within a jurisdiction, thus requiring fast managerial responses. Responses, whether fast or slow, are mediated by physical, economic, and policy feedbacks. Within a country, the consequences of tipping points may include violence, political discrimination, and even civil war. Between two or more jurisdictions (e.g., nation-states) conflicts that may have been simmering for years for reasons unrelated to climate change may boil over. A critical event occurs when the physical consequences of climate change spill over into water scarcity, famine, economic depression, and collapse of the health system even when earlier there was none. When an affected region sits below the poverty line, the effect of tipping points is amplified and can result in the local population being trapped inside the area at risk.

However, even a migration pattern generated by well-understood forces has outcomes stochastic outcomes. For instance, Black, Bennett, Thomas, and Beddington (2011, footnote omitted) observed that:

“Migration is often expensive, and those most vulnerable to environmental change are usually poor. For example, in Uganda, a relatively settled country with high 'entry costs' for housing, schools, and marriage, those who are wealthier are more able to relocate. In Mali, emigration decreased during the severe droughts of 1983–85 alongside a rise in rural poverty.”

In some instances, an *adaptation migration*, a positive relationship between migration and adaptation processes with anticipation and planning (Black, Bennett, Thomas, Beddington 2011; Vinke 2020), may be possible. Our work is a step toward characterizing and quantifying pivotal elements so that what may be a catastrophic migration to the areas affected becomes a rational process in which the spatio-temporal events and their consequences can be anticipated. The forces (e.g., drivers, forcing functions, and so on) that generate mass migrations are uncertain (neither their time nor magnitudes can be known with certainty); the fundamentals of the physical processes are known (e.g., physical law, mass and energy conservation) but are variable, and the socioeconomic processes (from employment to medical care) combine uncertainties and variabilities in part because the infrastructure can be unable to serve a rapid influx of migrants. The overall effect snowballs from a human-to-environment process to human-to-human conflicts. Understanding these concatenations of events before the fact (ex-ante) requires rational thinking, complex modeling, and rational choices that are generally not disclosed to most stakeholders. These three requirements cannot be assumed away. We wish to develop the means for a greater understanding of *adaptation migration* through critical analyses of human migration trends, how these trends can be recognized, and which strategies can be used by policymakers in anticipation of probable migrations and the areas affected.

We develop an integrated view of the usefulness of decision-theoretic methods (Figure 1) that account for uncertainty through probabilities, when used to identify optimal or preferable choices that inform – but do supplant -- the decisions of public decisionmakers. In other words, we follow this overall process of decision in which *M* is magnitude of the change, *pr* is the probability (also indicated by *p, q, r* such that the sum of those probabilities adds to 1.00). The changes are a puzzle ex-ante of the analysis because they are based on incomplete evidence (the past partially informs them), magnitude implies either the size of the change or the magnitude of the consequences. These are not listed but are shown as a deck of cards to emphasize their overall uncertainty (including the concept associated with the “fog of war”):

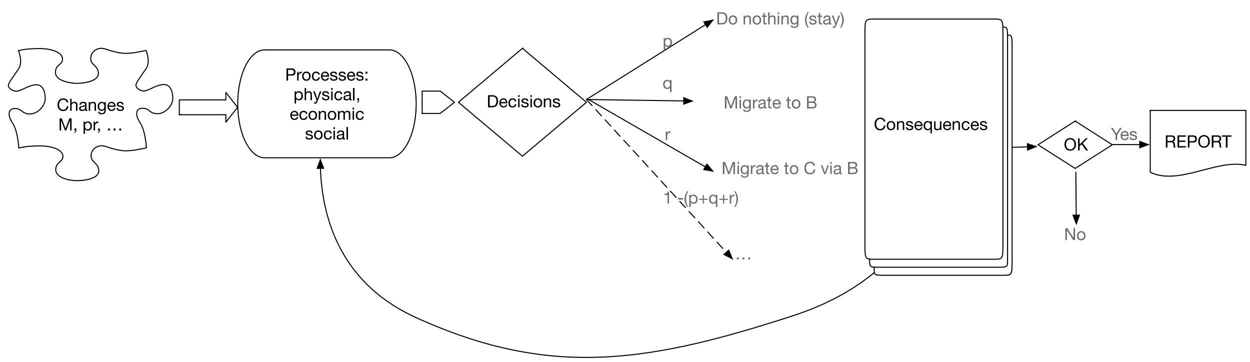

Figure 1. Integrated view of decision-theoretic methods (Ricci and Almeida, Forthcoming).

We aim to develop a bounding, policy level, integrated decision-making process that is formal and independently replicable. This process characterizes the prospective reality of concern – a cascading migration triggered by climate changes -- through modeling of choices that inform eventual decisions by agents that act on behalf of society. To the extent that migration implies different agents with conflicting objectives, analyses based on game theory can lead to the study of societal equilibria that can be optimal. In other words, formal analyses in which the aspirations of different agents are accounted for – if assessed before the migration take place -- may well lead to cooperation rather than conflict. This may be achieved by accounting for how climate change impacts human migrations, possible slow effects can precede migration, and how climate-driven causal factors influenced and will continue to influence governments and governance particularly in coastal areas.

Scope of Research

Climate Change: Prospective Migrations

According to the International Organization for Migration, IOM, (an agency of the United Nations, U.N.) (https://www.iom.int/about-migration) migration is not a defined term. Rather, it is:

"An umbrella term, not defined under international law, reflecting the common lay understanding of a person who moves away from his or her place of usual residence, whether within a country or across an international border, temporarily or permanently, and for a variety of reasons. The term includes a number of well-defined legal categories of people, such as migrant workers; persons whose particular types of movements are legally-defined, such as smuggled migrants; as well as those whose status or means of movement are not specifically defined under international law, such as international students."

This Agency notes that:

"At the international level, no universally accepted definition for "migrant" exists. The present definition was developed by IOM for its own purposes and it is not meant to imply or create any new legal category."

According to this agency, there are approximately 300 million migrants of whom 164 million are workers; as a population percentage, the migrants are approximately 3.6% of the global population involving transfers of funds of about 200 billion USD (IOM, 2020). Migration can open doors to those willing and able to relocate when there are mutually beneficial possibilities. These movements do not amount to large-scale migrations. Some of them are well established. For example, as the United States and other western areas of the world face an aging workforce, an integration of migrants to counteract the pace of retirement levels could be beneficial to the host (receiving) country, e.g., Australia, the U.S., and many other countries. However, for each migrant, the application and granting of migrant status may be complex and be based on a specific need identified by the host country. This type of migration, including the granting of individual refugee status, are not our focus. Rather, we are concerned with what we call *climate-forced migrations*. Mass population movements due to calamities that require administrative and logistic mechanisms for their orderly movement and acceptance should not be *ad hoc* even when due to a sudden catastrophic *tipping point*. The population at risk in a region may or may not be under an immediate threat, but actions are imperative as the threat is both real and has sufficient evidence of following the tipping point. The nature of the policy actions to be taken is beyond our scope. We simply wish to study how ex-ante analysis can help to identify an optimal, preferable, or second-best choice (each independent from the other) that informs an eventual policy. The immediacy of the threat, aid, preparations and staging's, external help, and so on, are independent of our work. What matters is how a portfolio of solutions can lead to one of these three choices so that administrative, physical, and other methods for migration support, control, and review can be optimized. The UN and other organizations have raised awareness that without the careful preparation, planning and management of future climate scenarios, the governments most affected by climate change could collapse as direct conflicts become prominent (Times & Lustgarten, 2020). Countries facing a climate crisis can be from poor to rich; from less affected to completely destabilized. There may also be transit countries: territories where migrants may unexpectedly decide to settle while moving. Migrants who need to pass through territory *B* on their journey of relocating from jurisdiction *A* to jurisdiction *C*, of whom some collectives may settle in jurisdiction *B*.

This can be observed (Faret et al., 2018) in Central and North America, where migrants with the intention to move north through Central America to reach the United States will settle in countries other than the United States if they find the opportunity to do so. Although the drive to migrate to the U.S. may involve a larger set of opportunities than those offered by the country of origin, a plausible assumption is that migrants prefer to relocate to an area with similar characteristics, habits, and culture, a South American will more easily adapt to migrating to countries in Central America and Mexico than they would in the United States. Under this assumption, what originally started as an attempt from migrants to relocate from *A* to *C*, now has major implications for *B*, because *B* has many of the characteristics of *A*. This uncertainty leaves decision-makers with having to find solutions for unknown outcomes, with the decisions that are being made needing to foresee events that may not happen for 5, 10, 20+ years, or even longer.

How do decision-makers prioritize alternative solutions? Is there a probability that two or more threats can occur simultaneously or are the threats sequential? If so, does that change the management plan or policy? Most importantly, how will the citizens of the host country be protected from cascading events that can arise from those threats? Suppose that there are three independent jurisdictions: *A* origin, *B* transition, and *C* final. For instance, some of the choices open to a public decision-maker in jurisdiction *C* could:

1) Ease pressure on jurisdiction *A* by allowing climate migrants to enter her jurisdiction C directly or through *B*, and settle in *C*.
2) Ease the of transit through jurisdiction, *B*, by aiding the crossing of *B* during migration to *C*.
3) Can shut its borders and the would-be migrants would either not (legally) enter or, if they entered, be detained.

In all possible cases the decision-makers in *A*, *B*, and *C* would have to assess their options and analyze the net benefits to each through game-theoretic means. The critical assumption is that *A*, *B*, and *C* have rational decision-makers. These simplifications are the mirror image of the use of theoretical decision-making procedures that we discuss. We will use axioms and models that are not only appealing but scientifically sound. Yet, there is a big caveat emptor: human decisions may seldom follow axioms and models. When so, why bother with theory at all? The reason for bothering is that those models provide a point of departure for organizing assessments and for providing a common base for relating reality to its modeling with the least possible distortion. What we think is reality is affected by how our sensory systems aggregate its information. Whether decision-makers conform to theoretical ideals or not is irrelevant: what matters is that axioms and methods based on those provide a fundamental commonality for all stakeholders. From the violation of axioms (e.g., through paradoxes) to the statistical variability of the data, stakeholders can be better informed and ask for the theory to be changed or discarded.

Methodology

Rationality: Informing Public Policy Decisions Through the Assessment of Choices

Choices made in the public interest should not be arbitrary. That is, the selection and identification of prospective actions or decisions, as opposed to the analysis of choices, should be based on reasoned and independently replicable assessments that allow their verifiability and validity. Practically, neutral analyses, rather than analyses characterized by either risk aversion or proneness, should inform decision-making; these can have behaviors that are risk-averse or prone and thus decide accordingly.

The decision-maker is an agent of society. We use single decision-makers: they are akin to the chief executives of public agencies or jurisdictions. The critical aspect is that those individuals will use a formal and replicable decision process in which, given a set of choices, their:

1) *Assessment and achievability* are independent of the decision-maker preferences (technical aspect)
2) *Utility* depends on the decision-maker preferences (subjective-behavioral aspect), and
3) *Optimality* of is constrained by 1) and 2) (technical aspect).

Optimality, if it can be determined, is conditional on both 1), 2), and the states of information and knowledge available and accessed by the decision-maker. An alternative to optimality is preferability through ranking and voting. This rationality, however, cannot guarantee that the optimal solution exists, will be adopted, and is stable for at least two reasons. The first is that information and knowledge will vary relative to their state at the time of the assessment. Choices are conditional on the state of knowledge at the time the choices are analyzed, all else being equal. The second is that decision-maker's also include political, ideological, and other constraints that are external to the notion of rationality we describe.

The private decision-makers objective is to maximize, at least in the long run, her expected net profits.[1] In this sense, her objective is unambiguous. On the other hand, a public manager may have to achieve vague, but legally mandated, objectives, such as safeguarding, to the extent possible, public health and welfare, as can rise under constitutional precautionary precepts. Making decisions about risky choices involves one

[1] In the short-term, she may operate at a loss to stay in business, something that public managers generally are not preoccupied with.

or more decision-makers who may have a different understanding of what vague legislative commands formally mean. Choices, under the control of the analyst but directed by laws, should directly account for the role of *uncertainty* (e.g., the *states-of-nature* of decision theory) that can foil a decision-maker's attempts to reach her objective.[2] The actions that a decision-maker considers are, at least in principle, under her control; however, the *states-of-nature* are not. Therefore, a formal (also called *procedural*) approach is necessary to represent the outcomes of each choice and to justify their ranking and the selection of one of them as being optimal (in some case-specific sense). Practically, the interaction between analysts and decision-makers pivots on the following four characteristics for the analysis of *choices* that informs an eventual *decision*:

1. *Acts*, A, from the set of acts, as discrete and separable choices (actions or options) available to the decision-maker,
2. *Pay-offs* or other *consequences*, C, from the set of payoffs or other consequences, modeled using damage, utility, and value functions,
3. *States-of-nature*, S, from the discrete and fully enumerated set of states-of-nature, representing the uncertain factors and the probabilities associated with each of them, and the
4. *Decision rule*, which guides the selection of the optimal act, for instance, the chosen act must be such that it is calculated from: [*max*(expected net total benefits)|*A, C, S*].

The relationships between the analysts and their choices imply an information process where agents inform analysts. This process is guided by statutory aspects – from constitutional laws to regulatory (secondary) laws discussed by Ricci (2020) and not be repeated here for the sake of brevity. An elementary process summarizes how these four critical elements (uncertainty is inherent to the states of nature) interact Figure 2.

[2] Defining *states of nature* as factors not within the decision-maker discretion follows tradition.

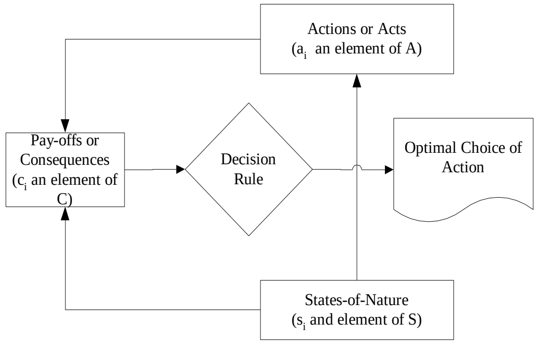

Figure 2. Elementary Components of a Decision-Making Process (Ricci and Almeida, Forthcoming).

The reasoning associated with Figure 2 is as follows:

If there were no uncertainty, action a_1 would surely lead to outcome c_1. However, uncertainty interferes by allowing the possibility that a_1 can either lead to c_1 with pr_1, or c_2, with pr_2. Choices must be mutually exclusive, and fully comprehensive (there are no other actions); *causation, $a_i \rightarrow c_i$, is known but is uncertain: $pr(a_i \rightarrow o_i)$.*

Decision analysis formulate the ways through which alternatives are linked to the payoffs from each choice, optimal or preferable choice is justified by a decision rule. In some cases, two or more decision rules may be studied (e.g., *max*(Expected value net benefit), median value) and reported so the agent-decision-maker can more fully understand the implications of the choices developed by analysts. Decision analytic criteria allow decision-makers to examine alternative courses of action (i.e., the optimal or preferable, in some analytical sense, choice from the set of choices) that result in outcomes or consequences: the *payoffs*. However, uncertainty interferes with determinism: the states of nature represent how uncertainty can foil her plans.

We formalize rationality, which we consider to be critical for public choices rationality as follows (Rubenstein, 1998). The preference relationship between choices {*a, b,* c, …}, forming the set A, has a relationship, $\succcurlyeq$ (preferred or indifferent). If $a \succcurlyeq b$, then it cannot be that $b \succcurlyeq a$. In terms of utility, the equivalent statement is that there is a monotonically increasing function, u(a), such that $u(a) \succcurlyeq u(b)$; it cannot be that $u(b) \succcurlyeq u(b)$.

