The Evolutionary Economic Geography of Climate Change

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ABSTRACT: The Evolutionary Economic Geography of Climate Change

The evolutionary economic geography of climate change is concerned with the processes by which the landscapes of greenhouse gas emissions and vulnerability to climate change are transformed from within over time. Unlike neoclassical economics, evolutionary economic geography is interested in how economic change is driven by innovation and shaped by structural, historical, and contextual factors at different scales. This thesis articulates an evolutionary economic geography perspective on three debates: (1) What factors influence human systems' capacity to adapt to climate change, and how can these factors be assessed? (2) What forces drive and inhibit economic change towards low-carbon economies, and how should governments induce and manage such shifts? (3) What role should climate finance play in promoting developing countries' shifts to low-emitting and climate-resilient economies, and how should it be managed? The thesis includes five academic papers. The first reviews the literature on vulnerability and adaptation. It argues that the adaptive capacity of human systems is constrained by structural and historical factors, and that the rich data necessary to identify these factors can only be obtained through qualitative research methods. The next two papers offer case studies from the Global Islands' Vulnerability Research Adaptation and Policy Development project, which assess the adaptive capacity of Soufriere, Saint Lucia and Whitehouse, Jamaica, respectively. The fourth paper examines the mechanics of three low-carbon shifts in Brazil: the diffusion of no-till agriculture, the decrease in the deforestation rate in the Amazon, and the growth of the ethanol biofuel industry. It found that the driving forces behind each of the shifts were far more varied and complex than the price-based market dynamics analysed in neoclassical economics. The final paper argues that climate finance will need to perform a variety of functions beyond attracting low-carbon private investment. It concludes that the institutional architecture governing climate finance should enable direct access to national governments to incentivise them to implement sustainable innovation policy regimes.

ACKNOWLEDGEMENTS

I have heard it said that doing a doctoral degree is a lonely experience. I am glad to say that my own was quite the opposite. Sure, there were certain tasks that could only be achieved through long periods spent with my own thoughts. But I found that throughout, I was able to share the experience with some very special people who not only provided welcome company, but who helped shape my perspective on the rather broad range of topics that I aimed to understand.

First and foremost, I would like to thank my two supervisors, Professor Dariusz Wójcik and Professor Sir David King, for taking a chance on me when I came to them with a research proposal only days before the application deadline. How different my life would have been had they not! After David retired from academia part way through my degree, Darek took sole control of the reigns, and, I must say, his exceptional abilities as a supervisor were a large part of what made my experience so enjoyable.

Although this thesis eventually grew into something much broader, it was largely borne out of a consulting project in which the Smith School of Enterprise and the Environment helped the Government of Rwanda to develop a *National Green Growth and Climate Resilience Strategy*. I was fortunate to be a part of this project, and am grateful to the entire team for making it a formative experience for myself. In particular, I am grateful to Megan Cole and Sally Tyldesley who, in the first year of my doctoral programme, became my research partners for two further consulting projects that laid the groundwork for Chapter 5 in this thesis on Brazil. Megan was also heavily involved in getting the GIVRAPD project off the ground, and I learned a great deal from her skills as a project manager.

Next, I would like to thank the hundreds of people in Brazil, St Lucia, and Jamaica who generously gave up their time to be interviewed for my research. I am deeply grateful for their insights, and hope that I have done justice to the experiences that they were so kind to share with me. I wish them all the best, particularly those whose lives and livelihoods are imperilled from climate change, environmental degradation, and economic hardship.

During the GIVRAPD project, I was accompanied by a wonderful team, who, beyond making the experience thoroughly enjoyable, shared many late night discussions with me that shaped my thinking about everything from vulnerability to politics. Most notably, I would like to acknowledge Jeremy Pittman and Dr Donovan Campbell for managing the field research in Soufriere and Whitehouse, respectively. I would also like to thank Sarah Corry, Wadzanai Madangombe and Marium Alleyne for their contribution to the fieldwork in St Lucia; and Steven Alexander, Thalia Balkaran, Maliha Majeed and Sherese Gentiles for their contribution to the work in Jamaica. Finally, I would like to thank Dr Machilu Zimba for her tireless work managing the GIVRAPD project, Dr Johanna Wandel for her guiding theories about vulnerability assessment, and Dr Murray Simpson for conceiving the GIVRAPD project and inviting me to join it.

I was fortunate to have excellent examiners during my transfer of status, confirmation of status and the final viva. Dr Patricia Daley, Dr Caitlin McElroy, and Dr Nicholas Howarth provided very insightful comments that not only gave me confidence in my progression, but also prevented me from heading down a few wrong paths. Professor Gordon Clark was my examiner at each milestone. He and Dr Tim Foxon made my culminating viva exactly what one ought to be – nerve-racking, challenging, thought provoking, and, in the end, immensely gratifying. I will never forget it.

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And then there were those who were not directly involved in my research, but who were an integral part of my life these last few years. I made some of my closest friends while at Oxford, and while many of them have moved on, I know that I will see them again for weddings, vacations, reunions, and perhaps even for collaborations. Having a network of your most trusted friends spread across the globe is indeed one of the most valuable assets that one can take away from a degree at Oxford.

I am forever grateful to my parents who took my brother and myself, from a young age, on travels far from our beautiful and comfortable home to experience

different ways of living, different value systems, and different paradigms. They encouraged us to take interest in the natural wonders and fragility of our planet, and fostered in us the idea that although an economic system based on the extraction and destruction of nature has become increasingly dominant over the last two centuries, it is by no means a superior societal organisation to those it displaces, nor is its relentless ascendance a *fait accompli*. My brother, David, cherished these lessons as much as I did, and I am inspired by the way in which he exhibits them in his own life's endeavours.

Lastly, but most deeply, I am grateful to my beautiful and brilliant wife, Dr Liliane Chamas, whom I shared the doctoral experience with every step of the way. Lily was the reason that I came to the UK in the first place. She encouraged me to apply for the doctoral programme at Oxford – a degree that I had never in a million years imagined myself taking, let alone obtaining. And through her ceaseless desire to live life to its fullest, she made the five years that we spent in Oxford the happiest of my life… so far.

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List of Abbreviations and Acronyms

ACP	African, Caribbean, and Pacific
ANFAVEA	Associação Nacional dos Fabricantes de Veículos Automotores
ARGeo	African Rift Geothermal Facility
BAU	business-as-usual
BBFFS	Bluefields Bay Fishermen Friendly Society
BPCA	Bluefields People's Community Association
CAPP	Canadian Association of Petroleum Producers
CARICOM	Caribbean Community
CATs	Clubes Amigos da Terra
CBCL	carbon border cost levelling
CBVA	community-based vulnerability assessment
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CDC	Community Development Committees
CDM	Clean Development Mechanism
CEMAM	Centre for Environmental Monitoring
CH_4	methane
CITES	Convention on International Trade in Endangered Species
CM	Club da Minhoca
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CoS	Conference of the Parties
CSO	Central Statistics Office
CTA	Centro de Tecnologia Aeronautica
D.Phil.	Doctor of Philosophy
DCA	Development Control Authority
DETER	Real-Time System for Detection of Deforestation
DICE	Dynamic Integrated Climate-Economy

EC$	East Caribbean dollars
ECLAC	Economic Commission for Latin America and the Caribbean
EIA	environmental impact assessment
EMBRAPA	Brazilian Company of Agricultural Research
ERA	emission reduction allowance
ERUM	emission reduction underwriting mechanism
EU	European Union
EUR	euros
EWS	early warning system
FAD	fish aggregating device
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GCM	General Circulation Models
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GIVRAPD	Global Islands' Vulnerability Research Adaptation and Policy Development
GoB	Government of Brazil
GoSL	Government of Saint Lucia
Gt	gigatonnes
GTZ	Gesellschaft für Technische Zusammenarbeit
ha	hectares
HEART	Human Employment and Resource Training
HVAC	heating, ventilation, and air conditioning
IAA	Instituto de Azucar e Alcool
IAM	integrated assessment model
IAPAR	Agronomic Institute of Paraná
IBAMA	Centre for Environmental Monitoring at the Brazilian Environmental and

	Renewable Natural Resource Institute
IFC	International Financial Corporation
IFI	international financial institutions
IMF	International Monetary Fund
INPE	Brazil's Space Agency
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
IPEAME	Intituto de Pesuisas Agropecuarias
IRR	internal rate of return
IT	information technology
JOAM	Jamaica Organic Agricultural Movement
KfW	Kreditanstalt für Wiederaufbau
kg	kilograms
km	kilometres
km^2	square kilometres
LAC	Local Adaptive Capacity
LDC	Least Developed Country
LULUCF	land-use, land-use change, and forestry
MAC	marginal abatement cost
MACC	Mainstreaming Adaptation to Climate Change
Mha	million hectares
MLP	multi-level perspective
MMA	Ministry of Environment
MPA	marine protected area
MPF	Federal Prosecutor’s Office
Mt	million tonnes
MW	megawatt
N_2O	nitrous oxide

NAMA	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Plan of Action
NCCPAP	National Climate Change Policy and Adaptation Plan
NEMO	National Emergency Management Office
NEPA	National Environmental Protection Agency
NGO	non-governmental organisation
NOAA	National Oceanic and Atmospheric Administration
ODA	official development assistance
ODI	Overseas Development Institute
ODPEM	Office of Disaster Preparedness and Emergency Management
PAR	Pressure and Release
PES	payments-for-ecosystem-services
PIOJ	Planning Institute of Jamaica
PMA	Pitons Management Area
PPCDAm	Action Plan for the Prevention and Control of Deforestation in the Legal Amazon
PPCR	Pilot Programme for Climate Resilience
ppm	parts-per-million
PVC	polyvinyl chloride
R&D	research and development
RADA	Rural Agricultural Development Agency
RCM	Regional Circulation Models
RCP	representative concentration pathways
REDD	reduced emissions from deforestation and forest degradation
SACCO	savings and credit cooperatives
SCC	social cost of carbon
SDC	Social Development Commission
SI	sustainable innovation

SIDS	small island developing states
SIOJ	Statistical Institute of Jamaica
SLCGA	Saint Lucia Coconut Growers Association
SMMA	Soufriere Marine Management Area/Soufriere Marine Management Authority
SNLT	Sectoral No-Lose Target
SRES	Special Report on Emissions Scenarios
SST	sea surface temperature
tCO_2	tonnes of carbon dioxide
tCO_2e	tonnes of carbon dioxide equivalent
UK	United Kingdom
UN	United Nations
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
UN/ISDR	United Nations International Strategy for Disaster Risk Reduction
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States dollars
USA	United States of America
USAID	United States Aid for International Development
UWI	University of West Indies
WASCO	Water and Sewerage Company
WRI	World Resources Institute
WTO	World Trade Organization

1 Introduction

1.1 Framing the problem

Since the origin of our species about 250 thousand years ago, *Homo sapiens* has demonstrated an extraordinary capacity to adapt to different environments and climates (J. Stewart & Stringer, 2012). Through unparalleled ingenuity, humans have carved out niches in landscapes as diverse as the frozen tundra of the Arctic; the soaring mountains of the Himalaya and Andes; the nearly arid steppe of Mongolia, the Sahel, and Australia; and the dense, humid rainforests of Papua New Guinea, the Congo, and the Amazon. However, it was in the fertile grasslands and great river valleys that humans thrived.

Evidence suggests that the gradual transition from hunting and gathering of wild animals and crops to domestication and deliberate cultivation began, at most, 13 thousand years ago in the Fertile Crescent of Mesopotamia. The surplus of food created by agriculture laid the foundation for the evolution of civilizations with sedentary lifestyles, complex social structures, divisions of labour, writing systems, experimentation with pottery and metal, and towns and markets (Diamond, 1997). This transition coincided with the end of the last ice age and the dawning of the current geological epoch, the Holocene. Between 12 thousand and 7000 years ago, the glaciers retreated and temperatures and sea levels increased to approximately pre-industrial levels. For the last seven millennia, temperatures fluctuated at most 1 to 1.5 °C above and below a mean (Stern, 2013, p. 840). It was in this context of a relatively stable climate that all of recorded human history played out.

Mounting evidence suggests that the planet is currently verging on another rapid shift in the global climate due to the changing composition of the atmosphere caused by recent human activity. Since the industrial revolution (~1760 to 1850), large-scale combustion of fossil fuels and changes in land-use has caused a rapid increase in the atmospheric concentration of greenhouse gases (GHGs): carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The growth in GHGs has caused the quantity of solar energy retained by the earth's atmosphere to increase, driving climate change.

Between 1850 and 2011, annual global emissions increased from under 200 million tonnes CO_2 (tCO_2) to 32.3 billion (WRI, 2014). As a result, the concentration of CO_2 in the atmosphere grew from 270 parts-per-million (ppm) before the industrial revolution to almost 400 ppm in 2012, a level not seen for at least 800 thousand years and probably not for three million years (Luthi, et al., 2008; NOAA, 2014; Pagani, Liu, LaRiviere, & Ravelo, 2010; Stern, 2013). When other GHG emissions are taken into account, the concentration of CO_2e[1] is 445 ppm (Stern, 2013). To put this in perspective, the Intergovernmental Panel on Climate Change (IPCC, 2007) estimated that to give a median chance of preventing temperatures from rising more than the commonly cited 2 °C threshold above pre-industrial levels, global atmospheric concentrations of GHGs must be stabilised at a level below 450 ppm CO_2e.

Stern (2013, p. 840) argues that another century of business-as-usual (BAU)[2] emission levels could add a further 300 ppm: "The last time CO_2 levels exceeded 750

[1] CO_2e is a unit of measurement of the global warming potential of GHG emissions over a given time period (generally 100 years). It is equal to the quantity of CO_2 emissions that it would take to equal the global warming potential of a given mixture of greenhouse gases.

[2] BAU levels are projections of future emission levels based on current policies and trends.

ppm, with surface temperatures well beyond 4 °C above preindustrial, was likely about 35 million years ago during the Eocene Epoch when the planet was entirely ice-free, which today would drive a sea level rise of 70 meters."

1.2 The Aims and Motivation for this Research

Addressing climate change will require significant change to human systems – economic change, technological change, socio-cultural change and institutional change. These changes are necessary both to adapt to the impacts of climate change and to reduce GHG emissions. It is the mechanics of these changes, and the latent capacity of human systems to adjust, that are the topics of this thesis.

Thus far, much of investigation into how these changes might occur, and how they can be managed, has been based on neoclassical economics and the related branches of environmental and welfare economics. This literature has been codified most prominently in the *Stern Review on the Economics of Climate Change,* published at the request of the UK government in 2006. The cover of the *Stern Review* features a photograph of Earth from outer space. Presumably, the intention of Lord Stern and his team in featuring this photograph was to convey a message about the fragility of the planet and about the entirety of the human species sharing in the predicament of climate change. However, the photograph also conveyed the message that Earth is a holistic entity that can be analysed as a single system. Whether intentional or not, this latter message resonates well with neoclassical economics. The field uses equilibrium models to analyse how prices and outputs in a market system are determined by the forces of supply and demand, and how each one of these elements – prices, outputs, supply, and demand – can be altered by tinkering with another in the system. Applied at the global scale, these models were used to promote the large-scale liberalisation of world trade in the latter half of the 20th century. In the *Stern Review*, and in other documents on the economics of climate change, they are used to prescribe universal price-based policies to induce a reduction in GHG emissions, such as cap-and-trade systems and carbon taxes.

I became familiar with literature on the economics of climate change prior to my D.Phil. as research officer with the Smith School of Enterprise and the Environment at the University of Oxford. Our team was contracted by the Government of Rwanda to help develop a *National Green Growth and Climate Resilience Strategy*, and I was based in the Ministry of Finance and Economic Planning in Kigali. Based on this experience, and others, I found that the literature on the economics of climate change failed to capture some of the most important (and in my opinion, most interesting) factors that determine levels of GHG emissions. As a result, this literature provided insufficient and sometimes inappropriate policy prescriptions for how to reduce emissions.

For example, in Rwanda, our team observed that the country's ability to shift away from using diesel to produce electricity had little to do with the price of oil (which was relatively expensive in the landlocked country). More relevant was whether Rwanda could develop the human capital necessary to harvest its rich geothermal energy reserves, or whether it could overcome the political barriers that existed with neighbouring states to develop the shared hydropower potential in the region. Likewise, in my own home country of Canada, where 25% of GHG emissions are released during oil production (Environment Canada, 2014), it is evident that the future trajectory of GHG emissions has less to do with the price of fossil fuels than it does with the outcome of fierce political battles raging between local communities, First Nations, multi-national corporations, and governments in Canada and the United States over planned pipelines that would allow oil from landlocked Alberta to reach a sea port. The Canadian Association of Petroleum Producers (CAPP, 2014) has made it clear that access to global markets is a prerequisite for it to fulfil its current plan to double oil sands production in the next decade.

The primary motivating factor for my D.Phil. research was my observation that literature on the economics of climate change has failed to capture the contextual factors associated with local politics, culture, and knowledge that I observed to be so important to outcomes in Rwanda and Canada. I began to search for other theories of economic change that provided more nuanced insights into mitigation and adaptation to climate change.

In contrast to neoclassical economics' efforts to identify universal laws and principles that govern how economies function, economic geography places contextual factors that cause spatial variation in economic activity at the centre of inquiry. Economic geography itself has different sub-disciplines and perspectives, but at its most basic, it applies geographical themes – such as space, place, and scale – to the study of the economy (Coe, Kelly, & Yeung, 2013):

- *Space* – Where within a physical space is an economic activity happening? How does distance affect flows of trade, knowledge exchange, migration, etc.? Why is economic activity uneven across space?

- *Place* – How do the unique attributes of a place – cultural, historical, ecological, institutional, political, etc. – govern its local economic activity?
- *Scale* – How do processes at different scales – household, local, regional, national, macro-regional, and global – interact with one another to shape the spatial variation in economic activity?

These themes I considered to be essential to any theoretical framework used to explain economic change in response to climate change. Therefore, the methodologies that I applied in each of the case studies discussed in the following chapters were designed to draw out relevant factors associated with space, place, and scale.

One final theme that I considered to be important – given the varying temporal horizons in which climate impacts are projected to manifest and the diminishing window of opportunity to reduce GHG emissions – is *time*. Economic geographers have long been interested in "understanding the processes of change in and across the economic landscape" (Clark, Feldman, & Gertler, 2000, p. viii). However, it was a new branch of economic geography, evolutionary economic geography, which I found offered the most powerful insights into how economic landscapes change over long temporal horizons. Evolutionary economic geography incorporates concepts from evolutionary economics such as the routinisation of human behaviour, bounded rationality, diversity, competition through innovation, shifting selection pressures and path-dependency.

The central argument of this thesis is that evolutionary economic geography provides a more nuanced understanding than neoclassical economics about the mechanics of economic change in response to climate change. Its focus on the empirical observation of forces that drive and inhibit change in real-world human systems, rather than in equilibrium models, offers a more powerful framework for understanding the processes of adaptation and mitigation. Moreover, its acceptance that economic change must be embedded in place, space, and scale(s) allows for an exploration of the non-price-based factors that shape economic change in a specific cultural, ecological, structural, and historical context. As a result of its more nuanced understanding of economic change, this thesis argues that evolutionary economic geography can provide valuable insights into the design of policy prescriptions that aim to induce and manage mitigation and adaptation to climate change.

As far as I am aware, this thesis is the most comprehensive application of evolutionary economic geography to the analysis of economic change in response to climate change. However, as discussed in the literature review, a number of studies have called for the application of an 'evolutionary approach' to environmental economic geography (Hayter, 2008; Patchell & Hayter, 2013). Howarth (2012) incorporated insights from evolutionary economics in his 'integrated approach' that focused on the mitigation of climate change, and Foxon (2011) called for a coevolutionary framework for analysing sustainability transitions. Furthermore, a number of rich, yet distinct bodies of literature – such as those on vulnerability to climate change, and on sustainability transitions – have applied theories, methods, and conclusions that closely mirror those of this thesis. Perhaps the most valuable contribution of this thesis is the proposition that evolutionary economic geography offers an alternative to neoclassical economics as an overarching theory of economic change within which these more narrowly focused studies on climate change adaptation and mitigation can be embedded.

While the title, *The Evolutionary Economic Geography of Climate Change*, may risk implying that the product will be a complete and coherent theoretical perspective on everything to do with economic change in response to climate change, the objective will in fact be much more modest. This modesty is largely due to the dynamic and highly contextual nature of the subject matter, which means that unlike the economics of climate change, in which the main arguments can be summarised neatly in a single document, the development of an evolutionary economic geography of climate change is an ongoing project that can never truly be complete.

Instead, the objective of the thesis is to articulate an evolutionary economic geography perspective on some of the central debates concerning climate change:

1. What factors influence human systems' capacity to adapt to climate change, and how can these factors be assessed?
2. What forces drive and inhibit economic change towards low-carbon economies? How should governments induce and manage such shifts?
3. What role should climate finance play in developing countries' shifts to low-carbon and climate-resilient economies, and how should the institutional architecture governing it be designed?

These questions are addressed in the following chapters.

According to Boschma & Martin (2010, pp. 6-7), evolutionary economic geography is concerned with "the processes by which the economic landscape – the spatial organisation of economic production, circulation, exchange, distribution, and consumption – is transformed from within over time." Based on this definition, an evolutionary economic geography of climate change would be concerned with the processes by which the landscapes of vulnerability and GHG emissions are transformed from within over time. Hence, a natural starting point for an evolutionary economic geography analysis of climate change would be an inquiry into the temporal and spatial variation of GHG emissions and the impacts of climate change. Sections 1.2.1 and 1.2.2 provide an overview of the changing landscapes of GHG emissions and climate change impacts, respectively.

1.2.1 The Changing Landscape of Greenhouse Gas Emissions

The degree of climate change is determined by the total global stock of GHGs. However, the source of these emissions has varied substantially across space. As seen in Figure 1, industrialised countries are responsible for most cumulative emissions.

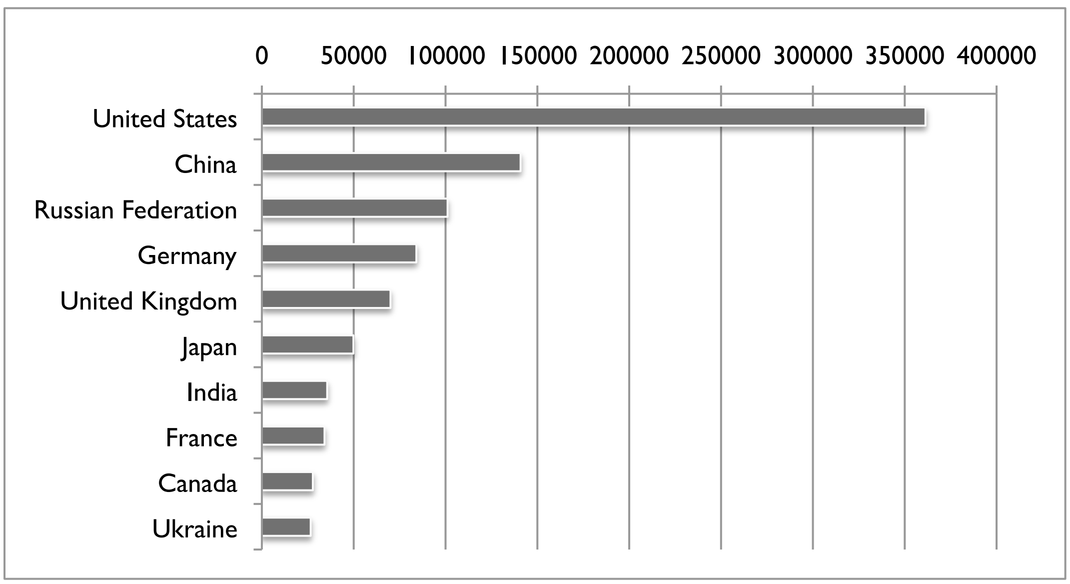


Figure 1. Cumulative CO_2 emissions of top ten emitting countries, 1850 – 2008 (in $MtCO_2$) (Data from WRI, 2014).

Recently, the spatial variation of GHG emissions has shifted rapidly. Despite having lower per capita emissions (Figure 2), large developing countries – China, India, Indonesia, and Brazil – have become the world's biggest emitters alongside the USA and

Russia (Figure 3). Figure 3 further demonstrates that the primary emission sources also vary across countries. Whereas the primary source of emissions in most highly polluting countries is the combustion of fossil fuels for electricity generation, transportation, and the buildings sector, the primary source in Brazil and Indonesia is land-use, land-use change, and forestry (LULUCF).

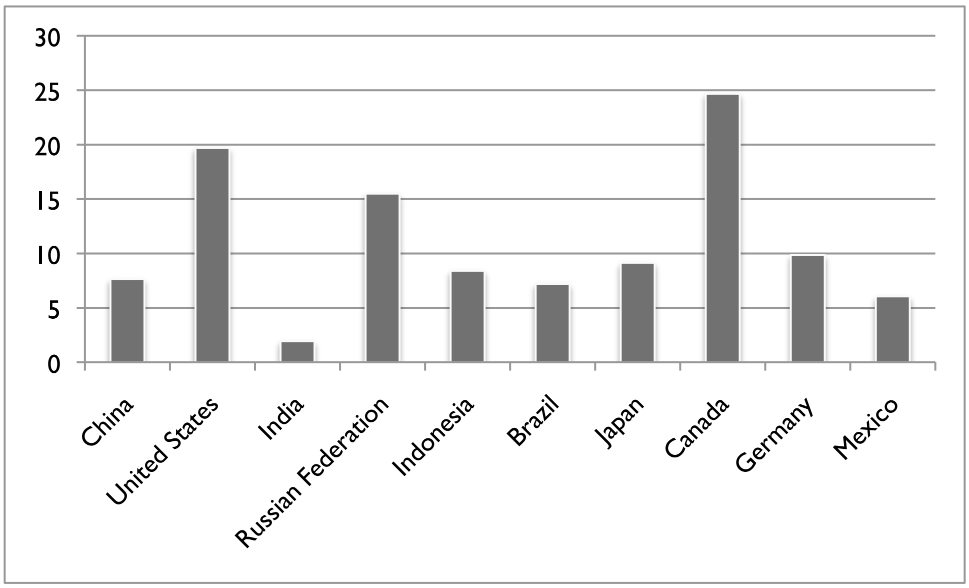


Figure 2. Per capita GHG emissions in top ten emitting countries in 2011 (CO_2e) (Data from WRI, 2014).

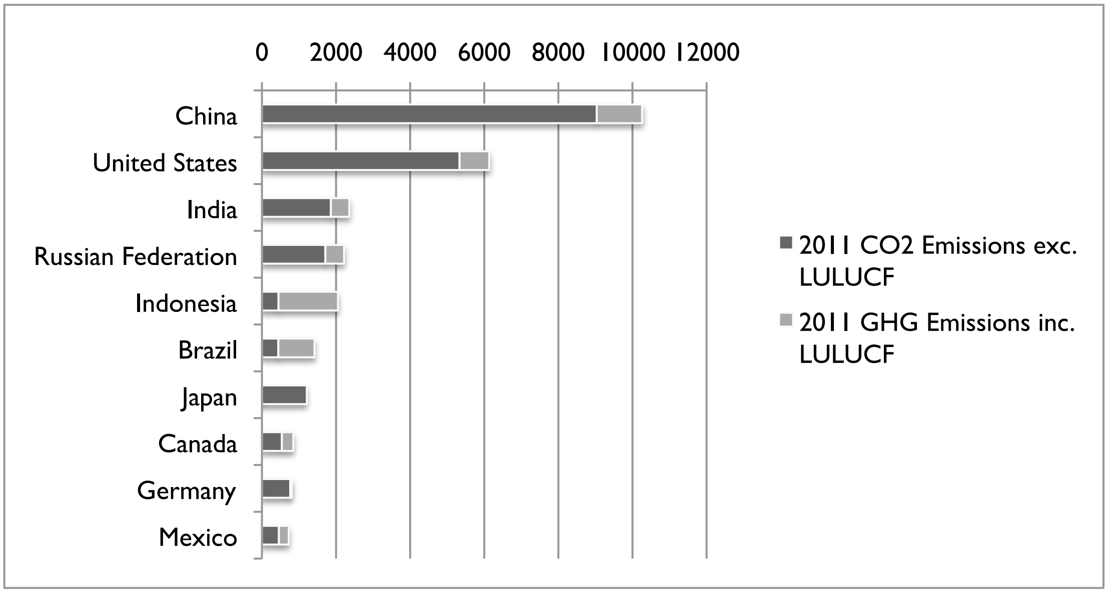


Figure 3. The world's biggest annual GHG emitters in 2011 (in $MtCO_2e$) (Data from WRI, 2014).

As seen in Figure 4, most growth in global emissions is projected to occur in developing countries (McKinsey, 2009b). As a result, even if developed country emissions are sharply reduced, the 450 ppm target cannot be achieved without reductions by large developing countries relative to BAU levels (R. Stewart, Kingsbury, & Rudyk, 2009).

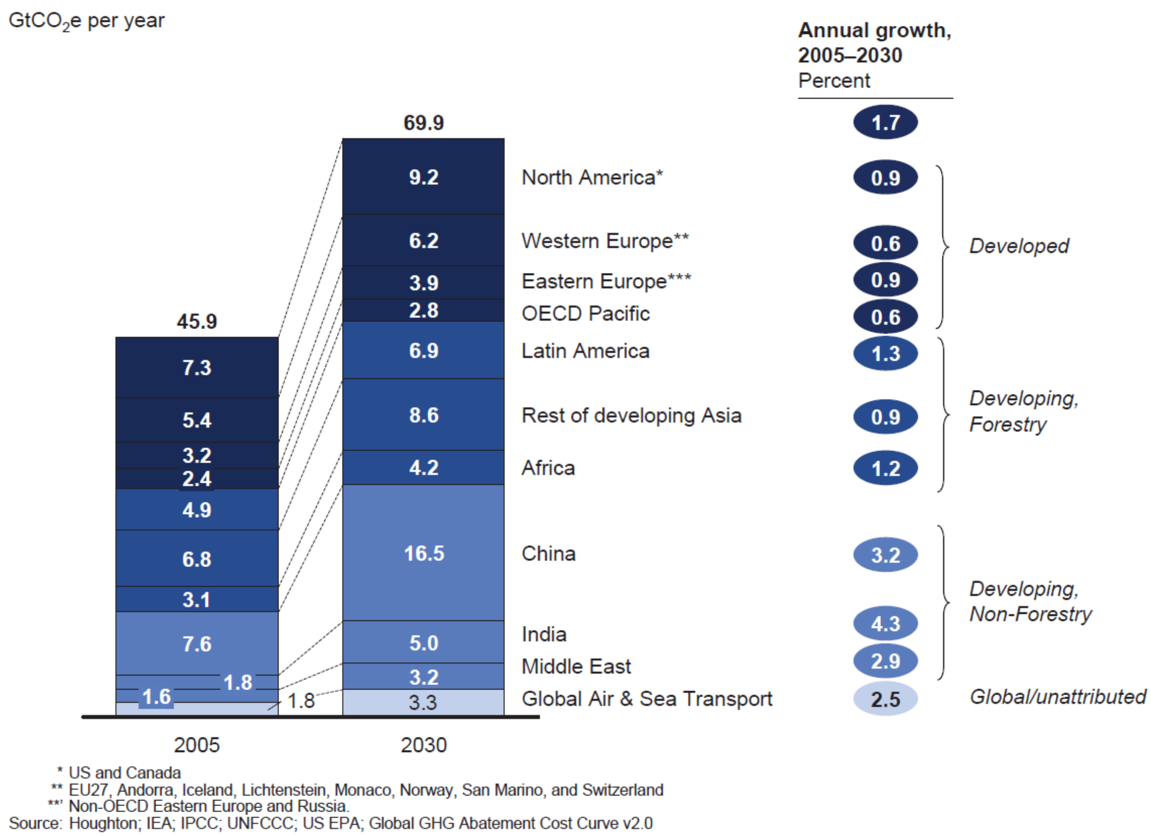


Figure 4. Business-as-usual emission splits between 2005 and 2030 (in GtCO$_2$e) (McKinsey, 2009b, p. 25).

The cost of abating GHG emissions also varies across space. Many of the most economically efficient measures to abate emissions are in developing countries. Emerging economic powers are currently investing in new large-scale infrastructure, which presents low-cost mitigation opportunities because installing efficient technologies at the outset is cheaper than retrofitting existing infrastructure (McKinsey, 2009b). Moreover, emissions from agriculture, forestry, and land-use – 90% of which occur in the developing world – represent 46% of global potential emission reductions (Bettelheim, 2009).

Whilst the landscape of GHG emission production has shifted towards large developing countries, the shift is not as drastic if GHG emissions are measured using consumption-based accounting. In consumption-based accounting, when GHG emissions are generated in one country during the production of goods that are consumed in another, those emissions are attributed to the recipient country. In 2004, around 6.2 Gt CO_2 (23% of total CO_2 emissions from fossil fuels) was emitted in the production of goods that were then consumed in a different country. Taking imported and exported emissions into account can either positively or negatively affect a country's overall emissions. For example, it was found that in developed countries such as Switzerland, Sweden, Austria, the UK, and France, over 30% of consumption-based CO_2 emissions in 2004 were imported. When calculated on a per capita basis these imports add just over 4 tCO_2 (50% of total emissions per capita) to those countries' emissions accounts (S. Davis & Caldeira, 2010). In China on the other hand, a net 22.5% of the emissions produced in 2004 were exported to consumers elsewhere, which reduces its contribution to global emissions to the point where it is no longer the world's biggest emitter. Figure 5 demonstrates these large-scale global transfers, showing how exports from China to the USA and Europe dominate 'emissions trade.'

