Predicting and Experimenting in Climate Migration Forecasting Models

by

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THESIS ABSTRACT

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In this paper, I pay close attention to the scientific literature to understand how knowledge is being synthesized in nine different forecasts of climate change induced human migration. I situate the extant and most updated models forecasting climate migration in the context of the development of climate migration research as a highly methodologically dispersed and historically contested field of inquiry. Within this formation, I consider how the tendency of competition in the sciences which might lead researchers to try to impose finality runs up against a limit imposed by the fundamental intractability of predicting future human migration. I theorize that a contradiction arises from the interaction between the performativity of scientific research trying to position itself as 'policy relevant' and the 'difficulty of reality' posed above which has led researchers to adopt a reflexive reflex in their own research to maintain their epistemic innocence. I explore how this reflexivity is enacted in a shift away from simulation as a predictive practice towards a more open form of active experimentation of the diverse drivers of climate-change induced migration which has yielded a different functional relationship between what this research is attempting to do and what it is actually achieving.

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TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

CHAPTER 1
INTRODUCTION

'There are no border controls between the real world and Model Land'

-- Erica Thompson in Escape From Model Land

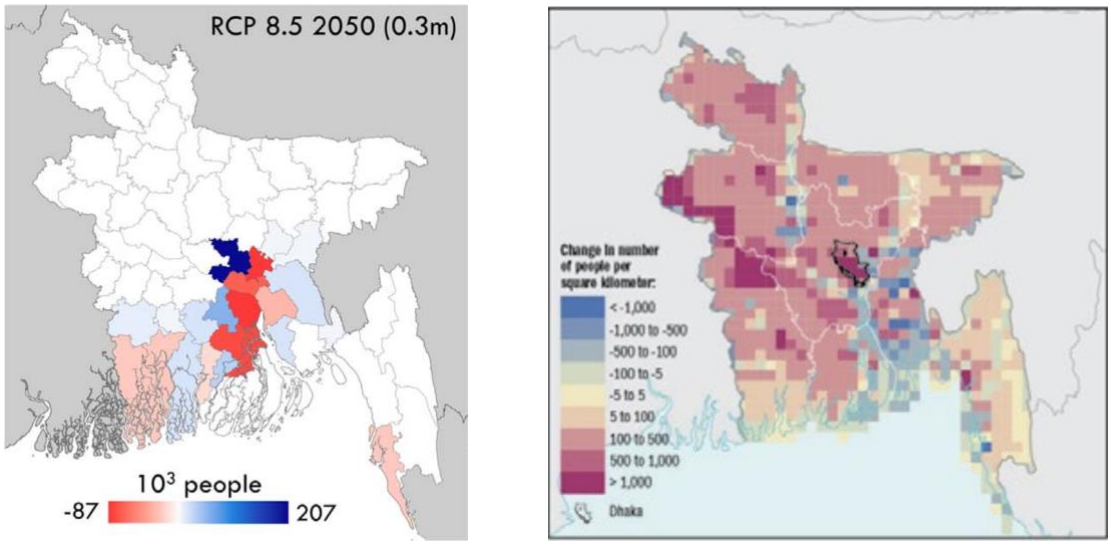

Figure 1.1 – Maps showing predictions of future climate induced migration in Bangladesh under the same warming scenario during the same time period. Left is taken from Davis et al. (2018) and right is taken from Groundswell Part 1

Figure 1.1 contains two maps taken from two different studies, both trying to represent the same phenomenon – additional internal migration within Bangladesh caused by climate change by the year 2050. Even a quick glance should be enough to convince oneself that they are saying different if not contradictory things. The map on the left, taken from the first installment of the World Bank's Groundswell Report on climate migration, estimates between 6.7 million and 13.3 million additional migrants most of

whom move from the south-east of the county towards the north-west under a pessimistic warming scenario (RCP 8.5). The map on the right, taken from a study conducted by Davis et al. (2018) at the Earth Institute of Columbia University, predicts 880,000 additional migrants in the same time period and under the same warming scenario. In significant contrast with the Groundswell prediction, this model suggests that migration will be concentrated in the southern part of Bangladesh with most immigration into the region surrounding the capital city of Dhaka. It was this kind of observation captured in the comparison between these two maps and the level of dissonance between them that motivated me to take on this area of research. I tried to put myself in the position of a Bangladeshi public official or urban planner mandated to plan for the effects of climate change. How to decide which one to choose? There is infrastructure to build, factories to locate and land to invest in – all in the present tense. But here, confronted by two predictions which both pass the scientific smell test (reputable sources, well cited, robust methodology), an anxious planner would be left stumped. The question I set out to answer is that in cases such as this, when scientific epistemology comes across as insufficient to address pressing societal needs, then where else does the utility of these predictive practices for understanding the impacts of climate change lie?

In this thesis I consider a variety of modelling approaches used to forecast the scale and economic, social and geographic distribution of future migration induced by climate change. Because displacement is one of the main anticipated societal effects of climate change, downstream of physical effects like changing weather patterns and shocks from natural disasters (IPCC AR6 WG II), this is a burgeoning area of research. However, given the rate of development of new models and new theories of migration,

moments of consensus are quite rare in this expanding space. This is partially because in addition to being driven by the physical impacts of climate change, climate migration lies at the intersection of two highly confounded political realities – (1) geopolitics in the era of climate change and (2) migration during and after twentieth century globalization and the attendant proliferation of borders (Mezzadra and Nielson. 2013, Balibar 2002) and 'proliferation of sovereigns' (Pritchett. 2009). The difficulty of the former is best characterized primarily as a collective action problem caused by the challenge of fairly managing a global commons of 'unparalleled magnitude'. (Stavins. 2011) The difficulty in the latter is found in the perception of cultural, economic and security threats posed by human mobility on especially wealthy nation states in the postcolonial political order which enforces remarkable world-wide discontinuities on wealth and opportunity. Both realities, marred by the competing interests of nation states, carry enough political weight that they have spawned their own mostly unrelated academic disciplines. It is not surprising, therefore, that this has been accompanied by a proliferation of scientific and social scientific research into the new convolutions whose understanding is becoming critical for our continued survival. In the newly emerging mix of academic inquiry into climate change, concepts which scientist have spent the last two centuries 'disciplining' (confining into specialized disciplines) are now breaking their institutional boundaries in unsurprising affinity with overflowing objects which they claim to represent. Or, as Clive Hamilton proposes, 'Social scientists must become geophysicists' (Hamilton, 2015). This has given rise to a new set of problems in situating the role of science in understanding the world. Bruno Latour writes, 'While the older problem of science studies was to understand the active role of scientists in the construction of facts, a new problem arises:

how to understand the active role of human agency not only in the construction of facts, but also in the very existence of the phenomena those facts are trying to document?' (Latour, 2014)

This fundamental dilemma is at the root of the current efforts to understand the causes and consequences of climate change because there is no way to credibly understand future radiative forcing from greenhouse gas emissions or the impacts of changing weather patterns without a deep understanding of social transformation. Even the most 'physical 'of the modeling projects involved, the Coupled Model Intercomparison Project (CMIP) whose domain is squarely that of Working Group I (The Physical Science Basis) has for its three organizing questions the decidedly non-physical factors of 'forcings', 'biases 'and 'uncertainties in scenarios', each one pertaining to the essential difficulties introduced by messy human subjects. Of course, this is hardly surprising given that none of the modeling enterprises involved, and certainly not the IPCC as a whole, would have achieved the scale and importance that they have if it was not for the fact that many things which were once purely scientific objects (clouds, gases, phytoplankton etc) are now reasserting themselves by threatening our well-being, a consequence, of course, of humanity's own role as a significant biogeochemical force.

Policy makers are looking to the academic fields for some kind of certainty to inform how to prepare for the effects of climate change. Scientists are responding to this demand by synthesizing many streams of disparately connected knowledge in time and information constrained contexts to produce useful models. However, consensus, as some have noted, only provides an illusion of certainty (Oppenheimer, 2007). Aggregating models or coupling them often conceals important elements of uncertainty and obscures

legitimate dissensus between the models. Furthermore, the types of research which are best able to serve up the function of certainty- the quantitative social and physical sciences - are not always the best equipped for the task at hand, especially when considering how to prepare for the future. This focus implicitly frontlines interventions whose determinism makes them easier to predict (Porter. 2020). This is also particularly true in the sense that the visions that scientific projections give voice to is a dominantly globalized one, insufficiently attentive to minority voices and local heterogeneity (Himes et al., in review, Terry et al. 2024). According to Pryck and Hulme (2022), this contributes to the production of an 'epistemic community' (such as the Intergovernmental Panel on Climate Change) whose role, in addition to synthesizing knowledge, is also to set the 'rules and norms about how to assess and synthesise such knowledge'.

In his foreword to the Foresight report on 'Migration and Global Environmental Change' commissioned by the United Kingdom Government Office for Science, the Chief Scientific Adviser to the UK, Sir John Beddington, writes that the report 'aims to provide signposts to important future challenges'. I note the language of 'signposts to the future' because it is a useful description for considering the work migration forecasts are doing in setting up our expectations for the future. In this sense they are not telling us what kind of future to expect, but rather pointing the way, like signposts, towards many possible futures. Moreover, unlike maps, signposts have the unique quality of being sensible only at particular junctures because a signpost removed from of its context effectively loses its meaning. This indicates that reports and analyses like the Foresight report, the more recent Groundswell reports or the many scientific papers which are

trying to achieve the same, must be taken within this context in which they find their motivation.

In this thesis, I pay close attention to the scientific literature to understand how this knowledge is being synthesized in climate migration forecasts which bring together the two worlds of socioeconomic modeling and biophysical modeling. I do so in keeping with the state of the art in Science and Technology Studies (STS) which understands anticipatory practices in the sciences as reciprocally engaged with sociopolitical forces in a dynamic of coproduction explored further in Section 2.1. In Section 2.2, I situate the extant and most updated models forecasting climate migration in the context of the historical development of climate migration research as a highly dispersed and contested field of inquiry. This context is important because studying scientific controversy, as many in the STS discipline have noted, is highly fertile ground for understanding the practices of science as they are revealed in the play of arguments and counterarguments where nothing is quite settled (Jasanoff. 2019). This position is intuitively tenable since it suggests that a good way to learn about something is in its very formation. Within this formation, I consider how the tendency of competition in science which might lead researchers to try to impose finality and try to 'settle questions' once and for all runs up against limit imposed by the fundamental intractability of predicting future socioeconomic developments including migration. In Section 4, I theorize that, instead, a contradiction arises from the interaction between the performativity of scientific research trying to position itself as 'policy relevant' and the 'difficulty of reality' posed above which has led researchers toward a *reflexive reflex* in their own research. I explore how this reflexivity is enacted in a shift away from simulation as a predictive practice towards

a more open form of active experimentation which yields a different (and in my opinion rehabilitated) functional relationship between what this research is attempting to do and what it is actually achieving.

CHAPTER 2
LITERATURE REVIEW

In this section, I present the theoretical background for my thesis. Because I am working on the border of recent developments in two fields, namely Science and Technology Studies (STS) and climate migration research, I have developed separate reviews for each. These two registers of research inform the review in this section which is split evenly between them.

Section 2.1 introduces the field of STS and begins by sketching out the dynamic of coproduction that, for most STS scholars characterizes, the relationship between scientific knowledge and society. I then describe how this dynamic bears out in recent STS literature on performativity in anticipatory practices in the sciences. This section aims to situate the thesis within the STS theoretical landscape around anticipatory governance and the performativity of model building by considering how other researchers have applied these theories to diverse sociotechnical fields from energy systems modeling to nanotechnology.

In Section 2.2 on climate migration research, I describe the development of the field from its roots in 19th and 20th century geography into the present day. I summarize the contention that arose after Myers' (1993) prediction of 200 million environmental refugees and its subsequent inclusion in the First Assessment Report (FAR) of the IPCC. I then outline some of the ways in which the state of the field has been construed by recent scholarship, literature reviews and meta-analyses.

2.1 State of the Art in STS

Science and Technology Studies is a developing academic field which tries to understand the relationship between scientific knowledge, technological development and society meant to 'position science and technology alongside, intertwined with, and integral to other important arenas of human activities.' (Felt. 2017) It is aligned with and has developed from other similar fields such as the philosophy of science, the history of science and the sociology of science. However, it departs from these by applying a more practice oriented critical lens to a broader field encompassing both science and technology as related participants in the production and application of knowledge.

2.1.1 Dynamic of Coproduction

In this thesis, I am drawing on a basic tenet of the field of STS which is that knowledge cannot stand entirely on its own. Within this view, in order to be properly constituted, scientific facts demand more or less robust political and cultural institutions to support them (Felt. 2017). In this moderately constructionist sense, many facets of modern life, the scientific methods themselves (mediated by living scientists working in particular research institutions), media which disseminate knowledge amongst a wider audience to the publics, which receive and act on it are all productive participants in scientific processes (Jasanoff. 2005). This means that if we are to have a good account of how scientific knowledge functions, science has to be understood within the contexts in which it is actually practiced and made relevant.

This coproduction - the inseparability of the 'ways in which we know and represent the world 'and 'the ways in which we chose to live in it '(Jasanoff, 2015) - is

sometimes misunderstood as a problem of biases or social constructions which good science should simply seek to 'correct for'. The misunderstanding stems from an overly idealistic conception of the process of scientific knowledge-making enshrined in conceptual artifacts like the scientific method, falsifiability, verifiability and the universalizing potential of rationality. But as Bruno Latour puts it 'While Science had certainty, coldness, aloofness, objectivity, distance, and necessity, Research appears to have all the opposite characteristics: it is uncertain; open-ended; immersed in many lowly problems of money, instruments, and know-how…" The point of the difference being made between Science and Research is that scientific facts do not come ready made; they are the paradoxical progeny of careful systemizations and messy collaborations which painstakingly collects evidence grounded in measuring instruments, representations (graphs and equations) (Lynch and Woolgar. 1988, Coopmans et al. 2014) and modes of legitimation (citations, peer review or impact factors for instance). Without broaching the metaphysical questions at hand, I understand this to mean that the common distinction between facts and values is more theoretical than practical in most scientific cases (Costanza. 2001, Polanyi. 1970, Latour. 2004). Furthermore, for Latour (2004), this distinction runs politics aground due to the fundamental incommensurability that it posits between society and nature, making the former meaningful (the multitudinous source of meaning) but unreal (lacking universality) and the latter real (comprised of universal empirical laws) but not meaningful (lacking agency). It is important to note that for Latour, Jasanoff and others in the field, asserting that science is political is not an accusation meant to destabilize the practice by insinuating that it is just another ideological exercise or that it is uniquely corruptible by politics, just another propaganda

machine. Instead, I take this assertion to mean either that science has always exerted some degree of legitimate political power (Jasanoff. 2005) or that science is tasked with representing already political matters of concern (Latour. 2004). The problem we are facing is with its practitioners and the wider public who insist on the former critique because of a well founded fear of some of the practical effects of collusions between science and the state. The task of my research is neither to describe a way to harmoniously unite the two domains, nor to describe away the difficulty of doing so. Instead, recognizing this difficulty, I hope to illustrate, in a new way, some of the pathways which *already* draw science and politics together.

Law (2017) writes that in STS, "theory, method and practice get rolled together with social institutions." This is because STS is applied on the borderline between the technosciences and sociology. As a form of boundary-work, there are two functions that this kind of research attempts to perform simultaneously (Law. 2017). One of the functions is to help inform the practical orientation internal to the field being studied, migration forecasting and mobilities studies in the case of this thesis. In this mode, the aim of research is to describe, clarify or synthesize developments that have taken place within the technoscientific field in a way that (hopefully) justifies the research to practitioners within it by providing insights into how technoscientific knowledge is composed or ways in which it might relate to social or political life. Without this possibility of intervening in the actual practices of science and technology, STS would have very little external relevance and almost nothing to recommend it as a field in its own right, with its own quandaries, methods and communities (Felt. 2017). It is in the context of STS as a field in its own right that the second function of much STS research

obtains. Because it is diverse and endlessly reflexive (Felt. 2017), research in STS draws from and aims to contribute to developing the methodological and metatheoretical basis of the field as a whole, situating itself within extant arguments or developing new arguments about how STS research might understand the object of their research. Felt (2017) refers to the metaphor of 'reflexive landscaping' to capture the shifting terrain of research and the evolution of methods and theories that contribute to it. Research, thus, contributes to the second function by engaging with the technoscientific object of inquiry as an observation unit or case study in more general phenomena in which the degree of generalizability is simultaneously informed by the object of inquiry as well as the theoretical allegiances of the researcher (Law. 2017).

2.1.2 STS Literature on Anticipatory Practices in the Sciences

Whereas the future has been a growing concern of sociologists (Delanty. 2021, Appuradai. 2013, Lompe. 1969), and future oriented practices have been prevalent across cultures for most of history (Terry. 2023), Akyut et al. (2019a) write that anticipatory practices, which have always helped to orient society, have undergone a process of scientisation and professionalization since World War II. They point to the proliferation of formalized approaches from cybernetics to econometrics that help us apprehend and act on the future. Anticipatory knowledge practices aim to make the future governable by turning it into an object which can be studied scientifically and therefore acted upon with the certainty derived therein. In Guston's (2013) influential formulation, anticipatory governance, is associated primarily with the development of new technologies such as nanotechnology or, more contemporaneously, Artificial Intelligence as a way of

managing their deployment and preparing for their effects. However, this specification is extended in many other usages of the concept to include the governance of the future writ large, with and without reference to the governance of future technology (Konrad et al. 2019, Akyul et al. 2019, Dolez et al. 2019, Heo and Sẹo. 2021, Fuerth and Faber. 2012). Here, I adopt the broader usage defined by Fuerth and Faber (2012) as a 'system of systems' , along with terms like 'anticipatory practices' and 'anticipatory knowledges' in order to refer to how the ways in which we build our expectations of the future (veracity of the predictions notwithstanding) bear on how we manage and understand the present.

Many STS scholars locate the work that technologies for anticipating the future do within the concept of performativity or performation (Callon. 2006) derived from John Austin's (1962) conception of the 'performative utterance' which unites speech and action (Diedrich et al. 2013, Callon. 2009). It is central to the proposal of theorists like Latour (1984) to replace an ostensive definition of society - one based on abstract principles like power or progress which are used unidirectionally to describe social practices - with a performative one based on practices that have the possibility of explaining and shaping the principles. Callon (2006) and MacKenzie (2006) elaborate on this notion of performativity in the context of economic sociology to show that by informing how actors (like stock traders) should act, economic models contribute to the constitution of market economies as an ongoing process, an enactment Callon refers to as performation. In this way scientific practices can build on theories which are themselves a form of practice in a mutually constitutive or self-fulfilling loop of representations. This is one instantiation of the coproductionist dynamic which forms a central tenet of science studies.