The element of set *A* is associated with a set of consequences **C** such that **A** → **C**. An agent acting for the decision-maker (the analyst) identifies a technical subset of choices (or possible acts): **A** = {a_1, a_2, …, a_i, … a_n} ⊆ **A**. The objective of this agent's analysis is to use a theoretically plausible (i.e., axiomatic) maximization rule, $max_{\boldsymbol{A}}$u(a_j) that produces a subset of choices that the informs the decision-maker eventual act or decision. The prospective nature of the choices and their consequences requires accounting for uncertainty. That is, consequences, **C**, depend on factors, **F**, (also known as *states of nature*) that are outside the control of the decision-maker: **A**x**F** → **C,** where *x* is the cross product. Thus, what the analyst presents to the decision-maker are: **A**, **F** ∈ **F**, and **C**. Consistency requires that when the choice selected for analysis is also contained in two or more subsets, the same choice should still be selected (the *choice* should be independent from *irrelevant* alternatives). However, there is no such strong requisite for *acts* or *decisions*, discussed elsewhere (Ricci, 2020). Rationality has substantive and procedural aspects. In procedural rationality, uncertainty requires probabilities to be consistent with established legal and scientific analyses; however, it may not be sufficient or appropriate. There are well-known forms of behavior that violate the *axiom* of independence from irrelevant alternatives. The first is the description of each choice, as may be the case when more than one individual identifies an issue: the wording (*framing*) of the issue affects preferences. Second, decision-makers and analysts may simplify the problems: rather than considering all options in A, they may use an already available list, A' << A, from an authoritative source: the set of choices is much smaller than the set that should be considered (an instance of *myopia*). Third, analysts may have in mind a limited number of choices, A'', that seemingly dominates all other choices in A. Substantive rationality deals with how to establish objectives, conditions, and constraints; procedural rationality is characterized by deliberative behavior. This demand can be very difficult to comply with. In its stead, Herbert Simon's *satisficing* solutions (1955), rather than being an abstract reasoning and a search for optimality, account for human imperfections. What we observe and do is limited by cognitive, computational, and temporal constraints: it is the result of dealing with *bounded rationality* (Simon, 1955). The reasoning process searches through alternatives that result, *satisfice* an agent's aspiration levels in the sense that *satisficing* choices dynamically exceeds the aspiration level selected for the assessment. The preferable choice (out of an inherently limited set of choices) may not be optimal, but it should be *satisficing.* The gap between *optimal* and *satisficing* choices is the practical aspect for the selection of the subset of choices that inform eventual actions. Satisficing choices may be limited by myopia (Cognitive thinking and decision making that are focused on close or recent circumstances at the expense of broader interests or long-term consequences). Using optimality principles and methods identifies locally from globally optimal solutions (such as those obtained using constrained optimization or dynamic programming) are still necessary but are constrained: the knowledge that defines the dimensionality of that surface or hypersurface acts as a constraint on that surface, much like a mathematical constraint reduces the available solutions. The need for theoretical modeling does not cease to be important. Rather, theory grounds what may be an arbitrarily limited search and guides practical searches that can otherwise be unbounded. As Rubinstein suggests errors of omission and commission are informative because they may illustrate (or be the symptom of) several changes, ambiguities, frames of mind, and other issues. Rationality affects acceptability, viability, and practicability of choices and directly influences the acts that a decision-maker may consider. As Selten (What is Bounded Rationality? SFB Discussion paper B-454, 1999) has suggested in his *aspiration adaptation theory*, optimization may not be possible when knowledge and information are limited. For public choices, their legislative, regulatory, and judicial aspects require, particularly for extreme events, careful assessment well before the catastrophe occurs. The development of optimized procedures and formal assessments should be an ongoing effort by the responsible agency correctly and equitably to allocate expenditures. Selten's *aspiration adaptation* is an important contribution to situations in which time is of the essence, the hazard is novel and has rapid onsets. In these cases, it complements criteria such as establishing either deterministic or stochastic dominance of solutions and should suffice to inform policy actions. Whether aspiration levels are accepted by all agents and stakeholders goes beyond our work.

Formalizing Physical Reality Leading to the Analysis of Choices

The physical reality of cascading catastrophes requires an integration that, to inform public policy choices, should be rational ex-ante of how reality is transformed into a model. A generalized view of a cascading catastrophe is conditional on its historical precedents, current scientific information, and knowledge. These form a time-dependent sequence of theoretical and empirical characterizations:

Physical Reality ⇝ *theory* ⇝ *data* → *mathematical representation of theory* → *statistical model* → *assess results* → *[feedback: accept, revise, reject model]* ⇝ *forecast* ⇝ *new data* ⇝ *update statistical model (e.g., using Bayesian updating)* ⇜ *new theoretical evidence* → *optimal stopping rule* (1).

In (1), ⇝ means *uncertain implication* and → *certain implication*, simplified by avoiding decision nodes and information feedbacks. The sequence of modeling is exemplified and depicted in Figure 3. The justification of policy decisions – informed by those results – is an ex-post deliberative process. We simplify the discussions to emphasize integration at the expense of loss of detail. However, our simplification is not an arbitrary cancellation: criteria from Occam's criterion to Bayes' factors exemplify different aspects of our modeling simplification. Figure 3 follows from (1) and depicts a simplified, high-level *physical* network of the processes that inform policy analysis. It is an example of *scientific* rationality that is the basis of the analysis of prospective choices. For example, in the context of migrations, climate changes are *forcing functions* on the environment of a jurisdiction, which is (by assumption) at a stable equilibrium. In Figure 3, this stable equilibrium is depicted under *prospective analyses*. This is the modeling of events and consequences phase that might begin with the second equilibrium from the left, last row. These contents apply to modeling from environmental (e.g., affects water cycles resulting in extreme droughts) to social disequilibrium (e.g., much-reduced food production, famine, economic depression) that may lead to migrations from country *A* to country *B* and other countries. One or more exogenous forcing functions (e.g., sine and cosine functions) represent seasonality and change the output of an otherwise unforced dynamic system. These systems have solutions (trajectories) modeled through coupled difference or differential equations (Figure 3) and can be perturbed through sensitivity analysis to simulate changes from initial states (e.g., indexed by t_0). In this Figure, the hazard's spatiotemporal aspects vary from low amplitudes and frequencies (slow-moving consequences) to high-frequency high amplitude (fast moving consequences) represented by a 3-D wave, an idealized representation of an index of adverse effect (e.g., economic changes from water scarcity over time and area). As water scarcity changes (measured on the *z*-axis, the *x*- and *y*-axes measure time and length of the scarcity) at some point on the surface of the wave, near one of its peaks, the population at risk is unable to cope with and begins a migration. After the migration, there could be a rapid decrease in the adverse effects, as depicted by the descending limb of the peak. In some situations, there may be a hidden threshold effect that triggers a migration. Decaying and transient effects, respectively, are depicted by the two panels to the left and right of a hypothetical probabilistic threshold. Alternating dynamic economic equilibria characterize peaks and valleys, as depicted by the leftmost bottom panels. The interactions between key variables are exemplified in the lower rightmost panels that depict, from left to right, three different forms of economic equilibriums, a static network of variables, and two coupled differential equations (dynamic model). These models may use unlabeled variable names for simplicity. The assessment step in Figure 3 integrates the physical processes with the possibility of two competing nations, X and Y, observing the same physical situation, having different responses about the effect of migration. Each jurisdiction has a formal analysis of choices process that accounts for risk aversion, proneness, and neutrality and that informs assesses each choice based on optimality or preferability criteria. To the extent that what is optimal for a jurisdiction may not be optimal for another, the assessment phase of Figure 3 accounts for these differences through variables and coefficients, as discussed next. Agents are assumed to be rational in the following sense. *Procedural rationality* has two formal aspects: i) *mechanistic rationality* (e.g., conservation laws cannot be violated), and ii) *choice rationality* (e.g., single decision-maker decision theoretical maximization or minimization; multiple decision-makers game-theoretic equilibriums such as zero-sum results or another criterion). Both inform decision-makers who, however, may or may not act rationally when *making* decisions: for instance, they may use military force to prevent the migration from occurring.

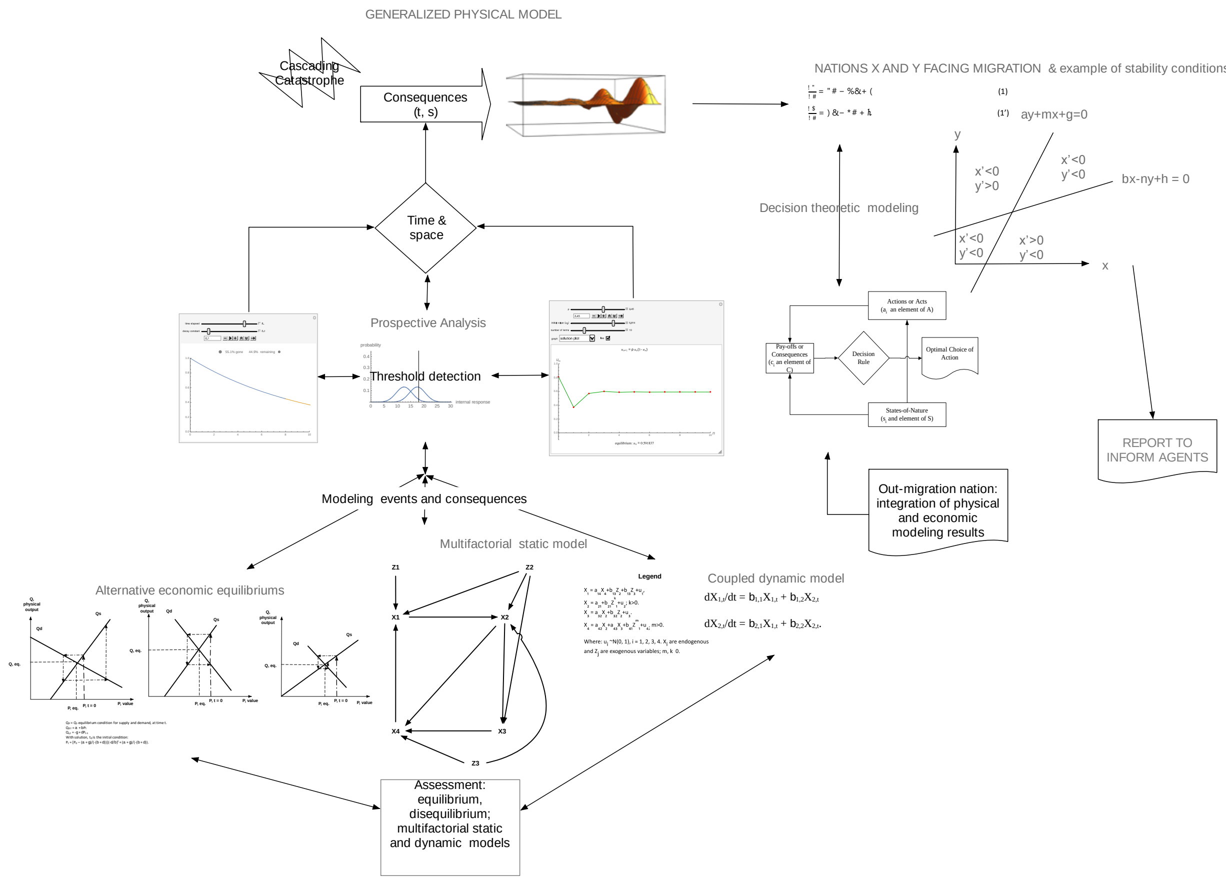

Figure 3. High Level Form of *Rational* Scientific Causation (in the assessment, X and Y are two nations, and the quantities of concern are x and y); *x'* and *y'* are derivatives with respect to time, *t.* (Ricci and Almeida, Forthcoming).

A relatively simple model of a reality of two countries *X* and *Y* that may be or become antagonists is Richardson's *arms race* model (1960). This model has generated discussions and modeling alternatives. In its initial (1960) form, it is a continuous dynamic system (changes are d(.)/dt) consisting of two differential equations:

$$\frac{dx}{dt} = ay - mx + g \tag{1}$$

$$\frac{dy}{dt} = bx - ny + h \tag{1'}$$

This *arms race* paradigm is directly relevant to studying the effect of migration because *changes* in expenditures due to migration are affected by internal mechanisms, the make-up of the political systems, and other factors. Migration directly affects budgets, alliances, make political views more extreme and inherently elicit antagonism (although altruism is a possibility for this discussion, pessimism is sufficient to crystallize ideas). Equations (1) and (1') model changes in expenditures (*x* and *y* are expenditures for armament) by two nations X and Y that are proportional to changes in expenditures by the opponent. The factors that affect each of the two changes are additive. These equations are structural in the sense that they are invariant to changes in each nation's political system: expenditures are economically constrained and internal (endogenous) and external (exogenous) behavioral factors affect change. A common monetary unit is used and is adjusted for inflation, purchasing parity, and other factors that allow direct monetary comparisons between the two countries. The coefficients *a* and *b* measure each country's reaction to the other country, *-m*, *-n* represent countervailing forces to reduce that spending, the constants *g* and *h* model the impact of other exogenous forces. The *g* and *h* coefficients can be changed to reflect more complete representations such as adding a seasonal component (Richardson's model used by Brown, 2008) as a periodic voting process in nation *X*. This dynamic model can be extended to include more complicated behaviors by *X* and *Y* and more nations *W*, *Z* and so on, by adding more differential equations and increase the number of coefficients. This model can be rewritten in matrix and vector form:

$$\frac{dy}{dt} = AY + g = \begin{pmatrix} a & -m \\ b & -n \end{pmatrix} Y + \begin{pmatrix} g \\ h \end{pmatrix}$$

(2)

The differential equations, x'(t) and y('t) are parametrized by the numerical values of their coefficients with a general solution: $Y(t) = k_1 e^{\lambda_1 t}\boldsymbol{v_1} + k_2 e^{\lambda_2 t}\boldsymbol{v_2} - \boldsymbol{A}^{-1}g$, in which λs are eigenvalues and ***v*** eigenvectors. Determining these trajectories requires developing estimates of the coefficients of matrix **A**, as may be available from historical time-series of past expenditures. Statistical estimation of the coefficients of the right-hand side of the last terms of (2) is an example of an expenditure model in vector and matrix form (Khan, Usman and Khichi, undated):

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \begin{pmatrix} 1.193 & 0.148 \\ 0.159 & 0.892 \end{pmatrix} + \begin{pmatrix} -66 \\ -6{,}4 \end{pmatrix}$$

(2')

Adding to the term *h* the periodic component $\left[q(0.5+\frac{\sin(\omega t)}{2})\right]$ implies the inclusion of a recurring forcing function (*Int*. means integration), Figure 4:

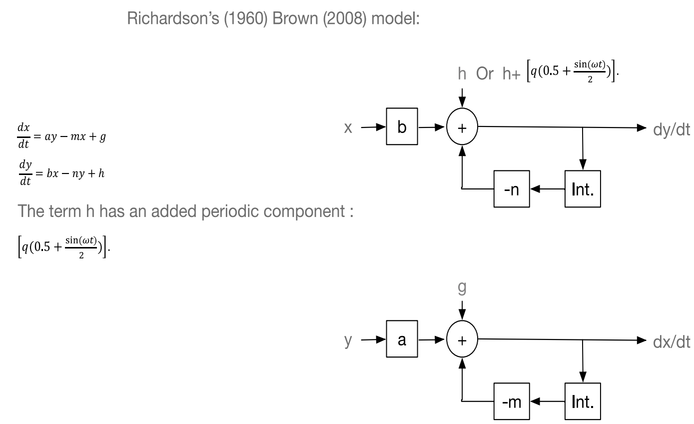

Figure 4. Coupled differential equations and single forced oscillator input: Richardson's arm-race model modified by Brown (2008).

Optimality, if relevant, can be discussed relative to an equilibrium between the state of the system time at time t_0. Theoretical equilibrium occurs when *y* at time *0* equals *x* at time *0*: $x_{t=o} = y_{t=0}$: the right-hand sides of the two equations cross at this point: $ay - mx + g$ = 0 = $bx - ny + h$. The states of the system are determined by the derivatives: dx/dt and dy/dt $\gtreqless$ 0, The location of the equilibrium is $x_0 = \frac{ha+mg}{an-ab}$ and $y_0 = \frac{gb+hm}{mn-ab}$. These allow studying the stability of the system (Caspary, 1967): the sign of the derivative and the locations of the equilibrium point identify critical possibilities, including the effect of a feedback that leads to increasing military expenditures. For example, if *ab* > *mn* (*g*, *h* > 0) expenditures increase in time relative to the equilibrium; if *ab* < *mn* spending will tend to equilibrium; if *g* and *h* are negative and *x* and *y* are below the initial equilibrium point, there will less budget over time: disarmament. However, above the same equilibrium point, these conditions lead to more budget being allocated to these expenditures and thus to a race.

For our work, Richardson's model is an extension of the more general *decision theoretic modeling* loop in Figure 3. It is both policy input into ex-ante assessment and an output that integrates its elements as an intermediary model between the waveform solution and how it informs the assessment of choices depicted in the decision tree and tables. In other words, the purpose of this work is not to develop more models, rather it is a means to integrate different disciplines, from law to mathematics, to understand the fundamentals for cascading, rare events, of which climate-induced migration is but a case. The direct causes of *mass migrations* are prospective catastrophes for two or more jurisdictions: they would not occur without climatic forcing functions. The reason for the term function is that different factors, often time and space dependent, can be modeled as mathematical functions that, through statistical analyses, can be parameterized and their variability shown using probability distributions. We are dealing with extreme and rare events that are inherently uncertain but capable of being formalized in known ways that allow sensitivity analysis, and other forms of assessment, useful to inform more completely decision-makers, stakeholders, and others. Equations alone are insufficient. What is needed is to determine how antagonistic or cooperative agents will use the information generated by mathematical models that inform them of equilibriums and non-equilibriums. There are many other ways to model the interactions between opponents. For instance, genetic algorithms and other machine-learning representations of interactions and predict outcomes and the uncertainty about those predictions. It is not our intent to review these, other than by noting their usefulness. We suggest that, by using principled but basic methods and explicitly avoiding a more complete enumeration of factors, their possible non-linear forms, uncertainty, and overall complexity aids managerial-level understanding of the quantification of the cascades generated by catastrophes and, through other formal aspects of assessing probable choices, may direct to better understanding of policy alternatives. The next section develops the aspects of the interactions between agents. Numerical payoffs and consequences are determined by mathematical and other quantitative methods; interactions between agents are viewed through the prism of every agent's risk aversions, proneness, and neutrality, as well as the behavior of each opponent. To simplify the discussions, we use examples involving either one or two rational agents acting as decision-makers.