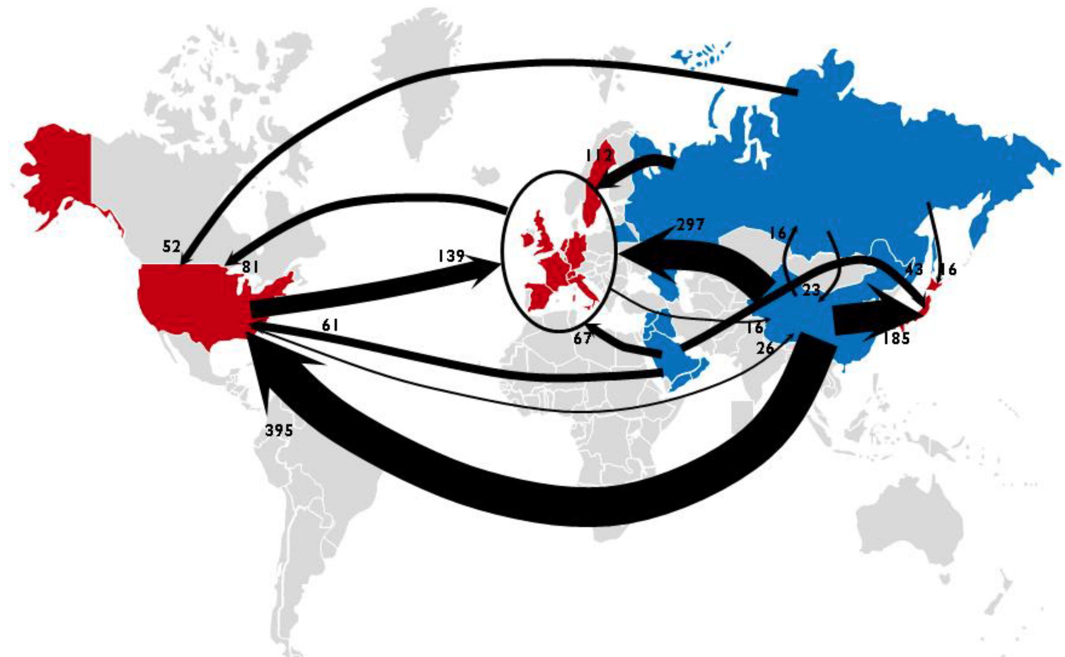


Figure 5. Largest interregional fluxes of emissions embodied in trade (Mt CO_2 y-1) from dominant net exporting countries (blue) to the dominant net importing countries (red). Fluxes to and from Western Europe are aggregated to include the United Kingdom, France, Germany, Switzerland, Italy, Spain, Luxembourg, The Netherlands, and Sweden (S. Davis & Caldeira, 2010, p. 5688).

1.2.2 The Landscape of Climate Change Impacts and Vulnerability

Observed and projected changes in the climate vary across space. Figure 6 and Figure 7, provided by IPCC (2014), illustrate the projected temperature and annual rainfall change across the globe for the years 2081-2100 in two different scenarios: ambitious mitigation (RCP2.6) and continued high emissions (RCP8.5).

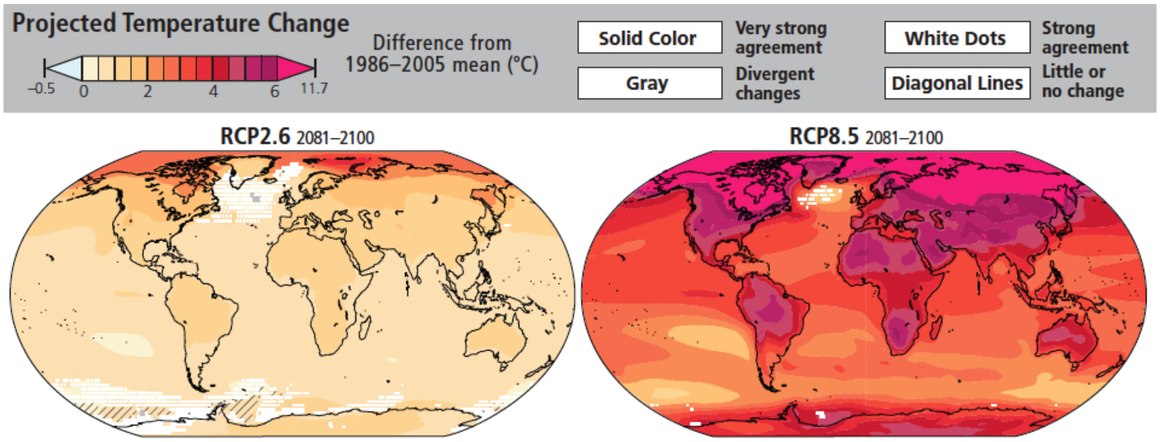


Figure 6. Projected changes in annual average surface temperature under ambitious mitigation (RCP2.6) and continued high emissions (RCP8.5) scenarios (IPCC, 2014, p. 57).

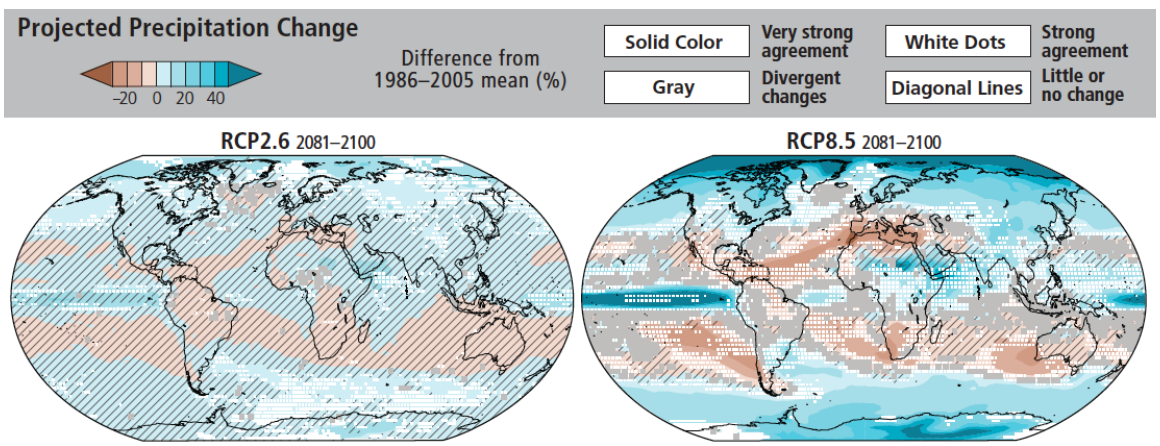


Figure 7. Projected changes in annual average rainfall under ambitious mitigation (RCP2.6) and continued high emissions (RCP8.5) scenarios (IPCC, 2014, p. 58).

The impacts of climate change will also vary significantly across space. The IPCC (1998, 2001, 2007, 2012, 2014) has provided thorough analysis of projected regional impacts. Figure 8 shows the change in flood frequencies across the globe by the 2080s in the RCP8.5 high emissions scenario. Figure 9 shows changes to freshwater availability between 2081 and 2100 in the SRES A1B emissions scenario, in which warming reaches 3 °C by 2090. Note the reduced freshwater availability in the Caribbean.

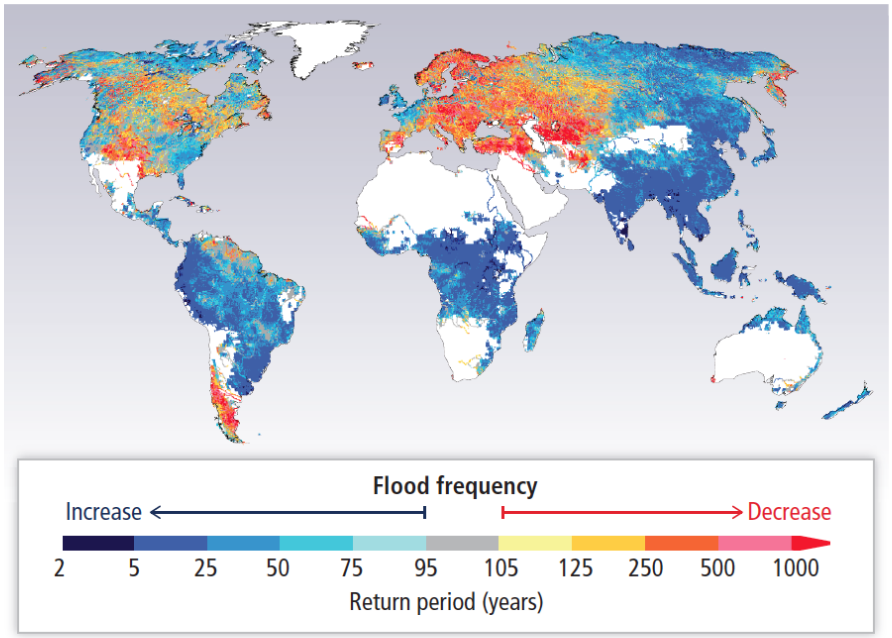


Figure 8. In the 2080s under RCP8.5, multi-model median return period (years) for the 20th-century 100-year flood (IPCC, 2014, p. 66).

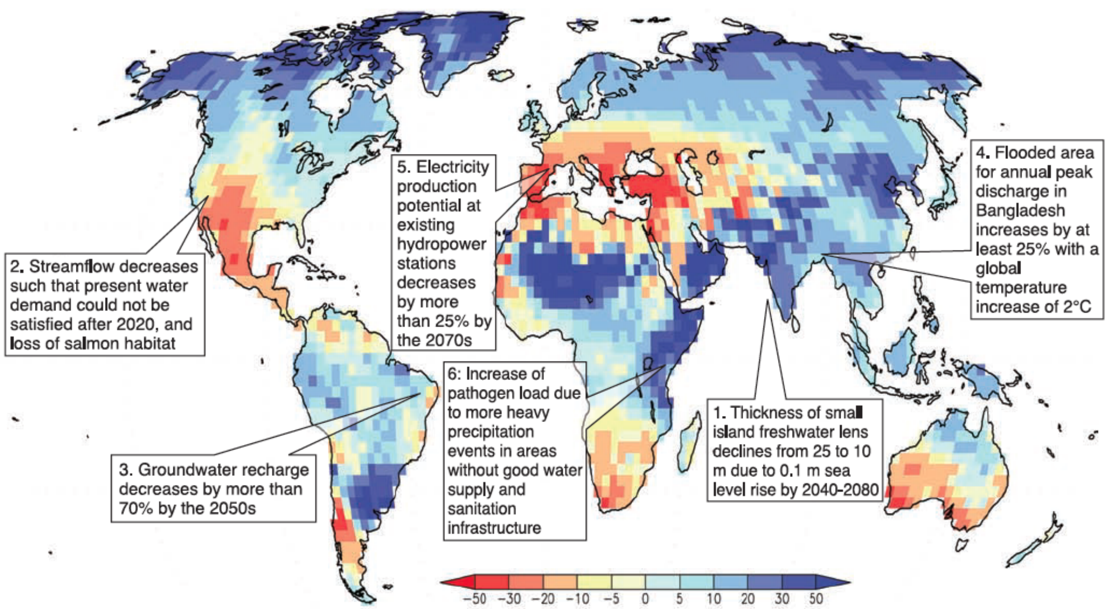


Figure 9. Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. Background shows ensemble mean change of annual runoff, in percent, between the present (1981-2000) and 2081-2100 for the SRES A1B emissions scenario; blue denotes increased runoff, red denotes decreased runoff (IPCC, 2007, p. 36).

Also relevant to the case studies in this thesis, Figure 10 illustrates a projection of changes in maximum catch potential of exploited fish and invertebrate species in the 2050s relative to the 2000s under the SRES A1B emissions scenario. Note the projected decrease in the Caribbean basin. Finally, Figure 11 examines areas in Latin America where climate change impacts are expected to be severe. Listed impacts in the Caribbean include threats to coral reefs and mangroves from warmer sea surface temperature (SST), further threats to mangroves from sea level rise, increased intensity of extreme events, and severe threats to biodiversity.

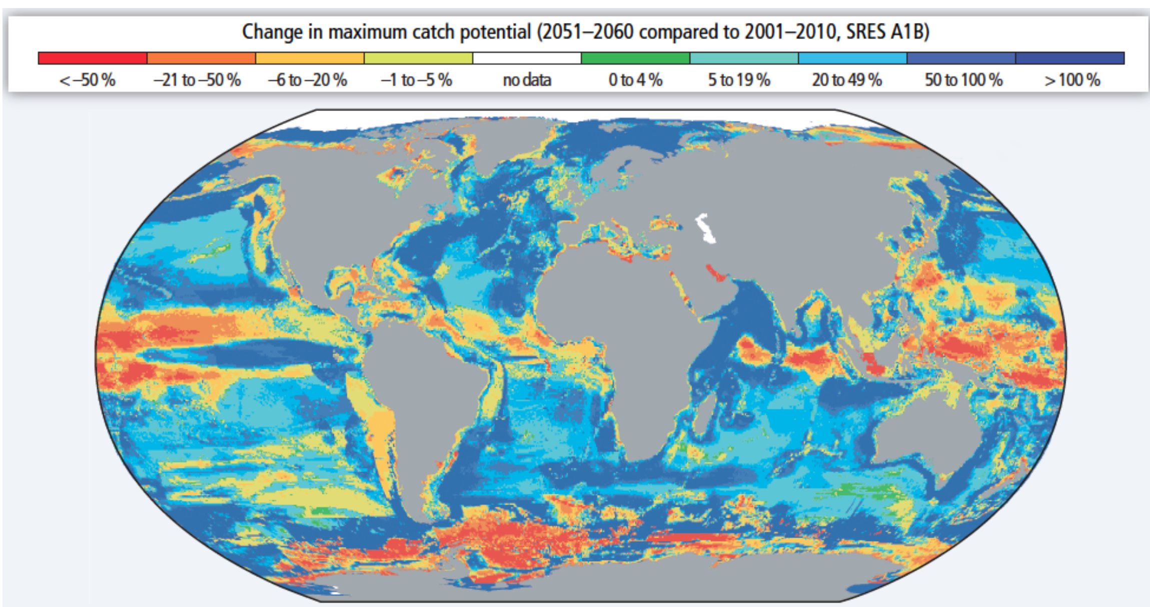


Figure 10. Projected global redistribution of maximum catch potential of ~1000 exploited fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using SRES A1B, without analysis of potential impacts of overfishing or ocean acidification (IPCC, 2014, p. 69).

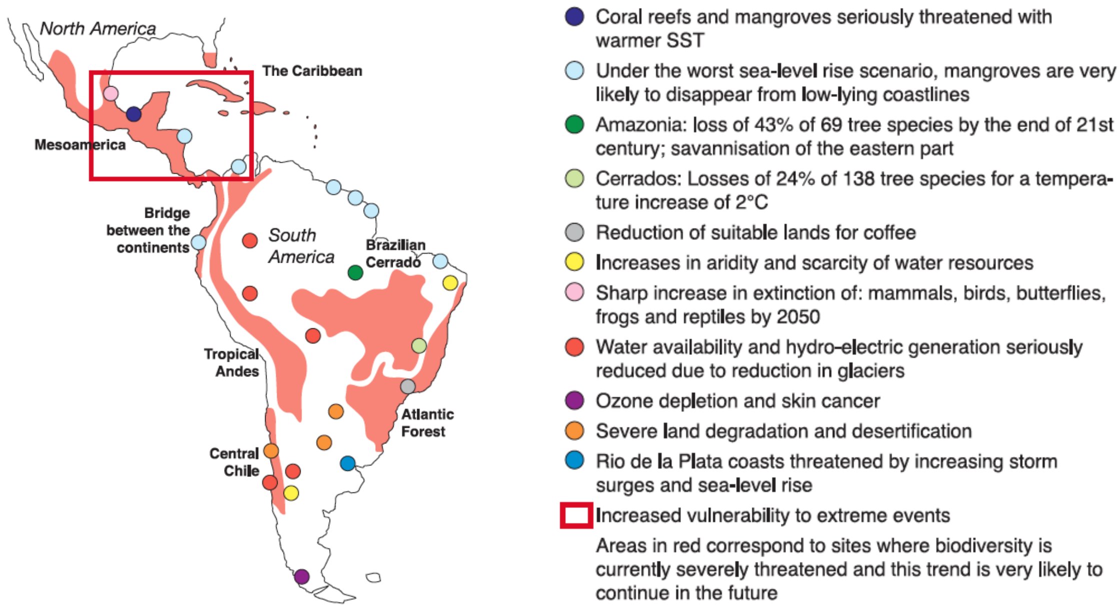


Figure 11. Key hotspots for Latin America where climate change impacts are expected to be particularly severe (IPCC, 2007, p. 54).

Within these regional trends, the manifestation of many climate change impacts – such as sea level rise, coastal erosion, and the availability of freshwater – will vary significantly due to complex localised factors including topography, coastal geology, and the local hydrological cycle.

Importantly, the exogenous exposure of a human system to climate change and associated impacts is only one component of *vulnerability* – or "the propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events" (IPCC, 2012, p. 69). Endogenous characteristics of the local system will also play a role in determining how climate change is experienced. Therefore, mapping the spatial variation of vulnerability to climate change requires an understanding about how human systems will respond.

1.3 Overarching epistemology and methodological approach

Each of the empirical papers in my thesis will have their own methodology section. This overarching methodology section aims simply to provide an epistemological justification for the use of qualitative case studies in this thesis.

In contrast to neoclassical economics' search for universal laws that govern economic activity, economic geographers are concerned with "understanding the social embeddedness of economic action, mapping shifting identities of social actors, and exploring the role of material and discursive contexts in shaping economic behaviour" (Yeung, 2003, p. 442). As argued by Boschma & Martin (2010, p. 6), this need to consider the embeddedness of economic activity is highly applicable to evolutionary economic geography approaches:

> *"[E]conomic transformation proceeds differently in different places, and the mechanisms involved neither originate nor operate evenly across space. The emphasis is on understanding the process and mechanisms that make for or hinder the adaptation of the economic landscape, and how spatial and historical contingency with systemic necessity"*

An evolutionary economic geography analysis therefore necessitates rich data about the contextual, scalar, structural, and historical elements that influence economic change in different locations. To uncover these contextual factors, economic geographers must apply different research methodologies than neoclassical economists.

One approach to gathering such contextual data is the use of qualitative methods to analyse specific topics or places through case studies. The use of qualitative methods in the study of economic geographies demands a whole series of epistemological questions. Qualitative methods are often perceived to be laden with researcher bias and to suffer from a so-called ‘crisis of representation.’ Scrutinisation of the practice of qualitative fieldwork, by feminist literature in particular, has raised doubts about the “possibility of truthful portrayals of others” and the “capacity of the subaltern to be heard” (Ortner, 1996, p. 190). In contrast, the set of quantitative methods used in neoclassical economics and certain branches of economic geography (e.g., randomized surveys, modelling, and hypothesis testing) has “often been perceived as ‘scientific’ and ‘objective’ in that it is ‘neutral’ in research execution and it separates the researcher from the subject researched” (Yeung, 2003, p. 443).

Clark (1998, p. 74) contested this perception, arguing that “academic objectivity, in a strong sense, is only plausible if we retreat to a theory of knowledge that idealises facts and strips bare the complexity of [social] life.” In other words, in the search for objectivity and universal truths, neoclassical economics has missed out on many of the important contextual factors geographers have observed to influence economic life.

This problematisation of the ‘scientific methods’ applied in neoclassical economics elicits questions about whether the social is world knowable at all, and if so, about the process of knowledge construction. After all, if objectivity is not possible, and social processes are context-specific, how can social scientists ever arrive at replicable theoretical conclusions? As asked by Yeung (2003, p. 453), “Are we happy merely with critical geography’s modest aims to ‘contextualize,’ ‘explore,’ ‘sketch,’ ‘tease out,’ ‘trace,’ ‘map,’ ‘allegoricize,’ ‘interrogate,’ ‘empathize with,’ and so on?’” And if so, what can the field possibly contribute to policy debates?

McDowell (1994) and Clark (1998) overcame this epistemological stalemate through the use of a metaphor that places theory and empirical observation on opposing ends of a see-saw. Both, they argued, are necessary to the process of knowledge-building. On the one hand, the discipline of theory is necessary to draw conclusions from complex empirical observations. On the other, empirical observation provides the opportunity to test the validity of theory and to amend it accordingly.

Whereas geographers have traditionally held to the empirical side of the see-saw, neoclassical economists rely primarily on theory. As explained by Clark (1998, p. 74), the latter's treatment of the efficient market hypothesis as 'fact' has had "far-reaching implications for what are legitimate questions of research […], what are legitimate assumptions about individual decision-making […], and what are legitimate arguments about regulation […]." This observation is particularly true in studies on the economics of climate change. This thesis will argue that empirical analyses of the contextual, scalar, structural, and historical elements in which economic change takes place will provide a much richer understanding of the landscapes of GHG emissions and vulnerability to climate change. It will therefore seek balance in its methodology between empirical observations made in case studies and developing evolutionary economic geography as a theory.

As argued by Gertler (2010), a comparative approach is preferable to stand-alone case studies, because it creates a foundation on which to build theory. Barnes, Peck, Sheppard, & Tickell (2007, p. 22) concurred with this perspective: "Sustained theoretical development by way of case-study research is hampered by an apparent disinclination across the field to invest in corroboration, triangulation, and interrogation across comparative sites." Multi-disciplinary empirical case studies allow for comparison across sectors, countries, and regions (Coenen, Benneworth, & Truffer, 2010; Gertler, 2010; Smit & Wandel, 2006). For this reason, this thesis will employ comparative case studies – across sites in Saint Lucia and Jamaica and across sectors in Brazil.

Qualitative methods 'crisis of representation,' discussed earlier in this section, is particularly relevant to the case studies in Chapter 4. In these studies a total of 300 individuals from Soufriere, St Lucia and Whitehouse, Jamaica were interviewed. Each of these individuals was related in some way to the tourism, agriculture, or fisheries sectors, but the boundaries of eligible relationships were loosely defined so as to enable the participation of diverse respondents including, for example, government officials that regulated the sectors, shopkeepers that sold local produce, and bankers that provided agricultural credit. As a result, the respondents varied widely in everything from wealth, to ethnicity, to livelihood, to political views and power. The sheer number of interview respondents meant that not everyone could be represented in the chapter through quotation.

The critique that a researcher can never truly escape his or her own personal biases when tasked with determining which respondents' views and quotations will be represented in the final manuscript, and how, is one that probably can never truly be overcome. Nonetheless, like Nagar & Geiger (2007), I believe that the value of fieldwork, in terms of the networks formed and the knowledge created and disseminated, outweighs its problematic context. It is the responsibility of the researcher to take measures to present as an objective an argument as possible.

One step in overcoming the crisis of representation, according to Marcus (1992, p. 490) is reflexivity: "Some sort of reflexive identification of the academic writer with the 'Other' interpreted, analysed or written about, is so important in re-establishing critical authority in the rubble of paradigms precisely because the most powerful and paralyzing aspect of the critique of representation has been its ethical implications for the very mode of communication – discursive, impersonal writing – so basic to academic work." Hence, it would be appropriate for me to comment that my positionality throughout the research process in Jamaica, St Lucia, as well as Brazil was one of an outsider. My identity as a White, middle-class, and Canadian man in his late-twenties likely influenced the research process in a number of ways (as did the identities of the other researchers on the fieldwork teams). My understanding about the local history, culture, and politics grew throughout the projects, which influenced the questions that I asked the respondents as well as the way in which I interpreted the answers. My identity also presumably influenced their responses – the so-called 'interviewer's effect' discussed in Yeung (2003, p. 448). For example, the respondents may have been more or less inclined to reveal insights about specific social dynamics to me, as an outsider, than to other members of the community. Furthermore, my ethnic identity carries with it inescapable social and political baggage – especially that which is tied up in histories of slavery and colonialism – that may or may not have influenced the manner in which the interviews proceeded.

These inherent weaknesses acknowledged, a number of methodological steps were taken to further the aim of objectivity.[3] First, the interview designs sought to promote a "*speaking-with* model of engagement between the researcher and researched" (Nagar & Geiger, 2007, p. 270, original emphasis). Although the interviews were semi-structured, each began with contextual questions about the individual's social and economic situation, followed by open-ended questions designed to explore, not probe. Each conversation was initially led by the respondents, and researchers adjusted their questions based on respondents' situations. Second, in both Soufriere and Whitehouse, local partners were included as part of the research team in order to increase the team's understanding about the local context. Third, in order to ensure adequate representation of the population, a snowball sampling methodology was employed in Soufriere and Whitehouse, in which 'snowballs' were purposely initiated in the most marginalised segments of the communities. Fourth, in the analysis of the interviews, the software NVivo was used to 'codify' the transcripts according to evolutionary themes. While the process of codification cannot fully remove the inherent biases of the researcher in determining how the interview respondents would be represented, it does force the researcher to consider each interview in full and to categorise the transcripts in a way that they can be easily compared across topics so as to avoid 'cherry picking' of quotes in support of their arguments. Finally, in each study, findings were triangulated using a variety of third-party sources, including other studies, government documents, and historical records.

[3] Chapters 4 and 5 provide more complete explanations about the methodologies employed in their respective case studies.

Finally, it would be remiss of me to fail to conclude this epistemological section of this thesis without furthering my critique of neoclassical economics of climate change. As explained by Nagar & Geiger (2007, p. 69), while it is generally expected that researchers using qualitative methods will explore the author's identity and positionality, no such expectation is extended to those using quantitative methods: "This unevenness implies that positivist research is immune to critiques of representation […]." However, as will become evident in the Literature Review, the design of the models used to project the social costs of climate change, and the policy prescriptions that are drawn from these models, are subject to a whole series of biases about the value of non-market goods such as human health, biodiversity, and ecosystems; and about the relative value of GHG emissions released by regions, individuals, and industries. Given the authority that literature on the economics of climate change conveys within policy circles, it would be prudent for these authors to also explore their identity and positionality in order to deconstruct their own inherent biases.

1.4 Thesis structure

This thesis will follow the 'Published Paper Route,' and will therefore consist of an introduction (Chapter 1), a literature review (Chapter 2), four academic papers (that form Chapters 3-6), and a conclusion (Chapter 6.1). Following this introduction, the literature review will offer a critique of the literature on the economics of climate change. In particular it will examine the shortcomings of the integrated assessment models used to determine the 'social cost of carbon' and the assumptions surrounding policy recommendations that rely primarily on corrective Pigouvian taxes and other pricing mechanisms. It will examine insights offered by the tradition of evolutionary economics. Finally, it will lay the foundations for an evolutionary economic geography perspective on climate change, building on the previous work of Geels (2002), Foxon & Pearson (2008), Coenen, Benneworth & Truffer (2010), Foxon (2011), Howarth (2012), and Patchell & Hayter (2013).

Chapter 3, entitled 'An Evolutionary Perspective on Assessing Human Vulnerability to Climate Change,' has been published as a chapter in a UNEP-edited book entitled *Preventing Disaster: Early Warning Systems for Climate Change*. The chapter builds on the Literature Review, and theoretically examines the mechanics of adaptation from an evolutionary economic geography perspective. It then discusses what an evolutionary approach can offer to studies that aim to assess the vulnerability of human systems to climate change.

Chapter 3 argues that through adaptation, human systems can alter their ability to cope with changes in the frequency or intensity of climate-related shocks – sudden-onset events like hurricanes, droughts, flooding, and fires – as well as slower-onset climate-related stresses such as sea level rise and desertification. Therefore, when assessing vulnerability to climate change, it is necessary to determine the human system's capacity to adapt to changing conditions. The paper contrasts behavioural and structural perspectives on the process of adaptation. The latter is elucidated through a case study of the 1970s famine in the Sahel and a comparison, using the Pressure and Release Model of the Progression of Vulnerability (Wisner, Blaikie, Cannon, & Davis, 2004), between the root causes of vulnerability in Haiti and Chile prior to their respective 2010 earthquakes. An evolutionary perspective is provided that offers insights into how agency and structure interact to shape different vulnerability trajectories.

Finally, it is argued that the rich data necessary to identify the elements that contribute to adaptive capacity in a human system can only be obtained through qualitative research methods. As an example, the paper presents the Global Islands' Vulnerability Research Adaptation and Policy Development (GIVRAPD) project – the topic of the following chapter.

Chapter 4, 'The Adaptive Capacity of Soufriere, Saint Lucia and Whitehouse, Jamaica to Climate Change – An Evolutionary Perspective,' compares two case studies that were part of a large research project, GIVRAPD. GIVRAPD was headed by the NGO Caribsave, and funded by the Climate and Development Knowledge Network. The project aimed to empirically analyse and compare the ways in which four communities in the small island developing states (SIDS) of St. Lucia, Jamaica, Mauritius, and the Seychelles – each of which are on the front lines of climate change impacts – are experiencing changing conditions and adapting. I only contributed to the first two studies in Soufriere, St Lucia and Whitehouse, Jamaica. For these, I was the primary author on two academic papers submitted to *Regional Environmental Change* and the *Journal of Rural Studies*, respectively.

The methodological framework of the GIVRAPD project was based on Smit & Wandel's (2006) community-based vulnerability assessment (CBVA) approach. Unlike attempts to measure the impacts of climate change through economic modelling, CBVA does not assume at the outset that adaptations will occur. Instead, it systematically explores local adaptive capacity using semi-structured interviews with community members. At each site, between 120 and 180 interviews were conducted with fishermen, farmers, and individuals connected with the tourism sector. Particular attention was paid to the process of knowledge generation and location-specific historical and institutional factors influencing decisions. The results were analysed using the Overseas Development Institute's (ODI) Local Adaptive Capacity (LAC) framework, which characterises adaptive capacity based on five elements: asset base; institutions and entitlements; knowledge and information; innovation; and flexible forward-looking decision-making and governance. The chapter contributes to the literature in three ways. First, it argues that many elements of the LAC framework correspond with an evolutionary perspective on adaptive capacity. Second, it offers in-depth case studies of the capacities of Soufriere and Whitehouse to adapt to climate change. Third, it offers a critical assessment of whether the LAC framework fully captures the important elements of adaptive capacity across different geographical contexts.

Chapter 5, 'An Evolutionary Perspective on Economic Change to Sustainable Pathways in Brazil,' builds on the Literature Review's discussion of evolutionary economic geography of mitigation through an empirical examination of the different drivers and barriers in three economic shifts in Brazil: the reduction in deforestation rates, the growth in no-till agriculture, and the growth in production and use of biofuels. The chapter has been submitted to the journal *Climate Policy*. It is based on fieldwork conducted in Brazil that aimed to identify the different drivers and barriers in the country's efforts to transition to a low-carbon economy, as well as a Smith School consulting paper that I co-wrote in the first year of my D.Phil. for the South African Centre for Development and Enterprise, which was entitled *The Response of India, China and Brazil to Climate Change*.

The fieldwork in Brazil was funded through a Santander Study Abroad Scholarship, and hosted by CentroClima, based in the Federal University of Rio de Janeiro, which specialises in research on climate policy. Eleven semi-structured interviews were conducted with key informants. The chapter draws from the evolutionary economic geography perspective on economic change discussed in the literature review, which goes beyond neoclassical economics' explanations for economic change to include contextual, scalar, structural and historical factors. The paper examines the insights that the three cases of reduced deforestation, no-till agriculture, and ethanol in Brazil offer about how governments should induce and manage transitions to sustainability.

Chapter 6, 'The Role of Climate Finance in a Sustainable Innovation Policy Regime,' was published in the *Journal for Sustainable Finance & Investment*. Based on the evolutionary economic geography perspectives on adaptation and mitigation developed earlier in the thesis, this chapter aims to contribute to policy discussions. Specifically, it addresses questions concerning the role that climate finance should play in developing countries' transitions to climate-resilient and low-carbon economies and how the institutional architecture governing climate finance should be designed.

First, the chapter examines the barriers that prevent developing countries from transitioning to low-carbon and climate-resilient economies, and finds that they are much more pervasive than a lack of incentives. Barriers include issues like insufficient knowledge flows and technical capacity in R&D and business; capital constraints due to undeveloped capital markets; and unstable and inappropriate policy regimes. The chapter then posits that climate finance will need to perform a variety of functions often overlooked by literature on the economics of climate finance. It will need to be deployed through technology-push policies, strategic niche management, and demand-pull policies. It will also need to incentivise and enable developing country governments to implement 'sustainable innovation policy regimes.' Concerning institutional arrangements, Chapter 6 argues that climate finance should flow through national funding entities, and that the United Nations Framework Convention on Climate Change (UNFCCC) should adopt crediting mechanisms for nationally appropriate mitigation actions (NAMAs) or Sectoral No-Lose Targets.

Finally, Chapter 7 concludes the thesis by revisiting the three debates concerning climate change highlighted in the Introduction: (1) What factors influence human systems' capacity to adapt to climate change, and how can these factors be assessed? (2) What forces drive and inhibit economic change towards low-carbon economies, and how should governments induce and manage such shifts? (3) What role should climate finance play in developing countries' shifts to low-carbon and climate-resilient economies, and how should the institutional architecture governing it be designed? It summarises the main lessons gleaned from the previous chapters, and articulates an evolutionary economic geography perspective on each of these debates. The chapter then reflects on the contributions that the thesis made to literature and policy, and concludes by considering future areas for research.

2 Literature Review

2.1 The Neoclassical Economics of Climate Change

Neoclassical economics examines the allocation and output of resources in a market economy. It hinges on economic equilibrium models where prices of a product or service, and the quantity produced, are determined by the forces of supply and demand. In order for these models to function, a number of assumptions need to be met:

- All resources are economic goods, i.e. they are scarce and desirable
- Consumers' demand for economic goods is insatiable
- Individuals and firms behave in a rational, self-interested, and profit-maximising manner

The most simple of these equilibrium models is illustrated in Figure 12.

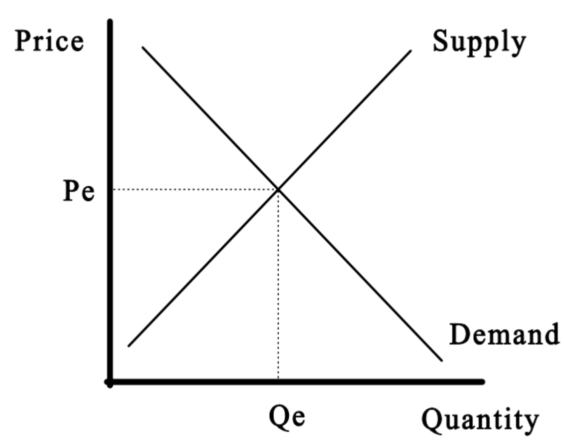


Figure 12. Market in Equilibrium (Figure from Dilts, 2004).

The demand curve indicates how much of a product consumers (as a whole) are willing to purchase at a given price. The downward slope demonstrates a 'universal law' in neoclassical economics: as the price that consumers have to pay for a product increases, the quantity that they are willing to purchase decreases; likewise, as the price decreases, the quantity demanded increases. The supply curve indicates the quantity of a product that producers are willing to sell at a given price. The *law of supply* is the inverse of the *law of demand*: as the price that producers can get for a product increases, the quantity that they are willing to supply increases; as the price decreases, the quantity that they are willing to sell decreases. In this manner, the market mechanism will trend towards an equilibrium (or market clearing price) in which the price and quantity produced is stable at *Pe* and *Qe*. At this equilibrium point, the total utility of consumers and producers is maximised.