Akyut (2019b) outlines how predictive practices in the sciences perform social reality in three interrelated ways. The first and most intuitive of these is the way in which predictive models are expected to work, by influencing how economic and policy actors imagine the future and therefore how they act based on those expectations. This is the mundane point that models are actively used in economic practice. The complication that this introduces is with normative assumptions playing a large enough part in the modeling process that model outputs are liable to preclude future trajectories. This is similar to Hulme's (2011) point that climate reductionism may work to foreclose the future, further corroborated by Beck and Mahoney (2017) who argue that 'projections of future climate function as a kind of regulatory science' in which climate scientists are necessarily implicated in the consequences of their research and are therefore unable to disengage from the field of climate politics as some critics (Büntgen. 2024) have called for.

Secondly, they draw on the concept of 'social performativity' to argue that forecasting models which are produced within and about 'organizational networks' can help to reorganize the relationship between actors in policy settings. This is true in Akyut's (2019b) own research landscape of energy policy assemblages where the network of various acting groups, 'the state administrations, energy experts, firms and activists' is itself the objects of theorization which foresight exercises can 'stabilise [sic] or to the contrary, unsettle and recompose.'

Thirdly, they cite work in the field of the 'new economic sociology' which shows that the ways in which predictive models are received can powerfully shape social reality because models can become part of a shared practice, 'linked not by shared causal beliefs

(although this may be the case), but by the common use of a material-semiotic artefact', i.e. the model. In this sense, competing models influence the formation of competing social worlds that are coordinated by the models which define them. Thus, performativity is pluralized in 'ecologies' or 'assortments of futures' that compete with one another in asymmetric terrains. This marks a shift away from the typical understanding characterized by the existence of 'one dominant knowledge practice, or by a privileged relationship between a producer of anticipatory expertise and a (political) centre of decisionmaking – often the state' (Akyut. 2019a). Braun (2014) provides insight into how models compete with one another in this regard using the evolution of macro-economic models from Keynes onwards to demonstrate how the discipline of economics tended to prefer models which provided a clear 'governability paradigm' over those which were comparatively more difficult for policy-makers to perform. This is an indication that performativity can be a crucial determinant of the success of models in a competing field.

Akyut (2019a) further argues that the pluralization of performativity opens up the possibility of democratizing anticipatory practices which are 'No longer a monopoly of a few academic or state institutions.' Jasanoff (2020) argues that anticipatory practices in the science disrupt the foundations of politics rooted in its materiality, presentism and localism by shifting the terrain of politics from the present into the future. This means that anticipatory practices are not only significant for the futures we build but also how we act in the present, opening up a range of regulatory devices for current implementation. Critically, for her, democratic sociotechnical systems depend on the civic body's ability to apprehend various objects of governance from potholes on highways (local and material) to markets (diffuse and immaterial). In this context,

nonknowledge or uncertainty about the future can be as powerful an impetus for action as knowledge because, as Haines (2019) argues in the context of Belize's water sector, it situates actors 'reckoning' in between the two poles of knowing and not knowing. Known, unknowns and the work of uncertainty is also evident in the 'scenario building' approach commonly used by scientists to circumvent the epistemic issues inherent in prediction. Scenarios allow researchers to construct storylines for possible futures without passing any judgment on their relative likelihood. In this regard, they amount to elaborate materialist fictions that are stabilized by quantification techniques. Van Beek and Versteeg (2023) differentiate the fictional element of scenario modeling in IAMs from more speculative novelistic climate fiction by pointing out that the IAM scenarios are overly determined by historic trends due to the justifiable emphasis on methodological transparency in scientific accounting mechanisms. However, this reliance on past trends can serve to entrench visions of the future based on the perpetuation of colonial inequalities (Hickel and Slameršak. 2022). This has led to calls from researchers for scenarios that grapple with more radical social and political scenarios in order to better understand the feasibility of alternatives to current pathways (Hickel at al. 2021). The scenario approach has also been criticized by some researchers for giving a false sense of the equal likelihood of different modeled scenarios whereas some are more probable than others (Pielke Jr. and Ritchie. 2021).

Hulme and others are right to claim that climate science, and forecasting in particular, has the effect of foreclosing the future by prematurely passing a judgement on what is possible. Some have picked up on this to suggest that science is an inherently conservative field in that it is often difficult to revoke orthodoxies especially when it

comes to our understanding of political change and 'human nature' (Foster. 2022, Lenzen. 2022). This has led scientists to consistently understate the possibility of change. This is evident in models predicting the economic impacts of climate change such as William Nordhaus' DICE models which many have criticized for being insufficiently attentive to the nonlinear effects of climate change on the global economy, thereby downplaying the economic costs of failing to cut emissions (Rosen and Guenther, 2015). In such cases, it is clear that scientific research displays a consistent preference for 'business as usual' scenarios which provide us the certainty of known relationships but discount the possibility of fundamental reorientations in society in the medium to long term. This points to the stark necessity of finding new ways to collectively imagine possible futures, ones that don't rely on the uncritical assumption of untenable configurations in the present. Otherwise, in the dynamic of coproduction we risk unintentionally committing ourselves to paths that are by no means a foregone conclusion.

2.2 Climate migration research

It is difficult for me to title this section because the field that I am choosing to call 'climate migration research' has hardly coalesced into any kind of officially designated field with clear disciplinary preoccupations yet. Nevertheless, I am referring to broad swathes of research interested in understanding the phenomenon of climate migration defined for my purposes as forms of human migration, whether voluntary or involuntary, caused at least partially due to the impacts of climate change on social, ecological or economic systems. This section aims to summarize advancements in migration and

mobility studies that have a bearing on climate migration forecasting as well as recent efforts to synthesize the landscape of models projecting/forecasting future climate migration.

2.2.1 Pre-history of Climate Migration Research

The prehistory of climate-related migration research can be found in the early study of environmental migration which was a primary feature of late nineteenth and early twentieth century migration studies (Piguet. 2013). According to Piguet, pioneering geographers like Friedrich Ratzel, Ellen Churchill Semple, Ellsworth Huntington and Ernst Georg Ravenstein amongst others saw the natural environment as the motive force for human mobility, with a nearly deterministic significance for where and when people chose to move for much of history and pre-history. This kind of broad environmental determinism found in descriptions of so-called 'primitive migration' (Petersen. 1958, Piguet. 2013) provided for a positivist certainty that was popular at time because it was based in and analogous to the natural science, especially the burgeoning life sciences (Hulme. 2011).

The biogeographical understanding of mobility took a back seat with the rise of economic and political paradigms in geography in the mid-twentieth century (Piguet. 2013). As a result, the role of the natural environment in migration came to be seen as much less central. It is unsurprising that this scholarly turn coincided with the development of flexibilized and tertiarized, planetary scale, transportation and production technologies which have increasingly untethered economic production from geographic space, a process Harvey (1989) referred to as 'time-space compression'. An effect of this

has been the progressive deemphasis of ‘nature’ in our construction of space and consequently a deepening schism in our understanding of the relationship between nature and culture where modern life is characterized as a total rupture or ‘decoupling’ between the two domains (Latour. 2004, Asafu-Adjaye et al. 2015).

However, with the growing consciousness of the risks posed by climate change to society, the environment (though it is no longer called natural) has been re-inscribed into our current accounts of migration, especially as they feature in the popular imagination of the future of climate change (Black. 2001). This change was first precipitated by environmental movements of the twentieth century which sought to demonstrate that negative anthropogenic impacts on the environment were being reciprocated (Ehrlich. 1968, Meadows et al. 1972, Merchant. 1980). This was accompanied by a return of some of the problematic environmental determinism and Malthusianism of the older geographical studies (Myers. 1993). Nevertheless, much of the contemporary social scientific literature on climate change is attentive to the subtleties of the relationship between climate change, environmental transformation and climate change. In this literature, climate change and associated environmental transformations are part of the nexus of interacting factors that influence migration networks.

Although researchers predict more human migration and displacement from environmental factors in the 21st century, there is no clear consensus on where it will happen or what that growth will look like (Schewel et al. 2022). Moreover, the impact of climate change on global migration networks is notoriously difficult to disambiguate (Black et al. 2011, Foresight. 2011, Beyer et al. 2023). Given the complexity inherent in

the dynamics of global migration networks and the stochasticity of climatic events that might displace people, there will almost certainly not be a direct causal relationship between climate change and migration. Current predictions of the extent of climate induced migration run the gamut from the benign to the catastrophic. Some projected scenarios take the form of cooperative models in which people redistribute themselves based on climate induced changes in economic activity and remittance flows. Others consider the possibility that planet wide disasters will force unmanageable displacement events across the world. Thus, corresponding estimates of the numbers of 'environmental migrants 'documented in the Climate Action entry of the Encyclopedia of the UN Sustainable goals range from 60 million to 1.2 billion. These disparate predictions have been repeated and recycled alternatively as hard objective estimates or qualitative warnings across a variety of scientific and media publications.

Climate induced displacement likely first entered the mainstream scientific consciousness with the publication of the IPCC First Assessment Report (FAR) in 1990 which reported that sea level rise could displace tens of millions of people (IPCC. 1990). These claims were further crystallized in the Second Assessment Report drawing on the work of Norman Myers who was an environmentalist and biodiversity specialist (Myers. 1993, Janetos. 1995). Despite drawing sharp criticism from many researchers, his central prediction, which has been described as a back of the envelope calculation at best, of 200 million to 250 million environmental refugees was adopted in many official reports (including the influential Stern Report) and cycled throughout the media (Cord and Methmann. 2012, Boas. 2019). In this way, replete with Malthusian overtones

displacement in the order of hundreds of millions of people became the common reference for many researchers trying to assess the impacts of climate change (Table 1).

Criticizing Myers 'research, Suhrke (1994) draws a distinction between minimalist and maximalist views on climate migration. According to Suhrke, maximalists like Myers tend to understand environmental degradation 'as a direct cause of large-scale displacement 'whereas minimalists who she calls the 'migration experts 'consider environmental change to be a 'a contextual variable that can contribute to migration', albeit one that is very difficult to empirically isolate. Suhrke's distinction between the minimalist and the maximalist school is important to note because in the last two decades most researchers have assumed a more minimalist approach to the question of climate migration (Hunter et al. 2015, Boas et al. 2019). Between then and now, climate migration research has evolved considerably and incorporated many diverse forms of scholarly thought from legal studies to economics (Piguet. 2010, Ferris. 2020, Piguet. 2022) which try to analyze how climate variables interact with economic and political drivers of migration.

The researchers who constituted the minimalist of school thought brought economic, demographic and sociological perspectives into thinking about climate change related migration. In particular, researchers built on preexisting economic migration models such as the Roy-Borjas model and the New Economics of Labor Migration (NELM) paradigm in order to inform their research by considering how environmental shocks and transformation might transform financial constraints and economic incentives for migration (Borjas. 1987, Stark and Bloom. 1985, Kleemans. 2015). These applications have gone hand-in-hand with the development of econometric tools to

evaluate the economic impacts of climate change (Aufhammer et al. 2013, Hsiang. 2016) as well as the application of these tools to measure general non-economic impacts on society like health, conflict and gender outcomes (Carleton and Hsiang. 2016) which in drive changes in migration networks.

2.2.2 Recent Developments in Climate Migration Research

Problems like these have led to the growth of diverse and overlapping academic programs for empirically studying the myriad of causes of climate migration and climate impacts more generally. Because this is a 'field in formation' (Ferris. 2020), one that has received significant amounts of interdisciplinary attention in a relatively short period (Piguet. 2022), it is difficult to synthetically describe how developments in the scholarship agree with or differ from one another. Moreover, studies on climate migration are aligned along many different geographic, methodological, terminological and process specific axes which do not necessarily intersect well with one another. This has made forming a comprehensive account of climate migration a relatively difficult task. This difficulty is compounded by the fact that there exist multiple 'strands' of research interest in climate migration from climate change scientists and migration researchers on the more academic side to humanitarian organizations and development actors on the more political side. Zander et al. (2022) group environmental migration research papers by topic to show, in broad brush strokes, how the focus of of the field has shifted over the last thirty years, away from conservation and conflict related issues towards topics that emphasize the impact of environmental changes on human mobility. They also discover that there is less overlap across the topics than might be expected and relatively

substantial research gaps. This has led to a competing field of research styles and interpretations with moments of consensus appearing few and far between (Ferris. 2022). Researchers have also noted that mobility outcomes are so highly context dependent that no results are likely to be generalizable across the entire field. Therefore, in the case of climate related migration where multifarious causal factors are known to be functioning simultaneously in the so-called 'climate-migration nexus 'of ecological disturbance, extreme disasters, political upheaval, capitalist exploitation and unequal economic exchange, where each one of these causal factors is in turn tied to its own mutually necessary causative chain, it is impossible to estimate the significance of one factor alone. Hence, UNHCR's rejection of the word 'climate refugee', though politically motivated because it reduces the scope of their mandate considerably, contains a significant grain of truth which is that such a strict classification defies empiricism because displacements do not have singularly assignable causes or modalities.

Trying to understand how climatic and non-climatic factors interact in the climate migration nexus is a primary aim of much of the literature. According to the IPCC (2022) (Chapter 7 Cross-Chapter Box MIGRATE), there is now high confidence that 'climatic conditions, events and variability' drive migration and displacement. In order to account for the impossibility of assigning singular causes, the IPCC conceives of migration (and other well-being related impacts of climate change) as taking placed within a complex of hazards, vulnerabilities and exposures. Moreover, there is a developing notion, amongst scholars of climate hazards that climate change acts as a 'threat multiplier' by exacerbating pre-existing systemic shortcomings (Huntjens and Nachbar. 2015). In their highly stylized framework of climate migration, climate factors and non-climate factors

significantly modify the hazard-vulnerability-exposure complex which creates risks for individuals. Migration outcomes (including immobility) are then understood to be a way of managing this risk once in-situ adaptation options fail. In this framing, migration as an adaptation strategy exists downstream of climate factors and downstream of in-situ adaptation which is seen as preferable in most cases (Boas. 2019, Bettini. 2017).

This framework draws upon the wider notion evident in the literature of adaptations to climate change (McLeman. 2016). Climate change adaptation refers to how people adjust to actual or expected climate change and its effects (IPCC AR6 WGII). There are many accepted pathways for achieving adaptation including developing climate resilient infrastructure, shifting/restructuring regional production and democratizing decision making (Thornton and Manasfi. 2010, Rahman et al. 2021, Field et al. 2014, Fankhauser. 2017). The framing of 'migration as adaptation' has gained significant traction in recent years. It's near universal acceptance in much of the literature can be seen in light of the fact that by emphasizing human agency in migration decisions, migration as adaptation provides a powerful antidote to many of the maximalist alarmist tendencies discussed previously (Black et al. 2011, McLeman. 2016, Sakdapolrak et al. 2023).

Piguet (2022) assess 1737 publications and 694 case studies available in the empirical literature on climate migration in order to propose the typology applied in the comprehensive CLIMIG database for broadly categorizing research method families linking climate change, environmental degradation and migration. This typology categorizes six families of research methods (not including legal studies of climate migration) based on the time period (historical or contemporary), content (descriptive or analytic), type of analysis (quantitative or qualitative) and data type (individuals surveys,

geo-data, or mixed methods) as follows: (1) Spatial analysis, (2) Multilevel, (3) Survey, (4) Historical analogues, (5) Hot spots, and (6) Qualitative. Piguet (2022) also describes developments in correcting for insufficiencies in the field noted in a 2010 paper of the same name (Piguet. 2010).

One of the most significant insufficiencies which they claim has been addressed since 2010 is the need for more crosscutting research that synthesizes information between different families of climate migration research. This is made possible due to the proliferation of academic research in the field which makes identifying patterns possible. In addition to Piguet's (2022) analysis, the literature reviews and meta-analyses that have been produced help map the landscape of climate and environmental migration according to different functional criteria. Some consider the geographical distribution of case studies of environmental migration (Piguet. 2018),

Hoffman et al. (2020) conducted a country-level meta-analysis of thirty studies which estimated the effect of environmental change on migration. Their results provide confirmation for the generally known positive relationship between environmental hazards and migration while adding differentiating context at the national level. They show that different environmental hazards produce different kinds of migration responses, with temperature fluctuations producing the largest increase in migration. They also show that environmental effects are more closely associated with internal migration flows than with cross-border migration. Moreover, according to the paper, environmental effects are largest in studies for studies investigating cross border migration to lower income countries. This indicates that environmental migration tends to be regional and temporary. Finally, they disambiguate effects based on the compositional

characteristics of countries included in studies. These characteristics include the level of economic development, agricultural dependence and the presence of conflict. An interesting result of this part of their analysis is that they find weaker environmental effects in samples of studies consisting of more low-income countries. This points to liquidity constraints of migration resulting in resource constrained immobility. The authors conclude that most environmental migration will likely be concentrated in Middle Income countries.

A separate literature review and meta-analysis conducted by Hoffman et al. (2021) found that most of the empirical quantitative research on climate migration focusses on lower and middle income countries, a finding supported by Piguet et al. (2018). By reviewing the literature from a methodological perspective, Hoffman et al. (2021) provides an overview of the most common approaches to quantifying the impact of climate change on migration as they arise from diverse academic disciplines. Crucially, they explore the implications of how quantitative methodological choices influence what kinds of interpretations are possible. This allows them to consider the common forms that migration research may take as well as identify methodological challenges in each step of the the research cycle arising from (1) identifying the relevant migration variables, (2) identifying relevant climate variables, (3) uniting these variables through data integration and aggregation, (4) using patterns in the data to make estimations or projections, and (5) potentially using the models to learn more about mechanisms and contextual influence in the relationship between climate change and migration. Each of these moments represents a significant point of departure for researchers interested in understanding how climate change drives migration.

Most recently, there has been a move to unite research through the concept of 'climate mobilities' (Boas et al. 2022) which emphasizes the role of power and inequality in structuring 'climate mobility regimes' which are seen as interconnected but relatively heterogenous. This perspective insists that climate mobility is 'not necessarily novel and exceptional', (Boas et al. 2022), but rather inscribed within a wider 'mobilities paradigm' (Sheller and Urry. 2006) in which migration has always been a central feature of human social life. Within this conception, climate mobility is not automatically considered part of a pathological response to climate change. Instead, it considers the diversity of responses (which include voluntary immobility) to the impacts of climate change as an indication of how communities normalize these impacts rather than overtly adapt to them.