One of the most important modeling aspects of the analyst-agent-decisionmaker interactions is the feedback.

Feedbacks

We consider one or more *causal* factors (input variables) that lead to an output or outcome. By using a single factor, F_t, we related it to the outcome, O_t, via an operation ***Op***, which can initially be a *black box*. For example, text messaging decrease attention to driving and thus a proportion of drivers who text message while driving have car accidents. The causal representation is: F_t [# drivers that text message], O_t [# of text messaging drivers that have car accidents while driving and text messaging], and ***Op*** [%]. The model is: F_t****Op*** = O_t, in which *t* indicates an interval of time, such as the same year. Depending on the event and its consequences, additional input factors, whether positive or negative, can influence the outcome. For example, if we take factors that additively impact the outcome, we build a linear equation in which the coefficients of the inputs (e.g., causal factors X and Y) for the outcome O_t; B_i are the coefficients of the model that can be positive or negative (and still linearly aggregate and thus ***Op*** is the operator $\pm$ or $\mp$):

$$O_t = \pm B_1 \pm B_2 X \pm B_3 Y\,)$$

The missing critical mechanism is the *feedback* process. For instance, positive feedback – exemplified ed by the constant *k* – modifies the output (paths that merge are either added or subtracted as depicted by the oval, in this case, the *plus* sign, noting that multiple input factors, one of them being *I* at time *t*, namely I_t, as depicted (Figure 5), may be either positive or negative (addition applies to both):

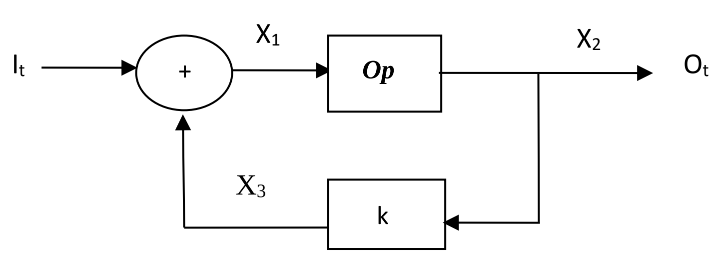

Figure 5. Scheme of the feedback process (Ricci and Almeida, Forthcoming).

An output O_t can be increased or decreased, depending on the sign of the constant *k*, and is fed back into the system until its complete evolution takes place and the value of O_t is determined. If the feedback is positive it *amplifies* the output, O_t, relative to a system without the feedback. The graph means that: $X_1 = I_t + X_3$; $X_2 = \boldsymbol{Op}(X_1)$; and $X_3 = k(X_2)$. That is: $X_2 = \boldsymbol{Op}(I_t + X_3) = \boldsymbol{Op}(I_t + k(X_2))$; it follows that: $O_t = I_t(\boldsymbol{Op}/(1 – k(\boldsymbol{Op})))$.[3] For many outcomes, exposures to detrimental or beneficial factors, may have to be lagged because they do not act instantaneously (response is not an instantaneous cause of an effect). For instance, a response at time *t* is caused by an exposure that occurred *t-k* periods of time in the past. We can exemplify the one-period lag (Figure 6) as E^{-1}: $E^{-1}(X_t) = X_{t-1}$. The process that allows for successive adjustments of the magnitude of the output, $O_t = X_2$, through negative feedback and a one-period lag, is:

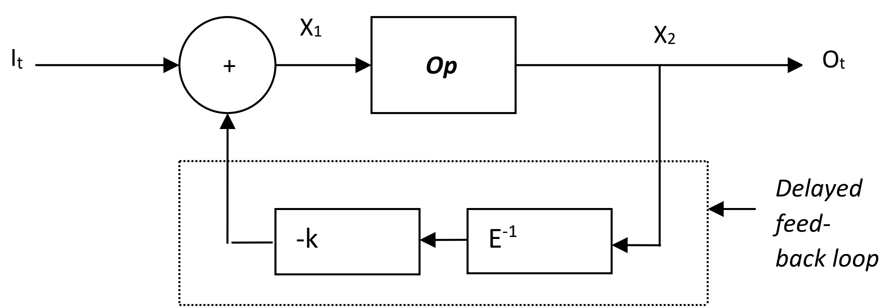

Figure 6. Example of a delayed feedback loop (Ricci and Almeida, Forthcoming).

This graph means that X_2 is changed through the feedback, –*k* and the delay affect the overall output. For example, E^{-1} may be a one-period delay due to some sub-process that is not expressly modeled but is represented by the delay. Formally: $X_1 = I_t + X_3$; $X_2 = \boldsymbol{Op}(X_1)$; and $X_3 = -k*E^{-1}*(X_2)$; $X_2 = O_{t+1}$. The time delay E^{-1}: $X_2 = \boldsymbol{Op}(I_t + X_3) = \boldsymbol{Op}(I_t – kE^{-}$

[3] Without subscripts: O = ***Op****I + k*Op*O, thus (1 – k****Op***) = ***Op****I, and thus O = (***Op***/(1 – ***Op***))*I. This is a representation of the *multiplier* $(1\text{-}MPX)^{-1}$ where X may be some quantity policy variable and the formula accounts for an infinite number of cycles within the system being modeled. It is a geometric series $1 + MPX + MPX^2 + … + MPX^n = 1/(1\text{-}MPX)$, as $n \rightarrow \infty$.

$^{1}(X_2)$); thus: O_{t+1} = ***Op***I_{t+1} – $kE^{-1}O_t$.[4] Qualitatively, the lagged (or delayed) negative feedback increases the leakage from the output: the output diminishes. It may be important to deal with differences: a change is input into the system and we wish to predict the effect of that change. Moreover, some effects can be cumulative (Figure 7), rather than just work as a multiplier (i.e., the positive feedback). We show a change in a variable *X* by the notation ΔX; if time is the argument, then ΔX_t is used.[5] Δ^{-1} is the inverse of Δ and is a cumulative operator that sums the paths leading into it and, when applied to Δ^{-1}, yields the original variable: we get back X:

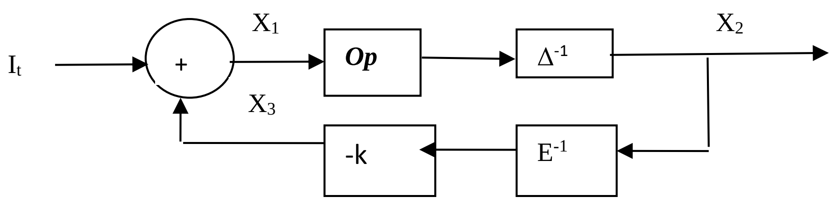

Figure 7. Example of a feedback loop with cumulative effects (Ricci and Almeida, Forthcoming).

Cumulative effects are the subject of many policy arguments, ranging from environmental to economic. Accumulation can be shown using the same variables as before. To show how, we use the simple input-output relationship $\Delta^{-1}I_t = O_t$. By definition, $\Delta O_t = O_{t+1} – O_t$ and, because Δ^{-1} is the inverse of Δ, $\Delta^{-1}(O_{t+1} – O_t) = O_t$. It also follows that $O_{t+1} = I_t + O_t$, and $E^{-1}(O_{t+1} = I_t + O_t)$ yields: $O_t = I_{t-1} - O_{t-1}$. Using $\Delta^{-1}I_t$ and substituting we obtain $\Delta^{-1}I_t = I_{t-1} + O_{t-1}$. Input variables may be characterized by exponents of degree greater than one, X^2 is an example, or that are multiplied, as when we study interactions such as X_1*X_2. An example that has both mathematical and statistical importance is the logistic equation: $Y_{t+1} = aY_t(1 – Y_t) + Y^t$. It can be represented as:

[4]Two technical conditions are required for these results: *homogeneity* and *superposition*. The first states that: (operator)*(constant)*(X_1) = (constant)*(operator)*(X_1); the second that: (operator)(X_1+X_2) = (operator)X_1+ (operator)(X_2). These can be extended to include more variables and coefficients.

[5]From footnote 2: $\Delta(aX_t)= a(X_{t+1} - X_t)$ and that $\Delta(X_t – Y_t) = \Delta(X_{t+1} – X_t) + \Delta(Y_{t+1} – Y_t)$.

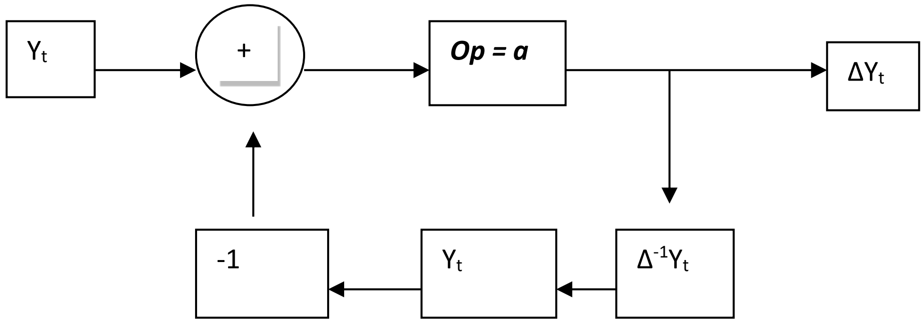

Figure 8. Logistic model for determining carrying capacity (Ricci and Almeida, Forthcoming).

That is: $\Delta y_t = Y_t(a/(1 + aY_t\Delta^{-1}))$, so that $\Delta y_t = aY_t^2 = aY_t(1 - Y_t)$, which is the logistic model (Figure 8). We describe its characteristics because it can be used in the context of determining the carrying capacity (the theoretical total population) of a nation. Of course, it is a first approximation to what would otherwise be a much more complex modeling effort. Nonetheless, it can be used by Country A to assess what Country B that capacity may be, in the simplest instance. Logistic maps are depicted in Figure 9 using the interactive Wolfram Demonstration by RM Lurie (2011) http://demonstrations.wolfram.com/ClassicLogisticMap/. Using different assumptions about the future states of the population by assuming different values for *r,* we obtain two very different trajectories described in panel 1; possible chaotic dynamics are described in panel 2.

Panel 1 Panel 2

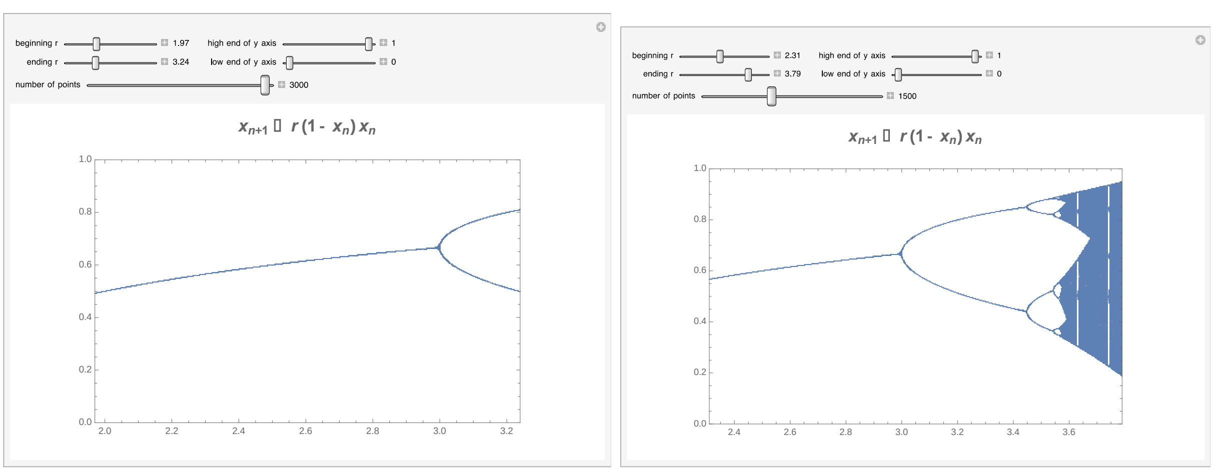

Figure 9. Logistic maps depicted by using the interactive Wolfram Demonstration (RM Lurie, 2011).

We use Normand, Remin, and Peleg (2014) Wolfram Demonstration http://demonstrations.wolfram.com/GrowthCurvesForAMixtureOfTwoSubpopulations/ to depict the growth of two populations after they merge (Figure 10). The growth curve of a population is generally sigmoid or concave downward and approaches asymptotic level, its overall *carrying capacity*. As these three Authors show, the mixture of two subpopulations also follows that trajectory. However, individual populations' growth parameters can result in an atypical, combined growth.

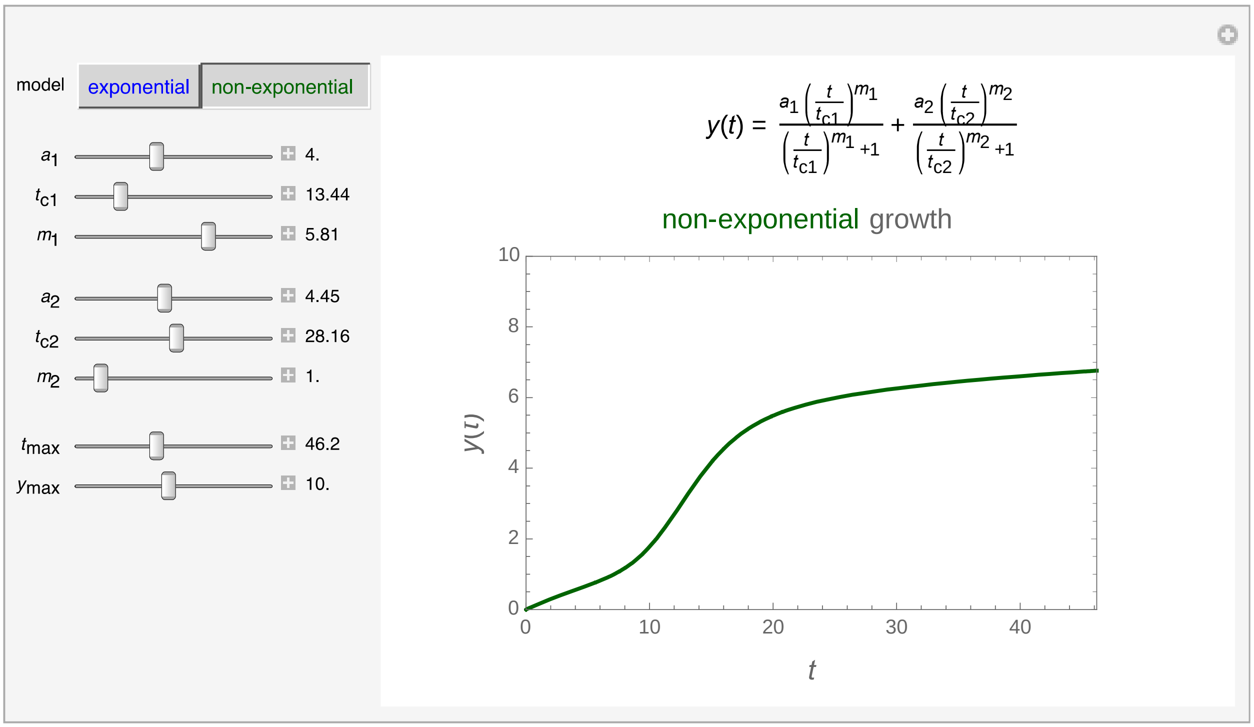

Figure 10. Depicting population growth by using the interactive Wolfram Demonstration (Normand, Remin and Peleg, 2014).

More specifically:

"… the regular and odd shapes are generated with a two-term general growth model y(t)=y1(t)+y2(t), where y(t) is either the net growth ratio (n(t)-n_0)/n_0] or the logarithmic growth ratio log((n(t)/n_0), where n(t) and n0] are the momentary and initial sizes of the population, respectively. The first definition applies to comparatively moderate growth levels and the second to intensive growth resulting in a population rise by several orders of magnitude. According to both definitions, at t=0, where n(0)= n_0, y(0)=0. The chosen functions for $y_1(t)$ and $y_2(t)$, whose complete formulas are displayed above the growth curve's plot, are the three-parameter stretched exponential model $a_i(1-\exp(-(t/t_{ci}])^{mi})$ or the non-exponential model $a_i(t/[t_{ci}])^{mi}/(1+(t/t_{ci})^{mi})$, both satisfying the condition that $y_i(0)=0$. According to both models, $a_i=y_i(\text{Infinity})$, the subpopulation's asymptotic growth level, t_{ci} is a characteristic time, and m_i is the steepness parameter. According to both the exponential and non-exponential models, the asymptotic growth level of the mixed population, y(infinity), is a_1+a_2."

This simplified analytical background describes a simple mathematical structure of temporal feedbacks and mixing population growths. These are critical information for assessing the effect that migration may have on population sizes. Unfortunately, the assessment of the impact of those changes over time has varying effects on the population of origin and destination, their infrastructure, and well-being. If the spatial extents of the effects were to be included, the deterministic and dynamic analyses would become more complete but also more complex.