Arrow & Debreu (1954) expanded on this model to demonstrated that an equilibrium can be found in a model of a competitive market economy at a set of prices where aggregate supply for every product and service in the economy equals aggregate demand. The fundamental theorems of welfare economics state that (1) an equilibrium reached in a perfectly competitive economy will be a Pareto optimal outcome – a static equilibrium in which no change to the allocation of resources is possible without making at least one individual worse off; and (2) that an equilibrium can always be reached through market forces regardless of the initial distribution of resources (Hindricks & Myles, 2013).

According to a welfare economics view, barring any 'market failure,' a free market will lead to the best possible outcome. Therefore, any government intervention will have a detrimental effect. When market failures do exist, such as the ones described in the following sections, government interventions are generally framed in terms of trying to recreate ideal market conditions to deliver economically efficient solutions (Foxon, 2007).

2.1.1 A Neoclassical Economics Perspective on Adaptation

From a neoclassical and welfare economics perspective, there is little need for government intervention to promote adaptation. In equilibrium models, rational, self-interested agents choose each course of action based on the *expected utility* that they will gain. The incentives to adapt exist naturally, and need not be created by government (Tol, 2005). Moreover, as argued by Bowen (2011, p. 1022), "Private economic agents will generally be in a better position than public authorities to assess most adaptation needs, given their variety and specificity to particular locations […]." Thus, adaptation will be driven by private companies and households making economic decisions in a changing environment.

It is widely acknowledged that the assumption of perfect adaptation is flawed. As far back as the 1930s, American geographer Gilbert White observed that vulnerability to extreme events is exacerbated by numerous, often irrational individual decisions – for example, the decision to develop hazard-prone land, destroy coastal mangroves, construct susceptible buildings and infrastructure, or fail to purchase adequate insurance cover. A whole body of literature called the behavioural approach has examined the range of factors that influence private agents' decision-making, and why it is not always optimal in reality (see, for example, Burton, Kates, & White, 1978). The behavioural approach is summarised in Chapter 3.

Within neoclassical economics, explanations for irrational behaviour are framed as different categories of market failure, including, among others: (1) *inadequate information* concerning the risk of hazard and methods of protecting against them; (2) *myopia*, or the tendency of agents to be short sighted; and (3) difficulties in coordinating *collective action* in regards to the management of natural resources, the provision of social services, and the development of infrastructure. Despite the unrealistic assumption of informed and rational behaviour, Milton Friedman (1953, p. 22) used the pertinent analogy of natural selection to demonstrate that, over time, any behaviour that is not consistent with maximisation of returns will be weeded out through the 'invisible hand' of market selection:

> *Let the apparent immediate determinant of business behaviour be anything at all – habitual reaction, random chance, or whatnot. Whenever this determinant happens to lead to behaviour consistent with rational and informed maximization of returns, the business will prosper and acquire resources with which to expand; whenever it does not, the business will tend to lose resources and can be kept in existence only by the addition of resources from the outside. The process of 'natural selection' thus helps to validate the hypothesis – or, rather, given natural selection, acceptance of the hypothesis can be based largely on the judgement that it summarizes appropriately the condition for survival.*

In cases of extreme market failures, most economists recommend government intervention to facilitate adaptation: "facilitative adaptation comprises those government actions that allow households, companies and lower authorities to adapt better […]" (Tol, 2005, p. 574). However, recommendations from a neoclassical economics perspective fall within the framework that if all market failures are corrected, market forces will drive adaptation towards a Pareto optimal outcome, and that intervention into the markets should be as minimal as possible. As explained by Tol (2005, p. 574), "I believe that, in most cases, facilitative adaptation implies the government doing less, not more. For instance, a water market is inherently a more flexible and therefore more adaptable way of allocation water than a system of seniority rights. Another example, subsidies reduce the incentives of farmers to switch crops, as it severs the link between productivity and profitability."

2.1.2 A Neoclassical Economics Perspective on Mitigation

Neoclassical economics views the primary cause of climate change to be market failure; more specifically, it views climate change as an environmental externality. Private actors that invest in emission-intensive activities are able to offload, or *externalise*, the negative costs onto society. These *negative externalities* will lead to an over-investment in GHG emission-intensive activities than is socially optimal. The inverse is true for those deciding on whether or not to make investments that will reduce GHG emissions. Although the global benefits of such investments will often outweigh the costs, the benefits will not necessarily be reflected in the returns to private investors. The *positive externalities* of low-carbon development will typically lead to less investment than is socially optimal in renewable energy and energy efficiency technology, low-carbon agriculture, etc. (Stern, 2007).

The textbook solution to address this market failure is for governments to align private and social costs and benefits through measures that add an extra price to activities that produce GHG emissions. Without a price on emissions, those engaged in highly polluting activities do not pay for the full cost of their actions and are effectively receiving a subsidy from society at large. With a price, households and firms will be incentivised to reduce emission-intensive activities if the cost of doing so outweighs the private benefit. Because emission-intensive activities will become more expensive, low-carbon activities will become more competitive. Pricing emissions is generally achieved through two policy instruments: by levying a tax on GHG emissions, i.e. a carbon tax; or by implementing a cap-and-trade system. The mechanics of each of these policies are demonstrated in Figure 13.

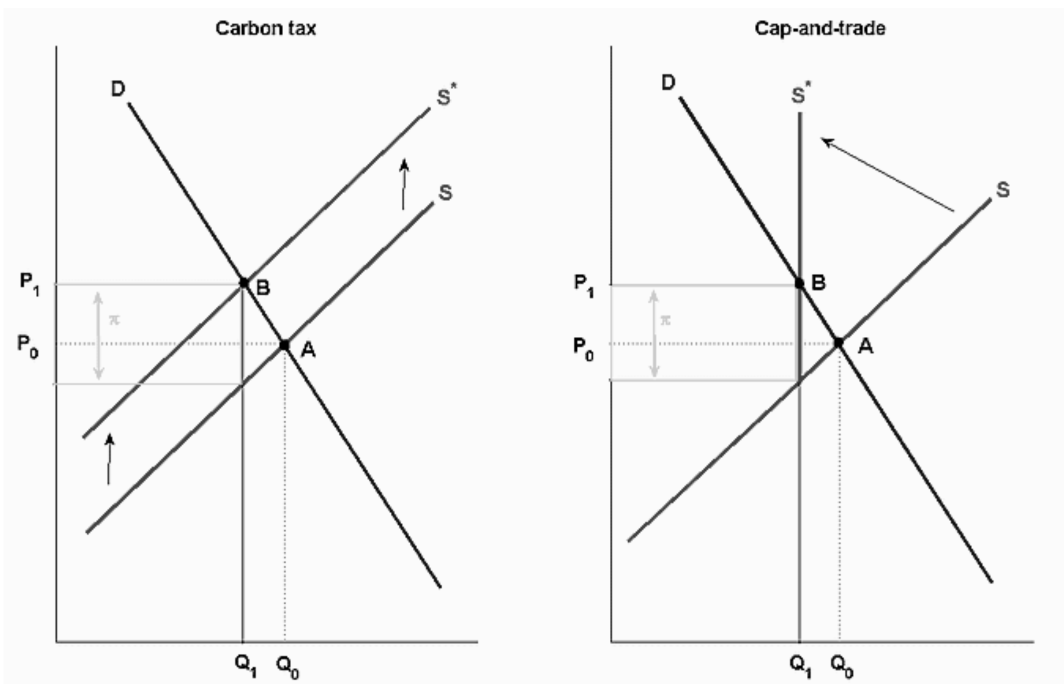


Figure 13. Graph of Carbon Tax and Cap-and-Trade Effects on Equilibrium (Figure from Gordon, 2008).

Prior to the implementation of a carbon tax or cap-and-trade system, the market for GHG emission-intensive products is in equilibrium at point *A* on the graphs with Q_0 produced and sold at the price of P_0. In the graph on the left, a carbon tax of π increases the price of supplying GHG emission-intensive products, causing the supply curve to shift upward from *S* to *S**. The demand curve is unchanged. However, because the price has increased, a new equilibrium is found at point *B* with the higher price of P_1 and the reduced quantity of Q_1.

In a cap-and-trade scheme, a regulatory cap is placed on the amount of emissions permitted in the economy, and 'emission rights' are auctioned or allocated to private actors. Those facing more expensive emission abatement choices are then permitted to purchase emission rights from actors with excess. The price on emissions is determined by the cost of abiding by the cap. In the graph on the right of Figure 13, a cap on emissions is set at Q_1. The supply curve responds by bending vertically at this point – no matter how high the price, supply cannot exceed Q_1. Given that demand has not changed, suppliers can charge the higher price of P_1, where a new equilibrium is found at point *B*.

Following Pigou's (1932) principles of corrective taxation, the size of a carbon tax should equal the marginal externalised social and environmental damage caused by GHG emissions, i.e. the social cost of carbon (SCC). The SCC is conventionally measured as the marginal externalised cost of one tonne CO_2e emissions.[4] In equilibrium models without further market failures, if the price on emissions is set equal to the SCC, market forces will drive a transition to an equilibrium state with an optimal level of GHG emissions, i.e. a state with the lowest net cost to society from climate change and climate change policies. According to Stern (2007), this optimal level of

[4] One carbon credit represents a reduction of one tonne of CO_2 emissions, or a reduction of a specific quantity of another GHG (methane, nitrous oxide, or chlorofluorocarbons) that has an equivalent global warming potential as one tonne of CO_2, termed CO_2e.

emissions is where the marginal abatement cost (MAC), or the cost of reducing one further unit of GHG emissions, is equal to the SCC. If the MAC is larger than the SCC, then the social gain from abatement would be less than the cost. Theoretically, in a cap-and-trade system, if the cap is set at this optimum level of emissions, the resulting price for emission rights will also equal the SCC. If the resulting price is lower than the SCC, then the cap has been set too high and *vice versa*.

This thesis argues that a neoclassical economics perspective on mitigation is problematic for two reasons: (1) the challenges in modelling the impacts of climate change make it impossible to estimate the SCC; and (2) the challenges in modelling how an economy will respond long-term to price adjustments make it impossible to predict the overall effect of GHG emissions pricing.

2.1.2.1 Difficulties in Estimating the Social Cost of Carbon

Determining the SCC requires a comprehensive estimation of the future global cost of climate change based on different emission levels. A number of studies have used integrated assessment models (IAMs) that combine climate models with economic models to predict the future economic impact of climate change, usually measured as a percentage change in GDP. Two papers published in 2013 – Stern (2013) and Pyndick (2013) – outlined how the IAMs used to estimate the SCC are deeply flawed. To demonstrate, I will go through each component of IAMs: the climate sensitivity function, the damage function, and the social welfare function.

Climate sensitivity refers to the change in the global climate system in response to a change in radiative forcing caused by increased or decreased CO_2e concentration in the atmosphere. It is conventionally measured as the eventual temperature increase that would result from a doubling of the atmospheric CO_2e concentration. The mechanisms that determine climate sensitivity are highly complex. They involve internal feedback loops in the earth's natural systems. Positive feedback loops amplify climate sensitivity; negative feedback loops dampen it. As explained by the IPCC (2013) Fifth Assessment Report there is risk that at a certain threshold of warming, sometimes referred to as a 'tipping point,' positive feedback loops could cause abrupt, large-scale, and irreversible changes in the climate system that would result in substantial disruptions in human and natural systems. Due to their complexity, many of these feedback loops are still largely not understood and as such are omitted from models examining climate sensitivity.

According to Stern (2013, p. 842), some of the more important factors that are generally omitted from the models because they are not well understood include the following:

- thawing of the permafrost and release of methane
- collapse of land-based polar ice sheets
- release of sea-bed methane
- complex interaction with ecosystems and biodiversity more generally

Stern (2013, p. 842) argues that other key factors are represented in the models, but their risks are likely understated, such as:

- ocean acidification and associated feedbacks
- collapse of the oceanic thermohaline circulation
- collapse of the Amazon and other tropical forests
- potential for chaotic and unstable behaviour of complex dynamic systems

Climate scientists have made progress in understanding some of these feedback loops; however they are upfront about the limits to our knowledge concerning overall climate sensitivity that will exist for the foreseeable future. Allen & Frame (2007) even argued that climate sensitivity was 'unknowable.'

Despite this lack of knowledge, economists have incorporated climate sensitivity in IAMs as an exogenous variable in efforts to calculate the SCC. In doing so, as explained by Stern (2013), they have focused largely on tractable parameters, such as temperature change. Many of those climate changes that are less predictable, but that are most likely to dramatically alter people's lives and livelihoods are largely ignored in the models. These changes include desertification, droughts and water stress, extreme weather events, storm surges, and the potential salinisation of fertile land, etc.

The output of the climate sensitivity models is then fed into the damage function of the integrated assessment model, which examines the effect that higher temperatures have on the economy. Two general approaches have been taken: the enumerative method and the statistical approach (Tol, 2009).

The enumerative method, employed by Nordhaus (1994b), Fankhauser (1994), or Tol (2002), uses sector-specific economic models to value the change in output associated with different climate scenarios. Tol (2009, p. 36) explained how these climate-impact assessments work: "For agricultural products, an example of a traded good or service, agronomy papers are used to predict the effect of climate on crop yield, and then market prices or economic models are used to value the change in output […]." The costs from each sector are then added up and extrapolated to the global level. The models do not involve an assessment of the local capacity to adapt to the impacts. Instead, they assume either that adaptation does not occur at all, that an arbitrary level of adaptation occurs, or that perfect adaptation occurs: "[…] more recent studies […] tend to assume agents have perfect foresight about climate change, and have the flexibility and appropriate incentives to respond" (Tol, 2009, p. 36).

Beyond the inherent questions concerning the accuracy of climate models, there are a number of problems with the economic modelling portion of this approach. As already discussed in the section on a neoclassical economics perspective on adaptation, the models' assumptions about levels of adaptation are unreasonable. Furthermore, the extrapolation of economic values for particular locations to the regional or global scale fails to account for location-specific factors, which will play a significant role in future impacts.

Another group of climate impact assessments (such as Mendelsohn, Morrison, Schlesinger, & Andronova, 2000; Mendelsohn, Schlesinger, & Williams, 2000; Nordhaus, 2006) used the statistical approach. Tol (2009) explained that this method estimates the economic impact of climate change by empirically observing variations in price and expenditures across space. It is assumed that all variation in economic activity is caused by differences in climate. The future economic impact of projected changes in climate is then estimated based on observed differences in economic activity. Local results are sometimes extrapolated to other countries.

Because these models are based on empirical observations, Tol (2009) argues that they implicitly factor in a realistic level of adaptation. However, they fail to take into account the variability of adaptive capacity over time and across locations, issues that will be discussed in detail in this thesis. Most problematically, they "run the risk that all differences between places are attributed to climate" (Tol, 2009, p. 33). As explained by Stern (2013, p. 44), "That is clearly to miss the basic point that most potential damages are from water-related and extreme weather effects (desertification, storms, floods, etc.), which are generated via global climate interactions (associated with rising average global temperature) with local characteristics."

The output of the damage function is usually an estimate of the future economic costs of climate change in terms of a percentage reduction in GDP. This percentage is subtracted from a BAU baseline of projected economic growth. As a result, economic growth is taken as exogenous and assumed to be positive. In this framework, lasting damages to the factors of production that could negate the assumed positive growth – for example from mass migration, conflict, or damage to infrastructure – are omitted from the equation (Stern, 2013). Furthermore, many of the models also apply a rate of time preference, i.e. a discount rate to future damages. The justification for applying a discount rate is that losses in near-term consumption resulting from investments to abate GHG emissions can be weighed against the future gains in consumption that results from those investments (Pyndick, 2013).

The consequences of so many assumptions, arbitrary variables like the discount rate and omitted high-risk factors in IAMs are numerous. First, when the models are used to estimate the economic costs of higher degrees of climate change, the results are so low that they border on absurdity. Ackerman, Stanton, & Bueno (2010) demonstrated that Nordhaus's (2008) DICE model would project that a 19°C increase in temperatures would cause only a 50% loss in GDP against a BAU baseline (assumed to be positive). Of course, as argued by Stern (2013), complete human extinction is possible if not probable at temperatures much lower than that. However, Stern (2013, p. 851) also argues that even at much more realistic levels of warming, the low economic impact projected by the models is problematic: "Taken together, the assumptions in most integrated assessment models […] lead not just to low estimates of the social cost of carbon, but also to recommendations that we should head for concentrations of, say, 650 ppm CO_2e (see Nordhaus, 2008). The science tells us that there are immense risks at these concentrations; some economic models apparently tell us they are 'optimum.'"

Pyndick (2013, pp. 4-5) explained that a second consequence of the numerous assumptions and arbitrary variables involved in IAMs is that it gives the builders of the models a high degree of discretion, and that as a result, estimates of the SCC vary significantly: "Nordhaus (2008) finds that optimal abatement should initially be very limited, consistent with an SCC around US$20 or less, while Stern (2007) concludes that an immediate and drastic cut in emissions is called for, consistent with an SCC above US$200.[5] Why the huge difference? Because the inputs that go into the models are so different."

However, Pyndick (2013, p. 3) argued that perhaps the most dangerous element of IAMs is that "their use suggests a level of knowledge and precision that is simply illusory, and can be highly misleading." These criticisms of IAMs should not be taken to imply that it would not be a good idea to apply a price on emissions to internalise the external costs of GHG emissions. Instead, they should simply be viewed as evidence that neoclassical economics can tell us relatively little about the SCC.

[5] In an updated study, Nordhaus (2011) estimates the SCC to be US$12 per tonne of CO_2.

2.1.2.2 Difficulties in Modelling the Effect of Emissions Pricing

One could argue that as an alternative to setting the price on emissions at the SCC, the price should be set at a level that equilibrium models project would result in a reduction of emissions to a level that would most likely avoid the most damaging impacts of climate change. While the logic of this argument is sound, it is unlikely that equilibrium models can reveal a great deal about the long-term effect of a price on emissions.

To illustrate, consider McKinsey & Co.'s (2009b) Global GHG Emission Marginal Abatement Cost (MAC) Curve, illustrated in Figure 14. It presents an estimate of the maximum potential of technical GHG abatement measures costing below EUR 60 per tCO_2e abated if each were pursued aggressively. Each bar represents an opportunity to reduce emissions below BAU. The height of the bar shows the cost of avoiding one tonne of GHG emissions (in Euros) from a societal point of view, and the width of each bar shows the potential quantity of GHGs that the initiative could negate (in gigatonnes) per year. Approximately one-third of the emission abatement opportunities – mostly those in buildings, transportation, and industry – can be achieved at a negative cost, meaning that they pay for themselves through energy savings (Metz, 2009).

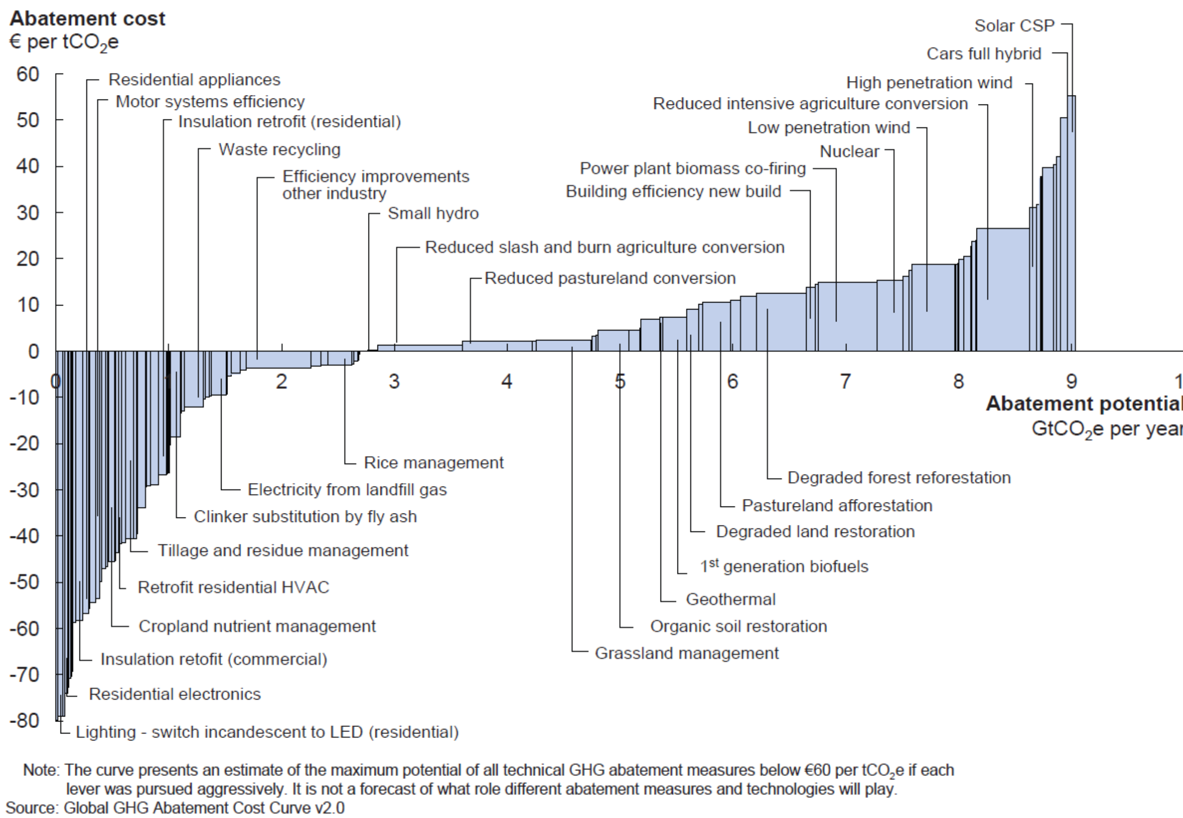


Figure 14. Global Greenhouse Gas Emission Marginal Abatement Cost Curve (McKinsey, 2009b).

Such MAC curves have been used to predict the success that carbon markets will have in promoting abatement measures (Bloomberg New Energy Finance, 2010). Implicit in such analyses is the assumption that by 'getting the price right,' market forces will drive a transition to low-carbon economies. However, it is evident from the cost-effective yet unexploited abatement opportunities on the left of the MAC curve that many sectors that are important in mitigating climate change do not lend themselves to policies that aim to optimise market forces.

As with adaptation deficits, neoclassical economics explanations for why, despite the existence of cost-effective low-carbon investments, market forces do not drive economic change towards an equilibrium with fewer GHG emissions are framed as a series of further market failures that lead to a mismatch between private and public interests and suboptimal decision-making by private individuals and firms:

- Split incentives - although the investments in mitigation may be quite profitable over the lifetime of the project, those who pay the costs (such as a landlord or building contractor) are not the ones reaping the benefits (the building buyer or tenant), and thus have the incentive to choose a cheaper carbon-intensive alternative (Cheng, 2008).
- High upfront costs and discounting - Many low-carbon investments entail significant upfront costs, but the benefits only accrue in the long term, possibly over generations. Most decision-makers apply a positive discount rate in that they favour near-term profit and savings at the expense of long-term gains (Clark, 2011).
- Public goods – Much of the knowledge and technology required to transition to a low-carbon economy has the characteristics of a public good – one private actor that invests in the technology or in creating knowledge cannot prevent another from capitalising on his or her investment – which tends to lead to less investment than is socially optimal (Bowen, 2011).
- Malfunctioning financial markets – Many low-carbon technologies are in an early stage of development, rendering investment highly risky; and the lack of experience in assessing the risk causes banks to be hesitant to provide capital on favourable terms (Bowen, 2011). These barriers make investing in low-carbon and adaptation initiatives an effort-intensive process beset with uncertainties.

Public interventions are put forward to overcome each of these market failures. Regulations such as building codes are permissible to remove split incentives; grants and concessional loans can relieve capital constraints; intellectual property law can overcome the public goods problem; and public guarantees and subordinated equity can reduce the risk to private investors.

Undoubtedly, these interventions will be crucial in promoting transitions to low-carbon economies. However, the reasoning behind them remains rooted in models in which optimisation of markets is the best approach to resource allocation (Lundvall, 2007); in which "actors are homogenous, rational, non-opportunistic, and capable of calculating best value optimal decisions in a world without uncertainty" (Cooke & Laurentis, 2010, p. 240); and in which economic change is a 'linear' process whereby market forces naturally trend towards a static equilibrium (Howarth, 2012).

Such models may hold value in analysing short-run market dynamics. However, the sheer magnitude of economic change necessary to reduce emissions to the level dictated by climate science, as well as the varied temporal scales over which it must occur, require alternative theories of economic change that are not based on equilibrium models. As candidly explained by economist Professor Michael Grubb at a 2011 public lecture on 'The Carbon Pricing Paradox' at the Australian National University:

> *The energy sector, along with buildings, is amongst the least innovative sectors in the economy. The research and development spend in pharmaceuticals relative to turnover is about 20%. In IT it's above 10%. In energy it's below 1%. We are seeking radical innovation in some of the least innovative sectors in our economy.*

That is a serious challenge. Simply sticking a carbon price on is not going to solve that challenge. The analytic zone that you are now in if you are looking over decades, infrastructure and innovation, is not a nice equilibrium carbon-price defined world. It's a world where, frankly, the best analysis we've got is around evolutionary economics. How do systems evolve, what is the path-dependence, what is the lock-in created by early decisions on infrastructure, what is the politics created by incumbent industries that will determine what politically can and cannot be done in the short-term.

2.2 Evolutionary Economics

The concept that the economy is constantly evolving dates back almost as far as the neoclassical economics notion that it is trending towards an equilibrium (which is generally attributed to Jevons, 1866). As explained by Howarth (2012), the origins of evolutionary economics can be traced back to Marx's (1867) *Capital* which used the analogy that the economy is a biological entity that is ever changing. During his eulogy of Karl Marx, Engels stated, "Just as Darwin discovered the law of evolution in organic nature, so Marx discovered the law of evolution in human society" (quoted in Bowles, 2004, p. 400). Over the next 150 years, while neoclassical economics gained enormous influence in policy debates throughout the world due to ground-breaking improvements in mathematical modelling, evolutionary economics remained largely on the periphery of economic thought.

There were notable exceptions. Thorstein Veblen (1898) criticised the discipline's growing preoccupation with equilibrium in his seminal essay entitled, "*Why is economics not an evolutionary science?*" (as cited in Howarth, 2012). Schumpeter (1942, pp. 81-82) argued in his seminal work *Capitalism, Socialism and Democracy* that, "Capitalism [...] is by nature a form or method of economic change and not only never is but never can be stationary." From Schumpeter's perspective, the driving force of economic change is innovation. Neoclassical economics treats innovation as an exogenous factor in economic models. Schumpeter argued that once innovation is taken as endogenous to economic systems, it is clear that assumptions of long-term equilibrium cannot hold.

It was Nelson & Winter's (1982, p. 4) *An Evolutionary Theory of Economic Change* that began to outline the mechanics of economic change from an evolutionary perspective:

> *Our theory emphasized the tendency for the most profitable firms to drive the less profitable ones out of business; however, we do not focus our analysis on hypothetical states of 'industry equilibrium,' in which all the unprofitable firms no longer are in the industry and the profitable ones are at their desired size. Relatedly, the modelling approach that we employ does not use the familiar maximization calculus to derive equations characterizing the behaviour of firms. Rather, our firms are modelled as simply having, at any given time, certain capabilities and decision rules. Over time these capabilities and rules are modified as a result of both deliberate problem-solving efforts and random events.*

Rather than constantly re-evaluating their actions to capture the greatest returns, Nelson & Winter (1982) observed that the actions of firms and individuals tend to become routinised. As such, the book viewed 'routines' to be analogous to 'genes' in evolutionary biology, due to the central role played by routines in dictating firms' and individuals' actions and in knowledge transmission. Heredity of routines can occur in a vertical manner amongst individuals, for example as parents pass down knowledge to their children, and within organisations through "'organisational genetics' – the process by which traits of organizations, including those traits underlying the ability to produce output and make profits, are transmitted through time" (Nelson & Winter, 1982, p. 9). However, unlike genes, heredity of socio-economic routines can also occur in a horizontal manner, as individuals and organisations learn from one another through education systems, media, inter-firm knowledge spillovers, etc. Hence, Nelson & Winter (1982, p. 11) stated, "[…] our theory is unabashedly Lamarckian: It contemplates both the 'inheritance' of acquired characteristics and the timely appearance of variation under the stimulus of adversity," referring to the pre-Darwinian naturalist Lamarck who believed that physiological changes acquired over the lifetime of an organism can be inherited by its offspring.

Nelson & Winter (1982, p. 18) conceded that it is convenient to assume economies trend towards 'temporary equilibrium' in order to discern short-run processes, such as those that determine "[…] a single price in the market in a single period. However, [they] emphatically do not assume that [their] model industries are in long-run equilibrium or focus undue attention upon the characteristics of long-run equilibrium."

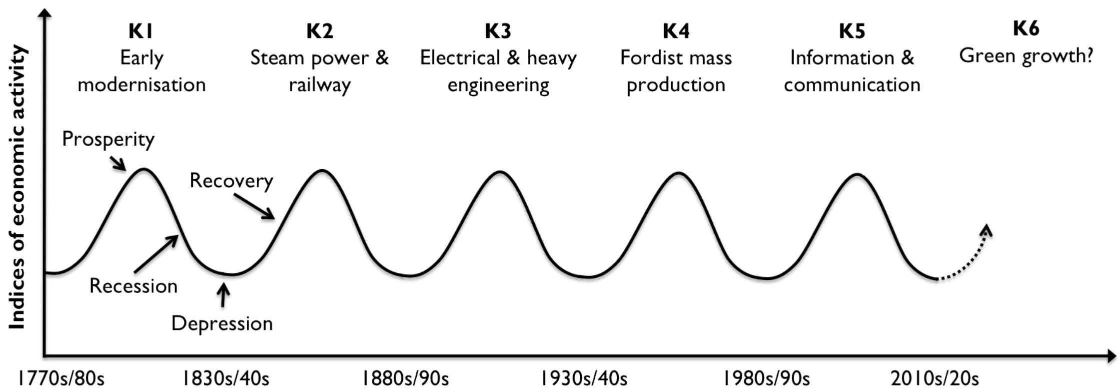
Like Schumpeter, Nelson & Winter (1982) argued that the reason for a lack of long-run equilibrium is innovation. They likened the process of innovation to that of mutation in biological evolution, as both introduce novelty into the system. Unlike mutation, however, innovation is often deliberate. Firms aim to gain a competitive advantage through activities designed to 'search' for new more efficient routines or technology, such as R&D or market analysis. The outcomes of these search processes are largely stochastic, and play a large role in determining a firm's capabilities and the overall the trajectory of an economy's evolution: "Through the joint action of search and selection, firms evolve over time, with the condition of the industry in each period bearing the seeds of its condition in the following period" (Nelson & Winter, 1982, p. 19).

While the evolutionary economic models of Nelson & Winter (1982) dispense with the assumptions of rational decision-making and long-term market equilibrium and allow for innovation and path-dependency, they ultimately concur with neoclassical economic models in that economic change occurs exclusively at the margin, driven by markets selecting for profitability and efficiency: "[…] over time, the economic analogue of natural selection operates as the market determines which firms are profitable and which are unprofitable, and tends to winnow out the latter" (1982, p. 4). Thus, the most economically efficient routines are retained, and the less efficient routines are gradually weeded out. In this manner, individuals, firms, industries, and economies adapt to become more efficient within current market conditions.

Within this framework, a large portion of the increase in efficiency takes the form of what the economic historian Rosenberg (1982, p. 62) called "[…] a slow and often invisible accretion of individually small improvements in innovations. […] Such modifications are achieved by unspectacular design and engineering activities, but they constitute the substance of much productivity improvements and increased consumer well-being in industrial economies."

However, within both economics and evolutionary biology, it has been observed that this type of gradual adaptation accounts for only a small part of evolution. Eldredge & Gould (1972) observed in the fossil record that a great deal of biological evolution is characterised by punctuated equilibria in which long periods of relative stasis are punctuated by short bursts of rapid change. Punctuated equilibria have also been observed in economic evolution. The pattern has, for example, been likened to Kondratiev long waves, in which periods of relatively slow growth alternate with periods of rapid growth and qualitative technological change (Kondratiev, 1925).

Kondratiev waves are approximately 40 to 60 years long and are divided into four phases: prosperity, recession, depression, and recovery. The recovery is phase is driven by rapid innovation and the emergence of a new technological paradigm. As seen in Figure 15, five historical Kondratiev waves are traditionally identified (Coe, et al., 2013). Vasquez-Brust & Sarkis (2012) observed that the economic slowdown that began with the financial crisis in 2008 might signal the recession phase of the information and communication wave that began in the 1980s, and optimistically argued that green technologies could be the engine of the sixth Kondratiev wave. This has been added to the right of the figure.



Key elements	Cotton and pig iron	Coal and transport	Steel	Energy-oil	Computer chips	?
Key technologies	Textiles Textile chemicals Textile machinery Iron working / castings Potteries	Steam engines Steamships Machine tools Iron and steel Railway equipment	Electrical engineering Electrical machinery Cable and wire Heavy engineering / armaments Steel ships Heavy chemical Synthetic dyestuffs	Automobiles Trucks Tractors Tanks Aircraft Consumer durables Process plants Synthetic materials Petrochemicals	Computers Electronic capital goods Software Telecommunication Optical fibres Robotics Ceramics Data banks Information services Biotechnology	Solar? Wind? Nuclear? Biofuels? Electric vehicles? Energy storage? Energy efficiency? Smart grids? Low carbon agriculture? Carbon markets?

Figure 15. Kondratiev-waves (Author's own; based on Coe, et al., 2013; Freeman & Perez, 1988; Vazquez-Brust & Sarkis, 2012).

Schumpeter (1942) viewed punctuated equilibria to be a necessary feature of capitalist economies:

[…] [The] history of the productive apparatus of a typical farm, from the beginnings of the rationalization of crop rotation, ploughing, and fattening to the mechanized thing of today–linking up with elevators and railroads–is a history of revolutions […] The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S. Steel illustrate the same process of industrial mutation–if I may use that biological term–that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of

Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in.

The causes of punctuated equilibria are highly contested. Schumpeter viewed one cause to be 'disruptive' innovation that causes dramatic cost-benefits over existing competitors:

The first thing to go is the traditional conception of the modus operandi of competition. Economists are at long last emerging from the stage in which price competition was all they saw. […] it is not that kind of competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization (the largest-scale unit of control for instance)—competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives.

Turning back to evolutionary biology, Vrba & Gould (1986) argued that punctuated equilibria indicate that more is at play than selection of the *fittest*. They argued that natural selection – a causal process, in that it drives a species to become more adapted to its environmental conditions – must be distinguished from other types of *sorting*, a broader term than selection that refers to all processes that result in differential 'success' rates among genes, organisms, and even species, but not necessarily in a causal manner. Vrba & Gould (1986) called for the development of a taxonomy of sorting mechanisms that operate at the different hierarchical levels of the gene, the individual, and the species.