CHAPTER 3
METHODS

This thesis began as a mapping exercise in which I was hoping to discover the values that guided the sociopolitical assumptions underlying the construction of the models sampled. To do so, I sought to apply a transparent hermeneutic approach involving iterative rounds of qualitative coding, where the codes represented categories of values identified within the sample and especially within the symbolic language apparent in the mathematical relationships of real world-phenomena they described. This was in the hope of revealing patterns in the dominant scientific reasoning and political imagination regarding human migration, border securitization, understanding damages from climate change etc. By revealing these orthodoxies, I also hoped to point out some of the political effects of the models as artefacts which I suspected were inadvertently prescribing actions as 'neutral' forms of political intervention not necessarily supported beyond the assumptions I was trying to clarify. Thus, my research was to serve as a critique of the dominant rationalities used to understand and govern climate migration. Exemplar spreadsheets from my coding and attempts to condense the information are in the Appendix.

However, I soon found my analysis was becoming unwieldly and tense. I could no longer tell if I was identifying uniformities across the sample or points of departure. I sensed that this was caused by ideological impulses of my own that I could not be sure I had easy access to. But I was afraid that they were leading me to impose interpretations of the models that were no more legitimate than the ones I was trying to criticize. For example, Burzyński (2022) makes the relatively unqualified assumption that high incomes countries are able to reduce productivity losses from climate impacts by 75%

through unspecified adaptive technologies whereas there is no adaptation in developing countries. It is fair to call this assumption an egregious simplification of the difference in adaptive capacity between rich and poor countries. But identifying this assumption and criticizing it is tantamount to just cataloging issues with models without amounting to a serious criticism because it is well understood that any model has reductive elements that will not measure up to reality. My temptation in cases like these was to derive a broader category from encounters with assumptions such as these that 'revealed' something about the researchers' understanding of the social world. However, for the most part, these categories appeared untenable because they enforced uncharitable accounts of the model-building process that I was unconvinced by. Especially in the performative setting it was difficult to abide by the possibility that so many brilliant social scientists were so unmoved by the social worlds they were describing in their models that they could possibly have an such an unreflexive relationship with the parts of their models which I was identifying as faulty.

Call it Stockholm Syndrome developed thanks to all my time held in captivity with the models I was studying, but realizations like this led me away from critique which was my initial aim towards understanding the forms of reflexivity that science like this is necessarily engaged in. I thus took on more of any anti-theoretical stance than I had initially expected in line with Actor Network Theory (ANT) which eschews many of the standard aggregates used by sociologists to describe social worlds (Latour. 2005). Instead, ANT notices that groupings are usually much more difficult to assign than people recognize because they are rarely very stable and should consequently be the explananda of a social phenomenon rather than the explanans. This is not a way of

denying the existence of groups but rather a way to transfer responsibility for their formation away from the sociologists who are analyzing them towards the actors who make them up. Thus Latour (2005) writes 'If I had to provide a checklist for what is a good ANT account … are the concepts of the actors allowed to be *stronger* than that of the analysts, or is it the analyst who is doing all of the talking?'

3.1 Sampling

In this section I lay out my sampling strategy as well as some methodological consideration which intersect with approaches available in STS literature. The empirical material for this thesis consists mainly of peer-reviewed journal articles, papers, reports and supporting material (appendices, blogposts, teaching slides) produced by various modeling groups to communicate their research to wider scientific and non-scientific audiences. Given the time constraints of the Master's thesis research setting, I was not able to pursue additional ethnographic research and interviews with practitioners typical of STS studies of this nature. Instead, I rely on the purely public-facing documentation of these materials which afforded a wider net to cast over more material so as not to suffer from a 'snapshot bias' (Hyssalo. 2019) which might limit the wider applicability of my findings. As outlined in Section 3.1, I also selected from a wide variety of models in order to generate what I consider to be a fairly representative sampling of the current state of climate migration forecasting.

For this research I chose to focus on models that make explicit forecasts of future climate change related migration including rate predictions, economic effects, effects on immobility and featuring international and/or internal migration. In order to maximize the

representativeness of the chosen samples with respect to the diversity of forecasting methodologies and disciplines, I chose not to constrain them to any particular geographic scale, location or prediction timeframe. However, to ensure their currency as representative of the scientific 'state of the art', I limited my analysis to only models published within the last ten years (2013-2023). Finally, in order to achieve my goal of 'close reading' as much of the supporting text, code and data for each of the selected samples within the timeframe of this research project, I chose to keep the sample quite small opting for depth over breadth of analysis.

This research did not involve any preselected sampling strategy. This is because there are a relatively small number of models forecasting climate migration produced each year (IOM 2020). Therefore, it was straightforward to manually scan the literature and select from models according to following sampling priorities (presented in order of importance).

1. Sampling from the widest possible range of methods to accurately represent the diversity of quantitative approaches to forecasting climate migration including different levels of complexity in model selection.
2. Sampling from models which explore diverse drivers of climate migration.
3. Sampling from a variety of publication types - peer-reviewed scientific journals, official reports and reputable 'data-journalism'[1].

[1] This was not necessarily an obvious choice because it could be considered a step outside 'normal' science.

Model	Summary	Method(s)	Driver(s)	Lead Author Discipline	Publication type/venue	Complexity
Abel et al. 2013	Their model used solicitations of expert opinions to inform priors in Bayesian extrapolation from past trends of total and environmental immigration to the UK	• Experts surveyed • Bayesian autoregression on past migration trends	• Agnostic	Demography	Journal focused on interdisciplinary research on social demographic aspects of environmental issues	Low
Benveniste et al. 2020 and 2022	Their models adds a migration term to the FUND Integrated Assessment Model to couple the SSP scenarios with human migration	• Gravity Model • Integrated Assessment Model • Scenario approach	• Economic losses (modeled separately in the FUND IAM) from climate change	Environmental Social Sciences	Highly Respected Interdisciplinary Science Journals (PNAS, Nature climate change)	High
Burzynski et al. 2022	They forecast migration using Random Utility Maximization model which accounts for heterogenous impacts of climate change on production in economic sectors .	• Random Utility Maximization model • Model sector specific damages by extrapolating from past trends. • Scenario approach	• Economic losses from Climate Change	Environmental Economics	Economics Journal	High
Chen and Caldeira 2020	They use the historic spatial relationship between climate factors (temperature and precipitation) and population to understand how climate change may change people's incentives to migrate	• Extrapolating from spatial analysis of past trends	• Temperature • Precipitation	Climate Science	Climate science journal	Low

Model	Summary	Method(s)	Driver(s)	Lead Author Discipline	Publication type/venue	Complexity
Davis 2018	They develop a simple 'universal' non-parametric stochastic model of human migration to understand how droughts will shape the future pattern of internal migration in Bangladesh	• Non-parametric radiation model	• Sea Level Rise	Environmental Science	Environmental science journal	Low
Groundswell 1 and 2	Groundswell uses a parametrized gravity model to understand the effect of slow onset changes, sea level rise and drought, on internal migration using predicted damages to agricultural sectors from the Inter-Sectoral Impact Model Intercomparison Project	• Gravity Model • Inter-sectoral Impact Model • Scenario approach	• Precipitation • Sea Level Rise	Economics	Institutional self published report	High
NYT/Propublica 2020	They extend the Groundswell report migration model in the context of migration in the Central America and Mexico to include more climate drivers, the possibility of cross-border migration and the effect of sociopolitical factors in influencing migration decisions.	• Gravity Model • Inter-sectoral Impact Model • Scenario approach	• Precipitation • Sea Level Rise	Data Journalism	News site	High
Smirnov et al. 2022	They apply an agent-based modeling (ABM) approach using certain stylized assumptions about human behavior to predict movement	• Agent Based Model	• Drought	Political Science	Migration Journal	High

Model	Summary	Method(s)	Driver(s)	Lead Author Discipline	Publication type/venue	Complexity
	in response to droughts.					

Table 3.1 – Table summarizing each of the models used in my sample.

CHAPTER 4
FINDINGS

Beginning with the most general result first, I note that every one of the models sampled exhibits the same or similar central contradiction in that they simultaneously narrativize the forecasting model on one hand through a practical justification of its significance and reflexively critique the results on the other in order to avoid criticism. In the first instance, researchers situate the importance of their work by invoking the principle of 'policy relevance' and emphasizing the ways in which their research could guide decision making and governance. In the second instance, researchers preempt criticism by cautioning readers about the inherent limits of predicting the future of socioeconomic phenomena as complex as climate migration, thereby establishing strong limits on the type of evidence model simulations can provide[2]. Here, I begin by exploring how these moves are affected discursively in publications and what makes these two moves incompatible with one another. I then argue that this syllogism creates the possibility of an *uncertainty principle* in research forecasting climate migration which allows researchers to simultaneously satisfy a distinct need for certainty in political discourse on climate migration while at the same time maintaining their epistemic innocence in the face of well-founded critiques of messy socioeconomic modeling. This is in keeping with what Sismondo (1999) referred to as the 'uneasy space between theory and experiment, between abstract and concrete, and often between the pressures of pure

[2] Parker (2022) questions the kind of evidence that computer simulations provide, arguing that the results of simulations function as 'evidence of evidence'. She notes that this is useful in epistemic situations where nobody has all the knowledge, thus allowing for evidence to be linked in generative ways.

science and the needs of pragmatic action'. In this section, I will sketch the uneasy space in its relation to the samples in order to further a discussion of what is possible once this space is opened up.

4.1 The Use of Narrative Justification

The first move in the performative contradiction is enacted in statements such as "With an eye toward policy remedies and governing prospects, [the model] offers valuable insights about drought-related human displacement and the potential effects of different choices facing policy-makers" from Smirnov et al. (2021) or "This scenario approach provides policymakers with a way to better understand and plan for the likely movement of people within their countries—over time and across different geographies—due to climate change impacts" from Groundswell Part 1. These kinds of statements are replete throughout the literature explaining the model's results. In the papers, this comes across as the necessary narrative work researchers have to do in order to convey the stakes of their models by convincing the public that their work has practical value. These discursive significations go hand in hand with the 'posture of "preparedness" ' which Luetz, writing in the Encyclopedia of the UN Sustainable Development Goals insists is a necessary condition if we are to understand the scale of the climate migration problem. Luetz leans into the contradiction posed above by arguing why 'measuring the immeasurable' makes senses. His argument appears to be responding to issues raised by quantification skeptics who criticize the 'endless quest for numbers' (Gemenne. 2011). Luetz contends that even bad estimates from so-called 'alarmist' (a term he rejects) predictions of migration provide the contours of unacceptable futures no

matter how remote they seem. This is a prospective and precautionary position that Luetz insists can galvanize action and inform some forms of anticipatory preparation. In exploring how Integrated Assessment Models (IAMs) have interfaced with policy, Van Beek et al (2020) suggest five phases between 1970 and 2015 in which IAMs played different mediating roles between climate science and the policy world. The evolution they document from the first phase in which these models emerged into the current phase where they bear the official responsibility for explicating mitigation scenarios is evidence of the increasing import assigned to future oriented simulations in the science-policy nexus of climate change.

However, in addition to directly suggesting the policy-relevance of the model, statements like these perform another important function. They help to establish continuity between the internal referent (model-land) and the external referent (the real world) of the model. Such a move necessarily depends on the suggestion that some aspects of realism are being conserved, that the representations captured by inscriptions, immutable mobiles (Latour. 1986) of equations, graphs, numerical predictions and even the maps are legitimate impressions of reality. For socioeconomic models which implicate elements of everyday life, this should be achieved quite easily because of the fact that the quantities being referred to in many cases have understandable or graspable real world analogues like GDP, population, temperature etc. However, many of these metrics appear more opaque when they are closely inspected. For example, GDP masks an entire system of accounting which varies significantly from one country to another (Waring. 1999) and has been criticized by many social scientists for making ‘the economy’ conceived as a self-contained whole into the systematic object of political

governance. In the case of population, granular, grid-level population counts have a difficult time capturing informal migration especially in developing countries. There are many other examples of this, but it doesn't only take an abstruse index or statistic for the opacity to be felt. For example, Burzyński et al. (2022) present density plots of income distributions standardized to the global average with a logarithmic horizontal axis. On the one hand, this is a very justifiable decision since it makes variations across the distribution much more visually apparent on paper. On the other hand, it is a partially unintended consequence of the dramatically unequally distribution of income across the world which if represented more simply would skew the distribution immensely to the left (Figure 4.1). While applying the log transformation is certainly standard practice because it provides the necessary level of detail for understanding variation in the distribution caused by climate change, it is intuitively quite difficult to connect this knowledge of the facts with understanding how these facts bear out in terms of actual inequality. Moreover, aggregating the data in this way also conceals important national and regional variations which are necessary to understand in order to grasp the effects of climate change on worldwide income distributions. One could argue that this problem is solved by accounting for the expertise level of the 'real audience' for a paper like this - that those economists and quantitative researchers expected to be more or less fluent in this style of analysis due to their specialized training might have a more intuitive relationship with the way the data is presented. While this is true to an extent, recent debates around the ergodicity problem in economics and dimensional analysis in economic modeling demonstrate that economists still do not pay as much attention to whether variables, concepts and functional relations like parameter estimates or variables

with composite units including stocks and flows resemble ‘real’ observables in the economic world with a degree of immediacy that make the models useful (Texocotitla et al. 2019, Peters. 2019).

This issue is of course not confined to the model presented by Burzyński et al. (2022) or to climate migration modeling. It is ubiquitous in this sample and throughout much the quantitative social sciences and science more generally. Much of the early work in the sociology of science, concerned with the problem of representation in settling the realist-constructivist debate, was to demonstrate that transformations in ‘representational devices’ such as visual images, graphs, maps and equations were integral moments for explaining the social construction of science (Lynch and Woolgar. 1988). Selection features prominently amongst the practices used to render scientific knowledge by way of processes identified by Lynch and Woolgar (1988) such as filtering, uniforming,

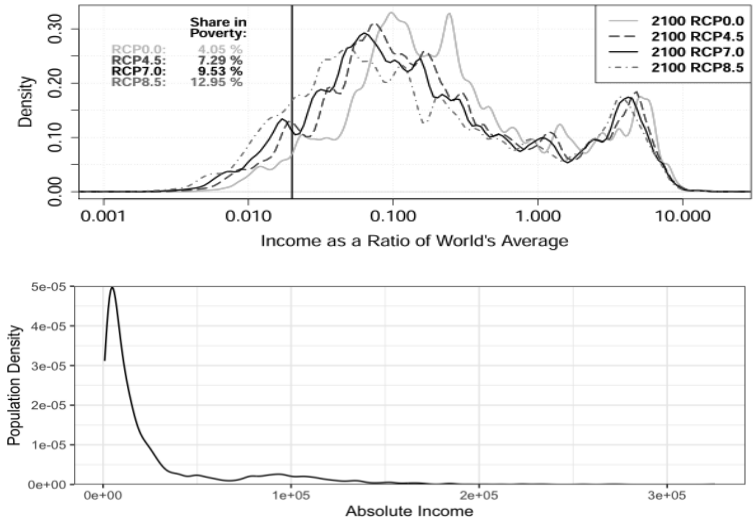

Figure 4.1 - Burzyński et al.’s graph of income distributions showcasing the effect of various warming scenarios on aggregated global income distributions (top) verses my reconstruction of their data for the current period based on

upgrading and defining.[3] One of the effects of these transformation in the infinite 'chain of references' that Latour (2000) argues link matter and form is that a trade-off is achieved between amplification of the scientific results on the one hand which produces many of the hall-marks of the scientific method, standardization, circulation and relative universality, and reduction or what is lost in terms of locality, particularity and crucially in terms of their realism.

I contend that researchers have to make up for this loss of realism by reaffirming the policy relevance of their work, not only because in the current political-economy of scientific research one has to demonstrate practical ends in order to secure funding, gain currency et cetera, but because the possibility of political intervention based on the knowledge gained is re-particularized in the justification of the research as having specific applicability outside of model-land. This is particularly evident in the Groundswell 1 and 2 reports and in the articles reporting on NYT/Propublica model. One can see how this functions in the following passage taken from one of the NYT articles titled "The Great Climate Migration" in which Lustgarten writes -

> "Our models show that much of the growth will be concentrated in the city's slumlike suburbs, places like San Marcos, where people live in thousands of ramshackle structures, many without electricity or fresh water. In these places, even before the pandemic and its fallout, good jobs were difficult to find, poverty was deepening and crime was increasing. Domestic abuse has also been rising, and declining sanitary conditions threaten more disease. As society weakens, the gangs — whose members outnumber the

[3] Hayek, writing about science in 1964 much before the major developments in the sociology of science appears to have accurately presaged this point. He wrote "The object of scientific study is never the totality of the phenomena observable at a given time and place, but always certain selected aspects... a historical process or period is never a single object of thought but becomes such only by the questions we ask about it." He criticizes overly scientistic accounts of the work of the social sciences for glossing over this necessary qualification.

> police in parts of El Salvador by an estimated three to one — extort and recruit. They have made San Salvador's murder rate one of the highest in the world.
>
> Cortez hoped to escape the violence, but she couldn't. The gangs run through her apartment block, stealing televisions and collecting protection payments. She had recently witnessed a murder inside a medical clinic where she was delivering food. The lack of security, the lack of affordable housing, the lack of child care, the lack of sustenance — all influence the evolution of complex urban systems under migratory pressure, and our model considers such stresses by incorporating data on crime, governance and health care. They are signposts for what is to come."