Decision-Making: Formal Aspects of Interactions of Agents-Decisionmakers

Throughout this section the term *choice* is to be synonymous with the term *act*: the latter of the two will be developed by the decision-makers (or agents) following a constitutional command, a statute, or other lawful public policy will ask analysts (experts) formally to assess. Once assessed to the optimal or preferable choice between the set of choices under assessment, it may become an act. One of the critical aspects of dealing with catastrophes is the interactions of agents that act on behalf of the collectives at risk. More specifically, our concern is with the behavior of individuals that, although heterogenous, in the aggregate form a homogeneous collective of strongly interacting individuals that often have weak connections with neighboring collectives. Those collectives can be considered as being – under specific external threats – as acting as a single agent. In other words, unlike many other situations, under threat, heterogeneity solidifies into homogeneity: the appearance of the individuals in the collective is monolithic. The permanence of that homogeneity, although critical to other analyses, can be taken as temporally fixed when under threat, but it is transient without the threat. The couplings of individuals within each collective justify assessing their prospective choices – as opposed to decisions – a being rational: lower losses are preferred to more losses.

Excluding altruism, we suggest that – for our work – this assumption is axiomatic. Moreover, because two or more collectives prospectively affected by an action will necessarily interact, the analysis of their behavior uses the formal methods of decision and game theories. In the best possible case, the interactions (also called *games*) are based on perfect information: all agents know the existing states of information and knowledge. Practically, information is often imperfect: partial knowledge rules.

Formal Decision Making: Single, Multiple Agents, and Stakeholders

A simple decision concerns a single analyst that also is a single decision-maker that faces several possible choices or actions and must determine if there is an optimal choice. The issue is that neither the analyst nor the agent can control the outcome of the action chosen because uncertainty – *states-of-nature* -- can prevent the desired outcome from occurring. This is the *decision problem under uncertainty* (Luce and Raiffa, 1957) in the example that follows.

Example. More is preferred to less. ***S*** represents a binary outcome that can yield payoffs that are different from those that would otherwise occur from three mutually exclusive acts (Act *1*, Act *2,* and *Act 3*). The payoffs (dimensionless) are (*5*, *-1*), …, (*2*, *-8*):

		***S* (*states-of-nature*)**	
Decision-maker chooses one of three		***Yes***	***No***
	Act 1	(5, -1)	(10, 40)
	Act 2	(1, -1)	(3,-10)
	Act 3	(0, 0)	(2,-8)

Entry (*5*, *-1*) means that if the agent chooses act *1* she can gain *5* units of value. If an alternative state of nature prevails, she loses the *1* unit of value, namely *-1*. In other words, a benefit from a decision can have a positive outcome but the external factor can cause a completely different outcome.

This example is deterministic: it does not account for uncertainty. To do so, we use probabilities: the problem become one of decision-making under risk the uncertainty is quantified by a probability distribution function. In the example below, it is a uniform discrete distribution (*Yes* and *No* each have an equal probability of occurring).

		***S* (*states-of-nature*)**	
Decision-maker chooses from one of three acts		***Yes***	***No***
	Act 1	(5, -1)	(10, 40)
	Act 2	(1, -1)	(3,-10)
	Act 3	(0, 0)	(2,-8)
Probability distribution for the states of nature		0.50	0.50

Probability theory deal with both uncertainty and variability in transparent, consistent, and coherent ways. The protocol for the analysis of probabilistic events suggests the following information generating process:

1. Define and identify the boundaries of the risky choice or problem: the agent-analyst information and knowledge flows,
2. Define working hypotheses, scientific conjectures, and *transcientific* issues,
3. Giving a qualitative description of the processes leading to all relevant outcomes,
4. State *statistical* hypotheses,
5. Determine the state-of-knowledge and represent it through *systematic* literature reviews,
6. Assess the need for additional experimental work, develop stopping rules for limiting the gathering of costly information based on the value of information, calculations, and explicitly includes the cost of adding information,
7. Assess the need for experiments designed to provide likelihoods (conditional probabilities),

8. Model empirical, causal relations between the source of hazard and adverse effect; accounts for uncertainty through measures of uncertainty (e.g., upper and lower probabilities, intervals, possibilities),
9. Inference from samples to the populations from which the samples came (e.g., using confidence bounds),
10. Establish formal expression of the relations between initiating events, outcomes, policy interventions, costs, benefits (including the discounting of economic costs and benefits) and the uncertainty about these,
11. Choose the criterion that is consistent with the policy actions and that can be formalized thorough the analysis of choices (e.g., minimax cost, minimax regrets, maximize expected monetary value or utility), explain the rationale for the choice of criterion for selecting the optimal or preferable alternative,
12. Identify residual hazards and their consequences (corollary to the main optimal or preferable choice),
13. Select the optimal strategy,
14. Develop policy outcomes monitoring and feedbacks from agents to stakeholders.
15. Resolve outstanding issues,
16. Report to responsible agents

The use of probabilities as measures of uncertainty in this process implies Bayesian reasoning. The prior probability is a subjective degree of belief, based on knowledge, encoded in either a probability or a distribution. The conditional probability describes the effect that the probability of an event that can occur will have on another event yet to occur: the two events influence one another. For example, for events *E that has occurred* and *A that* has not, then:

$pr(A|E) = [pr(A\ AND\ E)]/pr(E)$.[6]

If *A* and *E* are (statistically) independent, *pr(A AND E)* is simply the product *pr(A)pr(E)*. Bayes' theorem also applies to probability density functions and mass functions discussed

[6] Key axiom of probability theory.

in later chapters. Recollect that Bayesian probability theory updates subjective belief (which are expressed as a prior probability or distribution based on past information) through experimental results, the likelihood. Given a prior probability and the likelihood (which is a conditional probability), Bayes' theorem[7] yields the posterior probability. Bayesian methods are independent of the area of application. Thus, they have been applied to medical decisions, risk assessment of radioactive soil contamination, water resources analysis, risk management, and economic analyses. It is important to be able to capture subjective beliefs from such sources as the literature, experts, or other appropriate sources about the distribution of events before the experiment. Four key concepts of Bayesian analysis relevant to risk assessment and management are expanded next.[8] Recollect that: 1) a prior distribution is the distribution that a risk assessor *believes* to be true, for the problem she is assessing; 2) the experimental data is used to form the likelihood. Let *F(b)* denote the prior (subjective) joint distribution of uncertain quantities in the argument, *b*. Then, *(F|L)* is the posterior probability distribution (developed by applying Bayes' theorem to the prior distribution and the likelihood function) for the uncertain quantities in *b*.

However, Bayesian reasoning, despite its usefulness, can create difficulties or incorrect results. For instance, (Ricci, 2006):

1) *Posterior probabilities based on weights of evidence are ambiguous.* When the correct model is unknown and multiple models and weights are used, or when multiple sources of evidence giving partially conflicting posterior probabilities are combined, the resulting aggregate posterior probability distribution is *ambiguous.* An infinite variety of alternative models and weights are mapped by the formula

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[7] A demonstration of Bayes' theorem follows. From *pr(A AND B) = pr(A)pr(B|A)* and *pr(B AND A) = pr(A)pr(A|B)* equate the right hand sides to obtain *pr(A|B) = [pr(B|A)pr(A)]/pr(B).*

[8] The discussion uses the term *vector* which is a mathematical quantity characterized by direction and magnitude. A set of *n* observations on the random variable *X*, that is $[x_1, x_2, \ldots, x_n]$, is a vector. For example, a sample of concentrations of SO_2 in ambient air is a vector, a sample of counts of daily hospital admissions for September 2001 is also a vector (with *30* values, *n* = *30*), and so on. The data for a problem may require more than one vector. In this section we bold the letters representing vectors: $\mathbf{x} = [x_1, x_2, \ldots, x_n]$. Two or more vectors can be represented by a matrix.

[$w_1(F|L_1)$+,...,+$w_n(F|L_n)$] onto the same aggregate posterior probability distribution to obtain a posterior estimate using Bayes' theorem. A partial solution to these problems is to present posterior distributions and corresponding weights for each model separately. A weight is not a probability measure: all that is generally required is that the sum of each weight adds to 1.

2) *Not all scientific knowledge can be assessed probabilistically.* Some of the knowledge used to draw practical conclusions about risks can be abstract or non-quantitative. Other aspects of qualitative knowledge can be used to constrain probabilistic calculations, but these cannot be represented by probabilities. For example, the statement *the dose-response function is smooth and s-shaped* can be used to constrain non-parametric estimates of a statistical model. However, this statement is not about the probable value of a variable conditioned on the values of other variables. Hence, it cannot be explicitly represented in these terms.
3) *A set of mutually exclusive, collectively exhaustive hypotheses about the correct risk model is seldom known,* making the use of probabilistic *weights of evidence* for different possible models inexact. Probability models inherently make the *closed world assumption* that all the possible outcomes of a random experiment are known and can be described (and, in Bayesian analysis, assigned prior probabilities). This assumption can often be unrealistic because the true mechanisms may later turn out to be unforeseen. Conditioning on alternative assumptions about mechanisms only gives an illusion of completeness when the true mechanism is not among those considered.

Notwithstanding these issues, the usefulness of Bayesian analysis stems from several considerations. First, it provides a formal method for updating prior scientific knowledge by requiring the researcher to think in probabilistic terms. This requires the risk assessor to specify *how* past information can be folded into a distribution function. Second, the analyst deals with distributions, rather than with single numbers. Third, the likelihood links the sampling design to the structure of the model that is most likely to be determined by the sample. Fourth, the assessor must disclose the reasons for her choice of the prior distribution, which is shown through the form of the prior distribution function adopted and clarified by the reasons for adopting that distribution.[9] Finally, the analysis is transparent and can be discussed for lack of completeness, the arbitrariness of assumptions, and adequacy of the experimental results. Discussions, aided by a formal framework, provide a common and verifiable basis for assessing assumptions, defaults, methods for analysis, and data.

Unfortunately, as Anand (2002) states, the *simple, general message is that decision-making without scientific evidence, or well-defined probabilities, is far from unusual*. Yet, it does not have to be so. We list some of the determinants of the process for assessing prospective hazards that may resolve Anand's concern:

- Who evaluates the outcomes of the hazard and its context (actions, states of nature, consequences, and probabilities)?
- Who makes decisions by transforming the assessment of choices and their ranking into actionable items under the control of the decision-maker?
- Who is accountable?
- What are the objectives of the analyst?
- Who is at risk, who benefits, and who pays?
- Who assesses the analyst's work?
- How is the choice of actions implemented, by whom, and how will its outcomes be monitored?
- Who will enforce implementation or punish lack of implementation?
- What policy feedbacks will be put in place to inform stakeholders?

Practically, the first step in decision-making consists of having analysts develop the complete and fully exhaustive enumeration and description of each choice. The second step is the analysts' selection of methods for analysis and the criteria to decide which of the choices is either optimal or preferable. The third consists of accounting for uncertainty and variability. The fourth step is causal analysis. This step requires understanding the scientific basis of the causal links between hazards, emissions, exposures, and responses

[9] Distribution functions can be theoretical defined (e.g., Weibull and Poisson distributions) or empirical (e.g., histograms).

by those at risk (and thus their identification because the severity of response also depends on endogenous factors). The fifth step is the assessment itself and the discussion of the issues that remain unresolved. The final step informs the decision-maker.

In the discussions that follow we assume that there is an established principle-agent delegation to act: in other words, the collective at risk (or the collectives) at risk have properly delegated the authority to make choices on their behalf to an agent. *Choices*, the objective of an analysis where analysts inform decision-makers and stakeholders, and *actions* that decision-makers may take, are the same object. What changes is the perspective: an *action* can directly define a policy; a *choice* is a formal analysis that justifies an optimal or preferable alternative. Analytically these two objects are the same, substantively they may not be: the decisionmaker can ignore an optimal choice and opt for a second or third best for political or other reasons. In the next section we use these two terms interchangeably.

A useful way to represent the relationships of interest to a decision-maker (called the *normal form*) consists of developing a payoff matrix in which $c_i \in C$, (portraying the net gains or losses associated with each action, including the *do-nothing* action) for the fully exhaustive and mutually exclusive collection of available choices, labeled *actions*, $a_i \in A$, and states-of-nature, $s_i \in S$, in deterministic form, a set of losses, $l \in L$, associated with three distinct and separate actions, and three the states-of-nature that affect them. We emphasize that – this is complete a fully exhaustive representation of what is known: perfect information. The magnitudes of the losses are calculated exogenously by an economic or epidemiological study. The certainty of these numbers is a simplification. In practice, the uncertainty about each number is a random quantity characterized by upper and lower bounds; we presume the uncertainty to be much lower than the numbers in each cell.

Table 1. Deterministic Decision Table in Normal Form (Ricci and Almeida, Forthcoming).

	States of Nature, S, (losses, L, in arbitrary numbers)			***Comment* (the greater the number the larger the loss)**
Actions (or choices)	s_1	s_2	s_3	***Minimum Net Loss***
No action, a_1	$l_{11} = 0$	$l_{12} = 2$	$l_{13} =5$	**0 (minimax)**
Limited Intervention, a_2	$l_{21} = 10$	$l_{22} = 4$	$l_{21} = 3$	**3**
High Level Intervention, a_3	$l_{31} = 20$	$l_{32} = 40$	$l_{33} = 60$	**20**

The decision-maker must also have a criterion for choosing between the payoffs. A criterion for choice is to minimize the maximum loss, the *minimax* criterion. Applying this criterion to the data in Table 1 indicates that a_1 is minimax. Therefore, this is the action that should be taken, barring considerations external to this analysis. We include uncertainty using probabilities as follows. Suppose that the states of nature are as described in Table 2. In this Table, the intersection of c_1 and s_1 is the probability of obtaining observation x_1 and state-of-nature s_1; that is, $pr(x_1 \text{ AND } s_1) = 0.25$.

Table 2. Probabilistic Inputs in a Decision Table in Normal Form (Ricci and Almeida, Forthcoming).

	pr(X = x_j *AND* S = s_j)		
	States-of-Nature, S		
Choices, C (or actions)	***s_1***	***s_2***	***s_3***
c_1	0.25	0.41	0.50
c_2	0.50	0.42	0.30
c_3	0.25	0.17	0.20
Sum of Probabilities	1.00	1.00	1.00

From the data in Tables 1 and 2, the expected value of the losses is calculated and shown in Table 3

Table 3. Decision Table and Expected Value of the Losses, Conditioned the States of Nature: ***E(Loss)|(c_i, s_i)*** (Ricci and Almeida, Forthcoming).

	E(Loss)|(s_i, a_i)		
State of nature, S → ***Choices, C ↓***	***s_1***	***s_2***	***s_3***
c_1	0.25*0 = 0	0.41*2 = 0.82	0.50*5 = 2.5
c_2	0.50*10 = 5.0	0.42*4 = 1.68	0.30*3 = 0.90
c_3	0.25*20 = 5.00	0.17*40 = 6.8	0.20*60 = 12.0

Other calculations (Ricci, 2006) can yield further insights into making-decisions. For example, one of them is the *regret* of *not having guessed the right state-of-nature*. The *regret* values in the cells of a regret matrix are calculated (in monetary units) as [*loss* (a_i, s_j)-(*minimum loss value of* s_j)], the algorithm for the computations is independent of the problem being assessed. If expected values are used, *risk* is defined as (Chernoff and Moses, 1986) *[E[loss* (a_i, s_j)*]-E(minimum loss value of* s_j*)*, where *E(.)* symbolizes the expected value. Subjective probabilities can be used to calculate the *Bayesian Expected Loss*, BEL, for a given state of nature, as $BEL(s_j) = \sum(pr_i)[L(s_j, a_i)]$. In other words, the probabilities are subjective. In other situations, probabilities can be objective (e.g., frequencies).

Utility: Adding Behaviors to Choices and Consequences

We assume that the stakeholders are rational (meet von Neumann--Morgenstern utility axioms)[10] and as the individual members of society prefer one outcome relative to another, so does society. Table 3 depicts the utility function *u(x)* that describes increasing or decreasing *utility* for an attribute, *x*, and the behavior of the agent (e.g., a decision-maker, a stakeholder). More specifically, the prospective nature of the triplet choice, state of nature, and consequence, when it also accounts for probability as a measure of uncertainty in the consequence, is generally known as a *gamble* or *lottery*. The value of the lottery or gamble is calculated as $V = pr_1*C_1+pr_2*C_2$. The more general case is depicted in Figure 11, in which *pr* is labeled *p*.

[10] The axioms are *completeness* and *transitivity*; agents seek the optimal solution and they understand what and why is calculated for the best solution.