Gowdy (1992) incorporated this interpretation of punctuated equilibria into theories of economic evolution, arguing that selection of routines at the margin is not the sole explanation for evolutionary change. Instead, market selection operates as a mechanism of change at one level while simultaneously there are other sorting mechanisms at work at higher levels. These mechanisms may be causal, selecting for factors other than efficiency, or they could be entirely random. An example of the former may be an ideological and political shift in a society that enables the creation of a protected area. An example of the latter may be a natural disaster that impacts fit and unfit individuals and firms alike, such as a volcanic eruption or meteor strike.

Schumpeter (1942, pp. 82-83) acknowledged that higher-level processes often condition industrial change. However, he argued that the primary driver of change, gradual or radical, remains market selection and endogenous innovation:

> *[…] this evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action; this fact is important and these changes (wars, revolutions and so on) often condition industrial change, but they are not its prime movers. […] The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers, goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates.*

With the acceptance that higher-level sorting processes condition economic change, we begin to see a role for structures as well as agency. Whereas agency refers to the capacity of agents to choose their actions and act independently, structure refers to those features of society that limit actors' options and that cannot be changed by individuals (Barker, 2005).

The implications of incorporating structure into an evolutionary theory of economic change are profound. Unlike the narrow neoclassical economics lens, which views economic change solely as an outcome of agents making economic choices constrained only by income levels, the concept of sorting can allow evolutionary economics to incorporate insights from macroeconomic perspectives such as Marxism and Keynesianism. It also enables insights from institutional economics, which examines how formal rules (contracts, tax regimes, property rights, laws, etc.) structure economic processes, and political science, which examines the processes by which these laws evolve. Furthermore, incorporating structure into the equation expands the role that historical factors play in influencing economic change. History is not only important because, as Nelson & Winter (1982) observed, firms bear the seeds of previous periods. Structures also bear historical seeds; or, as more eloquently put by Karl Marx (1852, p. 1): "Men make their own history, but they do not make it as they please; they do not make it under self-selected circumstances, but under circumstances existing already, given and transmitted from the past."

A final analogy that I will borrow from biological evolution (which to my knowledge has not been previously incorporated into economic thinking) is *cladogenesis*, the process whereby one species is split into sister species due to the isolation of different populations. Socio-economic cladogenesis can be observed throughout human history in cases where populations became spatially isolated and developed novel cultures and economic systems. A fruitful direction of inquiry would be to examine the degree to which globalisation threatens to end socio-economic cladogenesis by preventing populations from becoming isolated. This question is particularly relevant in light of concerns raised by polemics – such as Wade Davis's (2009) *The Wayfinders: Why Ancient Wisdom Matters in the Modern World* and Naomi Klein's (2014) *This Changes Everything: Capitalism vs. The Climate* – about the long-term sustainability of the globally dominant de-regulated capitalist system and the rapidly diminishing alternative systems that could take its place. Here, however, I will limit my argument to the following proposition: If one were to incorporate the concepts of socio-economic cladogenesis and higher-level sorting processes into evolutionary economic thought, it would not only enable, it would demand a convergence with economic geography. Why? Because incorporating these two concepts into theories of evolutionary economics necessitates an examination of three core themes of economic geography: *space*, *place*, and *scale*.

Within economic geography, *space* refers to the physical area in which economic activity plays. Socio-economic cladogenesis involves the emergence of novelty due to the cessation of flows of trade, knowledge exchange, migration, etc. across space. The existence of socio-economic cladogenesis is evidence that because economic evolution takes *place* within unique structured and historical local contexts, the evolutionary outcome can be drastically different from place to place. Finally, although the hierarchical levels in which sorting and selection processes occur are not analogous to the economic geography concept of *scale* (because some sorting processes, such as cultural change, could play out at the local level), many of the higher-level sorting processes at work (globalisation, climate change, political change, etc.) do play out at national and international levels. Therefore, by incorporating the concept of sorting, evolutionary economics becomes no longer exclusively interested in the micro-economic processes at the level of the individual and firm; it is also interested in processes driving change at other *scales* – community, regional, national, and global.

2.3 Economic Geography of Climate Change

While other sub-disciplines of geography are well represented within debates pertaining to the impacts and mitigation of climate change, the explicit application of economic geography to these debates is, to a large extent, still fertile ground for novel study. Economic geography's relative absence from these debates is particularly surprising given the intimately intertwined relationship that the causes and impacts of climate change have, and will have, with many of its central topic of inquiry: globalisation, transnational firms, global production networks, technological innovation across space, etc. Furthermore, although it is improving, economic geography's poor representation within environmental policy debates is not limited to climate change. In 2002, Bridge argued that economic geographers have been conspicuously absent from policy debates concerning the environment more generally, resulting in "an apparent disconnect between the interests and capabilities of economic geography and many 'real-world' problems" (2002, p. 364). Gibbs (2006, p. 193) called for the creation of an environmental economic geography, arguing "not only that the environment is of key importance to economic geography, but also that economic geographers can make an important contribution to environmental debates, through providing not just a better analysis and theoretical understanding, but also better policy proscription."

Since this proposition, economic geographers have broken ground on a number of areas of environmental concern, including issues pertaining to climate change. For example, economic geographers have made important contributions to the conceptualisation of carbon markets (Bakker, 2012; Bumpus & Liverman, 2008; Knox-Hayes, 2009, 2010, 2013). Other economic geographers, most notably Robin Leichenko, have made contributions to the literature on adaptation, resilience and vulnerability to climate change, primarily in urban areas of developed nations (Leichenko, 2011; Leichenko, McDermott, Bezborodko, Brady, & Namendorf, 2014; Leichenko & Thomas, 2012).

Nonetheless, Leichenko & Thomas (2012, p. 327) argued, "While these studies have made important contributions to knowledge about how climate change may affect developed coastal cities and regions, there is substantial room for new engagement by economic geographers. In addition to a clear need for more work on the Global South, areas where economic geographers seem especially well-positioned to contribute include comprehensive assessments of coastal economic impacts which incorporate both market and non-market measures, investigation of the effects of climate change on patterns of growth and spatial inequality across coastal and related inland areas, and development of new theoretical understandings of how changing environmental baselines may influence regional economic growth and decline." Bridge (2008, p. 79) argued that environmental economic geography could make further contributions "[…] by documenting the various ways in which the 'economic' is embedded in the 'extra-economic' spaces and process that we conventionally label environment, and how the environmentally-embedded character of economic activity is significant for the functioning of economic systems and the livelihoods dependent upon them." After all, "[the] modality of integrating environment and economy – collapsing the former into the latter – may, of course, not be at all what [environmental economic geography] researchers have in mind when calling for a conversation between economic geographies and environment" (Bridge, 2008, p. 80).

With all its potential, environmental economic geography has been criticised 'as a loose assemblage of ideas' that lacks a coherent theoretical or 'epistemic project' (Bridge, 2008, p. 78). Indeed, part of the aim of this thesis is to advance the appeal of a growing number authors whom are calling for an 'evolutionary approach' to provide theoretical coherence to environmental economic geography (Hayter, 2008; Howarth, 2012; Patchell & Hayter, 2013), specifically in the realm of climate change. These author's contributions are discussed further in Section 2.3.2.

However, before discussing different theoretical approaches to the economic geography of climate change, it is important to clarify the core issue of the field's inquiry. What sets economic geography apart from other approaches to studying the relationship between the economy and climate change? As discussed in the introduction, I argue that the starting point for an economic geography analysis of climate change would be an inquiry into the factors that cause production of GHG emissions and the impacts of climate change to vary over space and time. Thus far, this literature review's analysis of the factors that cause GHG emissions and vulnerability, and the forces that drive mitigation and adaptation, has been relatively *aspatial*. An economic geography perspective would draw in the themes of space, place, and scale, to inquire how the landscapes of vulnerability and GHG emissions vary across time. This section examines two different perspectives: a neoclassical approach and an evolutionary approach.

2.3.1 A Neoclassical Approach to the Economic Geography of Climate Change

2.3.1.1 Neoclassical Economics Perspective on the Uneven Landscape of Vulnerability

As previously discussed, to predict the future costs of climate change, neoclassical economists employ IAMs. These models effectively impose projected future climate conditions on models of present day economies to predict the impact of climate change on different sectors or spatial scales. Table 1, on the following page, shows how IAMs have predicted that climate change will have different impacts across space (Tol, 2009).

Some consider the forecasted net cost, usually given as a percentage of GDP, to be indicative of the respective system's vulnerability (Smit & Wandel, 2006). However, as mentioned, the models assume a uniform level of adaptive capacity across space: "This work does not empirically investigate adaptations, examine the actual processes of adaptation or adaptive capacity, explore the conditions or drivers that facilitate or constrain adaptations, nor document the decision-making processes, authorities, and mechanisms involved in adaptation" (Smit & Wandel, 2006, p. 284).

IAMs lead to a number of problematic interpretations about the spatial landscape of vulnerability to climate change. First, the reductionist approach to studying the impacts of climate change in terms of economic costs fails to fully convey the potential human-felt impact of climate change in terms of loss of life, displacement, and social upheaval (Stern, 2013). Moreover, it tends to overstate the impact of climate change in areas with high levels of capital accumulation relative to areas with low levels of capital.

To provide a hypothetical example, although the models might project that sea-level rise will cause quantitatively more economic damage in Florida than in Bangladesh due to the former's higher level of financial capital, the latter would likely experience more severe social impacts.

Table 1. Estimates of the Welfare Impact of Climate Change (expressed as an equivalent income gain or loss in percent GDP) (Tol, 2009, p. 31).

Study	Warming (°C)	Impact (% of GDP)	Worst-off Region		Best-off Region	
			% of GDP	Name	% of GDP	Name
Nordhaus (1994b)	3.0	-1.3				
Nordhaus (1994a)	3.0	-4.8 (-30 to 0.0)				
Fankhauser (1995)	2.5	-1.4	-4.7	China	-0.7	Eastern Europe and the former Soviet Union
Tol (1995)	2.5	-1.9	-8.7	Africa	-0.3	Eastern Europe and the former Soviet Union
Nordhaus & Yang (1996)	2.5	-1.7	-2.1	Developing countries	0.9	Former Soviet Union
Plamberk & Hope (1996)[a]	2.5	2.5 (-0.5 to -11.4)	-8.6 (-0.6 to -39.5)	Asia (w/o China)	0.0 (-0.2 to 1.5)	Eastern Europe and the former Soviet Union
Mendelsohn, Schlesinger, & Williams (2000)[a,b,c]	2.5	0.0[b] 0.1[b]	-3.6[b] -0.5[b]	Africa	4.0[b] 1.7[b]	Eastern Europe and the former Soviet Union
Nordhaus & Boyer (2000)	2.5	-1.5	-3.9	Africa	0.7	Russia
Tol (2002)	1.0	2.3 (1.0)	-4.1 (2.2)	Africa	3.7 (2.2)	Western Europe
Maddison (2003)[a,d,e]	2.5	-0.1	-14.6	South America	2.5	Western Europe
Rehdanz & Maddison (2005)[a,c]	1.0	-0.1	-23.5	Sub-Saharan Africa	12.9	South Asia
Hope (2006)[a,f]	2.5	0.9 (-0.2 to 2.7)	-2.6 (-0.4 to 10.0)	Asia (w/o China)	0.3 (-2.5 to 0.5)	Eastern Europe and the former Soviet Union
Nordhaus (2006)	2.5	-0.9 (0.1)				

Note: Where available, estimates of the uncertainty are given in parentheses, either as standard deviations or as 95% confidence intervals.

[a] The global results were aggregated by Tol (2009) .

[b] The top estimate is for the "experimental" model, the bottom estimate for the "cross-sectional" model.

[c] Mendelsohn et al. only include market impacts.

[d] The national results were aggregated to regions by Tol (2009) for reasons of comparability.

[e] Maddison only considers market impacts on households.

[f] The numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol; Stern et al. (2007) adopt the work of Hope (2006).

Second, IAMs' assumption that agents have the capacity to adapt perfectly to climate change (or that they have another arbitrary, but universal, level of adaptive capacity) neglects the fact that adaptive capacity varies substantially across space. An assumption of perfect adaptation could significantly understate the vulnerability of those areas with a low level of adaptive capacity. Chapters 3 examines a whole body of literature that has emerged that aims to more realistically assess adaptive capacity, and Chapters 4 provides two case studies on how adaptive capacity can be assessed from an evolutionary perspective.

2.3.1.2 Neoclassical Economics Perspective on the Uneven Landscape of GHG Emissions

From a neoclassical economics perspective, the uneven landscape of GHG emissions outlined in Section 1.2.1 would be interpreted largely as a by-product of uneven economic development. The starting point for neoclassical theory on spatial development is that market forces will drive an economy towards a *spatial equilibrium* in which utility is constant across space (Glaeser, 2000). Therefore, any uneven economic development is seen as temporary. As illustrated by Perrons (2004, p. 56):

> *Labour and capital are predicted to move from areas of surplus to areas of deficit, stimulated by higher returns – wages or profits respectively. Thus, labour should move from poor to rich regions and capital should move in the opposite direction until wages and profits are equalised across regions resulting in an efficient and balanced pattern of development.*

Other factors of production, such as technology, are also predicted to disperse across space until spatial equilibrium is reached (Coe, et al., 2013).

More complex models, based on neoclassical location theory, have examined opposing forces, such as the friction of distance (e.g. transportation costs) or economic advantages gained from spatial agglomeration, and have come to the opposite conclusion: "[…] market forces, if left to their own devices, are spatially disequilibriating. Economies of scale and agglomeration lead to the cumulative concentration of capital, labour, and output in certain regions at the expense of others: uneven regional development is self-reinforcing" (Martin & Sunley, 1998, p. 201).

Krugman (1991, p. 485) even went so far as to argue that these disequilibriating forces could result in a polarised 'core-periphery' development pattern – reminiscent of Marxist interpretations of uneven spatial development (see, for example, Harvey, 2003) – in which manufacturing is "concentrated in one or a few regions of a country, with the remaining regions playing the 'peripheral' role of agricultural suppliers to the manufacturing 'core.'"

Each of these forces can be observed in the rapidly changing landscape of GHG emissions outline in Section 1.2.1. The growth in emissions from large-scale developing countries could be interpreted as a by-product of the market forces driving the dispersal of capital as firms search for cheaper factors of production (labour, raw materials, etc.) in new regions. The concentration of GHG emissions in certain regions could be interpreted as a by-product of manufacturing firms concentrating in specific locations (e.g. China) to take advantage of agglomeration economies. Finally, significant imbalance of trade in embodied carbon from developing to developed countries could be interpreted as a by-product of a core-periphery development pattern with the 'periphery' supplying the 'core' with cheap carbon-intensive goods.

Given the incentives for capital to flow to locations with cheap factors of production, neoclassical economists emphasise that efforts to apply a price to emissions must be done in a coordinated manner across countries (Stern, 2007). If a country takes unilateral action to make polluting more expensive for firms, those firms will be outcompeted at the global level and an incentive will be created for firms to (re-)locate in countries with less stringent regulations. Emissions reduced by the imposed taxes or regulations will simply be offset by an increase in emissions in other countries, a phenomenon referred to as 'carbon leakage.'

If a global price on emissions were implemented, market forces would theoretically drive a reduction in emissions in the most economically efficient locations, i.e. where they would incur the least economic costs. Unlike a carbon tax, a global cap-and-trade system would allow the costs of emission reductions to be shared across space as locations with expensive mitigation options would compensate locations with cheaper options through the purchase of emission reduction allowances (ERAs). Section 1.2.1 discussed how many of the most economically efficient measures to abate emissions are in developing countries. As is relevant to the case study in Chapter 5 of this thesis, McKinsey (2009a, p. 6) found that the costs for Brazil to reduce its projected emissions are relatively low: "Whereas the world average for 2030 is around €18 per tCO2e abated for initiatives with a positive cost, in Brazil the average cost of such alternatives is €9 per tCO2e."

If a global price on emissions cannot be achieved, many economists offer carbon border cost levelling (CBCL) as a second-best alternative (Grubb, 2011; Stern, 2007). CBCL involves extending carbon-pricing systems to include carbon embodied in products as they enter and/or exit an economy. Goods being imported into the country would be charged a tax or required to purchase emission allowances equal to a measure of embodied carbon; and to ensure that domestic products are competitive abroad, exports would be rebated the carbon taxes or emission allowances paid (Grubb, 2011).

Empirical evidence suggests that the fear over carbon leakage is overstated. For instance, a study on the economic impacts of the EU Emissions Trading Scheme in the iron and steel industry, two industries that are particularly exposed to international markets, found the amount of carbon leakage to be marginal (Quirion & Demailly, 2008). Explanations for the minimal leakage tend to point to the benefits of local production – such as lower transport costs, reduced exposure to exchange rate fluctuations and security of supply – which could outweigh the costs imposed by emissions pricing (Quirion & Demailly, 2008).

There is significant debate within neoclassical economics literature about the respective influence of different factors that promote or inhibit carbon leakage, or that disperse or concentrate economic activity. However, the explanations remain focused on how rational individuals with perfect information respond to price-based incentives. Little attention is paid to knowledge flows or the local social, political, cultural, or historical factors that govern decision-making. The following section discusses how evolutionary economic geography offers a more holistic alternative.

2.3.2 The Evolutionary Economic Geography of Climate Change

Over the last fifteen years, numerous papers have been published highlighting the potential for cross-fertilisation between evolutionary economics and economic geography. In 1999, Boschma & Lambooy (1999) posited that a number of concepts from evolutionary economics, such as *selection*, *path-dependency*, and *increasing returns-to-scale*, may be applied to topics in economic geography. Specifically, they argued that an evolutionary approach could provide insights into the process of localised 'collective' learning, the spatial formation of newly emerging industries, and the build-up of agglomeration economies. These insights led Boschma & Frenken (2006), over a century after Veblen (1898), to pose the question, "Why isn't economic geography an evolutionary science?" Finally, in 2010, Boschma & Martin published the *Handbook of Evolutionary Economic Geography*, solidifying the field's status as a distinct perspective.

In many areas, evolutionary economics and economic geography are already aligned. Both fields reject neoclassical economics concepts of 'rational' economic actors, and that markets trend towards equilibrium. In other areas, however, there was/is divergence. Whereas economic geographers reject neoclassical economics' notion that economies function according to universal laws and principles, and hence can be studied using mathematical models, many within the tradition of evolutionary economics, including Nelson & Winter (1982), have sought to develop mathematical models that factor in disequilibrium, routinised behaviour, and stochastic innovation. In more recent years, this agenda has been taken up by complexity economics (see, for example, Beinhocker, 2007). While complexity economics is a promising line of research, it is not compatible with a geographical perspective, which holds that however sophisticated, mathematical models based on theory cannot fully capture the complexity of the real-world economic processes, or the context in which they take place.

From an evolutionary economic geography perspective, change in human systems occurs when a behavioural routine, an institution, or a technology that provides a competitive advantage within local conditions is selected and retained. This process is highly contextual, often irreversible, and path-dependent, necessitating an understanding of historical and contextual factors associated with each *place*. Evolutionary economic geographers, therefore, object to the *universality* assumed by neoclassical economists.

As increasingly competitive features are selected and retained, human systems are thought to progressively adapt towards an optimal state in which no potential features exist that are more competitive. However, at best, optima can only exist within local selection environments and can only be temporary. Higher-level, structural change can lead to a different selection environment in which current routines and technologies are less well adapted or even *maladapted* (Rammel & van den Bergh, 2003). Shifts in the selection environment can be driven by climatic, ecological, technological, cultural, or institutional change. Hence, evolutionary economic geography is not only interested in the micro-economic processes at the level of the individual and firm; it is also interested in processes driving change at other *scales*.

A number of studies have begun calling for the application of evolutionary theories to questions concerning economic change in response to climate change. As far back as 2008, Hayter advocated for "an institutional approach, variously labelled as 'old', 'radical', 'dissenting' and (increasingly) 'evolutionary' economics' […] as a conceptual, analytical platform for [environmental economic geography]" (2008, pp. 1-2). Foxon (2011, p. 2258) proposed a "coevolutionary framework for analysing a transition to a sustainable low-carbon economy based on the coevolution of ecosystems, technologies, institutions, business strategies and user practices, within a multi-level micro–meso–macro perspective." The concept of coevolution is drawn largely from ecological economics, and refers to the mutually causal influences between evolving systems (Foxon, 2011). Howarth (2012) drew from a wide range of literature, including evolutionary economics, as well as sustainability transitions, political science, complexity economics and neoclassical economics, to develop 'an integrated approach' to the economics of climate change mitigation. Finally, Patchell & Hayter (2013, p. 112) called for the integration of environmental and evolutionary economic geography to form an EEG^2: "a multi-scalar co-evolutionary perspective that examines systemic relationships between social and environmental systems in which economic geography fully participates."

Hence, this thesis cannot claim to substantially break any theoretical ground. What it does claim to do is advance evolutionary economic geography as an overarching theoretical framework for the study of both adaptation and mitigation to climate change. The rest of this thesis is devoted to the task of shaping an evolutionary economic geography of climate change.

2.3.2.1 The Evolutionary Economic Geography of Vulnerability to Climate Change

Evolutionary economic geography is a particularly attractive lens through which to study adaptation and vulnerability. As economic metaphors, both 'evolution' and 'adaptation' have their roots in evolutionary biology. Here, adaptation refers to a biological trait that provides a functional benefit over its alternatives within specific environmental conditions, and to the dynamic evolutionary process through which this trait arises and is retained within a species (Rammel & van den Bergh, 2003).

The theory and terminology surrounding vulnerability and adaptation to climate change have been relatively well established over the last two decades, much of it drawing on literature about vulnerability to natural disasters that dates back much further (see, for example, White, 1945). However, questions regarding where and how this theory fits into broader theoretical traditions of economic change remain largely unanswered. Authors have engaged with the neoclassical economic paradigm, if only to use its assumption about rational and self-interested economic agents as a straw man against which to contrast their own observations (as did Burton, et al., 1978). However, the literature on adaptation and vulnerability to climate change has not adequately engaged with other broad economic traditions, such as institutional, Marxian, or evolutionary economics. The literature has encountered and even grappled with the question of structure versus agency in determining vulnerability and adaptive capacity (see Glantz, 1977; Hewitt, 1980; Torry, 1979; Wisner, et al., 2004), but it has not done so in any explicit manner. Nor does it address the question of whether economies trend towards equilibrium, as held by the neoclassical economic paradigm, or evolve along dynamic, path-dependent trajectories, as held by evolutionary and Marxian traditions. Likewise, aside from the previously mentioned work of Leichenko (2011) and Leichenko & Thomas (2012), the literature on adaptation and vulnerability to climate change does not adequately engage with that of economic geography (or *vice versa*). While it thoroughly discusses, often explicitly, issues of space, place, and scale, it does not address these issues in any systematic way or relate findings to any broader theories within the field of economic geography.

This lack of engagement is unfortunate, because there is potential for a great deal of cross-fertilisation between these various fields. Chapter 3 will aim to remedy this weakness in the literature on vulnerability and adaptation. It will identify two broad schools of thought within the literature – 'the behavioural paradigm' and 'the structural turn' – and relate them to broader economic traditions. It will then construct an evolutionary perspective on adaptation and vulnerability. Finally, it will examine methods of assessing local vulnerability from an evolutionary perspective.

2.3.2.2 The Evolutionary Economic Geography of Greenhouse Gas Emissions

In contrast to the literature on adaptation, the literature on mitigation of GHG emissions has been very engaged with the economics literature. As already discussed, much of it falls within the realm of environmental economics and neoclassical economics. However, a number of interrelated bodies of literature draw explicitly from evolutionary economics. These include innovation systems theory (Breschi & Malerba, 1997; Foxon, 2007; Lundvall, 1992; K. Smith, 2000), the multi-level perspective (MLP) on socio-technological change (Geels, 2002; Geels & Schot, 2007), and transition management (Foxon & Pearson, 2008; Kemp & Loorbach, 2003; Nill & Kemp, 2009). Innovation systems literature examines how learning processes and the flow of information between people, firms, and other organisations shape innovation and economic trajectories. As argued by Malerba (2002, p. 249), "[…] evolutionary theory provides a broad theoretical framework for the concept of sectoral systems of innovation and production. Evolutionary theory places a key emphasis on dynamics, process and transformation. Learning and knowledge are key elements in the change of the economic system. 'Boundedly rational' agents act, learn and search in uncertain and changing environments." The related transitions approach examines how human systems shift from one socio-technical configuration to another. This thesis argues that the MLP on sustainability transitions (seen in Figure 16) aligns well with an evolutionary economic geography perspective because, as discussed below, it incorporates both explanations for punctuated equilibria in economic systems discussed in Section 2.2 – disruptive innovation and higher-level structural change.

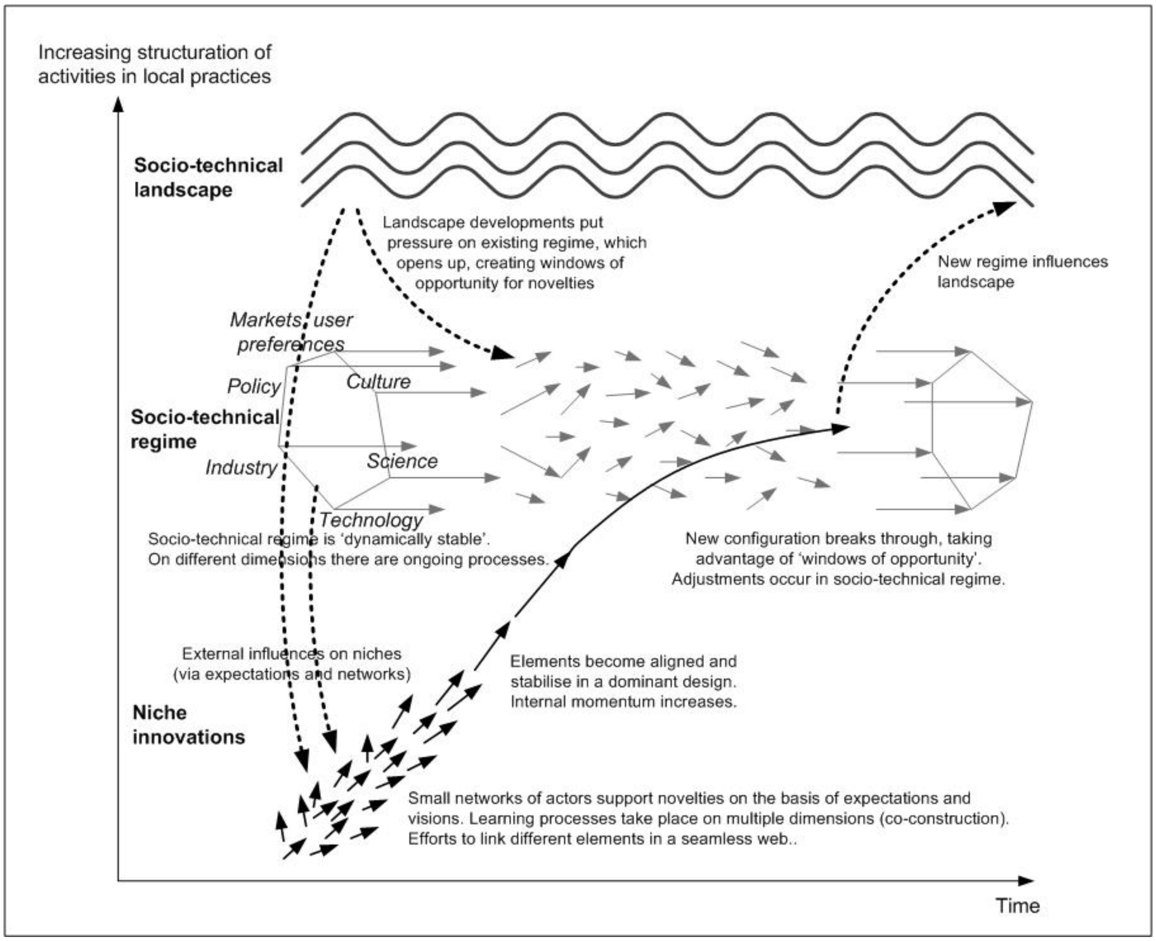


Figure 16. Multi-level perspective on socio-technical transitions (Geels & Schot, 2007, p. 401).

The premise of the MLP model is that economic change is impeded by the stable, self-reinforcing and coevolved web of social relationships and networks, scientific research and shared knowledge, cultural values, organisational commitments, sunk investments and vested interests, complementary infrastructures, and policies and institutional relationships that govern how societies solve technological problems, and tends to favour the status quo (Foxon & Pearson, 2008; Geels, 2002). Together, these elements form the meso-level of the MLP, a *socio-technical regime*.

Established technologies and behaviour cannot easily be replaced by radically new innovations when this also requires changes to other elements of the socio-technical regime (Geels, 2002). To illustrate, consider the interplay between road networks, gas stations, factories, established workforces, oil refineries, shareholder interests, and even subsidized military operations that works to perpetuate the primacy of the petroleum-powered automobile and inhibit the diffusion of alternative means of transport (Unruh, 2000). The inertia of socio-technical regimes, termed 'lock-in,' is reinforced by path dependency (Howarth, 2012). For example, the initial capital investment into a coal-fired power plant will lock-in a country into coal dependence for 40 to 50 years (Gosh & Watkins, 2009).

Even when a new technology or routine is more cost-effective than its incumbent alternative, such as those illustrated in the Global MAC Curve in Figure 14, widespread diffusion is not feasible in mainstream markets when it would require changes to other elements of the socio-technical regime. Nascent innovations are instead initially introduced in *socio-technical niches* where their strengths appeal to consumers who are typically ignored by existing market leaders. In a niche market, a new innovation can gain a competitive foothold away from the adverse selection processes of the socio-technical regime and benefit from positive feedbacks such as learning effects, the creation of knowledge networks, increasing returns to scale, and the development of a skill-base (Foxon & Pearson, 2008).

The macro-level of the MLP model – the *socio-technical landscape* – is the wider exogenous environment in which economic change plays out (Geels, 2002). It comprises slow-changing megatrends like globalization, cultural change, political change, and climate change. Shifts in *landscape pressures* can lead to a different selection environment in which current routines and technologies are less well adapted or even maladapted. The concept of the socio-technical landscape aligns well with Gowdy's (1992) and Rammel & van den Bergh's (2003) theory that higher-level sorting mechanisms can shift local selection pressures. However, unlike higher-level sorting mechanisms in biological evolution, which exclusively have a one-way and downward relationship with selection pressures, Foxon & Pearson (2008) argue that the socio-technical landscape has a two-way relationship with socio-technical regimes: a shift in the socio-technical landscape (for example, climate change) puts downward pressure on the socio-technical regime to adjust; an adjustment in the socio-technical regime (for example, to more low-carbon technologies) can impact the socio-technical landscape.

Based on the MLP model, Geels & Kemp (2006) classified economic change into three categories:

- *Reproduction* involves incremental and cumulative change along existing trajectories – similar to that described by Rosenberg (1982). It is referred to as 'reproduction' because it requires no reorientation of the dominant actors, key technology, and knowledge base within the socio-technical regime.

- *Transformation* refers to economic change that is driven by shifts at landscape level causing downward pressure on the socio-technical regime. In the transformation process, "The adjustment and reorientation to external landscape pressures does not happen in a mechanical fashion, but through negotiations, power struggles and shifting coalitions of actors" (Geels & Kemp, 2006, p. 9). Importantly, the position of the incumbent regime actors is not threatened. Rather, the same actors redirect the development trajectory and a new system emerges out of the old one.
- *Transition* occurs when landscape pressures from above correspond with disruptive innovation at the niche-level below, creating a 'window of opportunity' to shift to an entirely new socio-technical system with a regime made up of different routines, technologies, knowledge, regulations, and actors.

Geels has used the MLP model to analyse the mechanics of a variety of economic changes: for example, the British transition from sailboats to steamships (Geels, 2002), the transition from horse drawn carriages to automobiles (Geels, 2005), and the Dutch transformation from cesspools to sewerage systems (Geels, 2006). A transitions approach has also been used by a variety of authors to analyse the mechanics of economic shifts to sustainable pathways, and how those transitions can be induced and managed by governments. For example, Foxon & Pearson (2008) analysed low-carbon energy innovation in the UK; Rock et al. (2009) examined the mechanics of sustainability transitions in cement and electronics industries in East and Southeast Asia; and Verbong, Geels, & Raven (2008) examined the dynamics of the Dutch renewable energy innovation pathways. Chapter 5 adds to these case studies by providing case studies on three economic changes towards sustainable pathways in Brazil – the shift to no-till agriculture, the reduction in deforestation rates, and the growth of the biofuels industry. It categorises these three economic changes as reproduction, transformation, and transition, respectively.

Despite this thesis's incorporation of insights from transition theory into its evolutionary economic geography perspective on mitigation of GHG emissions, it must be acknowledge that the transition approach has not been without criticism. For example, Foxon (2011, p. 2260) criticised the approach for not incorporating evolutionary concepts like variation, selection, and retention; for "providing overly structural explanations, which do not provide significant roles for the choice of actors;" and for giving "relatively little emphasis to economic factors, such as investment and relative prices, in influencing socio-technical change." Coenen et al. (2010, p. 968) further criticised the transition approach for neglecting "where transitions take place, and the spatial configurations and dynamics of the networks within which transitions evolve." These criticisms resonate deeply with an evolutionary economic geography perspective. Hence, beyond adopting insights from transitions literature, this thesis will emphasise evolutionary concepts; agency as well as structure; economic factors such as prices and investment; and space, place, and scale.

A further dissimilarity between evolutionary economic geography and transitions literature is that the latter, like neoclassical economics, gives more weight to 'stylised facts' (universal laws) – a concept described in Clark (1998). Perhaps due to transitions literature's overly aspatial analysis (Coenen, et al., 2010, p. 968), it is less laden with the need to consider context, and more capable of providing normative policy prescriptions.