This passage exemplifies the journey from the internal referent which involves what the model does have epistemic authority over towards the external referent to which it gestures but cannot necessarily describe. The quote begins with a relatively sparse description of where the model predicts that population growth from in-migration will be concentrated, 'in the city's slumlike suburbs'. Leaving aside the question of whether or not the model is satisfactory for making such a prediction, what is interesting in this passage is the way in which the writers draw out the implications of this prediction by zooming in on the life of one of the migrants, Delmira de Jesús Cortez Barrera. Without making any explicit claims about the future, the vertiginous specificity of these descriptions conveys what may be at stake for those, like Cortez, caught in the mire of societal instability and environmental degradation caused by climate change. To be clear, their model includes broad estimations of the effect of instability/violence and corruption (captured in broad based indices developed by the World Bank) on migration, however these also lack the granularity of anything resembling stolen televisions and murders in clinics. My intention here is not to deny the power of serious journalism which, like the

ethnographies conducted by many climate migration scholars as a necessary antidote to overly quantitative empirical studies of the phenomena, has the capacity to tell important stories. I invoke this passage only to point out the relationship between the two worlds that the researchers erratically jump between, and how closely they need to be united for the resultant simulations to convey meaning. Without the evocations of stolen televisions, health clinic murders and lack of sustenance, the model results would have a much more difficult time standing for themselves. The last line, 'These are signposts of what is to come', is obviously reminiscent of the 'signposts to the future' from Beddington's comments in the Foresight report (discussed in Section 1), however it is noteworthy in the context of a quantitative model which relies on official censuses to represent mobility

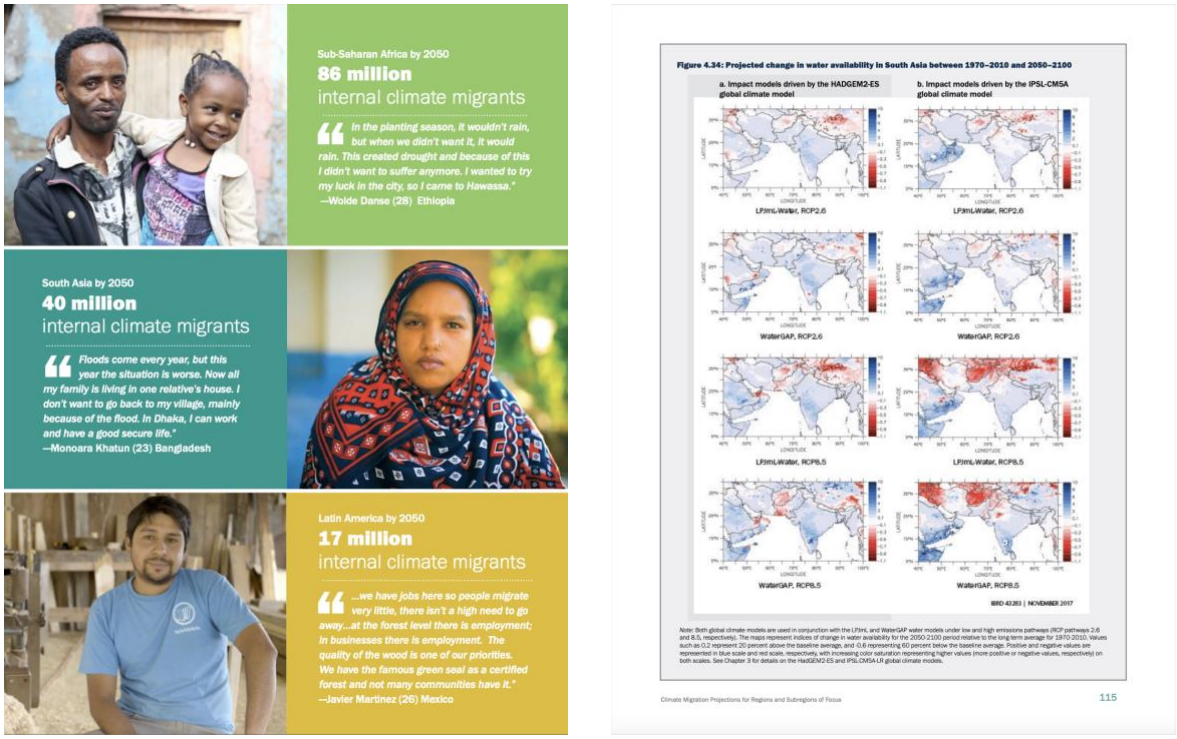

Fig 4.2 - Typical headline page (left) and typical chapter page (right) of the groundswell reports.

because such representations have a very difficult time capturing the forms of informal or undocumented migration which this description implicates.

Similarly, the World Bank's Groundswell reports are full of images, not necessarily of climate migrants, but of people living lives in the vicinities of places the models predict will be heavily impacted by climate migration, either as sources of future migration or the area to which they may be displaced. Methmann (2014) explores the effect of this imagery in constructing 'the field of visibility' of climate migration. He claims that in addition to constructing the discourse around climate migration in scholarly and public imagination, this 'field of visibility' has palpable effect of producing the very subjects that neoliberal systems of governance (in which the World Bank plays an integral role) are becoming anxious about and seek to manage. Once again, the models are linked with people 'on the ground' or 'in the field' (to use the shared language of scientists and development planners) in a way that sets the stage for political intervention, or, as Methmann claims, non-intervention in the case of climate migration.

One may (justifiably) argue against using these two examples since they rely on research works that are not part of the peer reviewed scientific literature and as such do not carry the same external obligation to be politically agnostic as the other sampled forecasts must. While I question the level of distinction granted by the scientific peer-review process given that the results of the Groundswell reports are regularly cited in peer reviewed scientific publications, this is an appropriate concern because, as Winner (2009) influentially pointed out, the political qualities of technical objects, 'artefacts' to use his terminology, depend on the institutional contexts in which they are produced and obtain their functions. However, as I note in the introduction to this section, all the

sampled works exhibit this tendency towards narrative translations. For example, Davis et al. (2018) write, “By knowing the origin and destination of migrants and accounting for the uncertainty in the number of migrants, it is possible to begin tailoring strategies that are more sensitive to cultural and social context, better accommodate the needs of the specific migrant group, and minimize conflict over limited services and resources”. And then to demonstrate the serviceability of this justification, their analysis leads them to estimate how migration will modify job, housing and food requirements in each district. This is notable because the actual calculation of these requirement does not really derive from their methods as it is just a first-degree approximation based on average consumption levels. As such, it functions exactly like the story-lining from the NYT/Propublica article and the imagery from the Groundswell report by evoking as references in the real world which are a little less plausible than the data and the simulation can accommodate. Whereas it might seem like this tendency is just a marketing trick, like a peacock’s plumage to increase the readability of the paper or to attract attention to it in the academic marketplace, it is important to be reminded that in the two-way chain of linkages, the external referent is vital for what goes on the inside of the model because these moments of plausibility become the handles of the levers which researchers reach for in designing their models’ manipulability. Researchers also must tell themselves about these stories to make sense of the world which they are attempting to construct. Without these moments, researchers would lack the material grounding to consider for themselves where the substantial interventions their forecasts are making may lie.

4.2 Four Movements in Reflexive Self-Critique

In Section 2.1, I traced the development of climate migration research from its roots in early 20th century environmental migration studies which tended to emphasize unidirectional determinism into more nuanced and multi-causal demographic, anthropological and economic research. One of the effects of this transformation is that this field has historically been informed by the many different scientific and social scientific disciplines that it has grown out of. This is evident in the selection of models I sampled which, despite their narrow quantitative focus and future orientation, represent research from many different fields. Additionally, as I also point out in Section 2.1, Myers' (1993) and Myers' (2005) 'prediction' of 200 million and 300 million climate refugees functions as an important *founding myth* for the field in that despite the tendentiousness of the claim and the criticisms it received from scholars, these numbers have percolated into the public imagination of climate change, perhaps irrevocably. However, like many origin stories, this is the story of a fall in that the whole field appears tainted by the prediction as the minimalist reaction to Myers has demonstrated. This is definitely true of the forecasts that I have sampled which, despite being developed more than two decades after Myers' predictions, almost ubiquitously reference them, and always in a negative way. Given this contingent history, and the infusion of diverse disciplines in the field, I argue that climate migration forecasters have developed a *reflexive reflex* when it comes to their own research in that they are always already responding to forms of criticism which they are aware of. Although a certain degree of self-skepticism is encouraged in the workings of 'normal science', the reflexivity exhibited in much of the research I sample extends a little bit into forms of epistemic

doubt that are particular to it in that they stem from this contingent history and exhibit a responsiveness to minimalist concerns voiced loudly by many others who study climate change and migration (Jakobeit and Methmann. 2012, Beyer et al. 2023).[4]

Lynch and Woolgar (1988), distinguish between two types of reflexivity apparent in science, a first type that is internal to 'the settings in which it is constituted' and a second usage which accepts first and foremost the insufficiency of the first kind of reflexivity in addressing 'deficiencies' and furthermore understands that any criticism

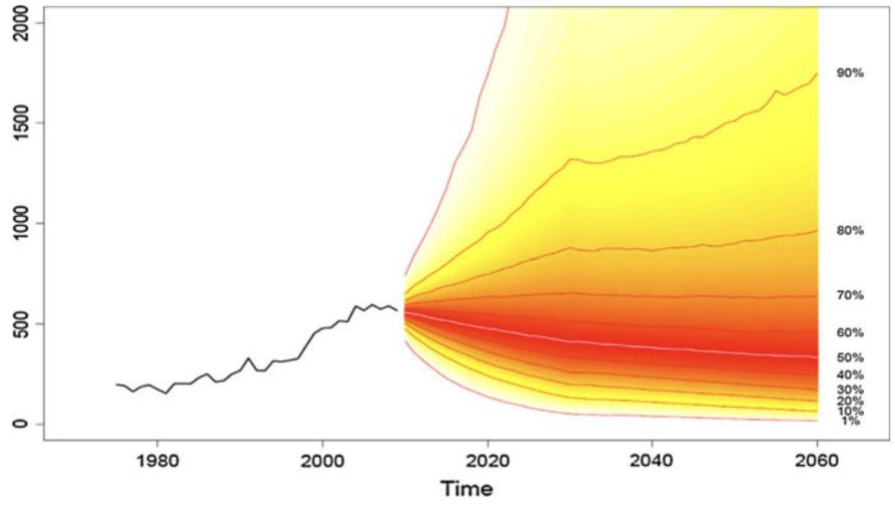

Fig 4.3 - This graph from Abel et al (2013) is clear representation of the level of uncertainty in forecasting future migration. Depending on how one squints, it might look like migration will explode dramatically, reduce or stay the same over the next forty years.

[4] It should be noted that a comprehensive like-to-like comparison of the degree of reflexivity displayed in climate migration forecast literature relative to other socioeconomic forecasting literature is beyond the scope of this paper. As a result I do not make any claims that the orientation I am describing is totally *unique* to this field. My claim of particularity is based mostly on the 'founding myth' of the field which creates a contingent set of external circumstances which climate migration researchers must constantly respond to. I also suggest that the sheer number of academic disciplines that climate migration research unites within its program adds a critical capacity to the research because scientists are required to consistently step outside their disciplinary niches. This effect is explored more in the next section.

(including self-criticism) of representations suffer from the same problems since they are representations of representations which cannot really be transcended in traditional academic discourse. Instances of this reflexivity can be found in statements they make qualifying the scope of their claims like this one from Benveniste et al (2021) made at the outset of their paper, "our aim for developing projections of various SSP components for zero migration is not to provide realistic forecasts of future developments, but rather to offer quantifications of migration consistent with the qualitative storyline for each SSP".[5] Likewise, scientists in all of the samples were quick to note the limitations of their models stressing that the models are internally consistent given their assumptions and the idealized relationships between the phenomena which they are modeling. But, as the quote demonstrates, this is not meant to act as a prediction of future migration. Abel at al. 2013 presents us with a highly interesting case of this self-consciousness amongst the researchers by making reflexivity the objective of their forecasting exercise to reveal the lack agreement amongst experts about what the future of climate migration will look like. They accomplish this through a modeling approach that solicits expert opinion (guesses of the rough trajectory of future migration as well as their subjective certainty in the guesses) to inform the posterior distribution of model parameters used to forecast migration. Their model is effectively 'trained' on expert opinion and as they note in their paper, the Bayesian basis of their forecast is ideal for revealing uncertainty in the prior estimations of how immigration to the United Kingdom will develop. The fan in Figure

[5] SSPs (Shared Socioeconomic Pathways) refer to the storylines that form the basis of our dominant socioeconomic projections of climate change. While they are not the only modeling framework available, they are the ones directly used by the IPCC and are therefore popular in much of the scientific literature on climate change. These storylines represent a scenario approach to dealing with fundamental uncertainties about the future.

4.3 is meant to capture the probability distribution for the evolution of immigration rates and speaks to the sheer diversity in opinion amongst the experts they sampled. This is the only model which is completely agnostic towards real world processes. Instead, it assumes that those it solicits from are not and and have mechanisms in mind tied to some kind of analysis underpinning their estimates and the confidence they assign them. What this yields is a graph in which it looks like migration will increase, decrease and stay the same simultaneously over time.[6]

Similarly, Ken Caldeira, one of the main authors of Chen and Caldeira (2020), penned an extensive blogpost in anticipation of possible push-back from migration specialists defending their use of simplifying assumptions for understanding complex socioeconomic phenomena. To do so he invoked the classic metaphor, by now a modern fable, of a 'spherical cow' invented by a physicist tasked with streamlining milk production. It is a classic example used to illustrate the importance of reduction in scientific analysis. There have, of course, been many appropriate criticisms of reductive attitudes in modeling socioeconomic systems. Many object to the mechanistic determinism inherent in these models for for their unwieldy emphasis on causal explanations, which cannot really be empirically assigned. This is the basis of the minimalist criticism of Myers, for example. Moreover, because of the stochasticity of the causal interactions caused by the uneven distribution of people around the world and the chaotic nature of environmental disturbances which do not follow any causally estimable

[6] For the sake of context, it should also be noted that Guy J. Abel is very prominent figure in the demographic modelling world of climate change. Many of the calculations of bilateral migration rates used in the other models are attributable to him.

trajectory, it is impossible to clarify any 'norm of reaction'[7]. When these interacting forces play out temporally, when the element of change is added to the chain of causation, then the objects to which external forces apply take on an active subjective role in comprehending, adapting to and actually altering the environment. Thus, as I noted in the previous section, any model which seeks to help people understand climate change simultaneously seeks to help people adapt and react to it. If so, how can these models account for their own effects?

Because this is not a paper on scientific epistemology or the philosophy of science, I will stay away from analyzing whether or to what extent the scientists provide adequate or 'correct' responses to the challenges summarized above[8]. Instead, I will note that all of these criticism are well known, well founded and explicitly acknowledged by all the researchers sampled. In one sense, Jakobeit and Methmann (2012) appear somewhat belated in issuing their corrective to modelers who they argue are still predisposed towards maximalists depictions of climate change because as Piguet (2010) documented, the main interests of climate modelers shifted from producing estimates of the magnitude of future migration, a goal which had become 'little more than a dream', towards investigating the role of the environment as one driver amongst other displacement factors. Modelers believe in the context dependence and specificity of their

[7] The 'norm of reaction' is the biological concept Levins and Lewontin use to describe distributions phenotypic variation that accounts for differences in genes as well as environmental differences. I am extending that usage here away from the purely biological meaning to connote any kind of discernible reaction (phenotype) to multiple intersecting material processes and historical structures (environment + genotype). It is just another way to problematize empirical determinism.

[8] This is in keeping with the 'symmetry principal' of the strong program in the sociology of science which states that the same explanations may apply to 'true' and 'false' scientific theories and should therefore be treated the same way (Barnes et al.1996).

claims and like Caldeira and Benveniste (quoted above) do not offer their forecasts as reliable predictions of the future. However the salient object of Jakobeit and Methmann's critique is still relevant in the context of more updated modes of analysis because their more substantive warning is against 'the dominant quest for numbers'. In one sense they are united with Piguet in advocating for increasing the focus on context specific causal mechanisms over global predictions. However, they are skeptical of the inclination of social scientists to reveal 'law-like explanations in the style of natural sciences'. The spherical cow analogy is meant to suggest that the simplifications assumed by the model carry *something durable* across the gap that separates the real world from model fictions.

Given that the starting point of any climate migration research has to be the fundamental intractability of predicting future migration, what is more interesting from the point of view of this thesis is exploring the disparate ways that researchers understand what parts of their model are durable and correspondingly respond to the problem thus advanced. Sismondo (1999) characterizes simulations as located somewhere between theory and material objects, 'pointing in both directions.' In this description, he is responding to an influential appraisal of scientific models by Redhead (1980) as either simplifying theories by substituting tractable forms and equations for intractable ones or as enriching theory by adding layers of complexity to its bones. Here, I identify four overlapping approaches used to navigate the intractability posed above with an illustrative example for each approach from the sampled literature as well as a discussion of how they are treated reflexively. The relationship between each of these approaches is an overlapping progression from a more predictive function to a more experimental function. Each identified approach is a necessary but not sufficient prerequisite for what

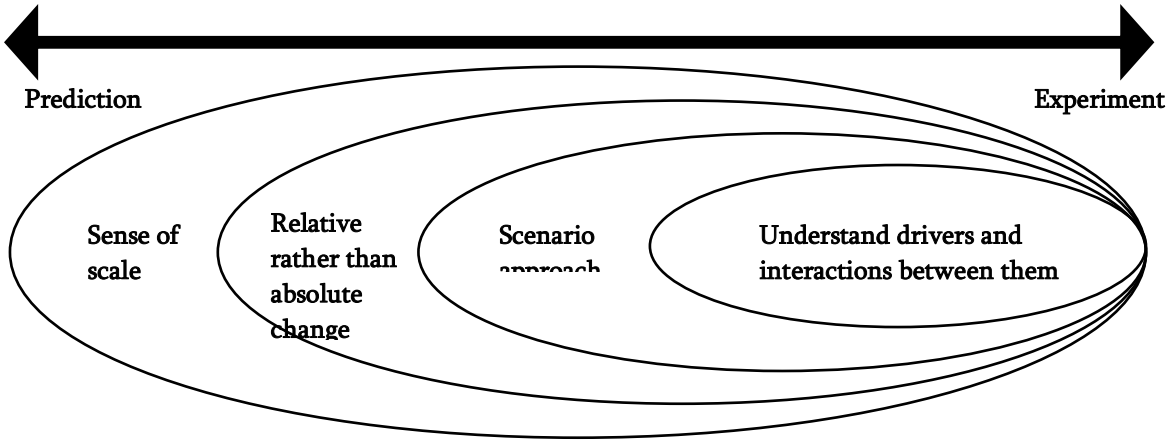

Fig 4.4 - General scheme of overlapping reflexive approaches demonstrated in the climate migration forecasts.

comes after in the order in which I have presented them. Figure 4.4 clarifies this relationship schematically. The dichotomy presented here makes use of the findings of Dowling (1999) that simulations can act simultaneously, either as representations in that they are constructed to function autonomously (Morrison. 1999) or as experiments to be tweaked, manipulated and used to test things. The intractability problem enforces a natural limit on how much of the world can be realistically represented by the simulations (i.e.. predicted) and therefore the more durable and useful parts of models must tend towards the experimental.