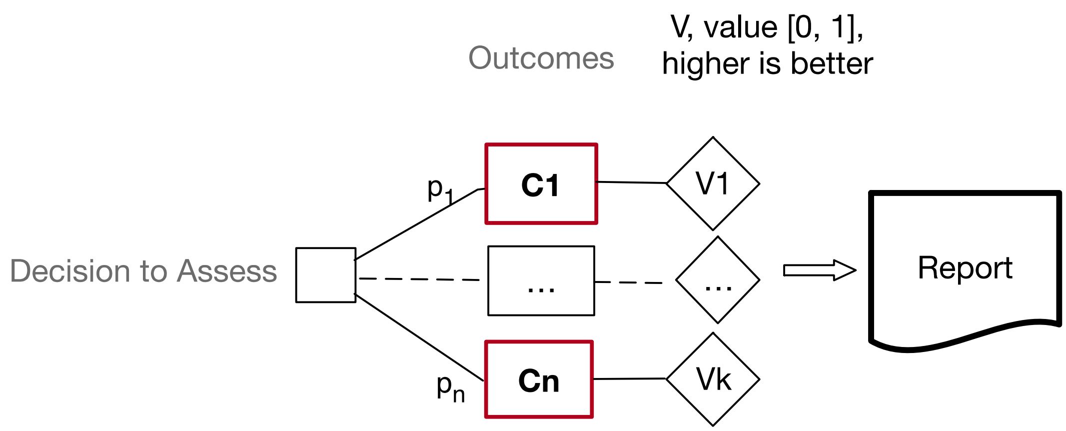


Figure 11. Diagram of a decision tree (Ricci and Almeida, Forthcoming).

In Figure 12 we depict a more complicated decision tree consisting of one evidence C_i, probabilities, p_1 to p_n, conditioning events ($B|C_i$) to ($B|C_n$) leading to other events, Br, with other probabilities, and values measured on the scale [0, 1]. These trees have several branches from which emanate more conditioning events. Experimental evidence may be generated by different studies: hence $p(Br|C_1)$ and so on.

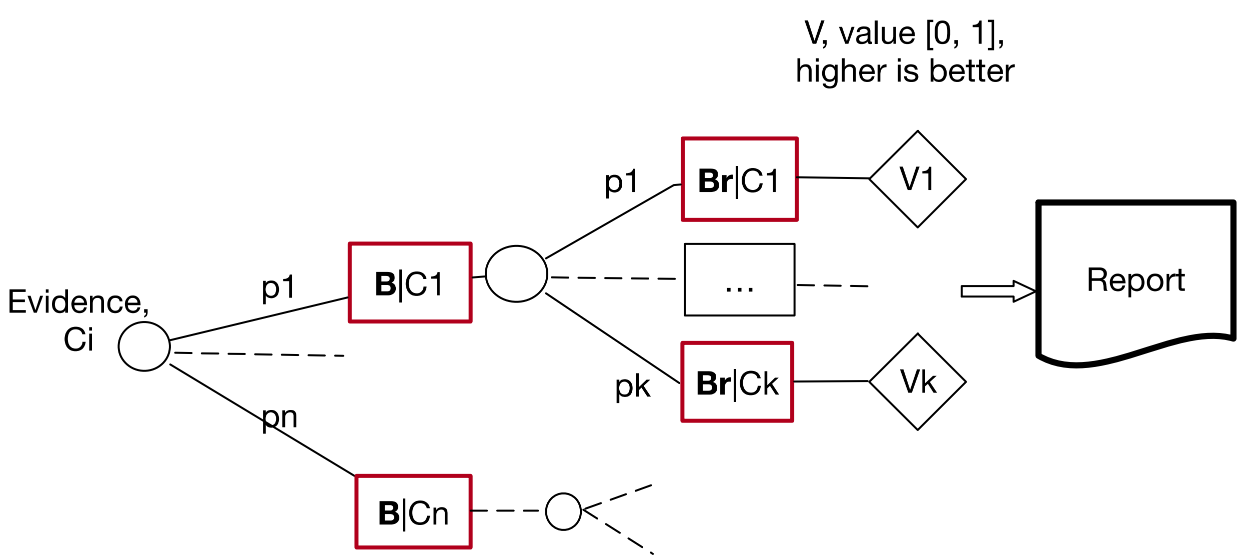


Figure 12. Decision tree consisting of multiple factors (Ricci and Almeida, Forthcoming).

More attributes, agents, and objectives can be assessed using multi-objective decision analysis and other methods (Haimes, 2009).

Table 4. Utility Functions: Risk Neutrality, Aversion and Proneness (Risk Seeking Behaviors) for an Attribute that Is *Increasing* in Utility (Ricci and Almeida, Forthcoming).

Behaviors	**Definitions**	**Utility Function (increasing utility)**	**Comments**
Aversion	The expected value of a non-degenerate lottery is preferred to that lottery	$u(x) = a_1+b_1[-\exp(-c_1x)]$, b_1 and $c_1 > 0$.	1) At least two consequences per lottery. 2) No division by 0. 3) exp = e. 4) If the coefficient *b* equals *-1*, the utility function is decreasing; if it equals *1*, the function is increasing. 5) Degenerate means that the lottery's probabilities are *1.0*: there is no uncertainty.
Neutrality	The expected value of a non-degenerate lottery is indifferent to that lottery	$u(x) = a_2+b_2(c_2x)$.	
Proneness (risk seeking)	The expected value of a non-degenerate lottery is less preferred to that lottery	$u(x) = a_3+b_3[\exp(c_3x)]$, where b_3 and $c_3 > 0$.	

For example, the attribute *cost* shows decreasing utility because a large cost is less preferred than a small cost (Table 4). The coefficients a_i and b_i are scaling coefficients so that *u(x)* is bounded between *0* and *1*. For the attitude towards risk described, the values of *x* are ordered, from low to high (meaning that x_0 is of lesser magnitude than x_1 and so on). If the attribute has *decreasing* utility, the functions begin at *1.0* and decrease as the magnitude of the attribute increases. Utility is bounded between *0* and *1*; that is ($0 < u(x) < 1$) and the domain of the attribute *x* is between *0* and the upper value x^*. Rational decision-makers and stakeholders are assumed to have preference ordering over choices and actions. Utility theory informs of the level of satisfaction and avoids the problem of monetary values that are known to have *diminishing marginal utility*: satisfaction decreases as the amount of money increases.

Savage (1972) developed a method for dealing with incomplete information using a decision-makers subjective probability distribution (mass or density functions, depending on the data) over the states relevant to making a rational decision. This method has the effect of *reducing the decision problem from one of uncertainty to one of risk*. Savage assumed that the decision-maker is *consistent* with respect to axioms I, III, IV, V VII, VIII and IX. He also developed axioms of *weak ordering*, (among other things) that matter to analysts (underscoring indicates that there is a direct and explicit analyst-agent) and, more broadly, user-developer relationship:

1. Preferences are well defined,
2. Two events can be compared through their probabilities,
3. Within the set of choices, there is at least one pair that is not indifferent to the *decision-maker*.

Savage derived two important theorems that justify probabilistic decision-making using utility theory. The first theorem results in *personal* (or subjective) probabilities; the second establishes the relationship between these probabilities and utilities. Using a *personal* probability means that elicitations can yield the relationship between expected utility and the decision maker's preferences that can then be analyzed. For our work, these are critical steps. Practically, four conditions provide a coherent method for evaluations based on utilities (Chernoff and Moses, 1986), Table 5. In practical applications, satisfaction is inherent to the attitudes (behaviors) of the decision-makers and case-specific characteristics. Thus, utility maps to probabilities.

Table 5 Conditions for Evaluation Using Utility Theory (Ricci and Almeida, Forthcoming).

Condition	**Description**	**Comment**
Outcome's Valuation	The measure of value is the utility	Utilities are numerical, the utility function is monotonic
Alternative's Valuation	The single measure for evaluation is the utility of the outcomes	Utility is the only measure used
Knowledge of states	Probabilistic measures describe knowledge about the states	The subjective belief of the decision-maker is a probability
Stochastic independence	The probability of the state does not depend on the action	Must be demonstrated, rather than assumed

Rationality defines choices that are made under: 1) certainty (i.e., each choice has a unique consequence, including no consequence); 2) exogenous uncertainty due to factors not under the control of the decision-maker; and 3) strategic conditions where other equally rational parties interact with the decision-maker. Throughout, the criteria for preferences between choices include the: i) maximization; ii) minimum of the maxima; iii) maxima of the minima, and dominance. We can take two choices, the set $A = \{a_1, a_2\}$, to develop the axioms necessary to deal with *partial* ignorance:

I. The set of choices is not empty (a solution or equilibrium between the agents, if it exists, can always be found).
II. The preferred choice is independent of the scale of measurement of the utilities.
III. The preferred choice is invariant to the description of the choices that represent them.

IV. If $a_1 \in A$ and a_2 are either preferred to a_1 or a_2, and is indifferent to a_1, then $a_2 \in A$.

V. If $a_1 \in A$, then a_1 is admissible.

VI. If the class of choices includes choices that are weakly dominated or that are equivalent to choices in the initial set, the optimality of the early choices is unaffected.

VII. If a choice is less than optimal, the addition of another will not change sub-optimality.

VIII. If two agents have the same set of choices and states, and one of them has a payoff that is independent of the choice, then the optimal choice will be the same as that of the other agent.

IX. If an agent considers a_1 and a_2 to be optimal; their mixture will also be optimal

If axiom IX does not hold, then the decision-maker faces what Luce and Raiffa have called *complete ignorance*. Dealing with *complete ignorance* adds three axioms:

X. The choice of the optimal set is independent of the states of nature.

XI. The deletion of a state with the same payoff as another does not alter the optimal choice.

XII. The deletion of a state equivalent to a probability mixture found in other states does not alter the optimal choice.

Game Theory: Formal Interactions Between Two or More *Rational* Agents Seeking Advantageous Solutions

Game theory provides formal methods to assess the implications of different choices for states of affairs between rational agents. It broadly concerns three general aspects: the selection of strategies, the creation of alliances, and the study of compromises between those agents. Alternately, it may be utilized to devise rules of behavior that result in fair results (Owen, 2012). Games may not be played by physical individuals: the “players” can be private entities, companies, government agencies, municipalities, stakeholders, collectives, and any other person or representative group that needs to engage in a decision-making process. Regarding the benefits of game theory as a method for the creation and evaluation of policy, the upside has less to do with demanding numerical processes and more to do with the utilization of the many theoretical aspects. This may result in a policy modeling approach that brings organization and rigidity to the research of social processes (Hermans et al., 2014). One of the main assumptions of game theory is that agents are presumed to be rational (Hermans et al., 2014). By assessing the contributions from games to legislation or policies, it may be possible to determine, ex-ante of formalizing eventual legislation or policy, which is preferred to other.

Gaming available choices can help discover which policies are less preferable. As an example, if only one agent has control, others will eventually lose interest and search elsewhere for ways to influence policy, and affect regulatory and managerial solutions, thus detracting from optimality. This was the case for a coastal management project that was developed in the Netherlands. (Hermans et al., 2014). After several years of repeating the same “sand distribution games” several players tired of modeling the project without any inputs being changed to address their needs: discussions were outdated. The agents (composed of municipalities, NGOs, other organizations, and provinces) steadily moved the policy dispute to other venues where they expected to find fresh ears to convey their needs and to open new doors that could lead to outcomes that would be favorable for them (Hermans et al., 2014).

A game-theoretic analysis requires at least two agents and a set of numerical payoffs that measure the value of the outcomes of the game. Each agent has a finite, exhaustive set of strategies that are mutually exclusive and separable; the strategies determine the outcomes. For instance, following Straffin (1993) two agents face one another in the context of a risky decision: each attempts to gain from the strategies taken by the other. If *Row* chooses *act,* she may gain *+10*, if *Column* also acts. But if *Column* chooses *do not act*, while *Row* acts, then *Row* loses *10* (that is, *-10*) and *Column* wins *+10*. If Row does not act when *Column* acts, then *Row* wins *+10* but *Column* loses *10*. If both do not act both lose. The preferential ordering of the options for *Row* is where *Row* prevails over *Column* (*+10*, *-10*); the *second-best* solution, both gain, is (*+10*, *+10*); the Nash equilibrium (-10, -10) is not the *best*.

	***Column*'s Strategies**		
***Row*'s Strategies**		***Act***	***Do not act***
	Act	+10, +10, *Cooperation as Best strategy*	-10, +10
	Do not act	+10, -10	-10, -10*, Defection, as Equilibrium Strategy*

Example, static game Agents *Row* and *Column* face the following payoffs measured on a scale from *-10* to *+10*, with deterministic payoffs:

	***Column*'s Strategies**		
***Row*'s Strategies**		***Act***	***Do not act***
	Act	+10, +10	-10, +10
	Do not act	+10, -10	-10, -10

If *Row* chooses *act,* she may gain *+10*, if *Column* also acts. But if *Column* chooses *do not act*, while *Row* acts, then *Row* loses *10* (that is, *-10*) and *Column* wins *+10*. If Row does not act when *Column* acts, then *Row* wins *+10* but *Column* loses *10*. If both do not act both lose. The preferential ordering of the options for *Row* is: *Row* prevails over *Column* (*+10*, *-10*); second-best solution: both gain (*+10*, *+10*).

Example, static game Consider the following game between *Row* and *Column*:

		Column's Strategies	
Row's Strategies		***Act***	***Do not act***
	Act	(2, -2)	(-3, 3)
	Observe	(0, 0)	(2, -2)
	Do not act	(-5,5)	(10, -10)

This is a *zero-sum* game because the pay-offs are symmetric in the sense that if *Column* wins *2*, then *Row* loses *2*. The selection of a strategy suggests a few rules. First, a strategy dominates another if all the outcomes in that strategy, *A*, are at least as preferable as those of another strategy, *B*, and at least one outcome of *A* is greater than the corresponding outcome in *B*. A rational decision-maker will invariably opt for the dominant strategy. Second, a *saddle point* occurs when an outcome is both less than or equal to a pay-off in a row and greater than or equal to a payoff in the intersecting column of the matrix of pay-offs.

A zero-sum game results from a situation where the wins and loses reach a net total of zero: this results in one agent wins while the other loses: – one player profits an amount that is the direct opposite, in magnitude, of the other. In contrast, in a negative-sum game occurs when an amount of value: the losses outweighed the gains. Each stakeholder can develop probabilistic strategies and use expected values to assess the outcomes of a strategy: Straffin (1993) gives complete examples and additional elaborations, as well as theorems related to these analyses and their conclusions. We can use the extended (rather than the normal form) of the representation of a game

(Figure 13) between two agents, A and B, with strategies x, y, w, and z, and payoffs (e.g., 4, 2) as follows:

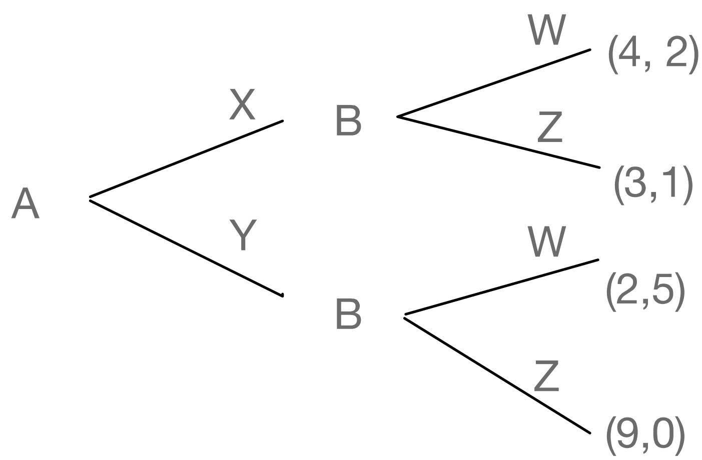


Figure 13. Representation of a game between two agents (Ricci and Almeida, Forthcoming).

Throughout these discussions, we have assumed that the information and knowledge needed to develop the games is known to all agents. The process of backward induction can then be used to assert the relative optimality of the solutions. We are not concerned with games that can be played an infinite number of times, nor that the game should stop. Catastrophic events, however prospective, may be simulated based on information and knowledge that follows established physical laws, economic regularities, and so on. What may change can be simulated by using different input values as well as sharpening the uncertainties by sharpening the probabilities as new evidence becomes available. In other words, the future reality can be approximated by incrementing the analytical structure of the decision process with new strategies and information as time progresses.

Properly framed, game theory can be adapted to be used not only to evaluate existing policies but also to form the foundations of the core strategy for driving future policies in a variety of contexts. Different aspects of game theory can be used in assessing the effects of changes in migration due to natural and human-made events ranging from sudden and delayed catastrophic events, such as those associated with climate change. In these assessments, feedforward, feedbacks, delayed feedbacks, lagged causes and effects, and more complex exogenous events. The latter include compositions of two or more exogenous physical, economic, and human forcing functions that affect the ultimate outcomes of concern, become clearer, and correctly inform decision-makers and stakeholders. In this context, a strategy is the formal description of the set of choices, states of nature, and consequences. A *pure* strategy game is deterministic; a *mixed* strategy game is probabilistic. The solution for a game may include an equilibrium, such as Pareto's or Nash. The latter, is a set of strategies taken by each agent, acting in their own self-interest, such that no single agent can improve their position by changing strategy. If a game is in pure equilibrium there may not be a Nash equilibrium, or there may be multiple equilibriums; a mixed strategy non-cooperative game has at least one solution that can be due to randomizing strategies. As a classic game-theoretic example, S. Lichtblau http://demonstrations.wolfram.com/ThePrisonersDilemma/ (2011) describes how two suspects, *A* and *B*, are interrogated without sufficient evidence for a direct conviction. The prisoners are separated and offered what is described in the Table below. If one of them confesses and testifies against the other, while the other still stays silent, the person who testifies will go free while the other will serve a very long jail time *L* (if convicted). If both confess, they both will be jailed a medium time *M*. Finally, if both stay silent, they will be jailed for a short period, *S*. Each accused prisoner may either incriminate the other or remain silent. The Pareto optimal solution is that both stay silent. However, each player's dominant strategy is to confess. The initial settings of the sliders *S*, *M*, *L* (0.5, 5, and 10) are very common values used in the prisoner's dilemma problem to show this. Slider setting $S > 0$ and $L > M$ leads to the same solution. Sliders can be configured so that the dominant strategy for both accused is not to confess, as depicted in figure 14.