The related bodies of literature on transitions and on innovation systems have come up with justifications for government intervention and policy prescriptions that differ from those of neoclassical economics. For example, arguing from an innovation systems approach, Smith (2000) reframed the rationale for public policy intervention with the concept of 'systems failures' – areas where market-based systems will generate systematically weak performance:

- Failures in infrastructure provision and investment – Both physical infrastructures, such as electricity grids and railways, and science-technology infrastructures, such as universities or technical institutes, are unlikely to attract adequate private investment due to their large scale, indivisibility, and long-time horizons of operation.
- Transition failures – Individuals' and firms' inherent 'bounded rationality,' caused by their limited technological capabilities and inability to gather perfect information, will restrict their ability to adopt new innovations or to adapt to changing conditions.
- Lock-in failures – Incumbent technologies, and the institutions that support them, have experienced long periods of increasing returns. Consequently, even if a new technology or practice is more cost-effective than the locked-in alternative, the inertia of the socio-technical regime may prevent widespread diffusion.
- Institutional failures – Markets require institutional frameworks to function properly. These include formal laws relating to contracts, property rights, etc., as well as broader political norms and social values that shape policy objectives. An

institutional failure exists where institutions do not provide incentives for socially desirable outcomes.

There are overlaps between the concepts of 'systems failure' and 'market failure,' for example between public goods and failures in infrastructure provision. However, systems failures are perceived to be a much more pervasive problem. Foxon & Pearson (2008, p. 157) argued, "In many cases, this concept of systems failure leads to similar or identical policy prescriptions to the economic concept of market failure, e.g. the use of policy instruments to internalise negative environmental externalities. The crucial difference is that it does not presume that public policy interventions can recreate ideal market solutions, which are assumed to have maximal economic efficiency." With the existence of systems failures, correcting market failures may permit incremental innovation along current pathways, but wide-scale transitions towards more sustainable socio-technical regimes would still be inhibited.

Whereas neoclassical economics argues that the practice of stacking multiple policies to overcome market failures is inefficient and can increase the cost of mitigation (see, for example, Fankhauser, Hepburn, & Park, 2011), Foxon & Pearson (2008) argued that overcoming systems failures to promote desirable socio-technical transitions requires a diverse mix of policy instruments called a *sustainable innovation (SI) policy regime*. Chapter 6 argues that while from an evolutionary economic geography perspective the composition of SI policy regimes should be context specific, transition management literature can provide important insights into debates concerning the use and institutional architecture of climate finance.

According to Smith (2000), systems failures justify a greater degree of intervention in ways that are contrary to conditions of perfect competition. For example, they justify niche management through policies that foster lax selection pressures to enable new technologies to gain from learning effects, the creation of knowledge networks, and the development of a skill base. As explained by Rock et al (2009, p. 242), "A central message in the literature is that transitions cannot be micro-managed and are, at best, guided indirectly through policies and initiatives that enhance the adaptive capacity of existing socio-technical regimes and encourage the development of a diverse array of technological niches and niche experiments. Moreover, most promoters of transition management recognise that sustainability transitions are often hard-fought inter- and intra-scalar contestations between old and new institutions, agents, and technologies." Given these contestations, transition management often involves a political as well as a technocratic component.

Finally, unlike neoclassical economics, both evolutionary and transition literature observes that economic change is often an irreversible process, and that higher-level structural change can cause the selection environment to rapidly shift. Indeed, because economic geography, evolutionary economics, and transition management perspectives understand that markets cannot, in the words of Howarth (2012, p. 150), "adjust frictionlessly up and down demand and supply curves," they are much more amenable to ecologists' notions of a precautionary principle: "If it is impossible to know how far it is safe to perturb the system we live in without triggering a catastrophic collapse, then the only reasonable policy is not to perturb it more than it has been perturbed by natural phenomena in the past" (Ayres, 1995, p. 99; as cited in Rammel & van den Bergh, 2003).

Given that the degree of climate change is determined by largely unknown thresholds, an evolutionary approach would caution against neoclassical economics' policy recommendations that seek to optimise market forces to promote maximal returns, maximum sustainable yields, and 'optimum' emission levels.

3 Assessing Human Vulnerability to Climate Change from an Evolutionary Perspective

3.1 Introduction

Vulnerability assessments aim to identify the different elements that contribute to a human system's vulnerability to climate change. Understanding how different elements produce vulnerability is essential in designing a methodological framework for vulnerability assessment. The concept introduced in Section 1.2.2 that human vulnerability to natural hazards is a factor not only of exogenous exposure, but also of endogenous characteristics of the system in question (be it a household, community or nation), can be traced through a rich and multi-disciplinary body of literature on natural disasters. Section 3.2 offers a brief, and in no way comprehensive, synopsis of this literature. It argues that evolutionary perspectives on socio-economic change can offer important insights into human system's vulnerability, particularly in regards to adaptive capacity.

Similar to ecosystems and biological organisms, human systems have a capacity to evolve to become more suited to local environmental and climatic conditions (Smit & Pilifosova, 2001b). Through the process of adaptation, they will develop an ability to cope to some degree with climatic shocks and stresses. Determining a system's adaptive capacity is critical when assessing its vulnerability to climate change, because the most severe effects of climate change are expected to occur over the medium- to long-term, and a system's ability to adapt to those changes can alter its vulnerability a great deal. From an evolutionary perspective, adaptation is driven by human agency – the behaviour, creativity, and entrepreneurialism of individuals and organisations. However, it is also structured by socio-economic, ecological, and historical factors. To fully understand how human systems adapt to changing climatic conditions, an evolutionary approach to vulnerability assessment would examine how structure and agency interact to create locally specific vulnerability trajectories.

Section 3.3 discusses the various methods that have been employed to identify and measure vulnerability within human systems. It describes the evolution from impact assessments that employ economic modelling to vulnerability assessments that involve quantitative and/or qualitative empirical research. This chapter argues that from an evolutionary perspective, qualitative research methods are necessary to capture the complex and structural elements of vulnerability in a manner useful for decision-makers.

3.2 Vulnerability – The Concept

In its Third Assessment Report, the IPCC defined vulnerability to climate change as “a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC, 2001). This function is expressed in shorthand in the following equation (Adapted from Yohe & Tol, 2002):

$$V = f\{E(AC); S(AC)\}$$

where, V denotes *vulnerability*, as defined above; E denotes *exposure*, the likelihood of the human system being affected by a natural event, or climate stimulus; S denotes *sensitivity*, the degree to which a system would be affected by the exposure; and AC denotes *adaptive capacity,* the ability of human systems to adjust to actual or expected changes in climatic stimuli.

Whereas exposure is determined by characteristics of the climate (i.e. the magnitude and duration of climate stimuli), sensitivity is determined by the *occupance characteristics* of the human system in question, the social, economic, cultural, political, and institutional factors that determine how a system will be impacted by a climate stimulus (Smit & Wandel, 2006).

The final dimension of vulnerability is *adaptive capacity*. Over time, human systems are thought to gradually adapt to local environmental and climatic conditions. As depicted in Equation 1, adaptive measures can conceivably modify both a system's sensitivity and its exposure. For example, "Vaccination against climate sensitive vector-borne diseases and early warning systems for heatwaves are examples of *adaptation* measures that reduce the *sensitivity* and *exposure* of people to climate-related health hazards, respectively" (Füssel & Klein, 2006, p. 318).

As human systems adapt to local conditions they will develop an ability to cope with slight-to-moderate variations in local climate stimuli (Smit & Pilifosova, 2001b). This concept is illustrated graphically as a *coping range* in Figure 17. The system depicted is able to cope with moderate variations in the moisture deficit, perhaps due to strategies such as rainwater harvesting to make it through drier years or the implementation of drainage systems to make it through wetter years. It is only vulnerable to levels of moisture deficit that breach the upper and lower *coping thresholds*, for example, in the case of a drought or flood. Though depicted as a fine line, in reality, coping thresholds are more likely to resemble gradations, in which the system increasingly vulnerable to greater deviation from the mean.

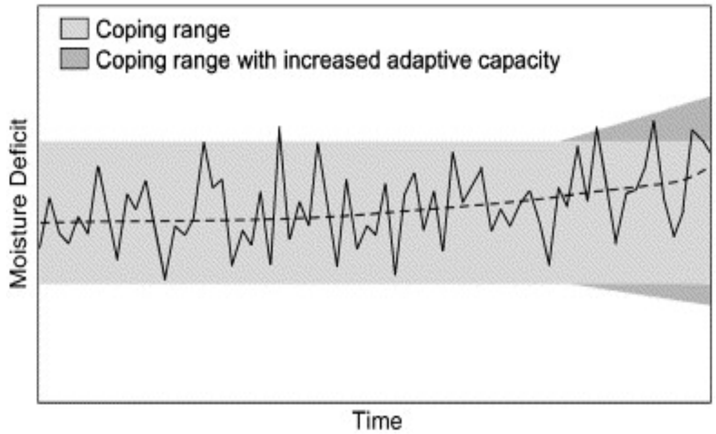


Figure 17. Coping range and extreme events (Smit & Wandel, 2006, p. 287).

Coping thresholds are dynamic. The coping range could contract due to a variety of factors, both exogenous and endogenous to the system. For example, a moisture deficit that is high, but not beyond the coping threshold, may not cause a disaster immediately, but it could result in a depletion of savings and thereby reduce the coping range. Subsequent years of the same high moisture deficit may then surpass the coping threshold (Smit & Pilifosova, 2003).

The coping range could also expand. A system's adaptive capacity refers to its ability to expand or shift its coping range in response to changes in the climate, such as changes in the frequency or magnitude of extreme events. As seen on the right-hand side of Figure 17, the system depicted was capable of adapting to an increase in the average moisture deficit, perhaps through new coping strategies such as the use of drip irrigation, crop insurance or early warning systems (EWSs). Similar graphical representations can be drawn for systems' ability to cope with other climate-related stimuli discussed in this thesis, including wind speed, storm surge, etc.

The capacity of human systems to adapt varies both between systems and internally, within a system (Smit & Wandel, 2006). As stated earlier, the degree to which a system can adapt to changes in climate can alter its vulnerability a great deal. To illustrate, Füssel and Klein (2006) provided Figure 18, which depicts five hypothetical trajectories for the level of climate-related impacts on five farmers. The lowest trajectory is a reference case with no climate change. The predominantly decreasing level of impact over time is caused solely by changes in non-climatic factors as the farmer continuously adapts to stable conditions. The other trajectories depict the impacts of a single climate change scenario on farmers with different adaptive capacities. The 'dumb farmer' has zero adaptive capacity, and does not respond to changing climate conditions at all. The 'typical farmer' adapts in a reactive manner to observed changes in climate. The 'smart farmer' adapts proactively to predicted climate changes. Finally, the 'clairvoyant farmer' has perfect foresight and adaptive capacity, and adjusts to future climate conditions accordingly. The bars on the right-hand side of Figure 18 show the different levels of climate-impact on farmers with different adaptive capacities ranging from the maximum potential impacts, assuming no adaptation, to impacts that are unavoidable, even with perfect adaptation (Füssel & Klein, 2006; Rothman & Robinson, 1997; Schneider, 1997).

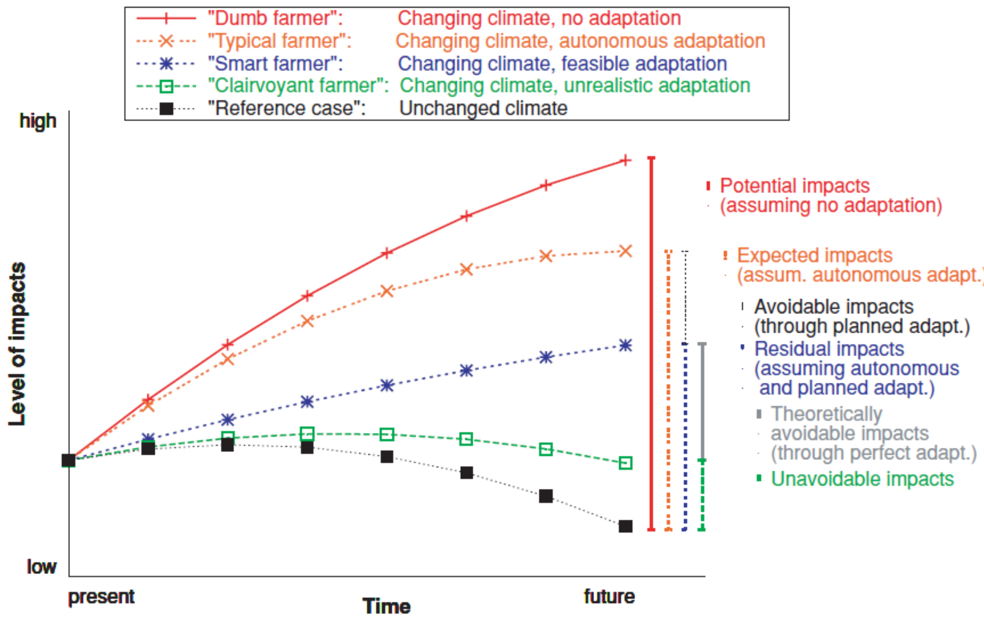


Figure 18. Climate impacts on farmers with different adaptive capacities (Füssel & Klein, 2006, p. 307).

To assess where a system's adaptive capacity falls within the spectrum of 'dumb' to 'clairvoyant,' one first must understand the different elements that promote or inhibit adaptation. The answer to this question is highly contested. Sections 3.2.1 and 3.2.2 summarise two different perspectives – the behavioural and structural paradigms on the factors that promote and inhibit adaptation. Section 3.2.3 outlines an evolutionary perspective on socio-economic change, which offers valuable insights into human systems' adaptive capacity.

3.2.1 Behavioural Paradigm

The *behavioural paradigm* holds that a system's adaptive capacity will depend on the ability of its agents' to accurately interpret risks posed by hazards and make rational decisions based on those interpretations. It was initiated in the 1930s and 40s by American geographer Gilbert White who stated, "Floods are 'acts of God,' but flood losses are largely acts of man" (1945, p. 2). White observed that vulnerability is often exacerbated by irrational decisions by economic agents.

The behavioural paradigm draws on psychological and economic theories of choice and (mis)perception of risks to explain human behaviour in the face of hazards (K. Smith & Petley, 2009). Earlier research used the neoclassical economics' 'rational choice' model as a starting point for analysis. In these models rational, self-interested agents choose each course of action based on the *expected utility* that they will gain. Explanations were then sought for why agents' decision-making is not always optimal in reality. As discussed in Section 2.1.1, from a neoclassical economics perspective, explanations for irrational behaviour were framed as different categories of market failure.

More recent literature within the behavioural paradigm has developed more nuanced theories of human choice and action. For example, Eiser et al. (2012) discussed the role of experience and learning processes in risk perception and decision-making. The paper draws on *cognitive heuristics*, which holds that individuals make decisions based not according to what is statistically rational, but on their own experience or the observed experience of others. Consequently, people will tend to over-generalise from their own relatively small data sets of experiences or observations: "By definition, low probability disasters occur infrequently within a given time period. If one has not experienced a disaster, reliance on personal experience may lead to an underestimation of the statistical risk. This can also lead to overconfidence in the effectiveness of safety procedures, the reliability of building and infrastructure, etc., essentially because they have not been fully put to the test" (Eiser, et al., 2012, p. 9). When unsafe behaviour is not immediately followed by harm, delayed reinforcement may increase a decision-maker's confidence in their actions; deficient feedback undermines the learning process, and risky behaviour is propagated.

3.2.2 A Structural Turn

In 1978, Gilbert White, along with two other prominent geographers, Ian Burton and Robert Kates, published *The Environment as Hazard*. One passage from the book reads as follows:

> *When a Bengal fisherman behaves like his neighbour in the face of the roaring cyclone, his action or inaction can usually be illuminated by examining three elements in the situation. These three are the ways in which people (1) recognize and describe [the hazard] 2) consider how they might deal with it, and (3) choose among the actions that seem to them available* (Burton, et al., 1978, p. 19).

Kenneth Hewitt (1980, p. 310) offered the following response:

> *This cool, reasonable view is […] not only asking a lot of someone facing 'a roaring typhoon': it is a far cry from the world most of us live in ordinarily. […] Man may appear in the long run to be a 'manager' […]. Few men have that opportunity. Human adaptation to environment is characterized by great plasticity of the individual but primacy of the society and its institutions in shaping the style of material life. Most people are raised and conditioned to rather narrow roles in the life of society. We observe a close conformity between a person's place in society and not only his or her behaviour, but what they know, think they need to know, and value. […] Does all this mean 'choice' is non-existent? No, just that it is highly*

circumscribed and unevenly distributed. More to the point, insofar as action is concerned, choice is largely regulated by the distribution of power in society. Within the general matrix of custom – the persistent, repetitive operations, the shared goals of a given social order – power of decision and implementation is jealously guarded.

Reminiscent of Marxian structuralism, Hewitt's critique is indicative of what can be described as a 'structural turn' in disaster studies that occurred from the late-1970s onward. This 'turn' was driven largely out of discontent with the lack of progress in reducing disaster losses in the least developed countries (for example, see Box 1). Agents were no longer seen as having choice within a wide range of theoretical adjustments to geophysical events. Rather, their choice of action was restricted by socio-economic factors including "[…] their social status, level of cultural literacy, access to credit sources, such as those embedded in kinship networks, technical expertise, size, and diversity of assets, employment options, household labour requirements, membership in voluntary organizations, productive capacity of capital, and commitment to cultural values and religious conventions" (Torry, 1979, pp. 372-373).

Box 1. Structure at the root of famine in the Sahel

A series of publications that examined the drought-induced famines of the early-1970s in the Sahel, the semi-arid region along the southern border of the Sahara desert, were at the centre of a shift in the way social scientists conceptualised natural disasters and vulnerability. A variety of social scientists – including the historians Paul Lovejoy and Stephen Baier (1975), the political scientist Michael Glantz (1977), the anthropologist and sociologist Jean Copans (1979), the economist and philosopher Amartya Sen (1983), and the geographers Piers Blaikie and Harold Brookfield (1987) – began to question the dominant view that the famines could be attributed to the so-called 'advance of the Sahara syndrome' in which irrational economic behaviour of the local population led to overgrazing, deforestation, and soil erosion.

These scholars painted a picture of a highly specialised traditional society that, through co-evolution with the local ecosystem, had adapted extremely rational behaviour to cope with the challenges posed by the local climate. A symbiotic relationship existed between pastoralists and subsistence farmers. Livestock would graze on the post-harvest remains of crops, and in turn fertilise the fields. In the event of drought, which sometimes lasted several years, nomadic pastoralists would migrate in search of greener pastures, and farmers would secure food through a highly developed regional trade network between the desert-edge and the savannah.

However, this system had been disrupted in recent years by structural changes. Borders established during colonisation, such as those between northern Nigeria and Niger, combined with globalisation and the introduction of cash crops, had the effect of redirecting trade towards the coast and overseas. Global demand for cash crops drove up food prices, thereby depriving drought-afflicted populations on the desert-edge from food surpluses that existed elsewhere in the region. The political division of the region restricted the movements of nomadic pastoralists, and the introduction of inorganic fertiliser for commercial farming undermined the service that they had formerly provided to the local agriculturalists.

In response to the drought, numerous development agencies supported programs to drill boreholes. While this technical solution increased water availability for human and livestock consumption, the increased amount of time that pastoralists spent near waterholes resulted in severe overgrazing which destroyed the local rainfall-dependent vegetation and led to further desertification.

The observations made of the drought-induced famines in the Sahel described in Box 1 served to shift focus away from irrational economic behaviour towards structural explanations for human vulnerability. In doing so, they highlighted that structural change is path-dependent and often irreversible: "The collapse of the traditional methods of fighting economic problems arising from periodical droughts may have played an important part in making the dry Sahel region more vulnerable to drought in recent years than it need have been. On some of these changes corrective policy actions are worth considering, but many of these developments are difficult to reverse" (Sen, 1983, p. 13). Piecemeal technical solutions to such structural problems, such as the drilling of boreholes, will often prove inadequate and may even exacerbate the problem. Instead,

"[…] problems such as deforestation, grass burning, erosion, overgrazing, overstocking, population growth, water resource management, and the like must be looked at systemically" (Glantz, 1977, p. 78). In other words, addressing vulnerability to natural hazards requires a holistic understanding of the structural root causes.

The structural perspective of vulnerability was largely formalised in the Pressure and Release (PAR) model, an adapted version of which is provided in Figure 19. The PAR framework was first published in Piers Blaikie, Terry Cannon, Ian Davis, and Ben Wisner's seminal book *At Risk: Natural Hazards, People's Vulnerability and Disasters,* and was re-published in 2004, and 2012. The PAR model illustrates how underlying 'root causes' of vulnerability, such as globalisation, social inequalities, and colonisation, place 'dynamic pressures' on human systems through forces such as political and economic marginalisation, corruption, armed conflict, and ecological degradation. Dynamic pressures, in turn, are manifest in unsafe conditions such low-income levels, construction in dangerous locations, and poorly designed buildings and infrastructure. These factors are manifest in different ways in different locations and different populations. When unsafe conditions coincide in space and time with a hazardous event, the system, and the people inside of it, are 'at risk to disaster' (Wisner, et al., 2004).

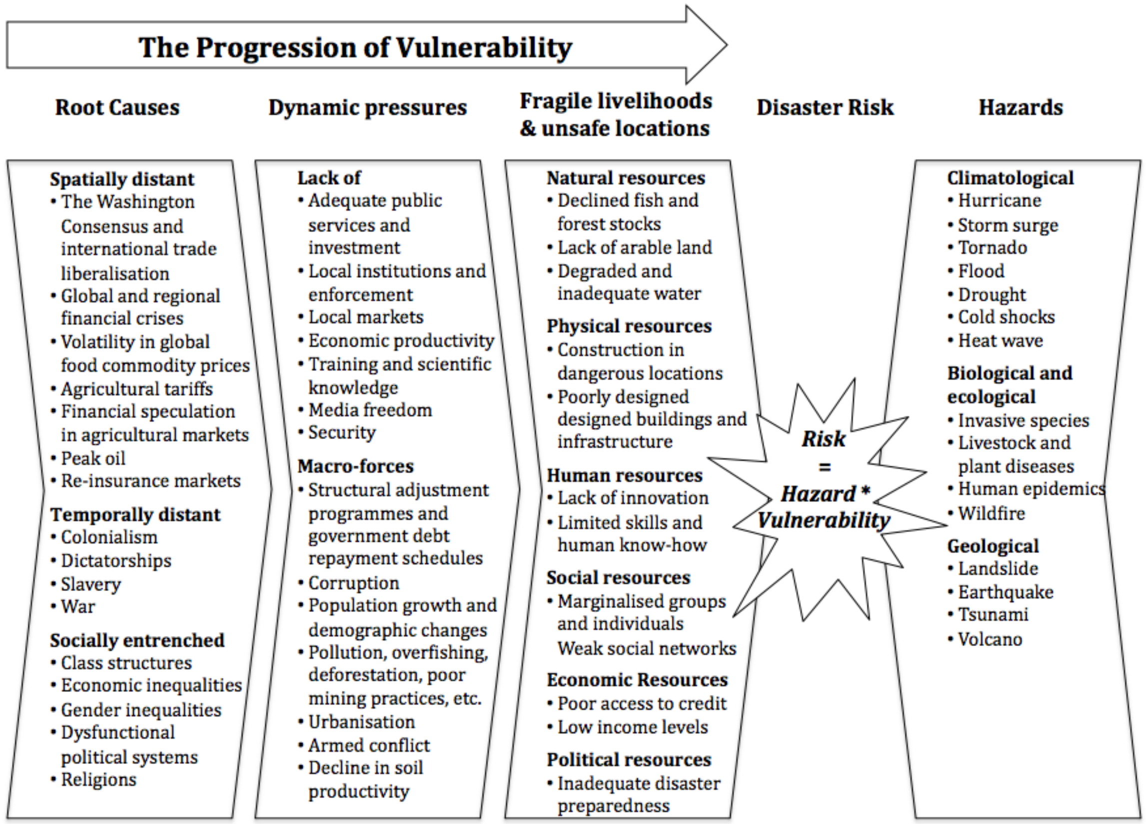


Figure 19. Pressure and Release model: The progression of vulnerability (Adapted from Wisner, Gaillard, & Kelman, 2012, p. 23).

To further explore the concepts outlined in the PAR model, Box 2 juxtaposes the impact of two events – the 2010 earthquakes that struck Haiti and Chile. These events, of course, were not climate-related; and comparisons of two extreme events of any variety need to be considered with a degree of scepticism. However, differences between Haiti and Chile in their level of vulnerability quite clearly contributed to the wide disparity between the two countries in the number of casualties, the economic impacts, and the duration and extent of recovery.

Box 2. Earthquakes strike Haiti and Chile

Late in the afternoon of 12 January 2010, an earthquake measuring 7.0 on the Richter scale struck Haiti. The epicentre was shallow at 13 kilometres underground, and was located 25 km west of the capital Port-au-Prince, home to 3 million people. Approximately 2.5 million people felt severe or violent shaking, which lasted for about 15 seconds (Hinrichs, Jones, Stanley, & Kleiner, 2011; Kovacs, 2010). The earthquake triggered a localised tsunami, measuring up to three metres, which hit a small fishing town (Gill, 2010).

Not two months later, in the early hours of Saturday, 27 February 2010, an 8.8 earthquake struck Chile. It was classified as the seventh most severe earthquake of all time, and was 501 times more powerful than the one in Haiti. The epicentre was located 34 kilometres underground and 115 kilometres north northeast of Concepción, the country's second largest city (Kovacs, 2010). Although the epicentre in Haiti was shallower and more proximate to Port-au-Prince, the Chilean earthquake caused a greater degree of shaking for a longer period of time (Hinrichs, et al., 2011). It lasted for about two minutes, and triggered a tsunami, the highest surge of which reached heights of 10-12 metres (Hinrichs, et al., 2011; Moehle, Riddel, & Boroschek, 2010). Over 12.5 million people, 75 per cent of Chile's population, were impacted by severe or violent shaking or by the tsunami.

The human and economic toll of the two earthquakes differed drastically. Official figures placed the number of fatalities in Haiti at 316 thousand[6] making it the second deadliest earthquake in recorded history.[7] A further 300 thousand were injured. Most people killed or injured had been caught in collapsed buildings. Only four were killed by the tsunami (Kovacs, 2010; US Geological Survey, 2012). Direct economic damages were estimated at US$8.1 billion (Cavallo, Powell, & Becerra, 2010), 122 per cent of Haiti's 2010 GDP. Roughly 105 thousand homes in Port-au-Prince and the surrounding communities were destroyed, and an additional 208 thousand were severely damaged. Over 1.3 million were forced to live in tents or temporary shelter. The quake damaged essential infrastructure, including 1300 schools and 50 medical centres, delaying recovery and preventing the injured from receiving treatment (Kovacs, 2010). It also led to a breakdown in social order. Gang-related crime, which had been declining in recent years, rebounded after nearly 5000 prisoners escaped from the national penitentiary and returned to the slums. Kidnappings, home-invasions, and murders all increased in 2010 (Overseas Security Advisory Council, 2011).

The situation after the earthquake in Chile paints a very different picture. The human cost was much lower with 523 fatalities, and about 12 thousand injured[8] (US Geological Survey, 2012). The tsunami alone killed 124 people, many of whom were camping on a low lying island with no means of escape. Most other fatalities were due to suffocation in collapsed buildings made of adobe bricks formed with sand, clay, sticks and straw (Kovacs, 2010; Vanholder, et al., 2011). The earthquake was second most expensive on record, with economic losses estimated at US$30 billion (Munich RE, 2010), 14 per cent of Chile's 2010 GDP. The government identified 81,444 houses that were

[6] Other estimates were significantly lower, perhaps lower than 100 thousand.

[7] The deadliest earthquake in history occurred in 1556 in Shaanxi, China, which killed an estimated 830 thousand (US Geological Survey, 2012)

[8] 24 were still considered missing as of May 2010.

destroyed, and 108,914 that were severely damaged. However, despite almost 800 thousand people being displaced by the earthquake and tsunami (Hinrichs, et al., 2011), only 70-120 thousand were in need of initial emergency shelter (Mellado, 2010). Most whose homes were ruined either remained on their property or with family or friends. Food and water were shared amongst the population in Constitución before external support arrived (Hinrichs, et al., 2011). Like in Haiti, hospitals were severely damaged, but only one suffered structural damage, and all maintained the capacity to provide basic services thanks to backup power and water supplies. Other essential infrastructure that was damaged was restored rapidly (Moehle, et al., 2010). The impact on social order was also not as severe as it was in Haiti. While sporadic arson and looting of supermarkets occurred in Concepción following the earthquake, it quickly subsided after the army arrived to assist in law enforcement on the third day (Hinrichs, et al., 2011).

The extent of recovery also differs markedly between the two countries. Almost $10 billion in immediate and long term recovery aid was pledged to Haiti by nations and organizations (UN, 2012). Three years later, about US$7.5 billion had been disbursed, yet reconstruction had barely begun (Schwartz, 2013). As stated by the World Bank's top regional official, the Haitian earthquake decimated the government's operating capacity. It only managed to establish its Interim Reconstruction Commission, responsible for coordinating recovery efforts, five months after the earthquake, and the decision to allocate land for the relocation of displaced persons was still pending after six months (World Bank, 2010). An estimated 358 thousand remain displaced, mostly living in large camps with inadequate sanitation and drinking water (IOM, 2012). Between October 2010 and March 2012, a cholera outbreak killed 7,050 and sickened over 531 thousand, 5 per cent of the population (Sontag, 2012). Security also remains dire, particularly for women and girls for whom tents and tarpaulin-covered shelters provide little protection against sexual violence (Doyle, 2012).

Chile received significantly less international support than Haiti, with an estimated US$197.5 million in aid in 2010 (World Bank, 2013). Yet its response and recovery were much stronger. The Chilean government's initial response to the earthquake was criticized for being delayed (Moehle, et al., 2010), its inadequacy blamed largely on an impending handover of government twelve days after the event. However, relative to Haiti, the overall response of the government was effective. The incoming president immediately formed an Emergency Committee to oversee the nation's response and recovery, and assigned it three tasks: first, to ensure that everyone's basic needs of food, power, and sanitation were met within one month; second, to ensure that everyone had shelter before winter (June 1st); and third, to deal with housing, debris removal, demolition, and restoration of basic services. The first two targets were met (Kovacs, 2010). The government provided food boxes to those in need, utilizing a bulk distribution system that was established prior to the earthquake to provide food for the poor. Where road access was blocked, helicopters were used. The government also provided 65 thousand temporary wooden cabins, which the army and nongovernmental organisations helped to manufacture, transport, and assemble. The majority of individuals were located next to the damaged or destroyed home. Others, mostly in tsunami-affected areas, were built in temporary camps. Communal toilets and showers were installed in the camps immediately, and electricity was provided within months. For reconstruction efforts, the government offered grants and concessional loans to those with destroyed or damaged homes (Hinrichs, et al., 2011). As of December 2012, 59 per cent of the 222 thousand homes repairs or replacements were complete, and 29 per cent were in progress (Manning, 2012).

The PAR model provides a useful framework for understanding the underlying forces that gave rise to the large disparities in vulnerability between Haiti and Chile. The further back an explanation is along the 'progression of vulnerability,' the more difficult it is to determine causality. Wisner et al. (2004, p. 52) explained that root causes are 'distant' in one or more of the following respects: "spatially distant (arising in a distant centre of economic or political power), temporally distant (in past history), and finally, distant in the sense of being so profoundly bound up with cultural assumptions, ideology, beliefs, and social relations in the actual lived existence of the people concerned that they are 'invisible' and 'taken for granted.'" For example, a spatially distant root cause of the vulnerability of Haiti to an earthquake in 2010 could have been the global trend of international trade liberalisation. As former US President Clinton argued, pressure on Haiti to reduce tariffs on food imports caused a decline in its rice production in the 1990s (Katz, 2010). A temporally distant root cause may have been Haiti's historically dysfunctional political system. In the last 200 years, Haiti experienced 32 coups and a long period of oppression by dictators. A root cause of the third variety may have been Haiti's 'restavèk' system, in which it is socially acceptable for impoverished families to send their children to work as servants for more affluent households. The UN (2009b) has called this system a modern form of slavery.

Dynamic pressures are the forces through which root causes give rise to unsafe conditions. For example, in Haiti, global trade liberalisation contributed to the dynamic pressure of declining agricultural livelihoods due to competition from cheaper imports. This decline caused Haiti to be highly susceptible to commodity prices spikes, such as the one that triggered food riots in Port-au-Prince in 2008. It also led to the further dynamic pressure of increased rural-to-urban migration, and slum formation. The root cause of the restavèk system created another dynamic pressure in which numerous children were growing up as slaves of families in slums, in many cases exposed to economic exploitation, sexual violence, and corporal punishment (UN, 2009b).

Haiti's historically dysfunctional political system may have given rise to the dynamic pressure of endemic corruption in its government. In 2009, Haiti ranked 168 out of 180 countries in Transparency International's Corruption Perception Index. Chile, on the other hand, ranked 25th (Transparency International, 2009). Corruption may have contributed to other dynamic pressures such as insufficient investment in education and training in appropriate skills, and a lack of economic productivity. In 2007, Haiti ranked 152 out of 181 countries in the UN's Education Index;[9] Chile placed 49th. Likewise, where prior to the earthquake 72 per cent of Haiti's population lived on under US$2 per day, 2.7 per cent of Chile's population lived under the same mark (UN, 2009a). Inadequate skills, corruption, and dysfunctional government may also have prevented the development of other important institutions, such as insurance programmes, and prevented the enforcement of others, such as building codes. Haitian

[9] The Education Index is calculated using the adult literacy rate and the primary, secondary, and tertiary enrolment ratios of a country. It is one of three indices used by the UN to calculate the Human Development Index. The other two are the GDP Index and the Life Expectancy Index.

authorities had banned building with brick after previous earthquakes in 1751, 1770, 1842 and 1946, and had mandated that new buildings be constructed of wood.

However, by 2010, despite research predicting future seismic activity, it had had long since stopped enforcing even minimal building codes. Chile's building codes, on the other hand, reflected present day international engineering knowledge regarding seismic safety (Kovacs, 2010). They were also widely adhered to, due largely to a law that requires building companies to compensate those who suffer loss in the event of partial or complete destruction of a faulty building (Hinrichs, et al., 2011).

Unsafe conditions are the way in which the vulnerability of a population to a specific hazard is expressed. In Haiti, the lack of enforced building codes manifest in the unsafe condition in which most homes were constructed of heavy walls of concrete blocks or of adobe bricks. They typically lacked a solid foundation or reinforcement and were highly susceptible to damage from shaking. In contrast, most structures built in the previous four decades in Chile were wood frame or reinforced masonry, and survived the shaking with little or no damage. In both countries it was the adobe buildings that experienced significant damage and their collapse caused most of the injuries and fatalities (Kovacs, 2010). Lack of insurance coverage presented another unsafe condition in Haiti. Of the estimated US$8.1 billion in economic losses, only $150 million were insured (Munich RE, 2010). The Government of Haiti did hold an insurance policy with the Caribbean Catastrophe Risk Insurance Facility (CCRIF), but only received a pay-out of $7.75 million due to its low coverage (S. Young, 2010). In contrast, over a quarter of the economic losses in Chile, approximately US$8 billion, were insured due to the high levels of insurance penetration in the utilities, commercial, and industrial sectors

(Munich RE, 2010). That being said, while 95 per cent of households with mortgages in Chile were required to carry seismic insurance, few without a mortgage did, and there was no cover available for adobe buildings which made up the majority residential losses (Moehle, et al., 2010).