Each step in this construction is outlined as follows:

1) Sense of scale

In response to the problem of the spherical cow, Caldeira writes, 'Therefore, we make no claims to predict future migration flows, but rather ask the question: "If climate were the only factor operating, how many people would we predict would want to migrate?" This might be some sort of strong upper bound on maximum likely migration flows.' This quote leads us in the direction of the first approach evident in *the sense of the*

scale of the problem discernible by his reductive approach, which is thought to be sufficiently informative of the phenomenon to justify the modeling exercise. In Chen and Caldeira (2020), scale is conveyed by the proposition that climate change might provide people with an 'additional incentive to migrate' and that such an incentive can be derived from the historical relationship between local climates and population extrapolated into a future where these climates are changing. However, they decline to address whether or not this incentive corresponds with actual migration since doing so would exceed the knowledge limits imposed by their methodological choices. In some ways this is another instantiation of the maximalist tendency which describes migration in terms of a small number of environmental drivers (See Table 3.1). However, by emphasizing that their results are not a prediction of actual migration, appealing to scale in this way (the number of people who *may* be affected but are not necessarily) leaves open the possibility of other stronger drivers and intervening forces in people's desires to migrate. This approach, then, exhibits a *weak maximalism* that is still present in every quantitative forecast of future migration which is a relic of and response to *strong maximalism* since the latter has succeeded in making the question of scale and the uncertainties therein a pervasive part of our thinking about climate migration.

The question of scale makes sense in the context of wider concerns about the effects of climate change from states seeking to protect economic bottom lines since they indicate the rough degree to which climate change induced migration will alter the conditions of habitability for society and therefore needs to be taken into active consideration. Such an assessment is fundamental to cost-benefit accounting which is the basis of the neoliberal response to the governance questions raised by the importance of

sustaining capital markets and the corporations which drive them in the face of climate change. The political economy of damages, either caused by the cost of mitigating climate change or those imposed by failing to do so, is, therefore a foremost motivation in the sociotechnical construction of climate migration and the inclusion of climate migration in this consideration is a simple function of the sense of scale of the problem that these models can convey.

2) Relative rather than absolute change

However, this sense of scale suffers in informational richness because it is ultimately a dull instrument. Having produced their results, scientists are obviously inclined to investigate what they mean and how they may be further decomposed in the temporal, spatial and societal differences and departures which their models account for. This leads them towards the second reflexive approach in which relative changes are considered to have more power than absolute change. This is because expressing figures relative to other figures often conveys far more meaning than just reporting factual absolute. An intuitive example of this is how curving or ranking grades is common practice in most classrooms precisely because it provides relative comparability - without such a basis for comparison a lonely number means almost nothing. Additionally, some researchers actively opt not to use absolute projections at all in order to avoid a false sense of certainty. For example, all the projections in Smirnov et al. (2022) are expressed in relative rather than absolute terms. They justify this choice by showing how the ratio of annual migration given different modeling scenarios (degrees of warming, and temporal periods) exhibits relatively little variation with different coefficient values for

maximum migration probabilities (MMP). Whereas the absolute number of migrants varies significantly across model runs within the same range of MMP values. They use this analysis to conclude that, absent a robust estimate of the real MMP values, absolute values can result in misleading estimates of the effect of climate change on migration. Instead, they present all of their findings in terms of the relative change in the number of annual migrants between end century, midcentury and the present and the relative difference in these projections between different warming scenarios and using climate models from across the ensemble. Even when absolute values are made explicit as in Burzyński et al. 2022, Groundswell 1 & 2, the NYT/Propublica report and Davis et al. (2018), they are usually presented in tables which include results from multiple model runs in a way that encourages relative comparisons which are also taken up in the discussion sections of the supporting literature as the main mode of interpreting the results.[9]

Relative predictions allow for the research to maintain relevancy because it holds on to a certain descriptive capacity 'for exploring 'possible futures and comparing the differences between them. They are also used to capture differences between spatial zones as in the case of 'hotspot' predictions in order to understand the parts of the world where climate effects might be concentrated. In both the temporal and the spatial sense, they add an extra dimension of skill to the sense of scale described above by explicating

[9] It is interesting to note that in the Groundswell reports, this kind of presentation is par for the course in the main body of the report, whereas the headline figures reported in bold early on in each chapter tend to feature absolute predictions without much hint of uncertainty. In doing so, the reports unite the maximalist and minimalist impulse in a way that can be disorienting for someone trying to understand how they fit together since the headline figures are not easily traced to results in the report.

differences which do not function as absolute predictions. While Smirnov et al. 2022 and Benveniste et al. 2020 and 2022 restrict themselves to expressing their results in relative terms, relative changes from *baseline scenarios* are a significant part of the counterfactual construction of climate migration in all the samples except Abel et al. (2013).

3) Scenario approach

Since modeling counterfactuals is the dominant method for causal inference in the quantitative social sciences, all the samples except Abel et al. (2013) rely on building these counterfactuals to compare different climatic and socioeconomic futures. This scenario approach is absolutely fundamental across many kinds of climate change research since it is an effective way to account for uncertainty in future development trajectories. Constructing scenarios is powerful because it allows researchers to construct plausible futures, as in elaborate 'what-ifs?', while remaining agnostic toward how likely they any of them is to actually transpire. Moreover, scenarios are often constructed specifically as responses to policy concerns in order to give insight into the effects of policy interventions. In this sense, they are an integral aspect of the narrative justification explored in the previous section in that they are what give the models manipulability with respect to planning and action. Thus, modelers engage in a form of proactive speculative world-building which has attracted comparisons with how the imagination functions in fiction and the creative faculties that need to be employed in order to keep the scenarios believable (Van Beek and Versteg. 2023) as well as criticisms for not being responsive

enough to the true range of possible futures (Lenzen et al. 2022, Kanitkar at al. 2024, Hicket et al. 2021).

This is evident in the Groundswell reports which present three possible socioeconomic scenarios, (1) a pessimistic reference scenario with high emissions and unequal development, (2) a more inclusive development scenarios with high emissions and moderate development, and (3) a more climate friendly scenario with low emissions and unequal development. These three possibilities circumscribe the range of possible futures quite narrowly, notably by omitting the possibility of an optimistic scenario with low emissions and high levels of development. However, these scenarios are themselves borrowed from the IPCCs scenario framework which includes five Shared Socioeconomic Pathways (SSPs) meant to represent socioeconomic developments until 2100 and seven Representative Concentration Pathways (RCPs) to cover future greenhouse gas concentrations. Each of these are also statistical aggregations (harmonizations) of multiple different IAMs, each with its own methodological basis and assumptions. The SSPs and the RCPs together represent our best effort to grasp the two axes of change as 'parallel processes' (Riahi et al. 2017), but linking them dynamically has so-far proved to be a challenging task. This speaks to an inherent limitation of the scenario approach which is that while they are designed to explore distinct future pathways, these pathways are unable to recursively account for themselves as part of the changes which may beget more change. As a result, they are necessarily confined to overly simplistic interpretations of historical processes, applied uniformly across regions. For example, the SSP storylines unfold over the course of the twenty first century inexorably and uniformly without any of the impossible to predict, yet dramatic,

reconfigurations that characterized the twentieth century. Moreover, the construction of these scenarios cannot possibly be value neutral process because it relies on how researchers 'backstage' of the idealized scientific process imagine society is meant to function and will evolve. The backstage elements of this process have been criticized because this is the step in modeling where the intrusions of social phenomena are most easily evident (Pielke Jr. and Ritchie. 2021). Whether or not one agrees with Pielke and Ritchie (2021) that this constitutes a situation of 'misuse and abuse', it is difficult not to notice that building scenarios empties the forecasts of some of their autonomy, making them more than accidentally acquiescent to the values and wishes of their creators. Hulme (2011) suggests that selecting scenarios is the crucial stage in impact assessment for creating the future, short-circuited from the outset by uninterrogated ideologies and values.

4) Understand drivers and interactions between them

As a reminder, in Section 4.1, I described the necessity of narrative justification for situating the work that climate migration forecasts are attempting to do. I also clarified that this justification has two potential valances, one related to the actual policies which the models might or hope to influence and the other related to discursive techniques for bringing the models to life and to bear on forms of life that they are investigating. However, even with this justification, it is difficult to see where the levers come from which make it possible for the researchers to 'raise the world' (Latour. 1983). Latour famously found this lever in the microcosmos of the laboratory or rather in its walls which, for him, are the physical negation of the boundary line between science and

society. I have already pointed out how models lose some of their independence from scenario building. However, as in laboratories, where subjects can be made to do things by researchers investigating their properties, the models may be turned into their own experimental sites with very different physical specifications than libraries, but many of the same properties. This should not be a controversial comparison. Indeed, 'experiment' is the term-of-art used by climate modelers to refer to model-runs with different idealized assumptions in order to understand how earth systems will react under varying conditions.

But to put a finer point on it, consider Burzyński et al. (2022) who construct three social/policy scenarios (in addition to RCP emissions scenarios). They use two border scenarios (more open and closed) and one scenario in which resource scarcity (modeled endogenously) causes conflict and resultant income losses. According to the More Open Borders (MOB) scenario, worldwide easing of border crossing restrictions are assumed to result in a doubling of the ratio of international migrants to stayers, which then impacts actual migration as a function in a new equilibrium of wage rates and congestion costs. Conversely the Closing All Borders (CAB) scenario imagines a world in which all international migration is summarily restricted resulting in zero cross-border movement. And in the Conflict (CON) scenario, countries which experience more than a ten percent increase in the price of consumer goods are expected to have conflict resulting in GDP losses of twenty percent in the ten most afflicted countries and ten percent in the next ten most afflicted. The reason I have chosen to spell out descriptions of each of the scenarios is that these one line descriptions I have provided encompass the total complexity of each of the scenarios respectively. Yes, they are thrust within a much more complex

simulation, but the trajectories being considered are, in many ways, blindingly simple. One need not argue that there is no possible world in which all nations multilaterally close their borders - that is an evident impossibility. It is clear therefore, that these scenario explorations have no possible predictive power at all.

Stengers (2015) found a similar situation amongst physicists during the cold-war, who, faced with the prospect of mutually assured destruction, developed highly simplified models of worst case scenarios. The point of building these models according to Stengers 'was no longer the classical one, that of "the power science gave to humanity". The point was the *creation* of a knowledge the very sense of which was its relevance for – or intrusive interference with – political matters.' The breakage she is pointing to here lies in the enlisting of non-facts – the basis of these highly simplistic scenarios whose claims were entirely beyond any empirical proofs – into the scientific service like soldiers in a desperate situation of potential nuclear war which Stengers explicitly compares with the current moment of climate change. The construction of what-ifs in this cased served not to show what could plausibly come to pass, but rather to give texture to an imagination of what could not possibly be allowed to happen. While the scenarios constructed in the forecasts spotlighted here of climate migration contain nothing as dramatic as nuclear winter, it is in uncovering knowledge of perhaps real relationships between social forces in a world that emphatically will not come to be (except artificially) that what we have is an experimental situation, a controlled environment of which the equations are the blueprint and the code the hardware of an experimental apparatus. At this point, there is no longer a pretense of interest in describing what the future will look like (which is how we are meant to understand

forecasts) but rather an active interest in clarifying present relationships according to what Parker (2020) calls the forms of ‘higher-order evidence’ available from computer simulations that can only play out in time and in the future; hence a forecasting approach is called for.

What kinds of relationships are clarified? What kind of evidence is this? There are currently many empirical studies which attempt to characterize the effects of particular environmental drivers of migration to ‘disentangle the environmental impact from other migration drivers.’ (Piguet. 2010) This style of empirical analysis is well outlined in Piguet (2010) and Carleton and Hsiang (2014). It is also not specific to climate induced displacement. Carleton and Hsiang consider the empirical approach to be a powerful tool in approaching a range of social and economic impacts of climate from the effect of global warming on energy demand to the relationship between precipitation and migration. By modeling the correlations of variations in weather with societal effects like migration, crop yield, GDP loss, profanity in social media posts or mortality, they attempt to describe a ‘damage function ’which captures the distribution of societal changes for a particular range of climatic conditions (Carleton and Hsiang. 2016). The results of these studies tend to focus on micro level changes (household to subnational level) and tend to be very context specific. Although the scale of this kind of model is only really limited by the availability of consistently comparable information. There are cases in which it has been applied at the global scale. However, these relationships, when isolated empirically, are taken from the contexts in which they are discovered. Reapplying them is tricky business because of how much variability there is in geographical and socioeconomic conditions worldwide. The same set of measured variables have been shown to have

orthogonal responses to the same drivers in different areas. The limits of intercomparability herein lead researchers away from descriptive quantifications towards the more prospective models I have sampled.

Benveniste et al. (2020) combines three different types of scenarios in their modeling approach. They make use of the SSP and the RCP framework, linking five scenarios between them (five SSPs and five RCPs) which are conceived of as complementary to one another; they are technically united into one composite set of climate scenarios. In addition to the SSP-RCP climate scenarios, they include four border policy scenarios which they develop. Without explicating each of these border policy scenarios, suffice it to note that as in Burzyński et al (2022), they are total idealizations with no plausibility. Moreover, some of the border policy/climate scenario combinations are strictly incompatible with one another. For example, SSP1 is specifically conceived of as being a scenario with high levels of international cooperation – all the internal assumptions are based off that narrative, so using SSP1 in concert with a closed border migration scenario is a forced marriage. The point of their research is to understand how different border policy regimes affect people's vulnerability and exposure to the effects of climate change. Figure 4.5 consists of graphs taken from Benveniste et al. (2020) summarizing some of their results. It shows how the model expects CO_2 emissions and temperature to change under different combinations of border policy scenarios and

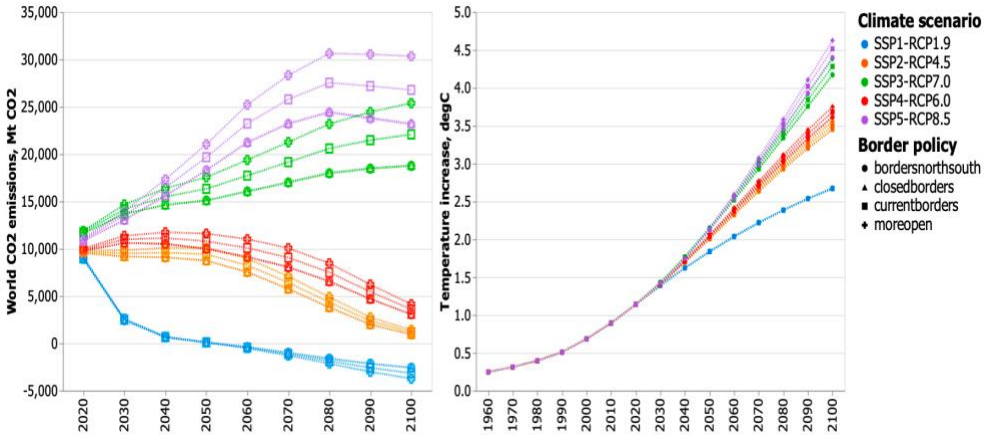

Fig 4.5 - Graphs showing results from Benveniste et al. (2020).

climate scenarios. It is clear from how colors representing climate scenarios are clustered together that most of the variability in these emissions and warming is caused by the choice of climate scenario while the choice of border policy scenario creates relatively minor variations within the given climate regime. In this case, the scenario approach is used for both prediction and experimentation simultaneously. 'Plausible worlds' represented by the climate scenarios are used to explore uncertainty in future trajectories which will proceed (unfortunately) more or less autonomously. Conversely, border policy scenarios represent more constrained representing more conscious forms of potential 'interventions' whose effects Benveniste et al. (2020) are attempting to ascertain. Moreover, these effects do not necessarily play out in a big way on the first order climate effects on migration that Benveniste et al. (2020) are investigating. Instead, the border policy scenarios are used to understand the relationships between drivers on a second order level such as remittance flows and carbon emissions.

This experimental function is the final way in which these forecasts reflexively side-step their criticism. They do this by effectively ceasing to be forecasts at all. Of

course, this move should not be taken for granted either as a pretextual default or as an accidental effect of the forecasting project. This is to say that, firstly, the somewhat spectacular aim of forecasting future migration is not just a convenient smokescreen for more sublunary and ultimately scholastic ends. Many of the models retain their predictions as legitimate for planning purposes under uncertain circumstances. Equally, this shouldn't be seen as a case of an outside observer of science perverting an innocent scientific project by reading more meaning into than properly belongs. In fact, as I have stressed, this form of reflexivity is more than available to everyone in the field and all I can say I have accomplished so far is typologizing it, giving it a shape and attaching significance to the discovery in a way that has bearing for what follows[10] from the observation of the performative contradiction introduced earlier. This is the fact that in the course of the cycle between the first movement and the second movement, pointing in both directions at once gives the researchers space to go on the reflexive journey I have described above. The scenario approach is emblematic of this since scenarios can occupy both predictive and experimental roles at the same time and both are justified without a clear sense of the differentiation between them. Ambiguity is of the greatest importance here. The emptiness at the center is like the hollow eye of a storm gathering and organizing powerful currents to fill up (and continue to fail to do so) a vacuous center.

[10] It is possible that I am opening myself up to the most common criticism of the field of science studies which is that everything we discover or claim to reveal about the inner workings of science is well known to practitioners and therefore trivial knowledge dressed up.

CHAPTER 5
CONCLUSION

Nevertheless, these currents are proof of presence rather than unrequited absence because the stuff swirling around the performative contradiction are very real political concerns, ecological questions and problems of planning and governance. Simulations like these are endlessly interesting from the perspective of STS because they exist on the border of many different object classifications simultaneously. They are technological artefacts at the same time as they are inscriptions, experimental sites – immaterial centers of calculation to use Latour's (1987) designation - as well as theories. This being the case, STS begs us to pay extra attention to the diverse materiality of these virtual laboratories where information is being processed and experimented upon. I am certain that a few more theses could be written on advances and limits to computing power, the assembly of technical skill required to build simulations (construct the instruments to use older terminology), the political economy of access to these computing sites and the knowledge required to use them, and more. However, I will conclude this thesis by drawing attention to the material that circulates virtually (immaterially) amongst the bricolage of models which helps to construct climate migration as a scientifically graspable phenomenon and therefore purports to help govern it.

Lynch and Woolgar (1987), drawing on Levi-Strauss (1962) and Garfinkel et al. (1981) identified bricolage with the creative work that scientists do to construct their representations in an improvisational fashion from 'a mixed bag of tools' at hand. This figure of the scientist-as-bricoleur is posed against that of the scientist-as-engineer who adheres to a strict blueprint in designing a study. Instead, bricolage is characterized as the

creative tinkering necessary to make experiments work. The concept was taken up by McKenzie (2003) in the context of the development of the Black-Scholes model for options pricing to demonstrate its applicability to more immaterial forms of scientific work than constructing laboratory experiments. One of the achievements of this piece is that it convincingly demonstrates how science gains from a disunity of competing practices common to the study of socioeconomic systems. This disunity stands in subtle contrast with Kuhn's (1970) study of scientific paradigms based mostly on the state of the physical sciences in the 20th wherein the 'constellation of beliefs, values, techniques, and so on' could be said to be 'shared by members of a given [scientific] community'.