	Prisoner B stays silent.	Prisoner B confesses.
Prisoner A stays silent.	A and B serve 4.6 years.	A serves 11.5 years. B goes free.
Prisoner A confesses.	A goes free. B serves 11.5 years.	A and B serve 8.6 years.

Prisoner A's dominant strategy is to confess.

Prisoner B's dominant strategy is to confess.

Figure 14. Representation of prisoner's dilemma (S. Lichtblau, 2011).

Discussion and Results

Migration and Climate Conventions

The basis for choices and actions is driven by national and international conferences, initiatives, and declarations that define the boundaries, objectives, and characteristics of the issues that will become incorporated into treaties, compacts, and other legal instruments. Eventually, these will be codified – and thus given enforceability -- into national laws. This section deals with the major conventions that drive the application of formal methods discussed earlier to the study of mass migrations induced by climate changes driven by increased temperature levels.

Cartagena Declaration

The 1951 refugee convention and its 1967 protocol assert that a refugee should not be returned to a country where they face serious threats to their life or freedom, these were then followed by the Cartagena Declaration on Refugees (1984) The Declaration is a non-binding agreement which was adopted by the Colloquium on the International Protection of Refugees in Latin America, Mexico and Panama, held in Cartagena, Colombia, 19-22 November 1984. The issue with these documents is that the refugees they were designed to protect do not include climate migrants. The Cartagena Declaration elaborates on the definition of a refugee, stating that "…persons who have fled their country because their lives, safety or freedom have been threatened by generalized violence, foreign aggression, internal conflicts, massive violation of human rights or other circumstances which have seriously disrupted public order" (Cartagena Declaration, 1984). However, an individual that migrates due to climate change is not covered under the same umbrella as those who migrate due to war or political turmoil. This is an example of why definitions are an important aspect of communicating science and why it needs to be strengthened moving forward.

The Nansen Initiative (2011)

The Nansen Initiative was created to help focus on the protection of people who have been displaced across borders because of disasters and climate change. Its foundation stems from the 2010 UNFCCC Cancun Agreements, which address methods that can be used to strengthen knowledge and collaboration regarding climate change and human displacement (Nansen Conference, 2011). Subsequently, after the 2011 Nansen Conference, Switzerland and Norway pledged to work together regarding a joint operation to emphasize the protection needs of those displaced across borders due to natural disasters and climate change. The Nansen Initiative was then launched as a state-led project with the support of additional countries and stakeholders in 2012 (Nansen Initiative Report, 2015). The Initiative was designed to include a variety of state-led consultations with government and public stakeholders in five different regions of the world. Countries from these regions gathered for a global discussion in 2015 to focus on creating new legal obligations or standards. The Nansen Initiative has functioned to create a global consensus on a unified structure for a protection agenda to assist those uprooted across borders due to effects of natural disasters and climate change, the goal was for this agenda to then be used to constitute several new laws and agreements at diverse levels (Nansen Initiative Report, 2015). The basis of the Nansen Initiative developed in the Agenda for the Protection of Cross-Border Displaced Persons in the aspect of natural disasters and climate change, which was endorsed by 109 government delegations in 2015 (Nansen Initiative Report, 2015). The Nansen Initiative set its sights to support these delegations by providing a framework to construct an extensive response before, during, and after human displacement while including examples of functional practices for short and long-term solutions. This framework also addressed migrants by highlighting techniques in which countries can manage risks by decreasing vulnerability and bolstering resilience, including adaptation migration as a strategy to cope with impacts of climate change and natural disasters. The advancements brought on by the Nansen Initiative generated positive feedback: governments wanted more sensible guidance on how immigration law can better support human migration.

The Regional Conference on Migration (2019)

The Regional Conference on Migration (RCM) was a diverse conference group consisting mostly of Central and North American countries who were brought together to endorse an "Effective practices guide" that was created which promoted effective practices for RCM Member Countries: protection for persons moving across borders in the context of disasters (UNHCR, 2019). The guide provides instruction to RCM Member Countries on how they can react to the provisional humanitarian needs of people affected by sudden natural disasters using examples from current laws, policies and protocols, with a spotlight on immigration law (UNHCR, 2019). The *effective practices guide* focuses on three groups of people:

1) People who wish to enter a foreign country in search of temporary protection and support before, during, or after a disaster has taken place in their country of origin

2) Those in a foreign country at the time that a disaster takes place in their original country and who desire to stay in this foreign country to avoid disaster-related impacts from their country of origin

3) People who are in a foreign country that has experienced a disaster and are in search of protection and support (Nansen Initiative, 2016).

The effective practices guide is based on the idea of looking at existing tools as opposed to developing new requirements. Since then, Costa Rica and Panama have adopted the guide, and they have been able to use it as a resource to develop the "Standard Operating Procedures" for joint responses to human displacement due to environmental factors along their shared border, therefor helping to trigger further measures to address the needs of those displaced (Kälin and Cantor, 2017). Facing the benefit of such a resource, the South American Conference of Migration (SACM) communicated its desire to develop similar guidance in 2017 (Kälin and Cantor, 2017). The SACM implemented its own guidelines the following year, including regional guidelines concerning protection and assistance for people displaced across borders and migrants in countries affected by natural disasters (Ramírez et al., 2019). These SACM guidelines focus on cross-border displacement due to natural disasters, as well as migrants who are already in countries experiencing natural disasters. The SACM, similar to its RCM correspondent, examines policies and practices that have been used to respond to human displacement (Ramírez et al., 2019). Although the RCM and SACM guidelines are non-binding and do not establish governmental commitment, they are recognized as important steps in strengthening protection for people displaced across borders by natural disasters, including being used as a tool for future policy development in these areas.

Kampala Convention (2019)

The African Union (AU) Convention for the Protection and Assistance of Internally Displaced Persons (IDP) in Africa, which is also known as the Kampala Convention, originates from ideas stemming from the guiding principles of internal displacement in many ways (Adeola, 2018) while also strengthening the integration of natural disasters and climate change, including by attributing specifically to people displaced by climate change (Adeola, 2018). The Kampala Convention, adopted in 2009 and implemented in 2012, includes in its definition of IDPs those who have been displaced because of or to avoid natural disasters, among other events (African Union, 2009). The Kampala Convention has multiple objectives, all of which are important to expanding human protection guidelines for environmentally displaced people who stay within the same national border. Some of these guidelines consist of

- Advancing national and regional efforts to prevent and address the original causes of displacement while promoting the development of resilient solutions.
- Developing a legal framework for preventing displacement and supporting displaced persons in the region, including a framework for cooperation in these efforts
- Identifying the responsibilities and obligations of both states and non-state actors related to preventing and responding to internal displacement (African Union, 2009).

Under Article V of the Kampala Convention, parties of the convention pledge to work to assist and protect people who have been displaced internally as a result of "natural or human made disasters, including climate change" (African Union, 2009). Other requirements include implementing strategies for disaster risk reduction and functional systems to prepare for and manage disaster scenarios. (African Union, 2009). In addition, members of the convention agree that everyone has a right to be protected from erratic displacement, including forced evacuations related to natural disasters and that states will be responsible for providing the expenses for reparations if they shy away from protecting and assisting IDPs affected by natural disasters (African Union, 2009). The Kampala Convention thoroughly addresses protections for people internally displaced due to both natural disasters and climate change. However, what is perhaps the most important component of the Kampala Convention is the fact that it is the first legally binding framework related to IDPs that covers the African continent widely, serving as an important milestone in the development of international law on internal displacement (Boswijk, 2012).

Paris Climate Conference (2015)

The 21st session of the Conference of the Parties (COP) to the UNFCCC, also known as COP 21 or the Paris Climate Conference, took place at the end of 2015. The conference resulted in the Paris Agreement, which came into effect in 2016. The agreement derives from the UNFCCC and expands government investment and action to tackle climate change (UNFCCC, 2015). Under the Paris Agreement, signatory countries promised to devote resources and research to the climate change threats by working to mitigate temperature increases and expanding the capacity of the nation-states to respond to its impacts (UNFCCC, 2015). The agreement recognizes that responses to climate change should adhere to not only the rights of migrants but also to the rights of each population affected. COP 21 also created the Task Force on Displacement (TFD), resulting in handing the responsibility of this task force to the Warsaw International Mechanism for Loss and having the task force report back to the UNFCCC (UNFCCC, 2015). The TFD was established to construct proposals on creating coordinated strategies for responding to climate change-related displacement. In the first few years of its work, the TFD examined four "areas" related to displacement (UNFCCC, undated):

1) National and subnational policy and practice.
2) International and regional policy.
3) Data and evaluation.
4) Framing and connections.

Now in its second phase, the TFD is working to achieve the goals of its plan of action that includes a wide scope of activities related to information dissemination and capacity building to strengthen awareness of and responses to environmental migration and displacement (UNFCCC, undated).

Climate Change and Involuntary Mass Migration

This section is based on current policy discussions principally developed by the IPCC. The first World Climate Report was released by the International Organization for Migration in 2000 mentions the “climate” twice, whereas the report released by the IOM 20 years later in 2020 mentions “climate” 219 times. Traditionally, migration was viewed as an event due to war, political unrest, or often dramatic socio-economic factors. While many factors (often in combination) force humans to migrate, changing climate is becoming another critical, recent factor. Creating a plan or proposal for planned relocation, considering a top-down approach where richer nations help poorer nations prepare for environmental changes and extreme weather events, instead of assisting them after an event occurs, are crucial strategies to be assessed at the policy-making stage. Richer nations need to raise awareness that, in the long term, assisting poorer countries and those who are more vulnerable to the effects of climate change will result in lesser migration, leaving more resources available (if the aid to prevent migration is cost-effective). The policy is basically to “invest now to save money and resources later”.

Even with the correct decision-making and the successful implementation of an adaptation migration strategy, there will be random or otherwise unpredicted events that can affect a well-designed policy. Examples include the Covid-19 pandemic and the 2008 financial crisis. These unexpected events add economic pressure (hat may disproportionately affect poor countries, as the lack of vaccines against Covid-19 has shown. Random and nonrandom events may cause a cascade of consequences that result in difficult choices for affected and unaffected governments and their societies. For instance, climate-change-related droughts that last several years, or a region that increasingly becomes more prone to flooding due to SLR, can trigger mass movement of people away from the affected areas. Combining these predictable effects with a random event, such a contemporaneous financial crisis can transform something that starts as an environmental issue into a geopolitical issue that involves several different countries and governments. Importantly, the background rates and magnitudes of migrations (e.g., number of migrants) have been increasing over the last 50 years (Table 6) and, if future predictions hold (IPCC, 2021), these numbers will continue to rise.

Table 6. International Migrant data from 1970-2019. (*UN DESA, 2008, 2019a, 2019b)*.

Year	Number of Migrants	Migrants as a % of the world's population
1970	84,460,125	2.30%
1975	90,368,010	2.20%
1980	101,983,149	2.30%
1985	113,206,691	2.30%
1990	153,011,473	2.90%
1995	161,316,895	2.80%
2000	173,588,441	2.80%
2005	191,615,574	2.90%
2010	220,781,296	3.20%
2015	248,861,296	3.40%
2019	271,642,105	3.50%

These problems do not generally happen overnight: they take years to percolate and over time become the roots of political and human rights issues. There are indicator events that may warn of the probability of a tipping point; alternatively, the tipping point may not be evident until it happens. From a management standpoint, it is critical to predict possible futures and to maximize net societal benefits. The question is: How is it possible to operate under time constraints and uncertain (e.g., probabilistic) inputs when attempting to obtain forecasts or predictions? In this work, we have outlined an integrated framework to do so in a way that accounts for a variety of uncertainties and attempts to minimize errors. The issue is becoming increasingly critical because, according to IPCC reports, society has crossed the point of no return. Although attempting to prevent further anthropogenic influence on the climate must continue, nations must also adapt to the changing climate. The IPCC (2018) stated that in 2017, the Earth's average temperature had increased by 1°C, relative to preindustrial levels, due to greenhouse gas emissions, and through modeling and physical observations, generated alternative predictions (i.e., trajectories) as possible scenarios for the future states of the climate. The IPCC stated that global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions were to occur in the coming decades. It is projected that climate change, combined with compound and cascading hazards, will impact coastal a very large number of the world's coastal regions ,and affect an estimated 2.5 billion people, mainly in Africa and Asia by 2050 (IPCC, 2022). As reported by Mianabadi et al., (2021) trends indicate that rural-to-urban migration will continue and most likely will accelerate in developing countries. This will require improved environmental management practices, regardless of measures that have already been implemented to mitigate some of the climatic impacts.

Chapter 13 of the 2021 IPCC report concluded that due to climate change, there could be an increase in the frequency and intensity of hot temperature extremes, onshore and offshore heatwaves, heavier than usual rains, ecological and agricultural droughts, intensified cyclone, and hurricane seasons, as well as diminished arctic sea ice, snow cover and permafrost. Many of the snow, ice, and SLR changes are irreversible and, under scenarios of increasing CO_2 (and other greenhouse gasses) emissions, ocean and land carbon sinks are estimated to be less adequate to slow the accumulation of CO_2 in the atmosphere. Urban communities and settlements in the coastal area are at the forefront of environmental change. These deal with most of the climate compounded and cascading risk of adverse effects; at the same time, they are a critical source of climate adaptation techniques regarding resiliency to climate changes.

A substantial part of the world's population, financial hubs, and significantly important structures are close to the sea, with almost 11% of the worldwide population (~896 million people) living on low-lying coasts, makes them particularly vulnerable to climate and non-climate coastal hazards (IPCC, 2022). Low-lying urban communities and settlements are encountering antagonistic environmental impacts that are superimposed on broad and intensive anthropogenic coastal changes. Contingent on their coastal characteristics, ongoing patterns of coastal expansion will continue to have an impact on the vulnerability of coastal areas to the hazards they will face. With unavoidable SLR and an increase in the occurrence of environmentally driven hazards in a warming world, the choices for accomplishing Sustainable Development Goals (SDGs) and advancing Climate Resilient Development (CRD) choices are discouraging as there are some goals like “no poverty” or “zero hunger” which are not realistically attainable by the agenda that was set to achieve all 17 SDGs by 2030 (UN, 2015). Nonetheless, coastal areas remain the root of SDG and CRD resolutions since these are hubs of innovation with a deep history of cultural ties to the land, a large number of which are universally associated with centuries of vessel traffic and trade.

Despite climate and financial scenarios, many urban areas and settlements face serious disruptions to coastal biological systems and communities by 2050 and across all urban areas and settlements by 2100 (IPCC, 2022). These disruptions are heightened by compound and cascading risks; their magnitude and probability will increase as exposure to climate and coastal hazards become more apparent. For example, droughts, floods, heat waves, effects resulting from SLR, typhoons and hurricanes, marine/land heatwaves, and ocean acidification; with a surge in susceptibility driven by an imbalanced and intense exposure resulting from urban development in at-risk areas (IPCC, 2022). Compounded and cascading environmental hazards regarding supply chain issues that impact coastal communities and settlements are not expected to increase overnight or all at once, but in increments over time. It is estimated that roughly $7-14 trillion of existing coastal infrastructure will be vulnerable to damage by 2100, contingent on ocean and coastal temperature levels and financial/population development (IPCC, 2022).

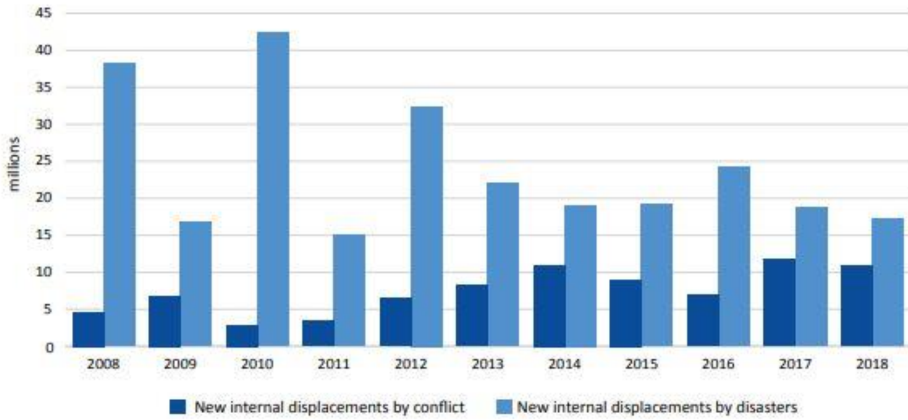
According to the sixth assessment report of the IPCC (2022), what were once considered rare natural events, are now expected to happen yearly in coastal areas by 2100; moreover, several populated atolls (in the South Pacific) are projected to be abandoned by 2050. This is a cause for concern for both island natives and governments around the world as the island natives will be forced to migrate to other nations and adapt to new livelihoods while essentially losing their homes and all cultural ties that once existed with their land. On the other hand, watching islands become inhabitable serves as a wake-up call for governments around the world as the physical effect of climate change will be noticeable and the impact it has on humans will be recorded, signaling that it is only a matter of time before more areas of the world become inhabitable. The report also states that coastal flooding hazards are projected to increase by 2-3 folds by 2100 if no adaptation or mitigation methods are used; these hazards are serious probable impacts on the people and economy in coastal areas. Impacts reach a long way past cities and settlements (e.g., disturbance to ports that can dangerously disrupt worldwide supply chains, resulting in national and international geopolitical and financial consequences). It is estimated that worldwide investments to support port development and adjust to SLR add up to roughly $223-768 billion preceding 2050, opening doors for coastal communities and settlements to build a more resilient future. An acceleration of SLR arising from rapid continental ice loss will have repercussions for decades; adaptation will need to happen on a much greater scale and faster rate than ever before – certainly needing to occur faster than the repercussions.