Unsafe conditions include not only those that put life or property at risk. They also include conditions that prevent people from reconstructing their livelihoods following disaster (Wisner, et al., 2004). For example, the half million people living in the Port-au-Prince slum of Cité Soleil were known to be particularly vulnerable prior to the earthquake due to a number of dynamic pressures. Social order was particularly fragile due to years of rule by rival gangs. Moreover, an estimated 44 per cent of all of the children living in Cité Soleil were restavèks, removed from the protection of their families (Pierre, Smucker, & Tardieu, 2009). While reportedly few of the slums cinderblock and corrugated steel shacks collapsed during the earthquake (Marlowe, 2010), this social group would have found it particularly difficult to (re)construct its livelihood after the earthquake, and as a result will be more vulnerable to subsequent hazard events. The tendency for sequential hazard events to cause an increase in a system's vulnerability was evident in Haiti's slow recovery from four tropical cyclones[10] that hit within the span of 30 days two years prior to the earthquake. These storms contributed to a series of unsafe conditions at the time of the earthquake, including social upheaval from the 793 dead, 310 missing, and 151 thousand displaced; economic turmoil from estimated damages in excess of US$1 billion (5% of GDP); and widespread

[10] Tropical Storm Fay, Hurricane Gustav, Hurricane Hanna, and Hurricane Ike

malnutrition due to the spoil of 70 per cent of the nation's crops (Masters, 2008; USAID, 2008).

The PAR framework highlights the need to think structurally about human vulnerability to natural hazards. It demonstrates that local vulnerability can have its roots in macro-scale forces and historical factors. However, from an evolutionary perspective, a complete understanding of vulnerability must also give weight to agents' abilities to both shape different vulnerability trajectories within current structural environments and to alter structural environments through political processes, social movements, etc. As explained by Gertler (2010, p. 2) "[…] locally-distinctive and evolving, multi-scalar institutional architectures interact with the agency of individuals and organizations to help create particular evolutionary trajectories over time […]."

3.2.3 An Evolutionary Perspective

Joseph Schumpeter (1942), a pioneer of evolutionary economic thought, argued that agents' actions are conditioned by structural factors, but the primary driver of economic evolution is the innovative capacity of economic agents. His ideas were taken up by Nelson & Winter's (1982) seminal work, *An Evolutionary Theory of Economic Change*, which argued that, rather than constantly re-evaluating their actions to capture the greatest returns, firms and individuals tend to act according to routines – a concept that aligns well with that of cognitive heuristics, described in Section 3.2.1 on the behavioural paradigm. However, beyond these routines, agents will aim to gain a competitive advantage through activities designed to 'search' for new more efficient routines or technology, such as R&D or market analysis. Adaptation occurs when a behavioural routine or technology that provides a competitive advantage within local conditions is selected and retained. This process is highly path dependent: "Through the joint action of search and selection, firms evolve over time, with the condition of the industry in each period bearing the seeds of its condition in the following period" (Nelson & Winter, 1982).

As increasingly competitive features are selected and retained, adaptation is thought to progress towards an optimal state in which no potential features exist that are more competitive. However, at best, optima can only exist within local selection environments and can only be temporary. Climatic, ecological or socio-economic changes can lead to a different selection environment in which current routines and technologies are less well adapted or even *maladapted*, resulting in an increase in vulnerability (Barnett & O'Neill, 2010; Rammel & van den Bergh, 2003). Due to the routinisation, path-dependency, and structural conditioning of human activity, human systems tend to exhibit a degree of inertia, and are liable to get *locked-in* to specific industrial, technological, and institutional constellations. Adaptations that limit flexibility in response to unforeseen changes in the selection environment, such as large infrastructure investments, are particularly liable to lead to *maladaptations.*

Excessive specialisation within current selective pressures reduces adaptive capacity by reducing the range of options that a system could use to cope with future pressures: "Evolutionary systems thus can be seen to express a sort of implicit trade-off between realizing short term local optimal (like specific criteria of efficiency) and maintaining evolutionary potential to achieve adaptability and stable long-term development" (Rammel & van den Bergh, 2003, p. 127). This phenomenon is particularly evident in the case of famine in the Sahel described in Box 1. The traditional pastoral and agricultural society of the Sahel had adapted a highly specialised system of reciprocity to deal with the adverse ecological conditions of the desert. However, when structural changes caused the selection environment to shift, the pastoralists found their nomadic lifestyle to be maladapted to the new conditions. Adaptive capacity is therefore a function of *diversity*. Just as genetic diversity is essential in the process of biological evolution, diversity within economic, socio-cultural, institutional, and technological spheres is an essential condition in the adaptation of human systems (Boyd & Richerson, 1985; Matutinuvic, 2002; Rammel & van den Bergh, 2003).

Diversity in a system is also likely to increase its resilience, i.e. its ability to return to its pre-disturbed state after a shock without experiencing any fundamental change. Linkages between biodiversity and the resilience of ecosystems have been well documented (see, for example, Tilman & Polasky, 2005); as have linkages between agrobiodiversity and food security (Di Falco & Chavas, 2009; Galluzzi, van Duijvendijk, Collette, Azzu, & Hodgkin, 2011). Biodiversity spreads risk across a variety of species analogous to the way diversity reduces risk in an investment portfolio. In this manner, biodiversity provides a threshold against irreversible and potentially catastrophic environmental change. Similarly, "diversity related to a wide range of activities, including agricultural techniques, industrial production methods, means of communication, languages, institutions, legislation, and informal rules (culture)" is thought to increase the resilience of human systems in the face of structural change (Rammel & van den Bergh, 2003, p. 128). Diversity in a system can be retained, for example through cultural or ecological conservation measures. It can also be created through innovative processes that add novelty to the system such as entrepreneurialism, academia, R&D, and technology transfer.

Central to adaptive capacity of human systems is the adaptive flexibility of institutions and governance structures in response to agents' attempts to alter them. On governance of ecological resources, Dietz, Ostrom, & Stern (2008, p. 1907) argued:

> *Devising effective governance systems is akin to a coevolutionary a race. A set of rules crafted to fit on set of sociological conditions can erode as social, economic, and technological developments increase the potential for human damage to ecosystems and even to the biosphere itself. Furthermore, humans devise ways of evading governance rules. Thus, successful commons governance requires that rules evolve.*

Adaptive governance necessitates the application of mixtures of institutional types nested at multiple scales; and that these institutions should be designed to be flexible and responsive to changing conditions through appropriate informational feedback mechanisms and the analytic deliberation of various informed stakeholders (Dietz et al. 2008).

The following section will discuss the different methods that have been used to identify vulnerable groups and assess vulnerability. Ultimately we argue that the data necessary to assess vulnerability from an evolutionary perspective can only be obtained through qualitative techniques.

3.3 Identifying Vulnerable Groups and Assessing Vulnerability

Various studies have attempted to assess human vulnerability to climate change using methodologies that incorporate techniques from both the social and physical sciences. As discussed in Section 2.3.1.1, climate-impact assessments have been used to estimate the potential impact that different climate scenarios would have on specific sectors and scales. Some consider the projected costs of climate change to be indicative of vulnerability (Smit & Wandel, 2006).

Vulnerability assessment offers an alternative approach, one with a long history of use in a variety of different contexts – food security, water security, livelihoods, natural disasters, etc. The approach is the inverse to that of impact assessment: "The starting point for impact assessment is the stimulus (the specified climate, usually average conditions from a climate change scenario); the starting point for vulnerability assessment is the system (the community or region or sector)" (Smit & Pilifosova, 2003, pp. 20-21). Importantly, unlike impact assessments, vulnerability assessments incorporate consideration of relevant non-climatic factors that affect the adaptive capacity of the system. The goal is to obtain realistic results that fit somewhere around the 'typical' and 'smart farmer' trajectories in Figure 18 (Füssel & Klein, 2006).

To evaluate the adaptive capacity of human systems, vulnerability assessments use a variety of empirical methods that range from relatively quantitative to highly qualitative. Quantitative frameworks use surrogate indicators of adaptive capacity, the value of which they obtain from open sourced data or measure using surveys (see, for example, Luers, Lobell, Sklar, Addams, & Matson, 2003; Yohe & Tol, 2002). As outlined in Table 2, some have adopted the five capitals of Sustainable Livelihoods approach to poverty reduction as proxy indicators of adaptive capacity (Hahn, Riederer, & Foster, 2009). Similar to the Human Development Index, the indicators are often combined into a composite index that allows diverse variables to be integrated. 'Weighted averages' are sometimes used to adjust the degree of influence of each indicator.

Table 2. Characterising adaptive capacity: the Sustainable Livelihoods framework (Krantz, 2001; Wisner, et al., 2004) and the Local Adaptive Capacity framework (Jones, Ludi, & Levine, 2010).

Sustainable Livelihoods framework		**Local Adaptive Capacity framework**	
Characteristic	**Description**	**Characteristic**	**Description**
Human Capital	Skills, knowledge, good health, and the ability to labour	Asset Base	Tangible (natural, physical, and financial) and intangible (human and social) capitals
Social Capital	Social relations, networks, social claims, affiliations, and associations	Institutions & entitlements	Equitability of access to key assets and the process through which institutions evolve
Physical Capital	Infrastructure, infrastructure, technology, and equipment	Knowledge & information	The system's ability to collect, analyse, and disseminate information
Financial Capital	Cash, credit, savings, and other economic assets	Innovation	Degree to which the systems fosters and retains innovations
Natural Capital	Natural resources, land, water, fauna, and flora	Decision-making & governance	Degree to which governance and decision-making systems anticipate change and respond accordingly

Within a policy-driven assessment framework, measuring vulnerability through the use quantitative indicators of vulnerability can enable more effective implementation and monitoring of progress, and can facilitate comparison across different countries or regions (Luers, et al., 2003). For this reason, *The Hyogo Framework for Action*, the ten year plan adopted by 168 UN Member States in 2005 to make the world safer from natural hazards, calls for the development of "systems of indicators of disaster risk and vulnerability at national and sub-national scales that will enable decision-makers to assess the impact of disasters on social, economic, and environmental conditions and disseminate the results to decision-makers, the public, and populations at risk" (UN/ISDR, 2005, p. 7).

Systems of indicators based on capitals and assets are useful in identifying the resources that a system can draw on to cope with extreme events and adapt to changing selection pressures. They can help to identify fragile livelihoods and unsafe conditions, as outlined in the PAR model. However, as argued by Jones et al. (2010, p. 1), "[…] asset-oriented approaches typically mask the importance of processes and functions in supporting adaptive capacity. Understanding adaptive capacity, therefore, entails recognising the importance of various intangible processes: decision-making and governance; the fostering of innovation, experimentation, and opportunity; and the structure of institutions and entitlements, for example." Adequate representation of local knowledge, experience, and decision-making processes is also a challenge in studies that aim to assess vulnerability using predetermined variables.

Jones et al. (2010) developed the LAC framework, which characterises adaptive capacity based on five elements: asset base; institutions and entitlements; knowledge and information; innovation; and flexible forward-looking decision-making and governance (see Table 2). The LAC framework is an improvement over capital-based approaches in that it examines the processes through which a system adapts, rather than just what it has that enables it to adapt. Its focus on institutions, knowledge, innovation, and flexibility in decision-making and governance corresponds with an evolutionary perspective on adaptive capacity. Jones et al. (2010) posited that indicators could be developed for each characteristic within the LAC framework. While such indicators would be useful in monitoring and evaluation, I argue that to unearth the historical root causes of vulnerability and the structural factors that shape evolutionary trajectories, rich descriptive data is required that can only be captured through qualitative methods.

Qualitative approaches to vulnerability assessment place strong emphasis on the local context – the local culture, history, social dynamics, and institutions – and how this context is shaped by forces at different scales (see, for example, Pittman, 2010; Pittman, Wittrock, Kulshreshtha, & Wheaton, 2011; Pouliotte, Smit, & Westerhoff, 2009; Wandel, Young, & Smit, 2009; G. Young, et al., 2010). It is not presumed that predetermined variables shape sensitivity and adaptive capacity. Instead, ethnographic methods, focus groups, and semi-structured interviews are used in which respondents reveal experienced or expected changes in exposure, the diversity of coping and adaptive strategies that they have at their disposal, and their decision-making process. During interviews and focus groups, respondents tell of the non-climate considerations in their decision-making process, such as local class systems, resource management, food security, and conflict. Empirical methods are then supplemented by thorough examination of third-party data concerning the local history, ecology, economy, culture, politics, government policies, and other institutions. In this manner, the stories behind the numbers emerge, which often get lost in quantitative analyses, and a more accurate picture is painted of how structure and agency interact to create local evolutionary trajectories.

3.4 Conclusion

When assessing a human system's vulnerability to climate change, it is necessary to evaluate its capacity to adapt to changing conditions. Through adaptation, human systems can alter their ability to cope with changes in the frequency or intensity of extreme events, as well as with slower onset climate-related stresses. From an evolutionary perspective, adaptation is driven by the human agents' innovation and adoption of behaviours and technologies that are more suited to local conditions. However, agents' ability to adapt is structured by socio-economic, ecological, and historical factors. As illustrated in the cases of the 2010 earthquakes in Haiti and Chile, these factors can vary significantly across space. The appropriate interventions to reduce vulnerability will depend on the local context.

Vulnerability assessments can help determine which interventions are appropriate in each context by, for example, identifying which geographic areas or particular stakeholder groups are most in need of early warning or unearthing the underlying root causes within the human system, such as class structures, that produce vulnerability. From an evolutionary perspective, vulnerability assessment must employ a methodological framework capable of capturing agents' decision-making processes, as well as the place-specific historical and structural factors that constrain their adaptive capacity. The methodology must examine the diversity of adaptation options available to agents, and their ability to retain diversity or create new diversity through innovative processes that add novelty to the system such as entrepreneurialism, R&D, and technology transfer; and it must evaluate the flexibility of governance structures and other institutions in the face of changing conditions.

Numerous methods have been used to identify and assess vulnerability. These have evolved from impact assessments that employ economic modelling to vulnerability assessments that involve quantitative and/or qualitative empirical techniques. There are advantages and disadvantages to each approach. Quantitative indicators of vulnerability can enable comparison across systems and more effective implementation and monitoring of progress. However, vulnerability assessments that rely exclusively on economic modelling or quantitative indicators fail to fully capture the root-causes of vulnerability.

This chapter argued that the descriptive data necessary to identify the locally specific processes of adaptation, as well as the deep-rooted structural and historical factors that constrain adaptive capacity, can only be unearthed through qualitative research methods. The rich historical and descriptive data obtain by such qualitative vulnerability assessments is critical in determining which vulnerability-reducing interventions are most appropriate, and how they can be effectively implemented. Chapter 4 discusses two case studies that used qualitative methodologies combined with the LAC framework to assess the local adaptive capacity in the small island communities of Soufriere, Saint Lucia and Whitehouse, Jamaica.

4 The Adaptive Capacity of Soufriere, St Lucia and Whitehouse, Jamaica to Climate Change – An Evolutionary Perspective

4.1 Introduction

Over the coming years, the Caribbean islands are expected to experience increasing temperatures and changes in wind and rainfall patterns. These climate changes are likely to result in a variety of other changes including sea level rise, ocean warming, coral bleaching, the loss of marine biodiversity, increased coastal erosion and landslides, changes in growing seasons, and increased prevalence of pests, invasive species, and contagious diseases (GoSL, 2003).

This chapter is part of a larger research project called GIVRAPD, which focuses on vulnerability and adaptation to climate change in four island communities in the Caribbean (St Lucia and Jamaica) and the Indian Ocean (Mauritius and Seychelles). Led by the not-for-profit organisation INTASAVE, the project aims to identify the multi-scale socio-cultural, economic, institutional, and ecological factors that shape local vulnerability. This chapter focuses specifically on the capacity of Soufriere, St Lucia and Whitehouse, Jamaica to adapt to climate change.

The project used a methodology, discussed in Section 4.3, which combined qualitative research methods with the LAC framework. The LAC framework was developed by the Overseas Development Institute (ODI) in 2010 during its Africa Climate Change Resilience Alliance project. As discussed in Section 3.3, it characterises adaptive capacity based on five elements: asset base; institutions and entitlements; knowledge and information; innovation; and flexible forward-looking decision-making and governance. The selection of these elements was based on the empirical experience of the ODI research team. However, the LAC framework has not yet been applied in different geographical contexts; nor has it been sufficiently grounded in academic theory.

This paper will contribute to the literature in three ways. First, in the following section, it will summarise the argument made in Chapter 3 that the LAC framework's focus on institutions, knowledge, innovation and flexibility in decision-making and governance corresponds with an evolutionary perspective on adaptive capacity. Second, after the Methods section, it will offer in-depth case studies on the capacities of Soufriere and Whitehouse to adapt to climate change (Sections 4.4 and 4.5, respectively). Finally, in the Discussion and Conclusion (Section 4.6), it will offer a critical assessment of whether the framework fully captures the important elements of adaptive capacity across different geographical contexts.

4.2 An Evolutionary Perspective on Adaptive Capacity

As discussed in Chapter 3, from an evolutionary perspective, adaptation occurs when a behavioural routine, an institution or a technology that provides a competitive advantage within local conditions is selected and retained. This process is sometimes path-dependent and irreversible in that events and decisions made in the past will limit the adaptive options available the future (Nelson & Winter, 1982). As increasingly competitive features are selected and retained, human systems are thought to progressively adapt towards an optimal state in which no potential features exist that are more competitive. In economics literature, such optimal states are characterised by maximisation of production and efficiency, harvesting of renewable resources at the maximum sustainable yield, and often specialisation in industry, technology, skills, behaviour, etc. However, at best, optima can only exist within local selection environments and can only be temporary. Over time, higher-level changes – climatic, ecological, technological, cultural or institutional – will lead to a different selection environment in which current routines and technologies are less well adapted or even *maladapted* (Barnett & O'Neill, 2010; Rammel & van den Bergh, 2003). Such shifts can be gradual or rapid, and can be triggered by processes at a variety of *scales*, not only by the micro-economic processes at the level of the individual and firm. Multiple shifts can also occur simultaneously making it difficult, if not impossible, to predict local outcomes (Hogarth, et al., 2014; Rammel & van den Bergh, 2003).

Adaptive capacity refers to the ability of human systems to adjust to changes in selective pressures, including changes in climatic stimuli. The determinants of a system's adaptive capacity are highly contested. To evaluate the adaptive capacity of human systems, a variety of empirical methods have been used ranging from relatively quantitative to highly qualitative. Quantitative frameworks use surrogate indicators of adaptive capacity, the value of which they obtain from open sourced data or measure using surveys (see, for example, Brooks, Adger, & Kelly, 2005; Luers, Lobell, Sklar, Addams, & Matson, 2003; Yohe & Tol, 2002). Some have adopted the five capitals of Sustainable Livelihoods approach to poverty reduction as indicators of adaptive capacity (see Hahn, Riederer, & Foster, 2009; Osman-Elsha, Elhassan, Ahmed, & Zakield, 2005).

While the availability of assets is essential, as argued by Jones Ludi and Levine (2010, p. 1) approaches based exclusively on assets ignore the importance of other factors that shape adaptation. They fail to capture the role of agency, i.e. the behaviour, creativity and entrepreneurialism of the individuals and organisations within the system, as well as the role that historical and structural factors play in constraining or enhancing those agents' adaptive choices. Relevant structural factors could exist at a variety of different scales and, among others, could include class systems, gender inequalities, dysfunctional political systems, underdeveloped financial markets, and institutions governing land-use, resource extraction, and domestic and international trade. Finally, asset-oriented approaches fail to give weight to agents' abilities to access information about hazards and adaptive options (Fankhauser & Tol, 1997).

From an evolutionary perspective, adaptive capacity is also a function of diversity. Just as genetic diversity is essential in the process of biological evolution, diversity within economic, socio-cultural, institutional and technological spheres is an essential condition in the adaptation of human systems (Boyd & Richerson, 1985; Matutinuvic, 2002; Rammel & van den Bergh, 2003). Excessive specialisation within current selective pressures reduces adaptive capacity by reducing the range of options that a system could use to cope with future pressures (Rammel & van den Bergh, 2003, p. 127).

Central to adaptive capacity of human systems is the adaptive flexibility its current components in response changing conditions. Due to the routinisation, path-dependency and structural conditioning of human activity, human systems tend to exhibit a degree of inertia, and are liable to get *locked-in* to specific industrial, technological and institutional constellations. Adaptations that limit flexibility in response to unforeseen changes in the selection environment are particularly liable to lead to *maladaptations.* For example, infrastructure is particularly susceptible to lock-in maladaptations due to the large sunken costs and long life spans of road networks, buildings, water and sewerage systems and electricity grids.

Institutions, the 'rules of the game' that structure behaviour, are also liable limit a systems flexibility (Geels, 2002). Well-designed institutions can promote rational forward-looking decision-making, the creation of economic opportunity and the conservation of diversity. Poorly designed or enforced institutions can lock-in maladaptive behaviour, undermine the functioning of organisations and promote irrational decision-making. Dietz, Ostrom, and Stern (2008, p. 1907) argued that institutions can be designed to be flexible with built in mechanisms such as appropriate informational feedback systems and the regular deliberation of informed stakeholders.

Therefore, beyond an evaluation of the asset base, a framework for assessing adaptive capacity must evaluate the adaptive flexibility of institutions and governance structures in response changing conditions. It must assess a system's ability to generate knowledge about hazards and adaptive options, and to disseminate that knowledge. Finally, it must take into account a system's ability to retain diversity – for example, through institutions that promote cultural or ecological conservation – and foster diversity through innovative processes that add novelty to the system such as entrepreneurialism, academia, R&D and technology transfer. To this end, Jones, Ludi and Levine (2010) developed the LAC framework. Table 1 (in Section 3.3) described the different elements that make up the LAC framework. Section 4.3 discusses the methodology that was used to assess each of these elements in the contexts of Soufriere and Whitehouse, respectively.

4.3 Methodology

The GIVRAPD project employed a CBVA methodology based on the work of Smit & Wandel (2006). Prior to each field study, interviews with key informants were carried out to determine which site-specific topics would be covered in addition to the general topics described below. The field studies comprised semi-structured interviews with community members within or related to the tourism, fisheries, and agricultural sectors. Local partners became part of the research team, with involvement ranging from introducing the GIVRAPD team to the field site to actively participating in interviews. Where English was not the respondent's first language, local interpreters joined the researchers. Respondents were selected through a snowball sampling methodology in which interviewed individuals were asked to suggest additional interview subjects. To ensure adequate representation of the population, multiple 'snowballs' were initiated, and interviews were carried out until 'saturation' was reached, i.e. no new information was being revealed by each additional interview. In total, 300 interviews were conducted (180 in Soufriere and 120 in Whitehouse), distributed approximately equally among the three sectors.

Semi-structured interviews were based on an interview guide with thematic topics. Researchers guided the conversation and adjusted their questions based on respondents' situations. Each interview began with contextual questions about the individual's social and economic situation, followed by open-ended questions designed to explore, not probe. General topics that were covered at each field site included, among others, (1) changes that the respondent has observed in their community, regarding culture, social dynamics, environment, and/or climate; (2) the respondent's livelihood strategies and the specific challenges that they face; (3) the diversity of practices and technologies within the respondent's occupation, how these have changed over the years, and whether these are 'good practice' in terms of quality, environment impacts, etc.; (4) interactions that the respondent has had with their governments and/or other community organisations; (5) the respondent's access to insurance, credit, and other sources of financial capital; (6) experiences that the respondent has had with climate-related stimuli, including both sudden shocks and slow onset stresses; and (7) the diversity of coping strategies that the respondent has at his or her disposal to deal with those challenges. After an open-ended phase of the interview, in which the discussion was led by the respondent, the interviewers probed into any specific topics that had not yet been covered. Finally, the interviewer would ask the respondent about whether they were aware of anticipated changes in the climate, how potential changes in their exposure to climate-related stimuli might affect their livelihoods and communities, and what coping strategies they might employ in different scenarios.

The interviews were transcribed, and the software NVivo was used to 'code' the transcriptions according to the themes outlined in the LAC framework. The process of coding allowed for reflection on each interview adding rigour to the analysis. Findings were triangulated using a variety of third-party sources, including other studies, government documents, and historical records. Sections 4.4 and 4.5 present the findings.

4.4 Results in Soufriere, St Lucia

Soufriere is the westernmost town and district of St Lucia, which is located in the Lesser Antilles between the Caribbean Sea and the Atlantic Ocean (see Figure 20). The town and district have a combined population of 8472.

Figure 20. Map of Soufriere (GoogleMaps, 2014b).

4.4.1 The Asset Base

This section examines the stock of natural, financial, human, physical, and social capital available to residents of Soufriere, how that stock affects their ability to deal with changing selection pressures, and, if applicable, how that stock may be affected by climate change.

4.4.1.1 Financial Capital

St Lucia is classified as a middle-income country, with a per capita GDP of US$5544.20 (CSO St Lucia, 2014). During most of the 20th century, its economy was based on a combination of tourism, agriculture, manufacturing, and fishing. However, international trade liberalisation has caused St Lucia to increasingly rely on tourism for foreign exchange earnings. Soufriere, in particular, has become specialised in tourism. As seen in Figure 21, between 1991 and 2012, the portion of residents in Soufriere with livelihoods in agriculture, fishing, and forestry declined from 25.5% to 8.3%. The portion of those in manufacturing more than halved from 10.9% to 4.9%, while the portion employed in hotels and manufacturing almost doubled from 15.6% to 29.9%.

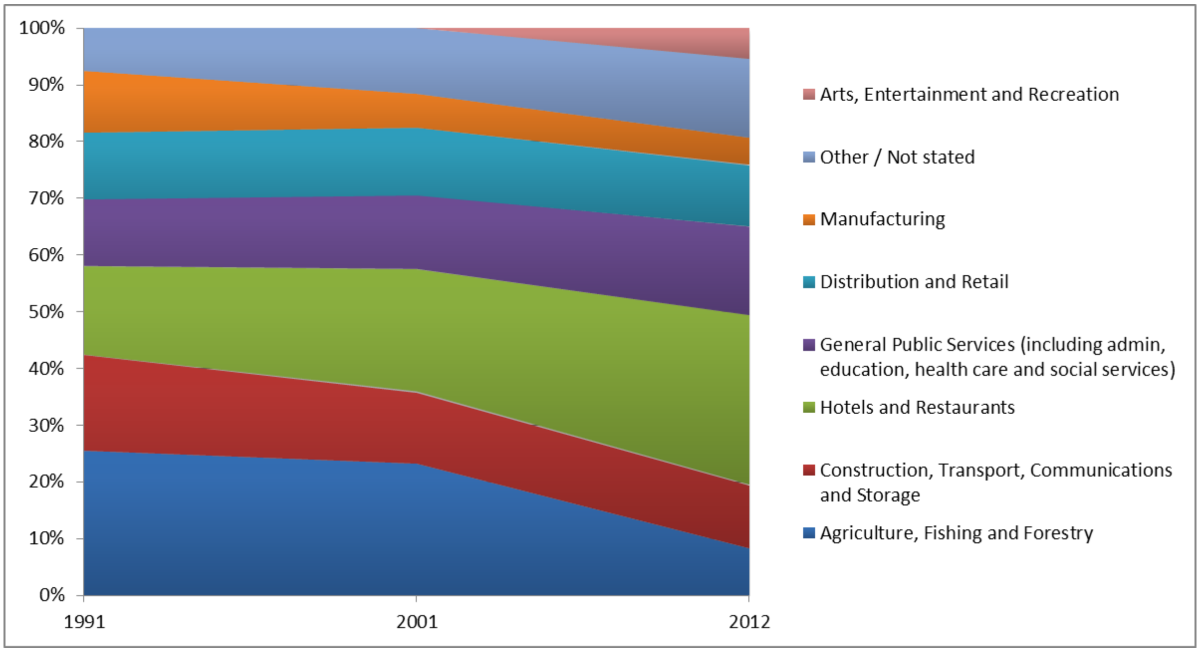


Figure 21. Employment in Soufriere by sector (Data from CSO St Lucia, 2014).

Agriculture and fishing have traditionally been the industries that have absorbed surplus labour in Soufriere. With the decline in these industries, there are now fewer employment options outside of the service sector. Although the service industry was able to absorb some of the excess labour created by a decline in fishing, agriculture, and manufacturing, unemployment in Soufriere remains high. In 2012, the unemployment rate was 23.8%, relative to a national average of 21.4% (CSO St Lucia, 2014). As seen in Figure 22, unemployment has consistently been higher among women than men since 1994.

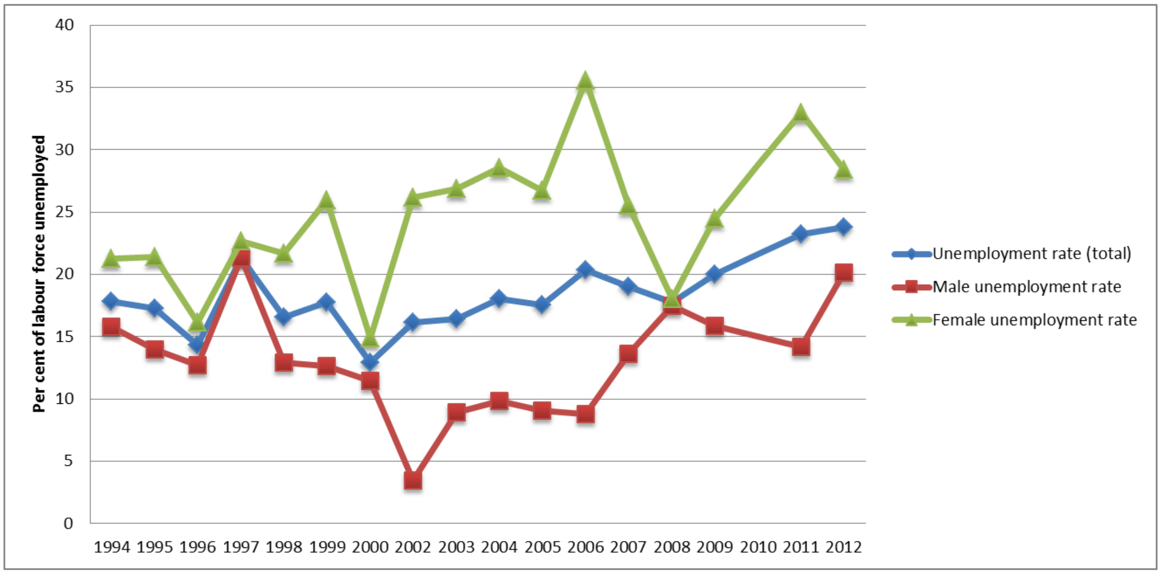


Figure 22. Unemployment rate in Soufriere, 1994 - 2012 (Data from CSO St Lucia, 2014).

Due to its high unemployment rate, Soufriere has one of the highest poverty rates in the country despite being a major tourist centre. A 2005 St Lucia Country Poverty Assessment commissioned by the Caribbean Development Bank estimated that the minimum amount of money necessary to meet basic food and non-food needs in St Lucia was US$5.22 per day. As seen in Figure 23, it found that 42.9% of the residents of Soufriere lived below this poverty line, compared to 30.4% nationally. Among children under 14, this figure increased to 59.3% (Kairi Consultants Ltd., 2006).

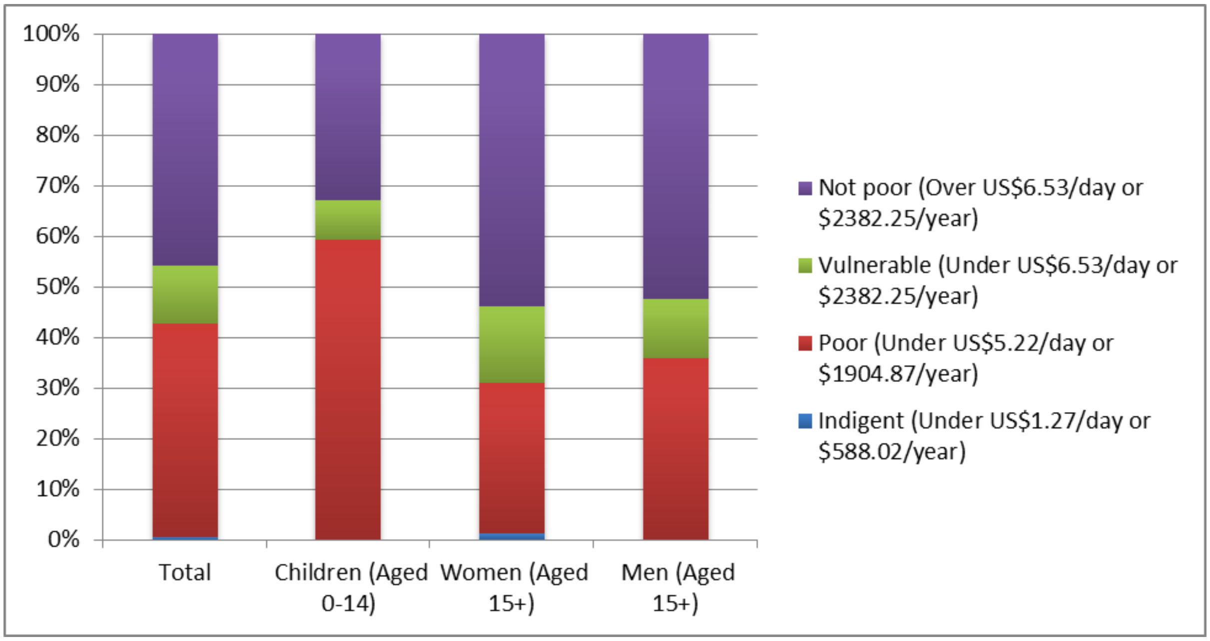


Figure 23. Poverty levels in Soufriere (Data from Kairi Consultants Ltd., 2006).

With little financial capital to invest in adaptive measures, the adaptive capacity of many of the residents in Soufriere is severely curtailed. Many respondents explained that they lack the financial capital to invest in adaptive technologies such as drip irrigation systems, water catchments, and greenhouses. Others were unable to invest in higher education. Some who wished to start a new business, for example, in agroprocessing, were hampered by their lack of investment capital.