Here, I recall the pluralization of performativity touched on in Section 2.1 wherein models structure relationships between actors in a competing epistemic terrain. Even within the narrow space of my sample, there is already evidence of this taking place. For example, the NTY/Propublica model is a derived and expanded version of the Groundswell model which found its narrative justification – and therefore the extra set of internal referents – in telling the kinds of stories American audiences (like the average New York Time's subscriber) were looking to learn about based on their concerns, the confluence of migration at the southern border and climate change. Another case of this is the relationship between Davis et al.'s (2018) non-parametric radiation model, specifically conceived of as a response to the gravity model of migration common in demographic geography. Whereas the call and response dynamics are par for the course in most scientific disciplines where models and dissenting laboratories compete with one another to assert competing theories against one another, Davis et al.'s (2018) offer the radiation model as a way, not to correct for an analytical flaw of the gravity model (in

fact one could say that the radiation model is a step away in terms of realism), but rather to make up for its data-intensity which renders the gravity model less applicable in certain settings. Where the NYT/Propublica model extends the complexity and data-intensity of the original gravity model, Davis et al. (2018) go in the other direction. Both moves still speak to the 'governmentability paradigm' which Braun (2014) claims is tied to the performative potential of models and makes them matter, however the way they enable governmentability is vastly different and applicable in different social contexts.

Zooming out a little bit to a slightly wider constellation consisting of socioeconomic models of the impacts of climate change more generally, one finds a highly promiscuous landscape with outputs, inputs, assumptions and theories circulating somewhat freely in ways that really suggest how opportunistic this kind of research is. This opportunism is expressed, for example, in Benveniste et al.'s (2020 & 2022) choice to ground their model in the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) IAM developed by Richard Tol and David Anthoff. According to Benveniste et al. (2020), this choice was based mainly on the fact that FUND is the only IAM which includes migration 'somewhat more explicitly' as a variable in its damage function. The thing to note here is that their justification for choosing FUND from amongst the dozens of other available IAMs which predict economic impacts from climate change was not based on a fundamental agreement with FUND theory or precepts of modelling, but rather the coincidence of outputs and inputs which allowed for a more streamlined modelling practice.[11] In many cases like this, such as when outputs from

[11] It should be noted that the FUND model has been specifically criticized by Ackerman and Munitz (2016) for optimistic assumptions about carbon fertilization in agriculture and the extent of adaptation which results in relatively low damage estimates. My intention in citing

biophysical models are imported into socioeconomic models, researchers likely lack the expertise to properly evaluate the models whose outputs they are using.

This kind of translation which arises out of the material compatibility of models is interesting given the movement from a predictive function towards experimentation I described in the previous section. Prediction – even expressed probabilistically as is often the case – is a display which carries the brave posture of finality (as in a closed loop). This is the basis of criticism of those like Hulme (2011) who are anxious about climate reductive storylines 'emasculating the future of much of its social, cultural or political dynamism.' In contrast, experimenting is an open program for multiplying collaborations and transformations without the concern for settling any questions once and for all i.e. ending the controversy. Here is a curious case of alignment between scientists like the ones I have sampled and STS scholar like myself where it appears that we are both invested in keeping the controversy open for the sake of learning because if Benveniste et al. (2020) (or any of the other forecasts in the sample) were content with simply trying to predict, then their analysis would fall flat on its face for making 'unrealistic' assumptions which evacuate human agency from the field. What makes the laboratory setting so fertile for science is precisely the active and continuous manipulation that takes place within. I argue that this plurality of simulations helps to generalize and mobilize the laboratory condition to the extent that it is difficult to say where and when they begin and end. A simple instance of this is available in Figure 4.1 where my altered reconstruction of the Burzyński et al. (2022) model outputs was only made possible because all their datasets

this disagreement is not at all to inveigh against the model or its assumption but to point out the significance of this kind of choice which would have demonstrable impacts on any derivative models and their downstream predictions.

and all their code sits in open access repository hosted by the Harvard Dataverse. The benefits (and drawbacks) of making code and data openly available are of course well understood in the scientific community which is currently pushing for this to be the norm. Moreover, the existence of consortiums of modelers such as the Integrated Assessment Modelling Consortium (IAMC) speaks to active attempts within the scientific community to operationalize this diffusion of translations.

I speculate that an interesting and unforeseen effect of what is taking place is that researchers may progressively be losing control of their creations as they enter networks of scientific practices that exceed the capacity of any single actor or institution to apprehend since these networks are drawing together many hitherto unalloyed disciplines. There is a thermodynamic effect at play here where this diffusion seems to be proceeding inexorably in the entropic direction towards a certain epistemic anarchy that no amount of heroic interdisciplinarity can truly hope to order and unite. Evidence of this chaos can be found in the rapid growth and increased importance assigned to the Intergovernmental Panel on Climate Change (IPCC), a scientific consortium completely unique in size and scope. However, despite the historic size of its most recent Assessment Report (AR6) encompassing '2500+ scientific expert reviewers; 800+ contributing authors; and 450+ lead authors; from 130+ countries; 6 years work; 4 volumes; 1 report." (Hulme and De Pryck. 2022), not to mention the thousands of scientific papers cited in the report and the policy makers who ratify it, many researchers still believe that this body is not up to the task of representing the scale of complexity we face in dealing with climate change. This kind of development is problematic for many because it implies the basic impossibility of technical governance in facing many of our current challenges.

One can and should sympathize with the hypothetical Bangladeshi civil servant whose frustration I invoked in the introduction for whom this diffusion would likely come across as a hopeless situation casting uncertainty on the expectation that 'science in the era of prediction' (Jasanoff. 2020) will transform politics by bringing a whole new class of objects into the realm of technocratic governance. Certainly, I admit that nothing I have argued in this thesis frees her from her dilemma or the weight of responsibility she faces making her decision in the current configuration of knowledge and action. However, perhaps what is finally being freed, at least in this telling of the story, is a scientific discipline that can no longer dimly be treated as an absolute backstop to reality. Instead, science in this register will have to 'think in the minor key' (Stengers. 2005) in horizontal associations, collaborations and competitions which actively resist the foreclosures that many are warning about.

APPENDIX: EXAMPLES OF NOTES

S1 – Table showing how different models consider different factors. A good way to visualize how complicated models are relative to one another

Factors	Benveniste et al (2020, 2022)	Burzynski (2022)	Chen and Caldeira	Abel et al. 2013	Smirnov et al. 2022	Groundswell 1 & 2	Davis 2018	NYT/Propublica
Climatic Drivers								
Temperature								
Precipitation								
Sea Level Rise								
Sudden Onset Disasters								
Impacts								
Agriculture								
Manufacturing								
Productivity								
Mortality								
Conflict								
Adaptation								
Crime								
Damages								
Non-climatic influences								
Wealth								
Resource availability								
Urbanization								
Education								
Geopolitics								
Conflict								
Economic/labor migration								
Distance								
Population								
Development								
Migration cost								
Culture (language, colonial history)								
Geographic factors								
International Trade								

S2 – Example of notes made about assumptions, inputs and outputs for one of the models

Model	Burzynski (2022)
Summary	They forecast migration using a Random Utility Maximization model which accounts for heterogenous impacts of climate change on production in economic sectors .
Notable Theories/Assumptions	• Constant Elasticity of Substitution • Quadratic 'inverted u-shaped relation' between temp and total faction productivity. • Linearity assumption in climate impacts - Additionally calibration of model is based on the historical relationship between climate drivers and productivity metrics in agricultural and manufacturing sectors. • High income countries are able to reduce productivity losses by 75% whereas no adaptation in developing countries • Only adults 30-60 migrate in response to climate change. • Income is assumed to be proportional with GDP • College education is used as a binary proxy for skill level. • Constant elasticity of substitution between skilled and unskilled workers • Technology increases the relative productivity of skilled workers over unskilled workers • Homothetic CES preferences over consuming agricultural and manufacturing goods. • Utility of migration decision determined by (i) wage attainable in destination, (ii) cost of moving, (iii) congestion externality caused by increasing population • 2 skill levels, 2 types of goods to capture 'heterogeneity' in migration decisions • More open borders scenario 'doubles the ratio of international migrant to stayers' - • Only scenario are ones in which borders are either unilaterally relaxed or tightened, whereas border responses tend to be reactive to increased migration pressure in reality. • CC induced conflict only in countries where agricultural prices goes up by 10% relative to no CC scenario • All citizen affected equally by conflict and only apparent in drop in income - 20% in top-10 conflict afflicted countries and 10% in 11-20. • Disregarding international trade
Key Inputs	• Averaged monthly values of max temp predictions from eight climate models for each RCP scenario • Population and age structure by pixel from WorldPop.org • distribution of education by pixel from the Institute for Health Metrics and Evaluation • Urbanization of pixels from WorldPop.org • the pixel-specific GDP estimates from Kummu, Taka, and Guillaume • fertility projections from the UN Population Division, • education wage gaps from Global Jobs Indicators Database (JoIn) by the World Bank • GDP levels and shares of agriculture in consumption and PPP rates from the World Bank • shares of HS population from Barro and Lee • international migration data by skill level from the OECD DIOC-E database • country- specific regional migration stocks by education levels are constructed using census data (IPUMS International), the WorldPop.org data (Sorichetta et al. 2016), and the Labor Force Survey data by Eurostat
Key Outputs	• Effect of climate change on GDP, population, skill share, urbanization and emigration share • Numbers of climate migrants over the 21st century aggregated at different spatial scales including migration paths with low skilled and high skilled migrants disambiguated. • Effect of climate change on the distribution of income as well as the effect of border policy within different climate regimes • Relationship between CC induced resource scarcity and conflicts and resultant effect on migration, GDP, skill share, urbanization and income distribution
Climate Drivers considered	'Three major dimensions of CC' - • Surface temperature (slow onset) • Sea level rise • Extreme events and disasters (fast onset)

Performative Contradiction	"A better comprehension of CC-induced migration patterns is required, not only to anticipate future migratory pressures, but also to identify vulnerable populations that are likely to be trapped in extreme poverty and require specific interventions. All of the above-mentioned challenges constitute the motivation for this paper."
Compact for safe orderly and regular migration	No
Clear Rate Prediction	Yes, for each kind of climate impact as well as at a variety of spatial scales.
Do they make policy recommendations (explicit)	No
Do they make policy recommendations (implicit)	Yes, they explore policy scenarios with borders to understand the impact of these choices on mobility and inequality.
How do they define climate induced migration	
Notes	This model predicts much smaller levels of internal migration than international migration - seems to contradict all the other studies. I wonder why that is, perhaps imposes too high a cost on migration, therefore the extra cost of a border crossing is not as significant.

S3 – Example of initial coding exercise with preliminary codes for one of the models.

Category	Subcategory	Description	Quote	Comment
Mobility	Drivers	The model specifies what factors determine people's decision to move. We can differentiate between models which choose to investigate how climate change will impact specific drivers and those that inspect the interaction between transformations to known drivers.		Mobility described as a function of population, income, distance, language, border and remittance flows. This is a gravity based model which does not force a distinction between involuntary and voluntary migration, opting instead for a spectrum of reasons -> and it is used to estimate stock flows. This is also the way in which climate change is involved in this particular analyiss - rather than recalculate the effects of heat on each countries 'liveability', 'vulnerability', the GDP and population changes predicted in each of the SSPs is the basis for generating future predictions of migrant flows - basically the coefficients here stay the same whereas the variables are allowed to vary. This form of thinking seems soo weak because it seems so evident that the relative strength of each of these predictors will have to be affected in various climate change scenarios of climate change is actually expected to

				produce any changes at all, especially if and when those changes are acute. I feel like this assumption would be really easy to dispute by using different date ranges before and after significant global shift, for example before and after the cold war, I bet those coefficients changed a lot. For a thorough critique of gravity models see Beyer et al. 2022 which basically shows that that while gravity models are pretty good at explaining spatial differences in migration flows, they suffer when applied to temporal changes.
			"Finally, we consider a corridor-specific risk of dying while attempting to migrate, δ. "	The model considers the corridor specific risk of dying although I am not really sure where they collected these estimates. The individual estimates can be found in deadmig.csv in the data folder. Should be noted that death risk does not really factor into the gravity model, implying that the authors do not think that danger of a particular migration pathway poses a significant obstacle to peoples desire to migrate contra many securitization narratives.
	Temporality	Whether the model considers slow onset factors such as gradual heating/desertification or extreme weather events such as hurricanes/floods.	Here, we focus on international, long-term migration dynam- ics in conjunction with exposure and vulnerability to climate change†	Longterm, slow onset changes until 2100 which is the classic timeframe of most GCMs, the CMIPs.
	Cultural Context	The model studies the impact of cultural factors like language, preexisting migratory pathways, colonial histories and urbanization on migration.		Shared language taken into account as a factor in influencing mobility decisions.
			"We derive remittance flows by assuming that only first-generation migrants send money back to their origin region in the form of remittances, for the duration of their life. This assumption coarsely illustrates the few empirical findings of the migra- tion literature focusing on second-generation remittances, suggesting that second-generation migrants are significantly less likely to send remittances to their parents and send smaller amounts (27): "	Uses empirical work which shows remittance flows being substantial only for first gen immigrants. Additionally, remittances are calculated for the life expectancy of migrants as determined by their destination location -> may be refuted by statistics showing differences in between life expectancies between native and foreign populations
	Environmental Context	The model studies the impact of environmental factors		Environmental factors are not an endogenous part of this model - instead, the researchers

		like temperature, precipitation and natural disasters on migration.		add a migration component to the preexisting FUND IAM, using predetermined impacts of climate change on population and income to estimate changes in bilateral rates.
	Rates	The model considers how the climate change will affect the physical number of people migrating or wanting to migrate in a particular context.	Overall, migration flows modify each region's population size by up to 0.9%.	Internal finding.
				Current bilateral migration flow estimates are borrowed from Abel and Cohen (2019) who themselves are using a model based approach (as opposed to empirical count) based on stocks estimates of migrant stocks in every country. "Demographic and bilateral migrant stock measures came from the United Nations Population Division (UNPD) as a sequence of bilateral migrant stock data covering all pairs of 232 countries for the mid-years of 1990, 1995, 2000, 2005 and 201517. At the time of writing (February 2019), this was most up-to-date set of bilateral migrant stocks available for all countries. Data were primarily based on birthplaces reported in censuses and population registers provided by national statistical institutes. The UNPD adjusted data to include available refugee statistics. When recorded data did not align to the mid-years at five-year intervals, the UNPD extrapolated values based on the change in the overall population size. For countries or areas without data, the UNPD used a similar country or group of countries to estimate missing bilateral stocks." Data thus obtained from official country census data is highly unlikely to fully reflect the extent of undocumented migration - this is problematic because it is safe to assume that especially under extenuating climate impact circumstances, migration will likely be highly mixed and therefore more independent of this estimation method which makes it essentially unfeasible for studying the phenomenon in the first place.

			We find that climate change affects migration numbers only marginally, increasing worldwide international migration by 0.3 to 1.1% in 2100 compared to no climate change at the same period, depending on the border policy and development and climate scenario considered.	This prediction is interesting because many would say that it is the most important result of this paper in that it refutes the main body of work on the future of climate migration and it appears unusually precise. While it is not passed exactly tentatively (because the authors don't dedicate words defending the positions or qualifying it), it goes completely unremarked upon in the paper, not even showing up in the abstract. Two probable reasons for this - 1. Authors are not really confident in this estimate. Given tail risks and tipping points, it may be quite irresponsible of them to make a minimizing prediction like this one. And their approach is not really ready to the task of refuting other forms of analysis 2. It would downplay in the importance of their research because a 1% change does not require the same kind of scrutiny than a larger one. However, it is also central to their work because they are suggesting here and elsewhere that migration should be treated more openly - if it isn't a huge burden than governments are more likely to listen?
	Agency		"Therefore, higher levels of climate change will likely reduce people's ability to move on their own terms, inducing both an increasing number of people who are forced to move (displacement) and an increasing number of people who are forced to stay in their origin locations (12).	The understanding conveyed here is that migration exists on a continuum of voluntary to involuntary, with climate change reducing peoples ability to chose.
	Spatial scale	The geographic scale under consideration and how the scale is defined. Here scale can be defined geopolitically by various administrative levels from municipal/subnational	Here, we focus on international, long-term migration dynam- ics in conjunction with exposure and vulnerability to climate change†	International cross border migration including available data from everycounttry - sometimes aggregated to geopolitical regions.

		migrations to international migrations. Scale could also be defined geographically or biologically such as by habitat or landmass.		
Governance	Rights	The model explicitly describes ways in which the impact of climate change on migration will impact people's ability to claim basic human rights.		Human rights not invoked.
	Conflict	The model explicitly attributes changes in the present and future likelihood of intergroup conflict to climate change.		No explicit consideration of conflict
	Justice	The model is explicitly used to assess the share of responsibility for the effects of climate change in order to better distribute the burden of mitigation/adaptation.		Nothing on justice
	Geopolitics	The model explicitly takes into account changes in present and future geopolitical arrangement including bilateral border policies, securitization, international agreements and trade relationships.	Furthermore, we find that border policy itself has a clear quan- titative effect on net migration in all regions. In most regions, closing borders between Global North and Global South has similar effects to closing all borders, which signals that most migration for those regions has taken place between Global North and Global South.	Modelers consider three geopolitical futures - bordersmoreopen, currentborders, closedborders , northsouthclosed. The question posed in this way reveal very interesting concerns and speculations of the future of climate migration. Will have to do a little thinking about what exactly.
			In a final step, we consider various scenarios for border policy. The use of scenarios for this key parameter appears jus- tified by the highly perilous character of border policy prediction over such a timescale. Note that border policies are generally effective at controlling border crossings at their targeted locations, yet can lead to unintended effects on population movement that can limit their effective- ness. The DEMIG## project identified four types of such effects, namely spatial substitution where migration takes place through other routes or other destinations altogether, categorical substitution through other legal or illegal channels, intertemporal	Looking at S1 for Global North and Global South Alignment shows that geopolitically, this formation is a little incoherent. Global North is Europe + USA + Canada + Japan + South Kore and Global South is everywhere else. It would have been better if they did first world, second world and third world countries. This feels like an egregiously bad approach given that the whole point of this paper appears to be considering the effect of border policy on exposure and vulnerability to climate change - it feels like nothing said in this paper would actually have any impact.