There has been increasing amounts of evidence that degradation and obliteration of environmental areas (such as sand dunes and marshes) results in increased overall human vulnerability (IPCC, 2022). Unsustainable land-use and land cover change, impractical utilization of resources, deforestation, loss of biodiversity, contamination/pollution and its impacts, will continue to have adverse effects on ecosystems, communities, and individuals. Loss of ecosystems and their services have a considerable adverse effect, with issues that percolate, cascade, and transform into long-term consequences for all. This weighs heavier on some more than others, such as indigenous people and small communities who are reliant on ecosystem services to secure basic needs as they feel the brunt of non-climatic factors which become intensified by environmental change. Worldwide, and even inside protected areas, the detrimental utilization of natural resources, loss of habitat, and ecosystem harm by toxins increase the exposure of ecosystems to climate change. Globally, less than 15% of the land, 21% of the freshwater and 8% of the seas are protected regions (IPCC, 2022). Future vulnerability of ecological systems to climate change will be impacted by the evolution of human attitudes. Worldwide focal points of human susceptibility to the effect of climate change are in West, Central and East Africa, South Asia, Central and South America, Small Island Developing States, and the Arctics (IPCC, 2022). Between 2010-2020, human mortality from floods, dry spells, and strong weather was several times higher in exceptionally vulnerable coastal areas, relative to areas with low vulnerability to environmental hazards (IPCC, 2022).

Vulnerability at various spatial levels is exacerbated by disparity and is connected to orientation, poverty areas, lack of government interest, or a combination of these, particularly for indigenous populations and smaller communities. Future human vulnerability will keep on increasing where the limits of local, city and public state-run administrations, networks and the private area are least ready to supply sufficient housing and basic needs. Under the current worldwide pattern of urbanization, humans will become more suspectable to environmental hazards by often illegally moving into unofficial settlements and rapidly developing settlements at a pace faster than they can be safely and responsibly accommodated. Key components include clean water, wastewater treatment, efficient communication between public and government agencies, and energy that will become increasingly vulnerable to failure if the land being used is unable to support those living on it. According to Jiménez Cisneros et al., (2014) this emphasizes the need to consider both anthropogenic climate change and direct human influences such as population increase or migration, economic development, urbanization, and changes in land use when planning water-related mitigation or adaptation strategies – all of which require long term vision and solutions.

Migration patterns due to climate change are difficult to predict as they depend on patterns of population growth, adaptivity of vulnerable populations, socioeconomic development and migration policies, and usually involve a mixture of these factors. In many regions, the frequency and/or severity of floods, extreme storms and droughts are projected to increase in the coming decades, especially under high gas emissions scenarios. Usually, these hazards occurring at the same time can severely increase the risk of displacement in the most susceptible areas. Under all global warming predictions, some regions that are currently densely populated will become unsafe or uninhabitable, with movements from these regions occurring through planned or unplanned relocation, causing a shift in human displacement (Table 7).

Table 7. Worldwide internal displacements due to conflict and disasters between 2008-2018 (IDMC, 2020).



It is crucial to understand the different interests and mindsets between governments that are involved when discussing climate change needs, with one common dominator needing to be that future strategies should be focused on adaptation and prevention. The European Union (EU) released their "Forging a climate-resilient Europe – the new EU strategy on Adaptation to Climate Change" report in February of 2021. This new strategy details a considerable number of steps that have already been implemented or that will be implemented soon. The report holds a long-term vision that in 2050, the EU will be a climate-resilient society, fully adapted to the unavoidable impacts of climate change, stating that the EU has already taken action to boost its resilience over the past years under the 2013 adaptation strategy. A highlighting factor presented in the EU adaptation strategy is that decision-making and acting in the face of climate uncertainty can be facilitated by forging decisions based on the latest science. This is an important declaration as often there is a clash between politics and science, an issue that has been exposed by the Covid-19 pandemic. Building from this adaptation strategy, the report states that these science-based decisions should be gathered using data from both private and public sectors and shared in a comprehensive and harmonized way. Data and decision making is needed to be transparent to avoid organizations or governments from using climate change as a trojan horse to enact laws or regulations that they deem appropriate, when in reality they can be counterproductive and benefit only a select group of people instead of society as a whole. An interesting but crucial point is brought up in the adaptation strategy, that the response to climate change must be systemic. Climate change does not only occur in the EU. It is an issue that reaches every corner of the globe: climate change does not intentionally discriminate between continents, countries, or regions.

What is the use of creating a climate-resilient EU if the countries in North Africa do not implement the consistent and forward-looking protective measures? Climate change is connected to the world as a whole, there are no borders in the atmosphere or in the ocean that enable greenhouse gases to be restricted to one region. Within first world countries it is possible to secure funding to adapt their respective countries to climate change; however, for the most vulnerable countries and people, this may not be possible and, as we have discussed, leads to climate-related migrations. Relocating to a country that has the capacity and financial means to assist migrants is an easy decision to make as an individual. It is a more preferable option than waiting for their country to develop protection – if the country is capable of doing so.

Communities in unofficial settlements (such as the homeless) will have higher exposure and lower capacity to adapt, with the people who are most at risk being women and children who make up the majority populations of these settlements. In coastal cities and settlements, risks to people and infrastructure will get progressively worse in a changing climate, sea-level rise, and with ongoing coastal developments potentially facing an “adapt or become abolished” scenario. However, the consequences from those hazards will not be felt evenly across cities, settlements, or within cities thus raising issues regarding the equitable distribution of the risk of death, injury, illnesses, and other adverse consequences.

European and United States Migration Policies

European Policies

Human migration is a dynamic process. The EU has always had to prepare for and regulate migration, however environmental migration is a new part of the puzzle that needs to be solved. The first acknowledgment of the relationship between climate change and migration transpired in 2007 in the Commission Green Paper “Adapting to Climate Change in Europe: options for European Union action” (European Commission, 2007). The Commission Green Paper emphasizes that the EU, combined with its Member States and other countries, must take adaptation and mitigation measures with respect to climate change. In addition, the Green Paper must also have an external dimension. In the section of the document that spotlights the external EU activities, it identifies that the EU Common Foreign and Security Policy has a pivotal role in strengthening the EU’s ability. Not only to prevent and deal with strife over limited natural resources but also to endure the effects of natural disasters caused by climate change, including forced migration and internal displacement of people (Barale, 2020). The Green Paper brought about the request to elaborate the “Joint Paper on Climate Change and International Security” (European Council, 2008) which recognized climate change as a “threat multiplier which aggravates existing trends, tensions and instability” with the highlighting factor being that it could put the EU under additional security risk. The document goes on to list negative consequences that may be a result of climate change: among some that also may be causes of migration, such as conflict over resources, economic damage, border feuds following a loss of territories as a consequence of retreating coastlines and land subsidence, with environmentally-induced displacement being discussed in the sense that “Europe must expect substantially increased migratory pressure” (Barale, 2020). More recently, in 2019, the European Commission’s European Political Strategy Centre published “10 trends shaping migration” (European Political Strategy Centre, 2019): the third trend analyzed is climate change, that “dwarf […] all other drivers of migration”. This document also goes on to recognize that between 2008 and 2016, there were more people internally displaced by natural disasters than by conflicts and wars.

Migration laws in the EU involve an interaction of national, regional and international laws. This sophisticated interchange of different ruling regimes is a consequence of diverse and at times, conflicting objectives and interests of the EU, its member states, and the law itself (Lang, 2017). To simplify migration laws in the EU, we can break down the impact that the three levels of the law have on the four migratory regulatory categories (Lang, 2017):

1) EU citizens
2) "Desired" third-country nationals
3) Asylum seekers
4) All other third-country nationals

When speaking about EU migration laws it is important to note that there is a clear separation between the rights that EU citizens have in comparison to third-country nationals, with issues in the EU asylum law that have been exacerbated due to recent influxes of refugees into the EU (Lang, 2017). The EU is known for its free movement rights of its citizens, like cross-border movement between member states. However, migrants don't always have the luxury of relying on this free movement due to them needing to follow the law of the member state they are residing in and not the EU law. For example, if a German national who lives and works in Germany marries a Brazilian national, their residence and family reunification rights are governed by German law. If the German law does not grant the Brazilian spouse the right of residence in Germany, the couple cannot rely on EU reunification rules as the situation is outside of the scope of EU law. Yet, if this same couple decides to move to Belgium, their situation is now under the scope of EU law and the German national can rely on EU family reunification rights which grants their spouse the right to work and live inside of the EU. In this hypothetical situation, the German national would be better off in Belgium than in Germany (Lang, 2017).

Third-country nationals are granted a limited set of EU rights, with their status being subject to their host Member State's national laws and this division is also noticeable in the terminology used for EU citizens and third-country nationals, for example "free movement rights" can be applied to EU citizens while third-country nationals are linked to the term "migration" (Lang, 2017). Another term that creates division is the difference between "desired" migrants and "regular" migrants, where "desired" migrants apply to business people, researchers, students, and short-term visitors, with these "desired" migrants being linked to the term of having "mobility" around the EU instead of "migration" and this can result in an “us vs them” mentality (Lang, 2017). While this type of migration issue is more specific and isn’t always applied to a mass migration movement, it provides insight on how the different levels of laws are applied to migrants and that there is not one general law that is applied to migrants.

EU National vs Regional Law

Another EU migratory objective is the EU Member States’ goal to maintain a certain level of national control over migration concerning their national territories as EU migration policy (combined with asylum, visa, and external border control policies, judicial cooperation in civil and criminal matters, and police cooperation) is part of a wider policy area that falls under the title Area of Freedom, Security and Justice (AFSJ) (Lang, 2017). The policy areas constituted by AFSJ are considered as having unconditional national importance as their roots stem from the core of national sovereignty and because of this, the European Union is not given the power to regulate AFSJ policies, but instead is inclined to share its competence with its Member States (Lang, 2017). Consequently, according to Lang (2017) the migration of third-country nationals into the EU is only somewhat coordinated at the EU level. This policy area is still heavily influenced by national and regulatory legislators, with notable differences in regulation among EU Member States. This divide between the regulation bureau of EU and Member States can be depicted by two examples concerning third-country nationals: First and most importantly, Member States possess the power to determine admission rates of third-country nationals to their territories for employment and self-employment purposes (Lang, 2017). Second, instead of a universal EU act (which would encompass the rights of all third-country nationals in the EU) the Union has opted for a sectoral approach, meaning that it regulates only the “desirable” third-country nationals and their rights as presumed acceptable by EU Member States (Lang, 2017). As Lang (2017) highlights: “The EU-level regulated categories consist of: highly qualified employees (the “Blue Card Directive”), students and researchers, seasonal workers, intra-corporate skilled transferees, family members of both EU citizens and of legally resident third-country nationals, long-term residents, and third-country national workers legally residing in a Member State.” Aside from the Blue Card Directive, the “Single Permit Directive” provides a single application procedure and issuance of a single permit covering both residence and work permits, as well as a common set of rights for third-country national workers legally residing in a Member State (Lang, 2017). In other words, third-country nationals are strongly governed by national law.

International Law and Mass Migration

International law comes into effect as an additional layer on top of national and regional law concerning the status of migrants in the EU. The reliance of EU asylum law on the Un Convention Relating to the Status of Refugees is a result of the third objective of EU migration laws, which is the setting and preservation of a high level of human rights, specifically relating to refugees as one of the most vulnerable of third-country nationals (Lang, 2017). Article 78(1) of the "Treaty on the Functioning of the European Union" (TFEU) and Article 18 of the "Charter of Fundamental Rights of the European Union" provide a legally binding commitment to respect the Refugee convention, however, due to the recent inflow of refugees into the EU, some noticeable deficiencies have surfaced regarding the EU Member States' national asylum laws (Lang, 2017). A side effect of this influx of migrants is how they are perceived by society, shifting from political leaders wanting to help them to starting to label refugees as "terrorists" or "poison", this type of political discourse has challenged Article 2 of the Treaty on European Union which contains principles of freedom, equality, human dignity and human rights (Lang, 2018). Political narratives like these have led to legal issues between international, national and regional laws that have violated other Member States laws, with some of these Member States either incorrectly implementing or refusing to apply EU asylum law (Lang, 2018). Nonapplication scenarios were the result of the EU's inability to respond to a high flow of refugees while maintaining an acceptable threshold of human rights standards, as a prime example of this inability to respond appropriately to an influx of migrants we can use the Dublin state-of-first entry rule, which puts the responsibility of examining an asylum application on the EU Member State where the refugee first entered the EU (European Parliament, 2013). This rule was problematic as it contradicts the principle of solidarity and responsibility-sharing, as stated by Article 80 of the TFEU which relies on mutual trust between the transferring and receiving Member States (Lang, 2017). EU Member States have violated EU asylum law obligations for reasons like security fears, inadequate capacity for the volume of refugees, or political reasons, leading to some countries to change their national laws to enable fast-tracking of asylum seekers and criminalizing refugees who enter the country illegally as well as any persons who assist them in crossing the border (Lang, 2017).

The EU's Member States' response to mass migration flows has been conducted through infringement proceedings due to a violation of human rights, these infringement proceedings are a mechanism initiated by the European Commission against a Member State that does not uphold its EU law obligations (Treaty on the Functioning of the EU, 2008). In 2015, the European Commission instituted a total of 48 infringement proceedings against 27 Member States regarding asylum law (Lang, 2017), this highlights the inefficiency of current EU asylum laws and the unwillingness of EU Member States to implement the guidelines set by the EU. While infringement proceedings are a powerful tool, they are not enough to prevent or reverse Member States' violations of human rights as these cases take years to play out and the Member States can continue their practices without any consequences (Lang, 2017). Another tactic that was used by the EU to handle the high flow of refugees was marked by the EU-Turkey Statement in 2016, which was essentially a ploy by the EU to pay Turkey to build refugee camps to keep the refugees inside of Turkey, preventing them from reaching Europe while sending newly arrived refugees back outside of European borders (European Council, 2016). This deal was heavily criticized as being morally and legally problematic, which once again mirrors the inadequacy of the EU to handle mass migration flows.

United States Policies

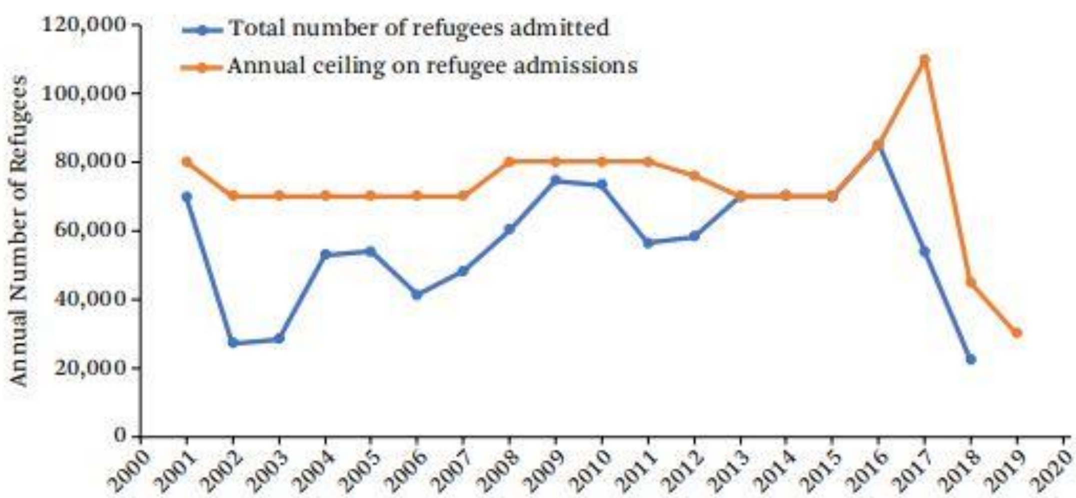
United States Immigration System

According to the American Immigration Council, the U.S. immigration law is based on the principles of the reunification of families, accepting immigrants with skills that are valuable to the U.S. economy, protecting refugees and promoting diversity. The body of law that governs U.S. immigration policy is known as the Immigration and Nationality Act (INA), this act allows the United States to allow up to 675,000 permanent immigrant visas each year as well as allowing an unlimited number of annual admissions of U.S. citizens' spouses, parents and children under the age of 21 (U.S. Immigration Policy, 2012). On top of this, every year the president is required to meet with Congress to set an annual number of refugees that can be admitted into the U.S. through the U.S. Refugee

Admissions Program (American Immigration Council, 2021). While there are over 20 types of Visa classifications (American Immigration Council, 2021) ranging from intracompany transfers, investors, religious workers, athletes, skilled workers and many others, our focus is not so much on these planned routes of migration, but on influxes of unplanned migration.