Also reducing Soufriere's adaptive capacity is the lack of insurance against climate-related damages. A survey conducted in Soufriere by CARIBSAVE (2012b) found that only 8.7% of the sample had flood, fire or storm insurance. The main reasons cited by our respondents for not purchasing insurance against flood, fire or storm risk were the high cost of premiums, lack of knowledge about insurance products, and a lack of trust of insurance companies. Furthermore, our research identified no farmers that had purchased crop insurance against weather-related risks, nor any financial institution providing such insurance products.

4.4.1.2 Human Capital

The stock of Soufriere's human capital is improving, but remains lacking. The Ministry of Education introduced universal secondary education in St Lucia in 2006. At that time, as seen in Figure 5, the majority of the population's highest level of education was primary school. Only 10.3% of St Lucia's population had any training beyond secondary school. Of those that have completed secondary school, few have received scientific and technical training, making the workforce unfit to take advantage of global technological advances. Furthermore, many of those from Soufriere that do receive technical training move to Castries or abroad to find work, resulting in a brain drain.

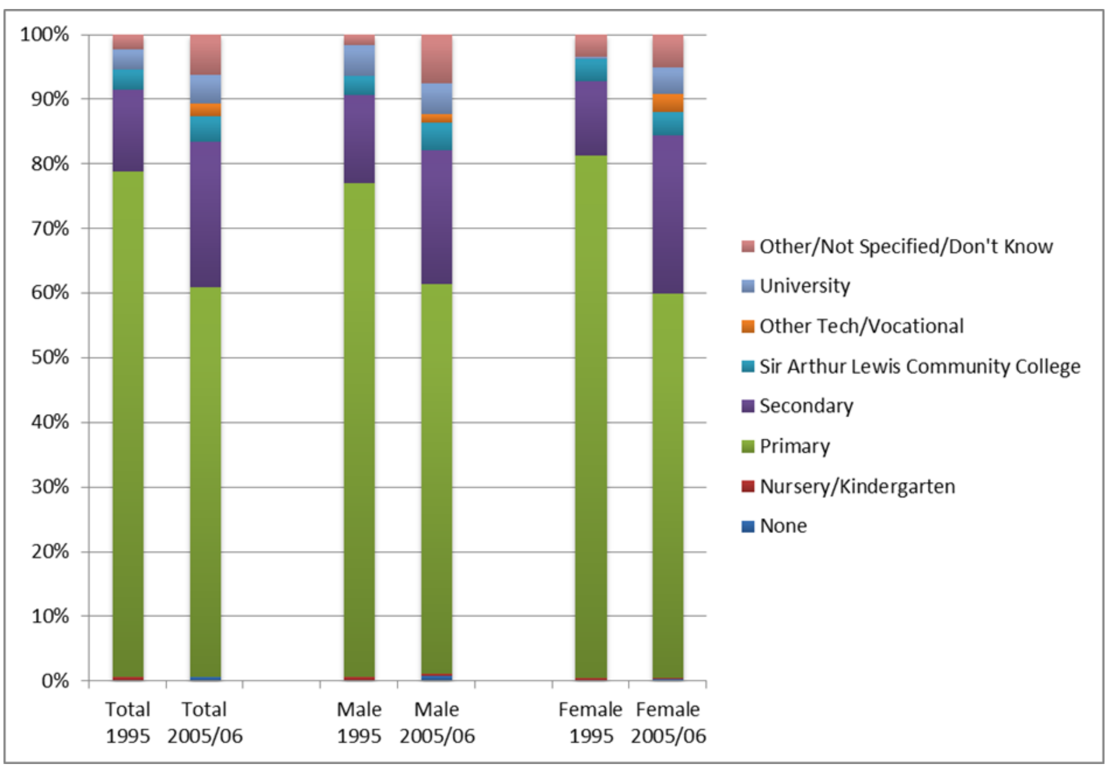


Figure 23. Highest level of educational attainment in St Lucia in 1995 and 2005/06 (Data from Kairi Consultants Ltd., 2006).

Soufriere's lack of human capital contributes to its high unemployment rate because its workforce is unable to compete in an increasingly knowledge- and service-based economy (Kairi Consultants Ltd., 2006). Respondents from both public and private organisations explained that a lack of human capital presents significant barriers in implementing adaptive strategies. A lack of technical expertise was cited as a major impediment to monitoring the coral reefs and to developing a national land-use plan. Springer (2005, p. 11) found that weak human resources also inhibited "water and wastewater management, pollution control, finance, integrated water resource planning, and the operation and maintenance of water-related infrastructure and services."

4.4.1.3 Natural capital

Soufriere has a rich stock of natural capital that underpins its three main industries – fisheries, agriculture, and tourism. The main tourist attractions in Soufriere are forms of natural capital. The Pitons, two volcanic plugs that rise 743 and 771 meters from the sea directly to south of the city, have earned Soufriere its status as a World Heritage Site. Tourists are also drawn to Soufriere's volcanic sulphur springs, tropical forests, sandy beaches, waterfalls, coral reefs, biodiversity, and comfortable climate.

Both tourism and agriculture rely on Soufriere's reliable supply of freshwater, and because agriculture in the area is predominantly rainfed, it depends on sufficient and predictable precipitation. Due to St Lucia's volcanic geology, groundwater sources are relatively few (CARIBSAVE, 2012b). However, if managed properly, St Lucia's water resources are believed to be sufficient to meet current and projected demands (CARIBSAVE, 2012b; Geoghegan, 2002), and as seen in Figure 24, Soufriere is less susceptible to drought than elsewhere on the island.

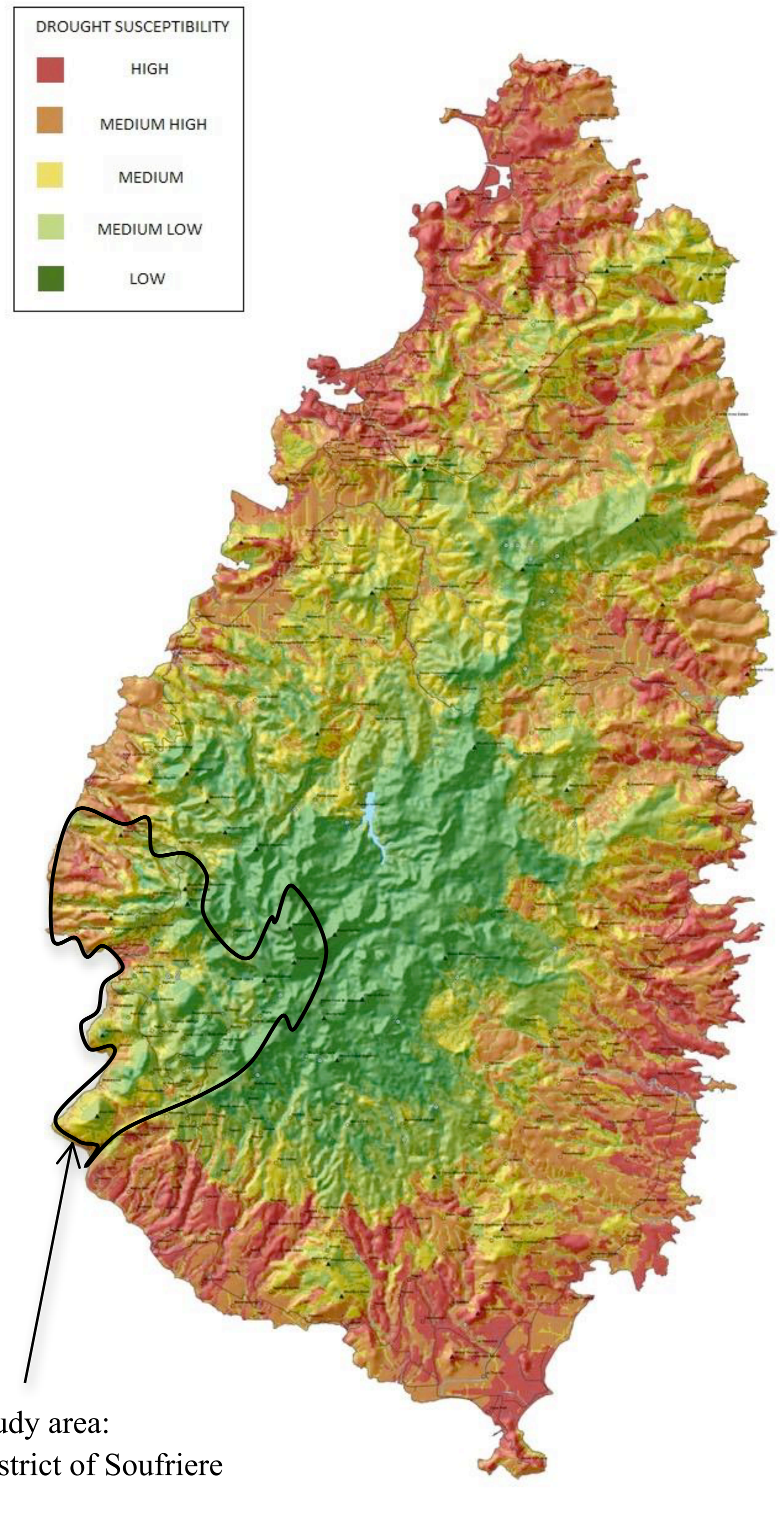


Figure 24. Drought susceptibility in St Lucia (modified from GoSL, 2005b).

The fishing industry in Soufriere depends on a diverse and renewable fish stock. Offshore fisheries target pelagic fish species including tuna, mahi mahi, flying fish, wahoo, and black fish, while the near shore fisheries target species that populate the coral reefs including grunts, snappers, parrotfish, and groupers. The near shore area around Soufriere is governed by the Soufriere Marine Management Area (SMMA), which was established in 1994 and is discussed in detail in subsequent sections. A baseline assessment of fish stock was conducted at the outset of the SMMA by Goodridge et al. (1997) and a follow-up study was done five years later by Roberts et al. (2001). As demonstrated in Figure 25, it was found that reef fish biomass increased four-fold within the marine reserves and three-fold within the fishing grounds during the five-year period.

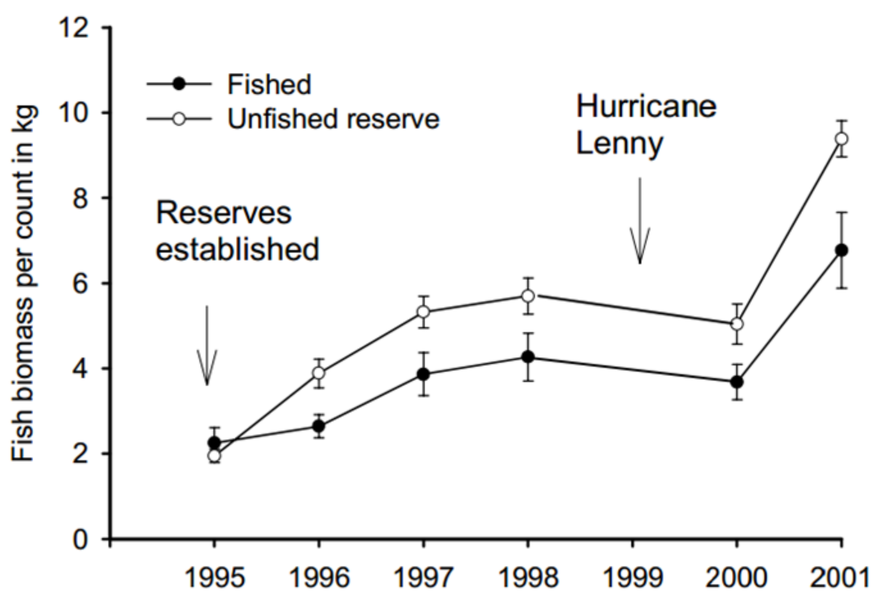


Figure 25. The mean biomass of commercially important fish per count in kilograms in fished and un-fished areas of the SMMA from 1995 to 2001 (Roberts, et al., 2001).

Much of the natural capital that is vital to fisheries, agriculture, and tourism is at risk from local human activity and climate change, and it is likely that without institutional or technical intervention, projected declines in natural capital will reduce Soufriere's adaptive capacity. Downscaled Regional Circulation Models (RCMs) based on the IPCC's higher emissions scenario project[11] that mean annual temperatures in St Lucia will increase by between 2.4˚C and 3.3˚C by 2080 relative to the 1970-1999 mean. While it is not yet possible to determine exactly what impact climate change will have on precipitation in Soufriere, most climate models point to a decrease in precipitation, and an increase in areas with rainfall deficit (GoSL, 2005b). Depending on what parameters are fed into General Circulation Models (GCM), projections of the change in average monthly precipitation range from a large decrease in rainfall of 37 mm (–66%) to a moderate increase of 7 mm (+14%) by 2080. In the higher emissions scenario, large reductions in precipitation are projected to occur in all seasons, except for the current wet season in September, October, and November (CARIBSAVE, 2012b).

Soufriere has already experienced occasional shortages of water during the dry season from February to May. One respondent explained that, during these shortages, the government-run Water and Sewerage Company (WASCO) has difficulty supplying water to the large hotels. Moreover, farmers explained that their productivity is reduced during water shortages. An impact assessment conducted by the United Nations Economic Commission for Latin America and the Caribbean (ECLAC, 2011a) projected that by 2050 increased temperatures and decreased rainfall in St Lucia will

[11] The IPCC's A2 scenario

lead to a decrease in yields of root crops, bananas, and other tree crops,[12] and an increase in the yields of vegetable crops.

The IPCC (2014) projects that warming ocean temperatures caused by climate change will lead to a poleward shift in the distribution of pelagic fish species. If these projections are accurate, St Lucia, at a latitude of 14° North, will likely experience a decrease in pelagic fish stock. Pauly (2009) estimated that by 2050 global warming will cause the Caribbean Large Marine Ecosystem to experience a decrease in catch potential of 10 – 20% relative to 2005 levels (all other things remaining constant). Currently, when the catch is poor offshore, fishers tend to rely on fishing in shallow waters. However, this adaptive strategy may not be an option in the future, because St Lucia's coral reefs and associate fish species are also under threat.

Despite the SMMA's success in reducing pressure from near-shore fishing, the coral reef ecosystem faces a number of other stressors. Coastal development, poor waste management and intensive agricultural practices have led to damaging sediment and pollution. Tropical storms cause mass sediment outflow by triggering erosion and landslides. The combination of Tropical Storm Debbie (1994) and Hurricane Lenny (1999) caused up to an estimated 50% mortality of the reefs around Soufriere Bay through sediment smothering (Australian Caribbean Coral Reef Collaboration, 2007). Respondents reported that Hurricane Tomas (2010) also had devastating effects. Finally, climate change will create significant stressors for the coral reef ecosystem. The IPCC (2014) predicted with *high confidence* that globally, even under the most optimistic

[12] While the models showed that the yields of non-banana tree crops will decrease, predicted increases in the prices of these crops caused their projected value to increase.

projections, warming oceans and ocean acidification will cause a 50% loss of coral to bleaching by 2050. Soufriere has already experienced two large-scale bleaching events, in 1998 and 2005. The 2005 event was reported to have affected 43.8% of the corals. Only 4.3% of the corals affected died in 2006. In St Lucia, climate models project that bleaching will occur every year after 2040 due to thermal stress, and coral calcification is projected to decline 10% due to ocean acidification (Australian Caribbean Coral Reef Collaboration, 2007). While the extent that coral bleaching will affect the near-shore fish stock in Soufriere is not yet clear, Pratchett et al. (2011) predicted that in a higher emissions scenario productivity of coastal fisheries in the Pacific will decrease by between 10 and 35% by 2100. Coral bleaching will also likely impact negatively on tourism as it will cause a decline in the quality of snorkelling and scuba diving (ECLAC, 2011b).

There is also risk that Soufriere's temperature and weather patterns will become less hospitable with climate change. Increased frequency of heat waves, water shortages, flooding, intensity of storms and risk of vector borne diseases such as dengue fever, combined with biodiversity loss and shoreline erosion, may reduce the attractiveness of Soufriere as a tropical destinations (ECLAC, 2011b; Simpson, Gossling, & Scott, 2008).

4.4.1.4 Physical capital

Much of Soufriere's physical capital is ill equipped to deal with current climate pressures, and there is risk that it will become increasingly maladapted with a changing climate. Respondents reported that Soufriere's drainage system reaches its capacity after an ordinary rainfall of only 25 minutes, and that larger rainfalls lead to flooding in parts of the town centre. St Lucia has only one large water storage facility, and few households have private water storage tanks. Hence, despite 98% of the population having piped-water in their houses, St Lucia remains vulnerable during periods of low precipitation. Moreover, after a heavy rainfall, treatment plants are sometimes incapable of treating water due to high water turbidity, causing some communities to lose access to water for up to four days (CARIBSAVE, 2012b).

As seen in Figure 26, the District of Soufriere is more prone to landslides than elsewhere on the island. These are usually triggered by heavy rainfall, often during hurricanes. The hilly farming community of Fond St Jacques is particularly at risk. In 2010, the wind and rainfall of Hurricane Tomas triggered a landslide that destroyed numerous homes and killed ten residents. The total impact of Hurricane Tomas on St Lucia was estimated to be US$336 million (ECLAC, 2011c). Relative to the rest of the island, Soufriere suffered the greatest damage to its housing stock (CARIBSAVE, 2012b). During Hurricane Thomas, the road to Castries was damaged by erosion and landslides triggered by Hurricane Thomas. Respondents reported that it has not yet been adequately repaired and poses a risk of further slippage. Some of the hillsides along Soufriere's roads and near residences have been reinforced, but the majority of them have not.

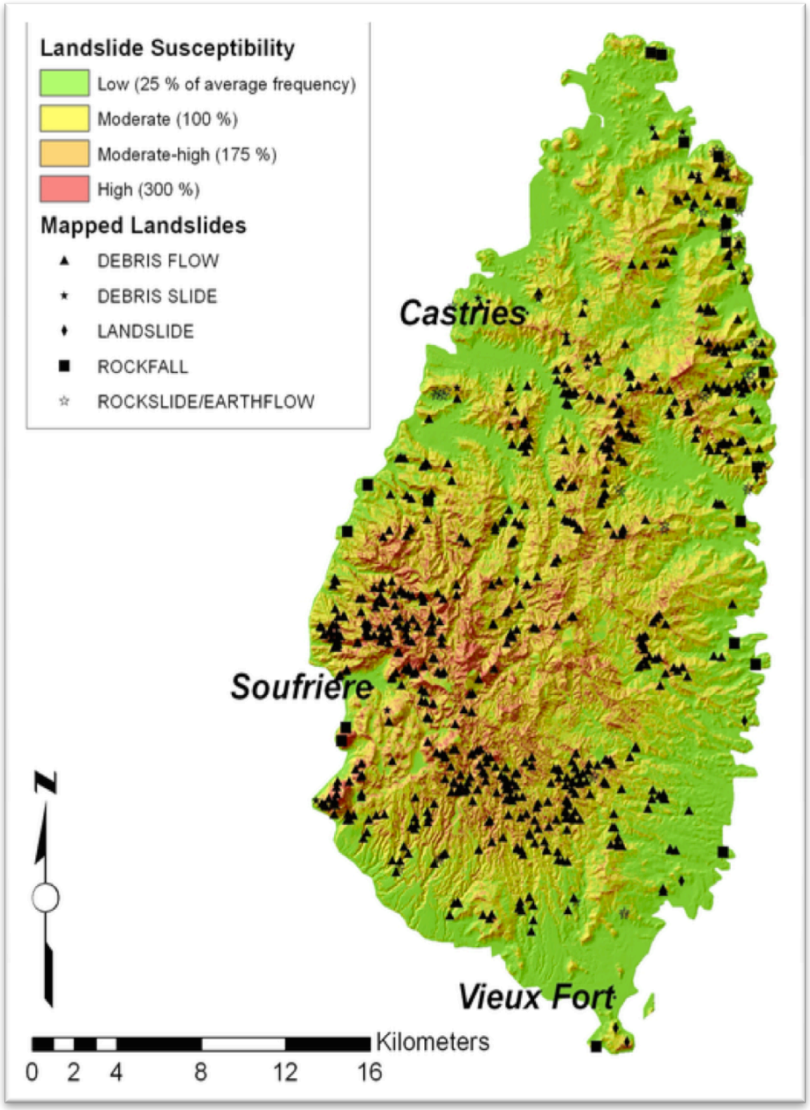


Figure 26. Landslide susceptibility map for Saint Lucia (Quinn, 2012).

Fond St Jacques also experienced landslides in 1960, during a tropical depression that became Hurricane Abbey, which killed six people and caused EC$4 million (US$1.48 million) in damage to physical capital; as well as in 1994, during Tropical Storm Debbie, which killed three people and caused EC$250 million (US$92.6 million) damage (GoSL, 2005a). Figure 27 tracks the historical hurricanes and tropical storms in the vicinity of St Lucia, giving an indication of frequency. The tracks of Allen, Debbie, and Tomas are in red.

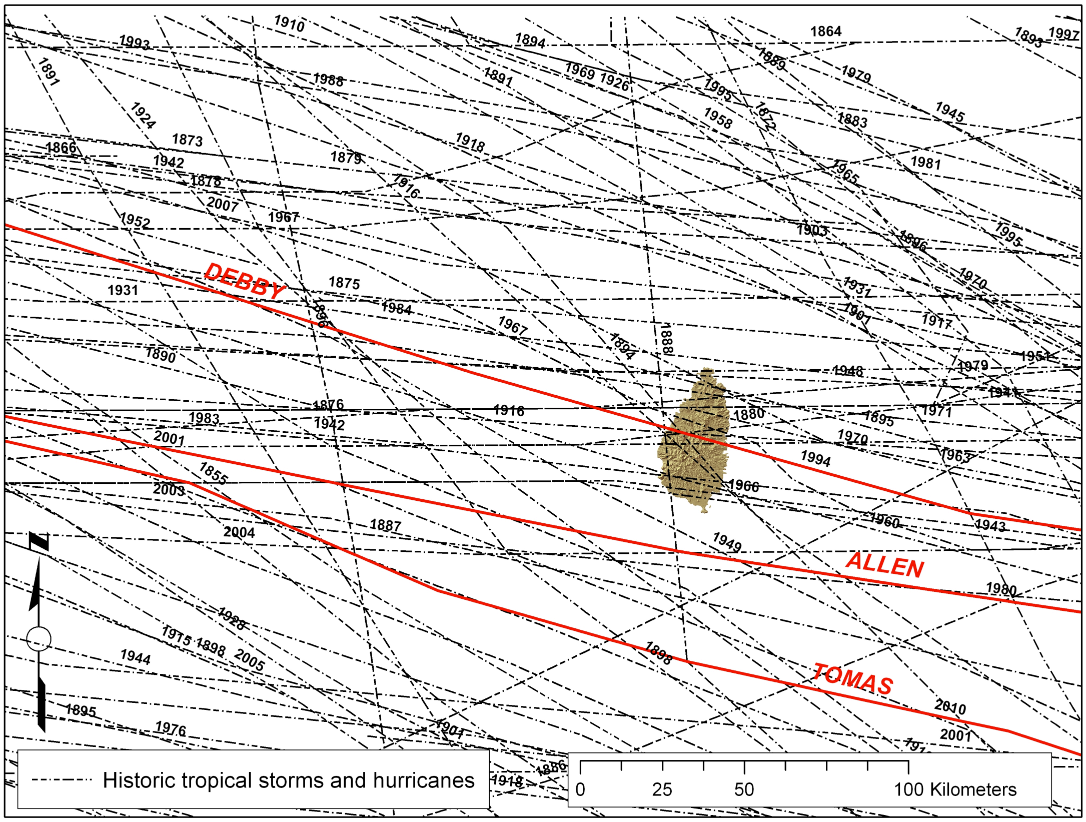


Figure 27. Historical storm tracks in the vicinity of Saint Lucia since 1848 (Quinn, 2012).

Hurricanes tend to strike St Lucia from the east placing Soufriere on the leeward side of the island. The exception to this rule was Hurricane Lenny, which in 1999 travelled an unprecedented eastward route from the southwest Caribbean through the Lesser Antilles to the Atlantic Ocean. Throughout the region, Lenny caused extensive damage to communities on western coasts, which, unlike eastern facing communities, had not evolved under direct exposure to hurricanes. Although the eye of the storm passed well to the north of St Lucia, and hence is not featured in Figure 27, the rough seas created by Hurricane Lenny damaged the seawall, the coastal road and numerous coastal homes in Soufriere. The most damage occurred to homes in Baron's Drive, a small fishing settlement on the southern shore of Soufriere Bay that consisted of approximately 100 households, many of which were of poor quality construction and lacked legal tenancy. Waves also inundated the river causing floods that cut off the southern half of Soufriere Town from the hospital (USAID, 2000).

While a reversal in the direction of hurricane tracks in the Caribbean is not a projected outcome of climate change, Hurricane Lenny illustrates how human systems will tend to evolve with little or no capacity to cope with extreme events unless they are foreseen and planned for. Much of Soufriere's infrastructure is built on or near the coastline, making it highly exposed to any increase in storms surge. The main road, jetties, town centre, numerous residences, hotels and resorts, hospital, and the police, fire, and ambulance stations are located just above sea level. One respondent explained that this location is largely a path-dependent outcome of St Lucia's colonial past:

> *That's where the British and the French put the stuff because they didn't have the technology to go in land and to tackle these hills.*

The position of Soufriere's infrastructure close to sea level also makes it sensitive to sea level rise. The IPCC (2014) projects that in the year 2100 the global average sea level will be between 0.35 to 0.70 meters higher than present day due primarily to thermal expansion (Church & Clark, 2014). However, there is also a possibility of much larger and irreversible sea level rise.[13]

While the onset of sea level rise will be slow, the adaptive capacity of infrastructure tends to be low due to the long life spans and the large sunken costs involved in constructing road networks, buildings, water and sewerage systems,

[13] Sustained warming could lead to the near-complete loss of the Greenland ice sheet over the next millennium or more, which would result in up to 7 meters rise in average global sea-levels (Church & Clark 2014).

electricity grids, etc. For this reason, without forward-looking planning and institutional interventions to guide private decision-making, the location and design of Soufriere's infrastructure will likely become increasingly maladapted.

Beyond the risk of maladaptation due to the physical impacts of climate change, Soufriere's infrastructure is also at risk of becoming maladapted in the face of the global institutions that may be implemented to combat climate change. Saint Lucia generates almost all of its energy through the combustion of heavy oil. Between 2002 and 2010, St Lucia's diesel consumption increased by 68% and its aviation fuel consumption increased by over 300%. If policies are implemented at the global level to tax or cap greenhouse gas emissions, given the lack of alternatives in place, the cost of energy and of long-haul flights to St Lucia would increase, both of which would be damaging to tourism (CARIBSAVE, 2012b).

4.4.1.5 Social capital

Social capital refers to the norms of reciprocity and trustworthiness between individuals. Social capital is thought to facilitate co-operation within communities because it reduces uncertainty and costs involved in enforcing contracts (Putnam, 1993). Therefore, communities with higher levels of social capital are better able to overcome problems of collective action.

In general, respondents felt that there was a scarcity of social capital in Soufriere Town. It was suggested that much of this lack of social capital is deeply rooted in history:

> *They know each other's history so they use it sometimes to say that they won't work with this person, because this person […] his family steals. […] It's a small*

community – everybody knows everybody. As long as I know your last name I can know who you are.

Another respondent felt that social capital has eroded over time:

A lot of our vulnerability comes from the fact that we are losing the things that give us strength. […] We are losing communities. We are losing community life. And so, not just the naturally vulnerable sectors, but everybody – the nation, the communities – are becoming more and more vulnerable as we lose our strength […] We are losing the very thing that gave us strength as a people – that we took care of each other within the community.

Lack of social capital reduces Soufriere's adaptive capacity for a number of reasons. It undermines institutions and increases enforcement costs. It also makes it difficult individuals to work together to implement and scale-up adaptive options:

In St. Lucia it is already difficult to get groups going because one other thing is lack of trust […] Everybody wants to be an individual […] We called it 'ti-mo-ti' in St. Lucia, which means small shop mentality […] It is not going to work here, because right now even the funding agencies don't fund individuals; they only fund groups.

Interestingly, there was noticeable difference in the views of respondents from Soufriere Town and those from Fond St Jacques. In Fond St Jacques respondents highlighted the community's strong social capital, and stressed its importance in coping with Hurricane Tomas and the landslide:

All the people in the community just came together as one after that storm, helped out, pulled people out that were trapped in their house, and put them on stable ground. We didn't need no paramedic to do that. That's my third hurricane that I *saw already here in that community. […] Debbie, I lost a cousin and two nephews. And Tomas, a cousin. […] It was the community coming together, because just a day or two after the hurricane you cannot expect government to do anything […]. It is 6-7 days after that you can expect the government will try to do something.*

4.4.2 Institutions and Entitlements

Central to adaptive capacity of human systems is the adaptive flexibility of institutions and governance structures in responding to changing conditions. This section will discuss institutions at different scales that respondents highlighted as having influence on their adaptive capacity.

4.4.2.1 Historical institutions of a plantation economy

As a colonial settlement in the 18th and 19th Centuries, Soufriere was the parish with the most sugar, coffee, and cocoa plantations on the island (Margot, 2006). When the British solidified control of St Lucia with the Treaty of Paris in 1814, the population of the island included "1200 whites, 1800 coloured, and 14,000 blacks, the vast majority of which were slaves" (Jesse, 1962). It was not until the 1830s, that the British Parliament passed the 'Act for the abolition of slavery throughout the British colonies' (Jesse, 1962).

It is difficult to determine the extent of the effects of Soufriere's history of slavery on today's community. However, it likely contributed to the inequality that still exists in the area. After emancipation, many of the newly freed black slaves began subsistence farming in small plots in the hills. Others began subsistence fishing (Soufriere Foundation, 2010). These livelihoods still dominate the lower-income populations of Soufriere. Others still continued to work the estates as free labourers in return for food and shelter. This economic model has only recently changed, as explained by one interview respondent:

> *My father used to pay the people EC$20. They now want EC$60/80. […] Back then the people respected the white man. […] He had just one set of guys. They would work from 7 in the morning until 1 o'clock; and from 1 until 4 o'clock would be their time to do the garden, their vegetable garden for themselves. So they would feed their family that way. […] You don't get people doing that anymore. […] The younger generation has moved away from farming and into tourism – quick money.*

A more tangible impact of slavery is Soufriere's pattern of land ownership. After Emancipation, with the plantations still in control of the most fertile and accessible agricultural land, freed slaves founded communities in the hills, including Zenon and Fond St Jacques, where they lived as small-scale subsistence farmers. This path-dependent land ownership continues to constrain the production and adaptive capacity of these communities. The steep slopes prevent mechanisation and irrigation and inhibit transportation. Without irrigation, farmers are limited in crop types and timing and at the mercy of increasingly unpredictable weather patterns. Perhaps most worrisome, the clearing of vegetation on this land has intensified soil erosion and increased the risk of landslides (CARIBSAVE, 2012b).

4.4.2.2 International trade law

International trade law has had a substantial impact on Soufriere's stock of financial capital and, as a result, its adaptive capacity. Over the last three decades, international trade liberalisation has led to a flood of cheap imports into St Lucia and the loss of its protected foreign markets for cash crops. In Soufriere, the industry hit hardest by increased cheap imports was coconut (copra) oil production. Since 1959, the St Lucia Coconut Growers Association (SLCGA) and Coconut Manufacturers Limited operated a copra factory in Palmiste, near Soufriere town. The factory processed coconut jelly into cooking oil, margarine, suntan oil, and soap, and sold the products within the CARICOM region. At its height, in the 1970s and 80s, the factory was a major source of employment in Soufriere, employing over 200 people, mostly women. Moreover, the factory created a guaranteed market for members of the coconut growers of the SLCGA, which numbered approximately 3000, 95% of which produced less than 10 tons of copra per annum. However, the availability of cheaper alternatives, including soybean and palm oil, due to international trade liberalisation caused St Lucia's copra industry to become increasingly reliant on the protectionist policies entrenched in CARICOM's Oil and Fats Agreement.[14] As these policies were relaxed in the 1990s, business for Soufriere's copra factory rapidly slowed and the factory went bankrupt the year before this research project began.

Across the entire island of St Lucia, the industry that was impacted the most by international trade liberalisation was banana production. St Lucia was historically entitled to privileged access to the EU banana market as a former UK colony.[15] However, after

[14] CARICOM's Oil and Fats Agreement provided for negotiated guaranteed prices for copra oil and strict controls on imports of substitutable products. In 1988, when this price was set at EC$1120 (US$415) per ton, CARICOM countries were purchasing edible oil from non-CARICOM countries at 50% the agreed upon price. Given this price differential the policies were relaxed somewhat in the 1990s. Despite common external tariffs on substitutable products, including 40% tariffs in 2007, the CARICOM market for copra oil was undercut by cheaper forms of edible oil.

[15] This access was formalised with the Lomé Convention in 1975, which allowed most agricultural and mineral goods from 71 African, Caribbean, and Pacific (ACP) countries to enter the then European Community free of duty. The goal was to allow former British, Dutch, Belgian, and French colonies to make the transition to independent statehood and grow their economies without recourse to foreign aid.

the World Trade Organisation (WTO) was formed in 1995, this privileged access was gradually eroded. Years of preferential treatment for Caribbean banana producers led St Lucian farmers to specialise in banana production, and the impact of the policy shift on St Lucia's economy was profound. Between 1992 and 2008, the number of banana farmers decreased 85% from 10 thousand to 1500 (Fairtrade Foundation, 2009). As seen in Figure 28, exports declined from 133 thousand tonnes in 2002 to 30 thousand tonnes in 2010, and revenues fell from EC$157 million (US$58 million) to EC$39 million (US$14 million) (CSO St Lucia, 2014). Already reeling from international trade liberalisation, the banana industry has subsequently had to face an influx of the black sigatoka disease, which between 2010 and 2013 infested an estimated 70% of St Lucia's banana plants (TaiwanICDF, 2013). The successive shifts in the selection environment, and their devastating consequences for St Lucia's primary export, demonstrate the perils of specialisation.

After the formation of the single European market in 1992, EU-wide tariffs were imposed on bananas from non-APC countries and country-specific guaranteed quotas were granted to ACP states. These policies enabled Caribbean countries to secure a 7% market share in the 1990s despite the fact that Latin American producers, which held three-quarters of the EU-market, were much more efficient.