			substitution precipitating migration in expectation of future stricter policies, and reverse flow substitution through the interruption of return migration encouraging permanent moves (50). The scenarios we use here, highly stylized, are not meant to provide real- istic descriptions of actual border enforcement on the ground, but rather to capture the plausible magnitude of border policy effects on various outcomes.	
	Management	The model explicitly considers the impact of techniques of managing migrants. Such techniques might range from setting up refugee camps to cope with in-migration to the formations and actions of international instruments like the IOM or the UNHCR in response to developing migration scenarios.	"We analyze how different border policies might affect people's exposure and vulnerability."	The aim of the paper is to use the IAMs to evaluate the effect of various border policies on peoples ability to adapt to climate change, ie. Changing exposure/vulnerability.
			restrictive border policy can increase exposure and vulnerability to climate change impacts by trapping people in areas that are more exposed than where they would otherwise migrate.	
			In this paper, we provide a quantitative analysis of the effect of border policy—a key influence on international migration flows—on exposure and vulnerability to climate change impacts, for migrants and origin and host communities. This analysis con- tributes to the ongoing effort toward endogenizing population dynamics in IAMs and constitutes a directly usable approach for assessing national and global policy interactions.	Endogenizing population dynamics
	Adaptation	The model explicitly conceptualizes migration as an adaptation to climate change.	1. "First, migration may be increasingly used as an adaptation strategy to climate change (5, 6)." -	Not sure how this might make its way into models, but the paper is premised on the understanding that migration is a form of adaptation - additionally one that might suffer if borders are mismanaged.
			First, migration and remittances can make a positive contribution to adaptation to climate change impacts.	
	Development	The model explicitly considers how various development pathways might influence people's desires and	reducing inequality between countries would also decrease the need and benefit to use international migration as an adaptation solution; hence con-	

		ability to move. This includes the supposition of benefits conferred by an increased capacity to adapt to climate change.	siderations of unequal levels of development across regions are crucial to understanding international migration flows and to a relevant assessment of climate change damages.	
Economics	Financial Constraints	The model explicitly considers the economic difficulty of migration, either from the perspective of individuals wanting to move or of international organizations trying to facilitate large scale movements.	1. In this paper, we provide a quantitative analysis of the effect of border policy—a key influence on international migration flows—on exposure and vulnerability to climate change impacts, for migrants and origin and host communities.	Remittance dynamics
	Damage function	The model undertakes an economic cost benefit analysis of migration to assess the impact of migration on communities undergoing out or in migration.	Effect of border policies on per capita income after remittances. Shown are results in the 16 FUND regions over the period 2015 to 2100 for SSP2 (middle of the road) coupled to RCP4.5. (*Top Left*) Per capita income levels for current borders. (*Top Right*) Relative change for more open borders compared to current borders. (*Bottom Left*) Relative change for closed borders compared to current borders. (*Bottom Right*) Relative change for borders closed between Global North and Global South compared to current borders. Fig.1	The figure shows the relative changes of border policy on GDP per capita.
				Cost of deaths arising from migration are included in the damage calculation using VSL. Authors appear very concerned with defending their choice to use VSL in this situation, having two subsequent notes dedicated to it implying an awareness its controversial status.
				The paper also tries to calculate the effect that migration will have on carbon emissions in the future by using estimates of Carbon footprint per unit GDP per capita.
			"Migration is driven by absolute and relative levels of economic development, but also affects development levels at destination. We account for that effect coarsely, by assuming that immi-gration does not modify destination income per capita	GDP is estimated in migration and no migration scenarios, but the GDP per capita is kept constant in both scenarios - implying that more people can only add productivity to a national economy. While I appreciate the difficulty

			levels and hence overall increases income levels (see above). This limitation is an inevitable consequence of the rather stylized fundamental structure of IAMs. “	that the authors face in considering the economic cost or benefit of migration, this approach sidesteps the fundamental concern that most nations have regarding the problem -> that migrants don’t necessarily add to an economy but that they actually displace preexisting workers by providing lower cost alternatives.
	Standard of living	The model considers how migrations might impact wealth and income of communities experiencing out or in migrations.	Cru- cially, we show that most migrants from developing regions tend to move to areas where they are less exposed than they would have been by remaining in place. This happens not because they intentionally move into less dangerous areas—our model does not capture detailed reasons of migrants’ intentions—but because wealthier regions also happen to be less exposed.	
	Equality	The model considers the effect of migration on global or national income inequality.	“reducing inequality between countries would also decrease the need and benefit to use international migration as an adaptation solution “	This is phrased as one of the three takeaways from the paper, however, it is really the starting assumption because migration is characterized as a factor of the income inequality of countries.
Science	Model lineage			The researches base their model on the GHG and warming estimates provided by the SSP framework - they conceive of their work as contributing directly to the further development and sensitization of the SSP framework by making migration and endogenous factor. However, it does not really take into account the storylines conceived by the SSP framework in that there is no feedback between individual pathways and the scenarios which they consider.
				The authors add an econometric estimation approach for migration to the SSP input and output framework.
	Publication			This is a peer reviewed scientific journal article published in PNAS which is the second most prestigious scientific publication. It has had 19000 views and 18 citations.

	Reflexivity			The paper itself does not show any overt signs of reflexivity or self-critique (except in a narrow scientific sene -what can be improved, what the paper doesn't consider). However, that might be attributable to the relative condensed format of this particular publication. In some sense, the researchers come out batting for the 'right' side, which is to say the most migrant sensitive side, of most issues, and in other papers as well. My sense is that this is not accidental and given the obvious problems in their methodology, not the result of some objective fact of climate migration - rather a reflection of slightly sublimated methodological choices which actually seem to vastly reduce the practical applicability of the work they are doing- such as, for example, not investigating the impact of migration on per capita income levels in receiving countries.
	Justification		A recent review of the literature on climate-related migration emphasizes that the development of projections of climate-related international migration is an important area for future research (3).	
			This analysis con- tributes to the ongoing effort toward endogenizing population dynamics in IAMs and constitutes a directly usable approach for assessing national and global policy interactions.	
	Criticism		Migration is at this point hardly included in commonly used IAMs. For most models, migration is absent from the IAM itself and considered only implicitly, as part of required input population growth scenarios.	
			The only IAM that includes it somewhat more explicitly in its damage function is FUND. Currently, displacement caused by sea-level rise is accounted for in FUND. However, its modeling includes arbitrary esti- mates of displacement costs, fixed destinations over time, and no economic adaptation such as remittances	

			Climate change damages, whose quantification informs assess- ment of exposure and vulnerability, are typically endogenized in integrated assessment models (IAMs). IAMs couple a single climate model to one of the global economy, by representing greenhouse gas emissions as well as damages on the economy resulting from climate change. Some IAMs provide a repre- sentation of mitigation costs and impacts as a single economic metric through their monetary-equivalent value (e.g., Dynamic Integrated Climate-Economy [DICE]; Climate Framework for Uncertainty, Negotiation, and Distribution [FUND]; and Policy Analysis of the Greenhouse Effect [PAGE]; for an illustration of IAM structure, see Fig. 4). Such IAMs are used for cost–benefit analyses centered on maximizing welfare to identify optimal climate change policies; calculations of marginal effect of emis- sions on social welfare, also called the social cost of carbon (SCC); as well as sensitivity analyses aiming at weighing the rel- ative importance of various climate change drivers, impacts, and policies. Both the Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences have called for improvements in IAMs' damage functions (13, 14).	Authors reiterate the importance of IAMs for calculating future damages from climate change. This is a presumed benefit of the IAM approach, although what comes after the damage function is not really made clear - in general the question this raises is whether the costs of mitigating and adapting to climate change exceed the cost to society of continuing with business as usual- original IAM by William Nordhaus says no.
			Furthermore, recent efforts have been deployed to study climate–migration interactions using a variety of non-IAM models. … Note that such models feature limited to no endogenization of the feedback of the economy on climate change in the form of greenhouse gas emissions.	

Memo	This is a first go at evaluating theoretical samples. This will also be my working template going forward. I think that this is a relatively efficient way to track my thoughts on a per model basis. Overall, this exercise was helpful for the following reasons- • I have not yet given any model such a thorough examination. I was really able to dive into many if not all of the working parts of the model and this left me with a lot to think about. • I found that given the fact that I have to treat the model rather synoptically, it is not helpful to pursue a more traditional coding approach of picking quotes and fitting them into categories. I feel like these categorical descriptions that I have developed in the notes section are more helpful because they allow for the flexibility of a thorough interpretation and self questioning - given that part of these models constitute (in complexity) at the level of a theoretical sample as a whole this approach provides micro-memos on the parts to construct comparable interpretations. With regards to the model I had the following impressions - • I was quite shocked by just how unconvincing I found the models methods to be - I think that I want to be charitable to researchers who (I think we all agree now) are probably unable to do a good job of predicting the details of how climate change will modify migration networks because I believe that there are questions that can be argued using models. But, at every turn I found more reason for skepticism in their approach. I won't cover all the reasons as they are well fleshed out in the spreadsheet. A difficulty I am having is that it is hard to separate 'criticism' from 'interpretation'. My instinct is to find faults with the methodology and use that as the basis for developing an argument, essentially *against* the paper or model - this is, obviously, the scientific approach - if the model is not good enough I identify what is wrong or incomplete and try to make it better. But I have to resist this temptation, even while being aware of defects etc because my actual task is to square the circle of the scientific work that I am analyzing with the sociological work I am taking part in - in this sense, it is not really useful for me to argue against a particular piece. Instead I have to 'think with it'. Additionally, I want to go beyond the clichéd by now conclusion that science is in fact a social practice - I want to consider the reality that this understanding is part of the condition of doing science and forming scientific imaginaries especially in heavily socially informed fields like migration studies. George Marcus writes "Thus, beginning to ask how scientists have faith in their own activity, or in what ways their perceptions of what they are doing are changing, given some form of distinctive consciousness about the social and cultural construction of their activity, generates a completely transformed and vast field of inquiry on which a distinctly cultural studies of science might establish itself". The paper itself does not show any overt signs of reflexivity or self-critique (except in a narrow scientific sene -what can be improved, what the paper doesn't consider). However, that might be attributable to the relative condensed format of this particular publication. In some sense, the researchers come out batting for the 'right' side, which is to say the most migrant sensitive side, of most issues, and in other papers as well. My sense is that this is not accidental and given the obvious problems in their methodology, not the result of some objective fact of climate migration - rather a reflection of slightly sublimated methodological choices which actually seem to vastly reduce the practical applicability of the work they are doing- such as, for example, not investigating the impact of migration on per capita income levels in receiving countries. In general, this particular research group seems to be trying to pick up on the most relevant 'unanswerables' in climate mitigation and adaptation and applying a modeling approach to them - the conceit may be flawed, leaving behind fundamental uncertainties in favor of positive concretions, but it does give you a sense of the other side of the imaginary.

REFERENCES CITED

- Appadurai, Arjun. *The Future as Cultural Fact: Essays on the Global Condition*. Politics/Anthropology. London New York: Verso, 2013.

- Asafu-Adjaye, John, Linus Blomqvist, Stewart Brand, Barry Brook, Ruth DeFries, Erle Ellis, Christopher Foreman, et al. *An Ecomodernist Manifesto*, 2015. https://doi.org/10.13140/RG.2.1.1974.0646.

- Auffhammer, Maximilian, Solomon M Hsiang, Wolfram Schlenker, and Adam Sobel. "Using Weather Data and Climate Model Output in Economic Analyses of Climate Change," n.d.

- Austin, J. L., and James O. Urmson. *How to Do Things with Words: The William James Lectures Delivered at Harvard University in 1955*. 2. ed., [Repr.]. Cambridge, Mass: Harvard Univ. Press, 2009.

- Aykut, Stefan Cihan. "Reassembling Energy Policy: Models, Forecasts, and Policy Change in Germany and France." *Science & Technology Studies* 32, no. 4 (2019b): 13–35. https://doi.org/10.23987/sts.65324.

- Aykut, Stefan, David Demortain, and Bilel Benbouzid. "The Politics of Anticipatory Expertise: Plurality and Contestation of Futures Knowledge in Governance — Introduction to the Special Issue." *Science & Technology Studies* 32, no. 4 (2019a): 2–12. https://doi.org/10.23987/sts.87369.

- Balibar, Étienne. "What Is a Border?" In *Politics and the Other Scene*, translated by Christine Jones, James Swenson, and Chris Turner. Radical Thinkers. London Brooklyn, New York: Verso, 2011.

- Beck, Silke, and Martin Mahony. "The IPCC and the Politics of Anticipation." *Nature Climate Change* 7, no. 5 (May 2017): 311–13. https://doi.org/10.1038/nclimate3264.

- Beek, Lisette van, Maarten Hajer, Peter Pelzer, Detlef van Vuuren, and Christophe Cassen. "Anticipating Futures through Models: The Rise of Integrated Assessment Modelling in the Climate Science-Policy Interface since 1970." *Global Environmental Change* 65 (November 2020): 102191. https://doi.org/10.1016/j.gloenvcha.2020.102191.

- Benveniste, Hélène, Jesús Crespo Cuaresma, Matthew Gidden, and Raya Muttarak. "Tracing International Migration in Projections of Income and Inequality across the Shared Socioeconomic Pathways." *Climatic Change* 166, no. 3 (June 9, 2021): 39. https://doi.org/10.1007/s10584-021-03133-w.

- Benveniste, Hélène, Michael Oppenheimer, and Marc Fleurbaey. "Climate Change Increases Resource-Constrained International Immobility." *Nature Climate Change* 12, no. 7 (July 2022): 634–41. https://doi.org/10.1038/s41558-022-01401-w.

- ———. "Effect of Border Policy on Exposure and Vulnerability to Climate Change." *Proceedings of the National Academy of Sciences* 117, no. 43 (October 27, 2020): 26692–702. https://doi.org/10.1073/pnas.2007597117.

- Bettini, Giovanni. "Where Next? Climate Change, Migration, and the (Bio)Politics of Adaptation." *Global Policy* 8, no. S1 (2017): 33–39. https://doi.org/10.1111/1758-5899.12404.

- Beyer, Robert M., Jacob Schewe, and Guy J. Abel. "Modeling Climate Migration: Dead Ends and New Avenues." *Frontiers in Climate* 5 (August 29, 2023): 1212649. https://doi.org/10.3389/fclim.2023.1212649.

- Black, Richard, Stephen R. G. Bennett, Sandy M. Thomas, and John R. Beddington. "Migration as Adaptation." *Nature* 478, no. 7370 (October 2011): 447–49. https://doi.org/10.1038/478477a.

- Boas, Ingrid, Hanne Wiegel, Carol Farbotko, Jeroen Warner, and Mimi Sheller. "Climate Mobilities: Migration, Im/Mobilities and Mobility Regimes in a Changing Climate." *Journal of Ethnic and Migration Studies* 48, no. 14 (October 26, 2022): 3365–79. https://doi.org/10.1080/1369183X.2022.2066264.

- Borjas, George J. "Self-Selection and the Earnings of Immigrants." *The American Economic Review* 77, no. 4 (1987): 531–53.

- Braun, Benjamin. "Why Models Matter: The Making and Unmaking of Governability in Macroeconomic Discourse." *Journal of Critical Globalisation Studies*, no. 7 (2014): 48–79.

- Büntgen, Ulf. "The Importance of Distinguishing Climate Science from Climate Activism." *Npj Climate Action* 3, no. 1 (May 8, 2024): 1–2. https://doi.org/10.1038/s44168-024-00126-0.

- Burzyński, Michał, Christoph Deuster, Frédéric Docquier, and Jaime de Melo. "Climate Change, Inequality, and Human Migration." *Journal of the European Economic Association* 20, no. 3 (June 1, 2022): 1145–97. https://doi.org/10.1093/jeea/jvab054.

- Callon, Michel. "What Does It Mean to Say That Economics Is Performative?" In *Do Economists Make Markets?*, edited by Donald MacKenzie, Fabian Muniesa, and Lucia Siu, 311–57. On the Performativity of Economics. Princeton University Press, 2007. https://doi.org/10.2307/j.ctv10vm29m.15.

- Carleton, Tamma A., and Solomon M. Hsiang. "Social and Economic Impacts of Climate." *Science* 353, no. 6304 (September 9, 2016): aad9837. https://doi.org/10.1126/science.aad9837.

- Chen, Min, and Ken Caldeira. "Climate Change as an Incentive for Future Human Migration." *Earth System Dynamics* 11, no. 4 (October 22, 2020): 875–83. https://doi.org/10.5194/esd-11-875-2020.

- Coopmans, Catelijne, Janet Vertesi, Michael Lynch, and Steve Woolgar. "Introduction: Representation in Scientific Practice Revisited." In *Representation in Scientific Practice Revisited*, edited by Catelijne Coopman, Janet Vertesi, Michaeland Lynch, and Steve Woolgar, 0. The MIT Press, 2014. https://doi.org/10.7551/mitpress/9780262525381.003.0001.

- Costanza, Robert. "Visions, Values, Valuation, and the Need for an Ecological Economics: All Scientific Analysis Is Based on a 'Preanalytic Vision,' and the Major Source of Uncertainty about Current Environmental Policies Results from Differences in Visions and World Views." *BioScience* 51, no. 6 (June 1, 2001): 459–68. https://doi.org/10.1641/0006-3568(2001)051[0459:VVVATN]2.0.CO;2.

- Davis, Kyle Frankel, Abinash Bhattachan, Paolo D'Odorico, and Samir Suweis. "A Universal Model for Predicting Human Migration under Climate Change: Examining Future Sea Level Rise in Bangladesh." *Environmental Research Letters* 13, no. 6 (June 2018): 064030. https://doi.org/10.1088/1748-9326/aac4d4.

- Delanty, Gerard. "Imagining the Future: Social Struggles, the Post-National Domain and Major Contemporary Social Transformations." *Journal of Sociology* 57, no. 1 (March 1, 2021): 27–46. https://doi.org/10.1177/1440783320969860.

- Diedrich, Andreas, Ulla Eriksson-Zetterquist, Lena Ewertsson, Johan Hagberg, Anette Hallin, Fredrik Lavén, Kajsa Lindberg, Elena Raviola, Egle Rindzeviciute,

and Lars Walter. “Exploring the Performativity Turn in Management Studies,” September 2013. https://gupea.ub.gu.se/handle/2077/34077.

- Dolez, Antoine, Granjou Céline, and Louvel Séverine. “On the Plurality of Environmental Regimes of Anticipation: Insights from Forest Science and Management.” *Science & Technology Studies* 32, no. 4 (December 13, 2019): 78–96. https://doi.org/10.23987/sts.64919.