An inflow of immigration can disrupt the strategy and equilibrium behind the United States immigration policy as the INA places numerical limits on how many immigrants can come to the U.S. from any one country, with no group of immigrants from a specific country being allowed to exceed seven percent of the total number of people immigrating to the U.S. in a fiscal year (Kandel, 2018). The intention of this strategy is not for there to be a quota to ensure that seven percent of a certain nationality enter the country, but rather it is a numerical ceiling to prevent any nationality from dominating immigration flows to the United States (American Immigration Council, 2021). The U.S. has always presented itself as a land of refuge and opportunity, however the extent of the policies surrounding refuge and which opportunities are possible for incoming foreigners reflect the current president and their foreign policies (Tran and Lara-Garcia, 2020). Understanding how the United States has dealt with an influx of mass migration requires understanding how the U.S. has handled recent waves of refugee admissions. Shortly after WWII, the U.S. began its refugee resettlement program after congress passed the Displaced Persons Act of 1948 which allowed for the admittance of more than a quarter-million Europeans that were displaced due to the war (Tran and Lara-Garcia, 2020). This act continued into the cold war era, welcoming refugees fleeing communist governments until 1975, however, after the collapse of Saigon, which initiated refugee flows from Southeast Asia into the United States (Zhou and Bankston, 1998), the United States had to create more legislation regarding the mass migration that had occurred. The after-effects of this wave led to U.S. President Jimmy Carter signing the U.S. Refugee Act in 1980, which was created to essentially develop a legal basis for refugee admissions and to establish refugee resettlement programs (Tran and Lara-Garcia, 2020). As stated by Tran and Lara-Garcia (2020), the United States has accepted more than 3.4 million refugees since 1975, with several migration flows being observed like after the fall of the Berlin wall in 1989, the collapse of the Soviet Union in 1992, an influx from African countries happening in the early 2000s which was followed by a flow of refugees after 2007 arriving from Asian and Middle Eastern countries. From 2006 to 2016, Bernstein and DuBois (2018) state that the annual U.S. refugee admissions more than doubled from 41,223 to 84,994, leading President Obama to designate the ceiling of refugee admittance to 85,000 in 2016 and 110,000 in 2017, a massive increase from the 70,000 cap that was set between 2013-2015. However, once the Trump administration took over, they introduced a travel ban that denied entry from seven (predominantly Muslim) countries which then reduced the refugee acceptance ceiling to 45,000 in 2018 (Table 8) and then proposed only 30,000 in 2019 (Tran and Lara-Garcia, 2020).

Table 8. Annual refugee admission and respective ceiling of admissions from 2000-2019. (Tran and Lara-Garcia, 2020).



Refugees and Asylum Seekers

The United States bases the admittance of refugees into the country on the basis of an inability to return to their home country because of “well-founded fear of persecution” because of their race, participation in a particular social group, political opinion, religion or national origin (Immigration and Nationality Act, 1952). Refugees are to apply for admission from outside of the U.S. which usually happens from a transition country rather than their home country, with some factors like the degree of risk the applicant faces, whether or not they are participating in a group that can be of concern to the government and whether they have family in the U.S. that are taken into account when it comes to the decision of their application being accepted or denied (American Immigration Council, 2021). Where refugees have to go through an application process before arriving on U.S. soil, asylum seekers can apply for asylum at a port of entry and this process is also available to a person already in the U.S. (within the first year inside of the country) whom are seeking protections based on the same grounds which refugees rely on (Immigration and Nationality Act, 1952). When it comes to granting asylum, there is no limit on the number of asylum seekers that can be accepted like how there is with refugees, with 46,508 people in 2019 alone being granted asylum (American Immigration Council, 2021). Noncitizens may be granted asylum if they can demonstrate that they cannot return to their home country by claiming fear or showing they are in danger of persecution or torture (U.S. Immigration Laws and Enforcement, 2021). The U.S. Government Accountability Office also states that a temporary protected status can be granted if conditions like a civil war or natural disaster prevent a country's citizen from returning home. The United States has transformed from dealing with overseas refugee flows to focusing on asylum seekers from the south due to influxes of immigrants attempting to cross into the U.S. mainly from its southern border with Mexico. The U.S. deals with illegal immigrants by either using a "catch and release" program which entails arresting persons illegally crossing the border and processing them and deporting them to Mexico, or by initiating the asylum process if the persons attempting to cross into the United States turn themselves in to border patrol to apply for asylum (O'Connor et al., 2019). The United States has long faced migration issues along its southern border, with between 1995-2000 seeing close to three million Mexican-born immigrants attempting to cross into the U.S. (Gonzalez-Barrera, 2015). As time went on those numbers began to diminish, with immigration numbers between 2005 and 2010 reflecting about 1.4 million Mexican immigrants, and between 2009 and 2014 the number of Mexican immigrants leaving for the U.S. was recorded to be about 870,000 (Gonzalez-Barrera, 2015). Immigrants who originated from other countries in Central and South America started to become more abundant than immigrants from Mexico, for example in 2014 the U.S. apprehended about 227,000 Mexican nationals, in comparison to non-Mexican immigrants which saw around 253,000 persons detained (Krogstad and Passel, 2014; Gonzalez-Barrera, 2015). Even with these numbers in decline, it is still estimated that as of 2019, there are roughly 11-12 million unauthorized immigrants residing in the United States (O'Connor et al., 2019). and even so, the U.S. essentially only has one response to illegal immigration – deportation.

This magnitude of illegal movements across international borders has an impact on national security and public safety, public and economic resources and leaves immigrants vulnerable to exploitation and abuse (U.S. Department of State, undated). Well-managed and legal immigration is crucial to the United States as the number of refugees that are legally resettled throughout the country, are tied directly to the funding of the programs used to assist the refugees (Brown and Scribner, 2014). As an example, due to the significant drop in the number of refugees admitted into the U.S. following September 11th, 2001, the federal funding distributed to refugee resettlement agencies was forced to be slashed; resulting in 58% of nongovernmental resettlement agencies needing to cut staff, with 25% of these agencies needing to cut more than a quarter of their employees (Nawyn, 2006). The Bureau of Population, Refugees and Migration (PRM) issues a percentage of funding based on the predicted number of refugees that will arrive in the U.S. which allows agencies to budget for the fiscal year, however illegal immigrants are not included in this predicted number and one of the main issues with the refugee resettlement system is the failure of collaboration between participating agencies to share and coordinate information efficiently (Brown and Scribner, 2014).

September 11th, also caused a shift in the government as to who oversees immigration, before 2002 immigration was primarily governed by the INS. This changed after September 11th terrorist attacks, with many immigration services being transferred to the then newly-created Department of Homeland Security (DHS), creating a new hierarchy that deals with immigration in the United States (LibGuides: U.S. Immigration Law Research Guide: Structure of U.S. Immigration Law, 2022).

Agencies Involved in U.S. Migration

The federal government of the United States is the main authority to exercise the power needed to regulate immigration matters in the country. The Department of Homeland Security is a branch of the federal government that oversees the United States Citizenship and Immigration Services (USCIS), Administrative Appeals Office (AAO), U.S.

Immigration and Customs Enforcement (ICE), and the U.S. Customs and Border Protection (CBP) (LibGuides: U.S. Immigration Law Research Guide: Structure of U.S. Immigration Law, 2022).

The Department of Justice's Executive Office of Immigration Review oversees the Office of the Chief Immigration Judge (OCIJ), Board of Immigration Appeals (BIA), and the Office of the Chief Administrative Hearing Officer (OCAHO) (LibGuides: U.S. Immigration Law Research Guide: Structure of U.S. Immigration Law, 2022).

The Department of Labor oversees foreign labor certification and the Department of State oversees the Visa Information Center and the Bureau of Population, Refugees and Migration (LibGuides: U.S. Immigration Law Research Guide: Structure of U.S. Immigration Law, 2022).

These agencies are responsible for coordinating together, as well as collaborating with Departments of Health and Human Services, the Organization of American States the U.S. Agency for International Development, the United Nations, Organization for Security, Co-operations in Europe, Organization for Economic Cooperation and Development and G-7 and G-20 summits (United States Department of State, undated).

As it can be noticed from the agencies and organizations listed above, there are several different levels of national and international government that need to work in sync to promote a well-managed, legal form of immigration into the United States. According to Tran and Lara-Garcia, (2020) the lack of collaboration between all government and non-government personnel involved with implementing and upholding immigration legislation has negative impacts on refugees, asylum seekers, illegal immigrants and creates an unfavorable societal perception of the government's ability to manage immigration flows.

Results

Linking of Discussions

The relationship between climate change, migration, decision-making, policy and management are glued by feedbacks: an event or decision created by one entity impacts all the others. It seems as if in the present day everyone speaks in vague generalities, there is an idea of a future plan, but how can a certain choice be justified to lead to that plan? Technology and data are advancing enough to quantify climate change: we can now assess and address issues that couldn't have been seen in the past. The goal of moving forward should not be as heavily based on producing the fastest technology or highest quality data, but more so on how currently available analytical (statistical and mathematical) tools can be made as transparent and yield quantitative answers that also account for uncertainty. Transparent terminology can clear doubts in law and policy on the national and international stage in both public and private sectors. In our migration work, policy should not be vague; rather, it should contain clear definitions and explanations of systematic and environmental processes that impact climate change and human migration. Transparency makes important details easy to understand. It identifies who is at risk, who benefits and who pays, who is held accountable, which choice should become an action, and so forth (as listed on page 35). Transparency is just as important in terminology as is collaboration and information sharing across all local, regional, national and international governments. This is fundamental to making rational decisions – not only regarding climate change but also to deal with any imperfect (i.e., irrational) decisions that may still have to be made. But, as game theory teaches, the optimal equilibrium may be difficult to find, or even impossible to achieve. This is a benefit of integrating heterogeneous information and knowledge: knowing what is not knowable.

Data, research and findings should be modeled when policies demand a causal explanation. It should be appropriate to understand how quantitative information is being generated, the outcome is only as good as the quality of information used for the input and the process that generates the information for policy use. Constructing a model allows us to recognize payoffs and consequences, probability distributions, and helps us define and identify the boundaries of a risky choice or problem. Modeling human migration using differential equations presents a transparent set of methods that generate trajectories (as solutions) that can be transformed into quantitative data. The difference between the data taken for the trajectory can be compared with new field data. Their combination will be assessed and be used to observe how cooperative or uncooperative agents will use the information in game-theoretic exercises: equilibriums and non-equilibriums can then be studied and areas of disaccord identified for further work. Essentially, decision-making should be done after analyzing the possible choices that are proposed, not necessarily to understand how productive an outcome can be based on a certain choice, but how counterproductive it can be. Being able to integrate the relationships and feedbacks between game theory and decision-making, decision-making and climate change, and climate change and human migration is paramount to guide future policy in the direction that will benefit both humans and the planet. Our goal is a first effort towards simplifying and integrating heterogeneous concepts from the sciences likely to be involved in developing prospective choices leading to regulatory decisions. We have presented and exemplified a practical perspective of how to approach a worldwide, and decades-long, problem. We suggest that a rational, quantitative framework that explicitly accounts for uncertain data and knowledge promotes prospective climate change policies and minimizes legislative and regulatory flaws. Migration has dynamic, static, decision-making, and causal aspects. As we have shown, a single, coherent, analytical approach can summarize the key aspects of an otherwise extremely complex policy and decisional process: it provides just enough trees so that the forest is not decoupled from them.

The use of Game theory and differential equations for predicting future migration trends can be used as a tactic to model the probabilities of certain aspects like if a certain population group wants to take over another group, how these populations game with each other and how policy and draws attention to the importance of mathematical transparency. These are critical factors to assess, as knowing which decision needs to be made is done by inherently assessing which players would collaborate or defect through examining which strategies are being used, which pacts currently exist, and how arrangements are made between the players. The tables presented on page 46 epitomize that collaboration is the best policy between players. A further example of this is the Prisoners Dilemma table that can be found on page 50 when discussing the Nash Equilibrium model. This example solidifies that working together helps achieve an equilibrium where everyone can benefit from using the same strategy to produce a positive-sum game. However worth noting, that other players will always be observant if someone is willing to collaborate or not. This can have future implications as governments will need to decide on which coalitions will need to be created or altered and which compromises will need to be made, this observance of who collaborates or who defects can play a key role in developing partnerships and alliances between governments. The effect that mass migration has on political systems and changes in expenditures can be represented by the arms race paradigm model that is explained on pages 19-21, this example of differential equations serves as a means to understand how components of different disciplines between law, mathematics and climate forcing cascading events are integrated. Once the relationship between these disciplines can be understood, a plan can be developed with the underlying mechanism of successful execution being to stick to the plan (collaboration) and not to deviate (deflect) from the plan.

Migration and causes of mass migrations are complicated, they can be sudden onset events and current policies are unable to cope with these abrupt changes that lead to a mass migration situation. Where planned migration can be regulated (as explained in the chapter regarding the United States immigration system) mass migration cannot. An influx of illegal immigration can unbalance a society that was previously in equilibrium. It is imperative to analyze all types of impacts that mass migration will have on society and its services, with the vital tactic being to decide on what needs to be done in an attempt to resolve the issue before the mass migration event happens. What can be observed is that countries or regions are not sufficiently able to manage a mass migration event. In the case for the United States, the country has both a strong asylum and deportation program, however their policy for granting asylum and refugees changes with each administration which makes migration a central talking point during every election cycle. When it comes to controlling a sudden influx of migration, the United States relies heavily on its deportation strategy, however, it is impossible to catch and deport every person who enters the country illegally. Aside from having substantial ramifications on a political scale, mass migration leads to added pressure on social services and can introduce disparity in communities between locals/natives and migrants. Unless migration is planned and asylum or refugee status are applied for, the United States' current deportation strategy does not seem to solve any issues – rather appearing to cause more problems as the migrants are sent back to try again and again until they are not captured by authorities, essentially transforming unplanned migration into a cat and mouse game. On the other hand, unlike the United States, the European Union does not have a "one size fits all" law for its Member States, with different policies and laws that incoming migrants need to adhere to depending on their country of entry. The EU relies on multiple layers of regulating authorities, from local to national to regional, and depending on the situation, one authority may triumph over another. Some international conferences, initiatives, and declarations like the ones mentioned starting on page 50 serve as a type of "commitment" that nations make with one another to work together to achieve future climate goals and to attain or sustain regulations that have been agreed upon. While countries come together to agree on certain benchmarks that need to be met to reduce the effects of climate change and to assist in the protection of people who are being forcibly displaced, none of these are legally binding – they are essentially empty promises with no way of being regulated or penalized if no action is taken to reach the goals that were decided on. Sticking to these goals is crucial for international collaboration and to make decisions today that will lessen the blow that cascading events will have on society and human migration in the future.

Conclusion

Catastrophic cascading events will become more frequent and these events will continue to materialize, ultimately having an impact on all spectrums of human life. As discussed in the "Climate changes, SLR, and Involuntary Mass Migration" chapter, current data shows that atmospheric and oceanic processes are negatively impacted by anthropogenic effects, with more intense and frequent natural disasters being forecasted in the future. Due to this, we can assume that there will be sporadic waves of mass human migration which will also be influenced by other events occurring before, during, or after a natural disaster. We must not ignore the fact that two rare events can happen at once, Covid-19 serves as a good example of how the unpredicted can transpire at any time, in any corner of the world. Combining a catastrophe like Covid-19 with a devastating flood, hurricane or drought can trigger mass migrations which may also have human health implications in the destination country. In essence, a natural disaster that occurs in one country can have a health impact in another country if people fleeing the disaster-stricken area transmit health issues from one country to another. Thus, undoubtedly there will be nations who will be unprepared in their managerial response to cope with the physical, societal, economic and policy feedbacks deriving from an influx of human migration. This is the reason we are trying to predict and prepare against time; we must promote a different perspective on how to put two and two together to clarify the root of the problem, the direction the issue is heading in, and most importantly, what options are available for mitigation. Through the integration of all of this material, it can be possible to accentuate which techniques need to be applied at which stage of preparations between gathering information, devising a plan, and executing said plan. The protocol featured on pages 31-32 serves as a guideline for the integration of methods and components that we have discussed throughout this report, allowing us to present a thorough analysis of the issue at hand, representing the probability behind which decisions would be most rational to make in a transparent, consistent and coherent manner, identifying outcomes and feedbacks and reporting the findings to the responsible agents to allow them to make the most productive, rational decision for all involved.

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