- Fankhauser, Sam. “Adaptation to Climate Change.” *Annual Review of Resource Economics* 9 (2017): 209–30.

- Felt, Ulrike, Rayvon Fouché, Clark A. Miller, and LAurel Smith-Doerr. “Introduction.” In *The Handbook of Science and Technology Studies*, edited by Ulrike Felt, Fourth edition. Cambridge, Massachusetts: The MIT Press, 2017.

- Ferris, Elizabeth. “Research on Climate Change and Migration Where Are We and Where Are We Going?” *Migration Studies* 8, no. 4 (December 1, 2020): 612–25. https://doi.org/10.1093/migration/mnaa028.

- Foster, John Bellamy. *Capitalism in the Anthropocene: ecological ruin or ecological revolution*. New York: Monthly Review Press, 2022.

- Fuerth, Leon S, and Evan M Faber. “Anticipatory Governance Practical Upgrades: Equipping the Executive Branch to Cope with Increasing Speed and Complexity of Major Challenges.” Institute for National Strategic Studies, 2012.

- Gemenne, François. “Why the Numbers Don’t Add up: A Review of Estimates and Predictions of People Displaced by Environmental Changes.” *Global Environmental Change*, Migration and Global Environmental Change – Review of Drivers of Migration, 21 (December 1, 2011): S41–49. https://doi.org/10.1016/j.gloenvcha.2011.09.005.

- Guston, David H. “Understanding ‘Anticipatory Governance.’” *Social Studies of Science* 44, no. 2 (April 1, 2014): 218–42. https://doi.org/10.1177/0306312713508669.

- Haines, Sophie. “Reckoning Resources: Political Lives of Anticipation in Belize’s Water Sector.” *Science & Technology Studies* 32, no. 4 (December 13, 2019): 97–118. https://doi.org/10.23987/sts.64650.

- Hamilton, Clive, Christophe Bonneuil, and François Gemenne, eds. “Human Destiny in the Anthropocene.” In *The Anthropocene and the Global Environmental Crisis*. London ; New York: Routledge, 2015.

- Harvey, David. *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*. Nachdr. Cambridge, Mass.: Blackwell, 2011.

- Heo, Kyungmoo, and Yongseok Seo. “Anticipatory Governance for Newcomers: Lessons Learned from the UK, the Netherlands, Finland, and Korea.” *European Journal of Futures Research* 9, no. 1 (July 11, 2021): 9. https://doi.org/10.1186/s40309-021-00179-y.

- Hickel, Jason, Paul Brockway, Giorgos Kallis, Lorenz Keyßer, Manfred Lenzen, Aljoša Slameršak, Julia Steinberger, and Diana Ürge-Vorsatz. “Urgent Need for Post-Growth Climate Mitigation Scenarios.” *Nature Energy* 6, no. 8 (August 4, 2021): 766–68. https://doi.org/10.1038/s41560-021-00884-9.

- Hickel, Jason, and Aljosa Slamersak. “Existing Climate Mitigation Scenarios Perpetuate Colonial Inequalities.” *The Lancet. Planetary Health* 6, no. 7 (July 2022): e628–31. https://doi.org/10.1016/S2542-5196(22)00092-4.

- Hoffmann, Roman, Anna Dimitrova, Raya Muttarak, Jesus Crespo Cuaresma, and Jonas Peisker. “A Meta-Analysis of Country-Level Studies on Environmental Change and Migration.” *Nature Climate Change* 10, no. 10 (October 2020): 904–12. https://doi.org/10.1038/s41558-020-0898-6.

- Hoffmann, Roman, Barbora Šedová, and Kira Vinke. “Improving the Evidence Base: A Methodological Review of the Quantitative Climate Migration Literature.” *Global Environmental Change* 71 (November 1, 2021): 102367. https://doi.org/10.1016/j.gloenvcha.2021.102367.

- Hsiang, Solomon. “Climate Econometrics.” *Annual Review of Resource Economics* 8, no. 1 (2016): 43–75. https://doi.org/10.1146/annurev-resource-100815-095343.

- Hulme, Mike. “Reducing the Future to Climate: A Story of Climate Determinism and Reductionism.” *Osiris* 26, no. 1 (January 2011): 245–66. https://doi.org/10.1086/661274.

- Hunter, Lori M., Jessie K. Luna, and Rachel M. Norton. “Environmental Dimensions of Migration.” *Annual Review of Sociology* 41, no. Volume 41, 2015 (August 14, 2015): 377–97. https://doi.org/10.1146/annurev-soc-073014-112223.

- Huntjens, Patrick, and Katharina Nachbar. “Climate Change as a Threat Multiplier for Human Disaster and Conflict,” 2015.

- Hyysalo, Sampsa, Neil Pollock, and Robin Alun Williams. “Method Matters in the Social Study of Technology: Investigating the Biographies of Artifacts and Practices.” *Science & Technology Studies* 32, no. 3 (September 14, 2019): 2–25. https://doi.org/10.23987/sts.65532.

- Jakobeit, Cord, and Chris Methmann. “‘Climate Refugees’ as Dawning Catastrophe? A Critique of the Dominant Quest for Numbers.” In *Climate Change, Human Security and Violent Conflict: Challenges for Societal Stability*, edited by Jürgen Scheffran, Michael Brzoska, Hans Günter Brauch, Peter Michael Link, and Janpeter Schilling, 301–14. Berlin, Heidelberg: Springer, 2012. https://doi.org/10.1007/978-3-642-28626-1_16.

- Janetos, Anthony C., Robert T. Watson, Marufu C. Zinyowera, and Richard H. Moss. “Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses.” *Ecology* 78, no. 8 (December 1997): 2644. https://doi.org/10.2307/2265930.

- Jasanoff, Sheila. *Designs on Nature: Science and Democracy in Europe and the United States*. 5. print., 1. pbk. print. Princeton, NJ: Princeton Univ. Press, 2007.

- ———. “Future Imperfect: Science, Technology, and the Imaginations of Modernity.” In *Dreamscapes Of Modernity*. Future Imperfect: Science, Technology, and the Imaginations of Modernity, 2015.

- ———. “Controversy Studies.” *The Blackwell Encyclopedia of Sociology*, 2019, 1–5.

- Jones, Bryan. “Modeling Climate Change-Induced Migration in Central America & Mexico Methodological Report.” Marxe School of Public and International Affairs, Baruch College and the CUNY Institute for Demographic Research (CIDR), July 23, 2020.

- Kanitkar, Tejal, Akhil Mythri, and T. Jayaraman. “Equity Assessment of Global Mitigation Pathways in the IPCC Sixth Assessment Report.” *Climate Policy* 24, no. 8 (September 13, 2024): 1129–48. https://doi.org/10.1080/14693062.2024.2319029.

- Kleemans, Marieke. “Migration Choice under Risk and Liquidity Constraints.” *2015 AAEA & WAEA Joint Annual Meeting, July 26-28, San Francisco, California*, 2015

AAEA & WAEA Joint Annual Meeting, July 26-28, San Francisco, California, 2015. https://ideas.repec.org//p/ags/aaea15/200702.html.

- Kumari Rigaud, Kanta, Alex de Sherbinin, Bryan Jones, Jonas Bergmann, Viviane Clement, Kayly Ober, Jacob Schewe, et al. "Groundswell: Preparing for Internal Climate Migration." Washington, DC: The World Bank, 2018.

- Latour, Bruno. "Agency at the Time of the Anthropocene." *New Literary History* 45, no. 1 (2014): 1–18.

- ———. *Pandora's Hope: Essays on the Reality of Science Studies*. 2. print. Cambridge, Mass.: Harvard University Press, 2000.

- ———. *Politics of Nature: How to Bring the Sciences into Democracy*. Cambridge, Mass: Harvard University Press, 2004.

- ———. "The Powers of Association." *The Sociological Review* 32, no. S1 (1984): 264–80. https://doi.org/10.1111/j.1467-954X.1984.tb00115.x.

- Law, John. "STS as Method." In *The Handbook of Science and Technology Studies*, edited by Ulrike Felt, Fourth edition. Cambridge, Massachusetts: The MIT Press, 2017.

- Lenzen, Manfred, Lorenz Keyβer, and Jason Hickel. "Degrowth Scenarios for Emissions Neutrality." *Nature Food* 3, no. 5 (May 2022): 308–9. https://doi.org/10.1038/s43016-022-00516-9.

- Lompe, Klaus. "Problems of Futures Research in the Social Sciences." *Futures* 1, no. 1 (January 1, 1969): 47–53. https://doi.org/10.1016/S0016-3287(69)80007-8.

- Luetz, Johannes M. "Climate Refugees: Why Measuring the Immeasurable Makes Sense Beyond Measure." In *Climate Action*, edited by Walter Leal Filho, Anabela Marisa Azul, Luciana Brandli, Pinar Gökcin Özuyar, and Tony Wall, 1–14. Cham: Springer International Publishing, 2019. https://doi.org/10.1007/978-3-319-71063-1_81-1.

- Lustgarten, Abrahm. "About Our Climate Migration Model." ProPublica, July 23, 2020. https://www.propublica.org/article/2020-climate-migration-part-1-methodology.

- ———. “The Great Climate Migration Has Begun.” *The New York Times*, July 23, 2020, sec. Magazine. https://www.nytimes.com/interactive/2020/07/23/magazine/climate-migration.html.

- Lynch, Michael, and Steve Woolgar. “Introduction: Sociological Orientations to Representational Practice in Science.” *Human Studies* 11, no. 2/3 (1988): 99–116.

- McLeman, Robert. “Conclusion: Migration as Adaptation: Conceptual Origins, Recent Developments, and Future Directions.” In *Migration, Risk Management and Climate Change: Evidence and Policy Responses*, edited by Andrea Milan, Benjamin Schraven, Koko Warner, and Noemi Cascone, 213–29. Cham: Springer International Publishing, 2016. https://doi.org/10.1007/978-3-319-42922-9_11.

- McLeman, Robert, David Wrathall, Elisabeth Gilmore, Philip Thornton, Helen Adams, and François Gemenne. “Conceptual Framing to Link Climate Risk Assessments and Climate-Migration Scholarship.” *Climatic Change* 165, no. 1 (March 19, 2021): 24. https://doi.org/10.1007/s10584-021-03056-6.

- Methmann, Chris. “Visualizing Climate-Refugees: Race, Vulnerability, and Resilience in Global Liberal Politics.” *International Political Sociology* 8, no. 4 (December 1, 2014): 416–35. https://doi.org/10.1111/ips.12071.

- Mezzadra, Sandro, and Brett Neilson. *Border as Method, or, the Multiplication of Labor*. Durham: Duke University Press, 2013.

- Myers, Norman. “Environmental Refugees: An Emergent Security Issue.” In *Session III (Environment and Migration)*. Organization for Security and Co-operation in Europe, 2005.

- ———. “Environmental Refugees in a Globally Warmed World.” *BioScience* 43, no. 11 (1993): 752–61. https://doi.org/10.2307/1312319.

- Oppenheimer, Michael, Brian C. O’Neill, Mort Webster, and Shardul Agrawala. “The Limits of Consensus.” *Science* 317, no. 5844 (September 14, 2007): 1505–6. https://doi.org/10.1126/science.1144831.

- Parker, Wendy S. “Evidence and Knowledge from Computer Simulation.” *Erkenntnis* 87, no. 4 (August 1, 2022): 1521–38. https://doi.org/10.1007/s10670-020-00260-1.

- Peters, Ole. “The Ergodicity Problem in Economics.” *Nature Physics* 15, no. 12 (December 2019): 1216–21. https://doi.org/10.1038/s41567-019-0732-0.

- Petersen, William. “A General Typology of Migration.” *American Sociological Review* 23, no. 3 (1958): 256–66. https://doi.org/10.2307/2089239.

- Pielke, Roger, and Justin Ritchie. “Distorting the View of Our Climate Future: The Misuse and Abuse of Climate Pathways and Scenarios.” *Energy Research & Social Science* 72 (February 1, 2021): 101890. https://doi.org/10.1016/j.erss.2020.101890.

- Piguet, Etienne. “From ‘Primitive Migration’ to ‘Climate Refugees’: The Curious Fate of the Natural Environment in Migration Studies.” *Annals of the Association of American Geographers* 103, no. 1 (January 1, 2013): 148–62. https://doi.org/10.1080/00045608.2012.696233.

- ———. “Linking Climate Change, Environmental Degradation, and Migration: A Methodological Overview.” *Wiley Interdisciplinary Reviews: Climate Change* 1, no. 4 (July 1, 2010): 517–24. https://doi.org/10.1002/wcc.54.

- ———. “Linking Climate Change, Environmental Degradation, and Migration: An Update after 10 Years.” *WIREs Climate Change* 13, no. 1 (2022): e746. https://doi.org/10.1002/wcc.746.

- Piguet, Etienne, Raoul Kaenzig, and Jérémie Guélat. “The Uneven Geography of Research on ‘Environmental Migration.’” *Population and Environment* 39, no. 4 (June 1, 2018): 357–83. https://doi.org/10.1007/s11111-018-0296-4.

- Polanyi, Michael. “Science and Man.” *Proceedings of the Royal Society of Medicine* 63, no. 9 (September 1, 1970): 969–76. https://doi.org/10.1177/003591577006300948.

- Porter, Theodore M. *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. New paperback edition. Princeton, N.J: Princeton University Press, 2020.

- Pryck, Kari de, and Mike Hulme, eds. *A Critical Assessment of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom ; New York, NY: Cambridge University Press, 2022.

- Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O’Neill, Shinichiro Fujimori, Nico Bauer, et al. “The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview.” *Global Environmental Change* 42 (January 1, 2017): 153–68. https://doi.org/10.1016/j.gloenvcha.2016.05.009.

- Rosen, Richard A., and Edeltraud Guenther. “The Economics of Mitigating Climate Change: What Can We Know?” *Technological Forecasting and Social Change* 91 (February 1, 2015): 93–106. https://doi.org/10.1016/j.techfore.2014.01.013.

- Sakdapolrak, Patrick, Marion Borderon, and Harald Sterly. “The Limits of Migration as Adaptation. A Conceptual Approach towards the Role of Immobility, Disconnectedness and Simultaneous Exposure in Translocal Livelihoods Systems.” *Climate and Development* 16, no. 2 (February 7, 2024): 87–96. https://doi.org/10.1080/17565529.2023.2180318.

- Schewel, Kerilyn, Sarah W. Dickerson, and Gabriela Nagle Alverio. “Evaluating Climate-Related Migration Forecasting Models.” Reserarch Technical Assistance CenterWashington, DC, 2022.

- Sheila Jasanoff. “Imagined Worlds: The Politics of Future-Making in the Twenty-First Century.” In *The Politics and Science of Prevision: Governing and Probing the Future*, edited by Andreas Wenger, Ursula Jasper, and Myriam Dunn Cavelty. CSS Studies in Security and International Relations. Abingdon, Oxon ; New York, NY: Routledge/Taylor & Francis Group, 2020.

- Sismondo, Sergio. “Models, Simulations, and Their Objects.” *Science in Context* 12, no. 2 (July 1999): 247–60. https://doi.org/10.1017/S0269889700003409.

- Smirnov, Oleg, Gallya Lahav, John Orbell, Minghua Zhang, and Tingyin Xiao. “Climate Change, Drought, and Potential Environmental Migration Flows Under Different Policy Scenarios.” *International Migration Review* 57, no. 1 (March 1, 2023): 36–67. https://doi.org/10.1177/01979183221079850.

- Stark, Oded, and David E. Bloom. “The New Economics of Labor Migration.” *The American Economic Review* 75, no. 2 (1985): 173–78.

- Stavins, Robert N. “The Problem of the Commons: Still Unsettled after 100 Years.” *American Economic Review* 101, no. 1 (February 2011): 81–108. https://doi.org/10.1257/aer.101.1.81.

- Stengers, Isabelle. “Accepting the Reality of Gaia: A Fundamental Shift?” In *The Anthropocene and the Global Environmental Crisis*, edited by Clive Hamilton, Christophe Bonneuil, and François Gemenne. London ; New York: Routledge, 2015.

- ———. “Introductory Notes on an Ecology of Practices.” *Cultural Studies Review* 11, no. 1 (2005).

- Suhrke, Astri. “Environmental Degradation and Population Flows.” *Journal of International Affairs* 47, no. 2 (1994): 473–96.

- Terry, Naomi, Azucena Castro, Bwalya Chibwe, Geci Karuri-Sebina, Codruţa Savu, and Laura Pereira. “Inviting a Decolonial Praxis for Future Imaginaries of Nature: Introducing the Entangled Time Tree.” *Environmental Science & Policy* 151 (January 2024): 103615. https://doi.org/10.1016/j.envsci.2023.103615.

- Texocotitla, Miguel Alvarez, M. David Alvarez-Hernández, and Shaní Eneida Alvarez-Hernández. “Dimensional Analysis in Economics: A Study of the Neoclassical Economic Growth Model.” *Journal of Interdisciplinary Economics* 32, no. 2 (July 2020): 123–44. https://doi.org/10.1177/0260107919845269.

- Thornton, Thomas F., and Nadia Manasfi. “Adaptation—Genuine and Spurious: Demystifying Adaptation Processes in Relation to Climate Change.” *Environment and Society* 1, no. 1 (January 1, 2010). https://doi.org/10.3167/ares.2010.010107.

- Tuihedur Rahman, H. M., Amia Albizua, Bernard Soubry, and Wesley Tourangeau. “A Framework for Using Autonomous Adaptation as a Leverage Point in Sustainable Climate Adaptation.” *Climate Risk Management* 34 (January 1, 2021): 100376. https://doi.org/10.1016/j.crm.2021.100376.

- Van Beek, L., and W. Versteeg. “Plausibility in Models and Fiction: What Integrated Assessment Modellers Can Learn from an Interaction with Climate Fiction.” *Futures*, June 9, 2023, 103195. https://doi.org/10.1016/j.futures.2023.103195.

- Waring, Marilyn. *Counting for Nothing: What Men Value and What Women Are Worth*. 2nd ed. Toronto ; Buffalo: University of Toronto Press, 1999.

- Zander, Kerstin K., Stephen T. Garnett, Harald Sterly, Sonja Ayeb-Karlsson, Barbora Šedová, Hermann Lotze-Campen, Carmen Richerzhagen, and Hunter S. Baggen. “Topic Modelling Exposes Disciplinary Divergence in Research on the Nexus between Human Mobility and the Environment.” *Humanities and Social Sciences Communications* 9, no. 1 (February 1, 2022): 1–9. https://doi.org/10.1057/s41599-022-01038-2.