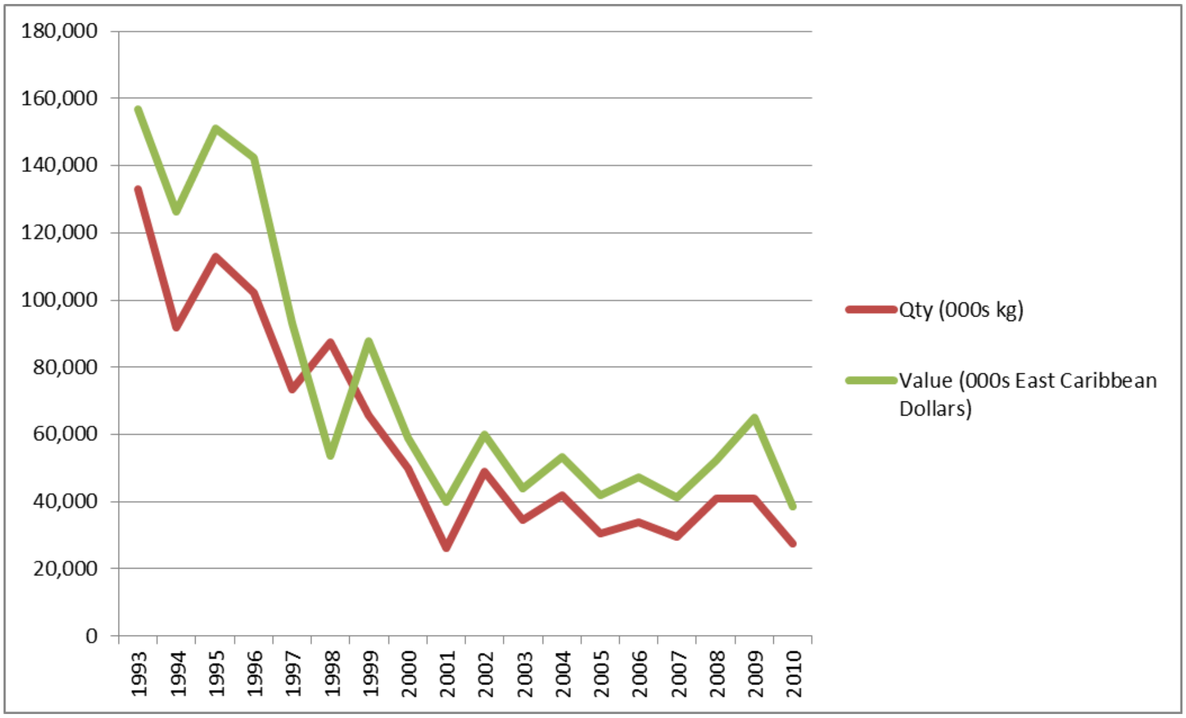


Figure 28. St Lucia banana exports, 1993-2010 (Data from CSO St Lucia, 2014).

Soufriere did not specialise in banana production as much as other parts of the island due to its hilly terrain. However, interview respondents explained that other regions' preoccupation with export markets had allowed Soufriere to secure a large share of the domestic market for vegetables. As the banana industry in St Lucia declined, competition in the domestic vegetable market increased. Hence, the indirect effects of the decline of the banana industry on farmers in Soufriere were significant.

4.4.2.3 Institutions surrounding land-use and construction

Institutions surrounding land-use and construction have significant implications for adaptive capacity, because they influence private decisions that have long-term consequences. Major developments in St Lucia are subject to approval of an environmental impact assessment (EIA) by the Development Control Authority (DCA). Respondents raised a number of concerns about the EIA process. One explained that

EIAs were not made public, and due to a lack of transparency, there was inadequate public discussion and consultation about the approval of developments. Another was concerned that when approving developments, inadequate consideration was given to landslides and flooding.

St Lucia has a building code. However, it is considered a guideline, not an instrument of law, and is therefore not enforced by the DCA. One respondent explained how the enforcement has allowed for myopic decision-making during construction:

> *The building of houses still hasn't taken into account hurricanes. […] Older buildings, in the 19th century, 18th century, they have been built with gable roofs, principally for hurricanes. That's the whole idea of the gable roofs in the tropics […] everything was to offset the weight. Now that we [can] forecast hurricanes […] we seem to [have] less care […] with the kind of designs – flat roofs and things without hurricanes in mind. And you see it in public buildings, which shouldn't be. […] Before we had a widely distributed public water system, every house was to have some water harvesting system. Either they would use their own oil drums or they would use these metal tanks […] to collect rainwater for use. With the emergence of the public water system, people started building houses of all sizes with no allocation for water harvesting. Incidentally, in the Developing Control Authority Act […] every household above a given size is supposed to have its own water harvesting equipment. Nobody pays heed to it.*

Immediately prior to this research project, the government had revised the voluntary guidelines so that wind speeds up category 4 and 5 hurricanes would be taken into account when considering the structural engineering of public buildings. Moreover, the Caribbean region is in the process of developing a Caribbean Uniform Building Code (CARIBSAVE, 2012b). Nonetheless, lack of enforcement of the both the building code and EIA within private sector remains problematic.

Compounding the issue, a portion of construction and farming in Soufriere occurs without legal tenure in place, thus is not subject to any regulations at all. One respondent explained how insufficient regulation has contributed to Soufriere's vulnerability:

> *It's contributing to the changes in use that make our environment more vulnerable to further degradation and to damage or impacts by storms and global warming and climate change. […] Those types of interventions by squatters, they will not pass under the scrutiny of planning. The guys go in and cut down, build on a steep slope, put a house there. […] And so we saw a lot of that in Hurricane Tomas that, a lot of the places that were affected were places that had less than optimal standards in construction and planning standards.*

Another institution that influences land-use in Soufriere is the Pitons' status as a World Heritage Site. World Heritage Status was granted to the 29 km^2 Piton Management Area (PMA) with various conditions that regulate development. The PMA is considered a multiple-use site, with some areas in which development is not permitted at all. In other areas, the Government was required to put a moratorium on further development until it completed a study on the limits of appropriate change. Hence, the PMA aims to conserve natural capital vital to Soufriere's tourism industry. However, in 2011, the Government of St Lucia removed the moratorium, granted five tourism development approvals, and then replaced the moratorium. In 2012, the World Heritage Committee considered adding the PMA to the list of World Heritage Danger List but refrained.

4.4.2.4 Soufriere Marine Management Area

In 1986, the Government of St Lucia passed legislation designating many reefs in St Lucia as marine reserves. However, without funds for marking boundaries or enforcement, the legislation proved ineffective. Meanwhile, in Soufriere, conflicts were breaking out between fishers, yachtsmen, scuba divers, and snorkelers over entitlement to the use of near-shore resources. In 1992, the Department of Fisheries began a consultation process to identify the conflicts between the various users and the condition of coastal resources around Soufriere. In 1994, the Government of St Lucia approved the creation of the SMMA and the designation of a local NGO, the Soufriere Marine Management Association, as the Local Fishery Management Authority. The SMMA was launched in 1995.

The SMMA's boundaries stretch along 11 km of coastline (See Figure 20), and its width extends either 100m off shore or to a depth of 70 metres, whichever is greater. Within the SMMA there are five different types of management zones: marine reserve, where no fishing is permitted; fishing priority areas; recreational areas; yachting areas; and one sanctuary, where no activity permitted, except scientific studies.

The governing board of the SMMA comprises eleven members – five representatives from government, five from local NGOs, and a Chairman appointed by Cabinet under the recommendation of the Minister of Agriculture, Lands, Forestry, and

Fisheries. The board members from local NGOs represent different SMMA user groups, giving voice to the various stakeholders.

The SMMA has enhanced Soufriere's adaptive capacity in multiple ways. First, it has reduced conflict over near-shore resources, hence increasing social capital. Second, as discussed in Section 4.4.1.3, it has conserved biodiversity and increased local fish biomass. Gell & Roberts (2003) attributed this success to the SMMA's design, in which continuous reef habitat across the zones allows fish to breed in four no-take marine reserves and 'spill-over' into fishing priority zones. Respondents also highlighted the importance of the consultation process in laying the ground for high levels of compliance.

4.4.2.5 The Soufriere Foundation and institutions governing entitlement to tourism revenues

As previously discussed, much of the financial capital in Soufriere is generated through tourism. The majority of this is private, generated by hotels, restaurants, car rentals, land and water taxis, craft salesmen, and tourist operators. The Soufriere Foundation was formed as a not-for-profit company in 1991 in efforts to increase the benefit that the local community received from tourism. In the mid-1990s, the government of St Lucia transferred ownership and management of both the Sulphur Springs Park and the main jetty in Soufriere Bay, both of which generate revenues. In 2009, the year of the most up-to-date financial statement available, the Foundation's income amounted to EC$3.523 million (approximately US$1.3 million). Beyond the operating expenses for these two projects, the Foundation has invested in the development of the Tet Paul Nature Trail; the annual Creole Jazz and Carnival Festivals;

various infrastructural projects; and scholarships and skills development training for community members. It is a likely source of financial capital for capital for community-level climate change adaptation initiatives.

However, some respondents felt that the Soufriere Foundation was wasteful with its resources. The Foundation was originally governed by an appointed Chairman and Deputy Chairman, and a board of nine directors made up of representatives from local NGOs and government.[16] In 2008, the institutions surrounding decision-making and accountability in the organisation were changed to allow the Prime Minister to appoint the entire board, as well as the Chairman and Deputy Chairman. Some respondents felt that this change has led members of the government body to be selected based on political patronage, rather than their qualifications, and that the high turnover of members with each new government has led to discontinuity the Foundation's agenda and lost organisational knowledge. These criticisms bring into question the leadership role that the Soufriere Foundation could play in planning for and adapting to climate change.

4.4.2.6 The Belle Vue Co-operative and institutions governing institutional representation of farmers

The Belle Vue Co-operative was founded in 1984 to provide support services to small-scale local farmers by securing affordable inputs and credit, trialling new seedlings in a nursery, linking farmers with markets, and lobbying policy makers on their behalf. In

[16] The board was made up of representatives from the Soufriere Town Council, the National Mothers and Fathers League, the St. Lucia Chamber of Commerce, St. Lucia National Trust, St. Lucia Tourist Board; Ministry of Planning, and later the Fond St. Jacques Development Committee, the Soufriere Fishermen's Cooperative Society, and the Soufriere Taxi Association.

2012, the Co-operative employed 27 full-time staff members, had a membership of 240 to 250 members, and an annual turnover of EC$1.7 million (US$630 thousand).

The institutional structure of the Belle Vue Co-operative is highly inclusive in that the members elect a board of seven directors at an annual general meeting. The board of directors then elects a general manager to handle day-to-day operations. In this manner, the board and the manager are ultimately accountable to the general members making it highly responsive to their changing needs.

The Belle Vue Co-operative frequently negotiates with the Ministry of Agriculture. For example, to shelter local farmers from competition from cheaper foreign products, it will request that import licenses of specific products be reduced when it foresees a glut in the market. In this manner, the Co-operative has enhanced the adaptive capacity of small-scale farmers by working to increase their financial capital as well as their institutional representation.

4.4.3 Knowledge and Information

Adaptation to any change in selection pressures requires that agents have an understanding, not only about the pressure itself, but also about their adaptive options (Fankhauser & Tol, 1997). In general, most respondents in Soufriere were aware of climate change, but had a poor understanding of how it might affect them and how they might respond. Particularly concerning was the lack of awareness amongst individuals whose livelihoods are highly sensitive to climate change, such as farmers and fishers, as well as those that live or work in high risk areas, including areas on the waterfront and areas on steep slopes.

There are a number of measures in place in Soufriere to both generate knowledge about hazards and adaptive options, and to disseminate that knowledge. The CARIBSAVE Partnership has been influential in producing detailed climate modelling projections for St Lucia and disseminating the results in an easily interpreted Climate Change Risk Atlas (CARIBSAVE, 2012b). CARIBSAVE also developed maps of areas at risk of inundation from sea level rise elsewhere on the island, but not of Soufriere. It is not yet scientifically possible to project the many of the impacts of climate change with precision, hence the large ranges provided for projected annual precipitation and sea level rise. Public officials explained that this uncertainty makes it difficult to make decisions concerning long-term infrastructure investments.

The information that is available about potential future impacts has not always resulted in sufficient systems being put in place to monitor those impacts. For example, it is known that climate change will likely result in coral bleaching, which will in turn impact the health of fish populations within the SMMA boundaries. However, multiple respondents explained that monitoring of corals and fish is done on an ad hoc basis, largely by foreign researchers. Coral bleaching is generally reported to the SMMA informally by scuba diving tourist operators. Adaptive governance necessitates much more systematic and thorough monitoring.

In other areas, appropriate monitoring systems have been put in place. For example, water supply is monitored at stations that measure rainfall across St Lucia, and in 2006, approximately 90% of the water users on the island had meters installed in 2006, allowing for monitoring of water demand (CARIBSAVE, 2012b). Likewise, the Met Office monitors approaching storm systems in the Atlantic.

To enable a response, these monitoring systems must be linked to systems that disseminate information about hazards to all stakeholders. Most respondents agreed that the early warning system in place for hurricanes is effective. The Met Office red flags any approaching storms for the National Emergency Management Office (NEMO), the Cabinet Secretary and the Prime Minister. NEMO then informs District Disaster Committees, which hold pre-strike meetings. The Prime Minister initiates meetings with government agencies and ministries and utility companies. Hurricane warnings are then disseminated to people via NEMO's Facebook page, text messages via the telephone companies, radio stations, and the cable service providers.

NEMO recently installed a pilot early warning system for flooding in the community of Corinth in northern St Lucia. However, there is no early warning system in place for flooding in Soufriere. The Ministry of Agriculture and the Water Resources Management Authority are in the early stages of developing an early warning system for drought, and the Ministry of Health has early warning systems in place for epidemics, etc. Such systems could prove vital in increasing Soufriere and St Lucia's capacity to cope with extreme events.

A number of government agencies have taken steps to get information about adaptive options to relevant stakeholders. For example, the Department of Fisheries has an Extension and Technology Adaptation Unit that offers presentations and training programmes for fishermen on new practices and technologies. At the time of research, an exhibition had recently taken place on environmental considerations in diving and other water-based activities. The Forestry Department engages in awareness campaigns targeted at farmers about maintaining forest cover on slopes to mitigate the risk of landslides. Finally, the Development Control Authority offers training workshops on the northern part of the island for architects, planners, builders, engineers, and contractors on construction practices that take into account the risk of hurricanes. These workshops were not offered in Soufriere.

4.4.4 Innovation

Innovation is the process through which economic agents 'search' for new products, processes, and forms of organisation that offer a competitive advantage in local selection pressures, and bring those novelties into use (Nelson & Winter, 1982). It is a socio-technical process that involves dynamic interplay between knowledge flows, market forces, social norms, politics, and institutions (Sovacool, 2009). The diffusion of knowledge about the new behaviour or technology, and the development of skills, organisational structures, and financing mechanisms necessary to apply it, is often as important as the discovery of product or practice. Innovation is central to adapting to climate change, because it involves the adoption of new behaviours and technologies that are more suited to changing local conditions.

In general, Soufriere has few formal processes in place to actively 'search' for novel behaviour or technologies. A notable exception would be the nursery of the Belle Vue Farmers' Co-operative's, which trials new seedlings to determine which are most appropriate within the current local climatic conditions. Future changes in temperature and precipitation will likely change the species and strains of crops that are suitable locally. There was no evidence of research being conducted – among private actors, NGOs or by the government – to determine the most appropriate crops in projected future climate conditions.

The Fisheries Department had implemented ad hoc 'search' processes, such as a one-off exchange in which three fishers were taken to Grenada to be trained in long-line fishing in hopes that upon their return, the technique would diffuse among the other fishers.[17] The ultimate goal was to continue to shift the fishing effort to pelagic fisheries in order to reduce pressure on the near-shore stock. However, the new technique did not catch on as hoped, reportedly due to a lack of lack of training for other fishermen and the lack of financial capital for new equipment.

The Fisheries Department has been much more successful in shifting the burden through its technology transfer of Fish Aggregating Devices (FADs), which consist of a float attached to concrete blocks on the ocean floor and serve to attract schools of fish. FADs are often run over and dislodged by large ships, and need to be replaced frequently. The Fisheries Department hopes that eventually it will be able to hand the FAD programme over to the local fishermen co-operatives, but the technical capacity among fishers is not yet adequate. At the time of research, the Fisheries Department was training fishermen in FAD construction.

Indeed, the lack of soft technologies – the knowledge, technical skills, and the availability of financing mechanisms – combined with the lack of financial capital, were frequently cited as the main barriers to the adoption of fitter technologies and practices. For example, greenhouses and drip irrigation systems are technologies that could increase farmers' capacity to cope with current selective pressures, let alone future

[17] Long-line fishing involves floating a surface line, which, at intervals at different depths, has branch lines drop off with baited hooks. The advantage is that is uses significantly less fuel than the predominant local method of trolling.

climate conditions. Respondents repeatedly cited a lack of financial capital as a barrier to uptake of both of these technologies.

In efforts to overcome these barriers, the Belle Vue Co-operative has partnered with the Fond St Jacques Credit Union to secure affordable loans for its members for the purchase of adaptive technologies, including greenhouses. It has also partners with external agencies to promote innovation in agricultural practices. For example, to adapt to the rising costs of fertiliser, and to try to restore the fertility of its topsoil, it has partnered with the Global Environment Facility to implement a project that promotes the practice of supplementing or substituting the use of chemical fertilisers with natural compost.

Numerous respondents felt that there was also room for innovation and entrepreneurialism in the area of agro processing. They pointed to the frequent gluts of fruit, many of which go to waste in farmers' fields due to lack of markets. One agro processing initiative that has been successful is Rainforest Cereal, a group of women supported by the Soufriere Foundation that produces granola. Respondents generally cited lack of human capital and financial capital as the main barriers to further agro processing businesses.

In contrast to fisheries and agriculture, the tourism industry in Soufriere has displayed a high degree of innovative and entrepreneurial capacity with nascent businesses and varieties of tours emerging regularly. Despite this capacity, the tourism industry has demonstrated limited capacity to innovate in the area of water conservation. While recycling wastewater to water lawns and gardens has become common practice, water conservation technologies remain inadequate and rudimentary (CARIBSAVE, 2012b; Springer, 2005).

4.4.5 Flexible forward-looking decision-making and governance

Central to the adaptive capacity of a system is the capacity of the agents within that system to anticipate changes in selection pressures and to respond accordingly (Jones, et al., 2010). Responding to an anticipated change often requires long-term planning in order to prevent maladaptive behaviour (Ayers & Huq, 2009). In theory, private actors have the incentive to plan for anticipated changes in selection pressures. However, private decision-making is often myopic due to asymmetric information, public goods, externalities, a lack of financial capital and the tendency of individuals and organisations to act according to routines. Examples of myopic behaviour that have been discussed in this paper include the clearing of steep land for agriculture, the construction of homes in areas prone to landslides or flooding and the use of weak building materials. In cases where private decision-making tends to be myopic it is often necessary for more centralised planning, either by government or community groups, and/or the creation of institutions to guide private behaviour.

Successful planning initiatives to guide decision-making have occurred at the local and national levels. At the local level, the launch of the SMMA marked a significant step in planning the use of near-shore resources in Soufriere. The SMMA's success in protecting the biodiversity and ecological resources is integral to maintaining Soufriere Soufriere's adaptive capacity. However, the challenges faced by the SMMA are dynamic. Further planning is required to address the challenges that Soufriere's near-shore resources are expected to face in the future including coral bleaching and the decline in near-shore fisheries, invasive species, and increased intensity of storms.

St Lucia developed its National Climate Change Policy and Adaptation Plan (NCCPAP) in 2003. The NCCPAP broadly outlines the government's policy goals and objectives of addressing potential impacts of climate change including impacts on marine and terrestrial biodiversity, water resources, human health, infrastructure, and agriculture. The Plan provides a useful framework for government action on climate change. A number of sector specific plans that address challenges created by climate change have also been developed at the national level. In 2004, St Lucia developed a National Water Policy, which governs the allocation of water among competing uses; and in 2009, the Cabinet approved a revised Water Management Plan for Drought Conditions. During periods of drought, WASCO manages abstraction levels and rations water resources to prevent overuse (GoSL, 2009). In 2006, St Lucia passed a National Disaster Management Act, which defines the roles of various agencies involved in disaster response, including NEMO, and sets guidelines for emergency shelter operations.

Planning at the national level in St Lucia has partly been driven by funding and initiatives at the regional and international levels.[18] Despite this support, a number of

[18] St Lucia has participated in the Caribbean Planning for Adaptation to Climate Change project (1997 to 2001), the Adaptation to Climate Change in the Caribbean Project (2001 to 2004), and the Mainstreaming Adaptation to Climate Change project (2004 to 2009). These projects sought to build adaptive capacity in the region by encouraging governments to mainstream adaptation considerations into development agendas. St Lucia has also benefited from World Bank funding to help strengthen the government's capacity to respond to adverse natural events such as hurricanes and floods. Finally, the country is part of Pilot Programme for Climate Resilience (PPCR), a long-term project with US$60-75 million dollars in grant funding for the Caribbean region from the Climate Investment Funds, which are managed by multilateral development banks. Like previous projects, the PPCR aims to integrate considerations of climate risk into national development planning.

priority actions listed in St Lucia's NCCPAP have yet to materialise. For example, a high priority action was to "Develop a comprehensive national land-use and management plan, which, *inter alia*, incorporates climate change concerns and which based upon such concerns, makes prescriptions regarding the location of future settlements and urban development without compromising water supply and other such requisites for the sustainability of settlements" (GoSL, 2003). This priority was reiterated by numerous respondents who argued that private decision-making about land-use has frequently resulted in myopic behaviour such as the clearing of steep hillsides for agriculture and construction in areas prone to landslides, flooding, and inundation from sea level rise and storm surge. Such decisions are highly prone to maladaptive outcomes due to the path-dependent and often irreversible nature of development. To reduce this risk, respondents stressed that a national land-use strategy must incorporate no-build zones in high-risk areas and begin to accommodate sea level rise through coastal setbacks.

The Ministry of Physical Planning and the Environment has developed planning guidelines that call for setbacks from the high water mark, buffers next to rivers and ravines, and consideration of slopes in construction (Walker, 2006). Nonetheless, no binding institutions have been created that mandate coastal setbacks, the relocation of settlements at risk or the types of developments allowed in areas along the coast or on steep slopes (CARIBSAVE, 2012b).

Respondents explained that St Lucia's existing institutions concerning land-use are inflexible and make land-use planning unlikely. The country's constitution guarantees landowners' rights to enjoy their land, which could be interpreted broadly, and there is reluctance among politicians to pass laws that may encroach on these rights:

Government needs to show that it has vision and it has the wellbeing of the residents at heart. […] They'll articulate a policy, but the enforcement of will not go ahead because that affects political survival.

Such political impasse can sometimes be overcome during windows of opportunity created by external pressures or events. For example, the damage to property caused by the storm surge from Hurricane Lenny created a window of opportunity for the Government of St Lucia to engage with the residents of Baron's Drive regarding resettlement away from the shoreline. A new settlement was built on what was subsequently named "Lenny's Hill" and with government support, a number of households on Baron's Drive relocated. The event also prompted the government to begin the process of coastal development planning in Soufriere (USAID, 2000).

4.5 Results in Whitehouse, Jamaica

Whitehouse is a small town located in the southeast corner of Westmoreland parish, on the south coast of Jamaica. The boundaries of the area studied were defined as those of the Whitehouse Development Area, an administrative unit of the Government of Jamaica's Social Development Commission (SDC) that includes Whitehouse and the adjacent communities of Bluefields and Beeston Springs (see Figure 29). In 2008, the populations of Whitehouse, Bluefields and Beeston Springs were estimated to be 3476, 4708, and 1989, respectively (SDC, 2014). Henceforth, the area as a whole will be referred to as Whitehouse and the town will be referred to as Whitehouse Town.

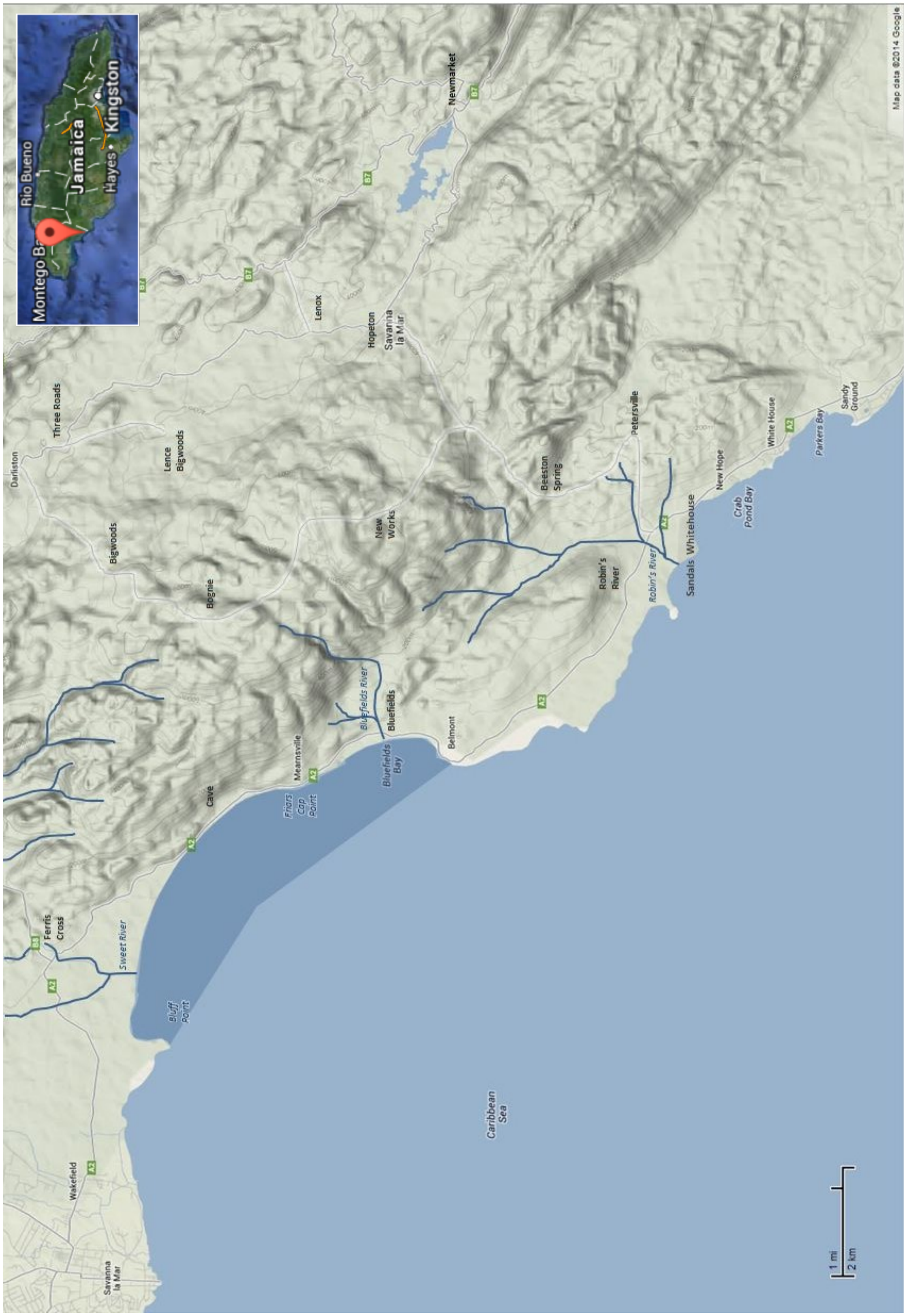


Figure 29. Map of Whitehouse (GoogleMaps, 2014a).

4.5.1 The Asset Base

4.5.1.1 Financial Capital

The main income generating activities in Whitehouse are fishing, farming, and the service sector. Tourism is less developed in Whitehouse than in either Soufriere or the northern part of Jamaica and the neighbouring city of Negril, on the western tip of Westmoreland Parish. Despite the nascence of the industry, a major development in the last decade was the addition of the 360 room all-inclusive resort, Sandals Whitehouse, about four kilometres to the northwest of Whitehouse.

While respondents in the tourism industry painted a picture of an industry with significant growth potential, interviewed fishers described an industry in decline due to depleted fish stocks. Whitehouse Town, a community built on fishing, has especially suffered from the industry's downturn:

> *Boy, let me tell you it has really changed because it is we as fishermen that really support the shopkeepers and the taxi drivers, and now that fishing is not doing well they are suffering the consequences. […] So it's a whole community of people within the district, and even people outside of the district, that have been affected right now at Whitehouse.*

The fishing sector in Whitehouse can be divided into three categories: small-scale artisanal fishers that use seine nets and fish pots in the near shore waters; medium-sized commercial operations, most of which fish for pelagic fish, conch, and lobsters off Pedro Cays, located about 80 kilometres south-south-west of Jamaica; and an increasing number of spear fishermen.

Most agriculture in the study area is concentrated in Beeston Springs and Bluefields. Westmoreland Parish, as a whole, produces approximately 20% of Jamaica's total food production, and exports cane sugar, cocoa, coconut, coffee, citrus, and pimento (Carroll, 2013). However, most farming in the study area occurred at a small-scale, with produce sold to local markets in Whitehouse or New Market in St Elizabeth. Farmers interviewed in the study repeatedly discussed how these local markets, which were almost exclusively supplied by small-scale farmers prior to 1990, had been flooded by cheap imports in recent years:

Farming has changed. […] There's no market. Imported goods are destroying everything. […] It's 'cause they are cheaper, people want them more. For instance, many tomatoes are planted in Jamaica. […] You can't get any sale for them, because crates of tomatoes are coming into the country.

The challenges faced by the fishing and agriculture sectors are particularly concerning, because, like in Soufriere, these are the industries that have traditionally absorbed surplus labour. According to a 2009 socio-economic survey conducted by the SDC, 17.9% and 18% of households in Bluefields and Beeston Springs were headed by unemployed individuals, respectively (SDC, 2014). Similar local data is unavailable for Whitehouse Town.

With such high unemployment levels, financial capital in Whitehouse is limited. A 2008 Survey of Living Conditions found that mean per capita consumption in Westmoreland was J$188 thousand (US$1677) per year,[19] 12% below the national average. An estimated 10.7% of Westmoreland's population lived below the national

[19] Exchange rate, 14 September 2014 on www.xe.com: J$1 = US$0.0089047

poverty line[20] (PIOJ & SIOJ, 2013). Most of Westmoreland's population is concentrated in the larger centres of Negril and Savanna-la-Mar, and parish-level statistics hide significant inequality between rural and urban areas. The most up-to-date local data for Whitehouse is based on the 2002 Survey of Living Conditions, which found the poverty rates in Whitehouse to be between 21.8 and 32.9% in 2002. Since this survey, the national trend was a decline in rural poverty from 25.1% in 2002 to a low of 15.3% in 2007 (Government of Jamaica, 2009). However, rural poverty in Jamaica increased to 23.2% in 2010 (Henry-Lee, 2012; Planning Institute of Jamaica, 2010).

Like in Soufriere, a lack of financial capital hampered respondents' abilities to invest in adaptive technologies such as drip irrigation systems and greenhouses. Many were unable to invest in higher education. Some who wished to start a new business, for example, in ecotourism, were hampered by their lack of investment capital. Of immediate concern, lack of financial capital also limited the capacity of the lowest income population to cope with current climatic conditions:

> *When the storm was coming here, only thing I bought, a pack of candles. […] No food. I didn't have no money to prepare no food. […] Every time storm coming I don't have no money to prepare no food so if famine to come, I surely know that I am going to die before it reach. I can't prepare for it. I don't have the funds.*

Also reducing coping capacity is the lack of insurance against climate-related damages. In a national household survey conducted for the Planning Institute of Jamaica

[20] The official poverty line in Jamaica is based on a level of consumption expenditure necessary to purchase a basket of goods and services deemed adequate to provide the "minimum nutrition and associated basic necessities" (Government of Jamaica, 2009). Between 1999 and 2009 this line progressively increased from J$38,049 (US$348.15) per year to J$110,099.56 (US$1007.41) per year (Henry-Lee, 2012).

(PIOJ), only 14.7% of respondents reported having home insurance, of which only 28.6% had insurance against climate-related events such as hurricanes or other natural hazards (Caribbean Institute of Media and Communications, 2012). Our research identified no farmers that had purchased crop insurance against weather-related risks, nor any financial institution providing such insurance products.

Beyond the lack of private financial capital in Whitehouse, there is also a significant lack of public financial capital. For decades, the government has borrowed extensively from capital markets causing its debt to grow from 83% of its GDP in 1999 to 147% in 2012 (see Figure 30). As a result, the government had to allocate almost half of its revenue to debt servicing in 2011, leaving very little funds for public investment (see Figure 31) (International Monetary Fund, 2014).

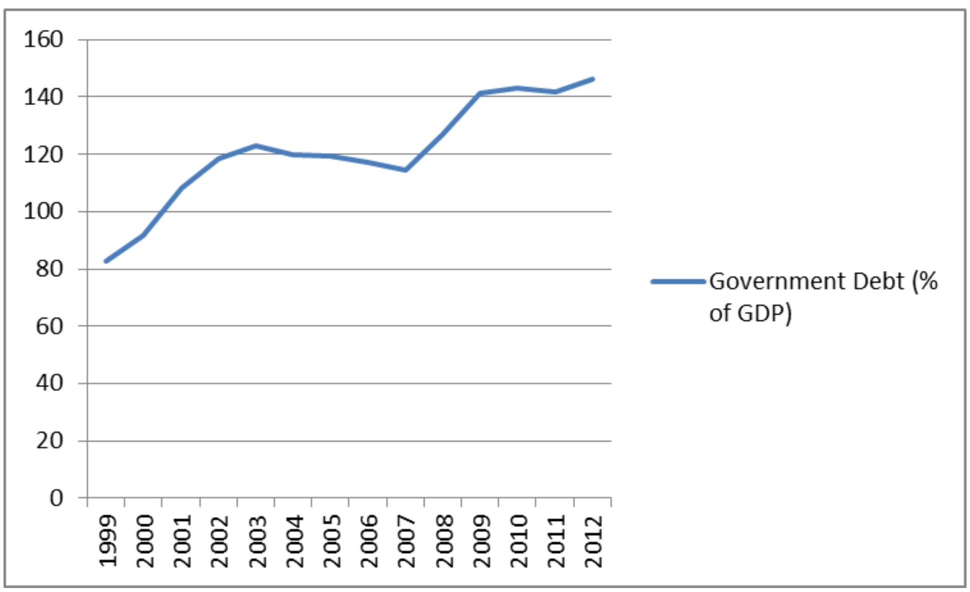


Figure 30. Government Debt to Gross Domestic Product, 1999-2012 (International Monetary Fund, 2014).

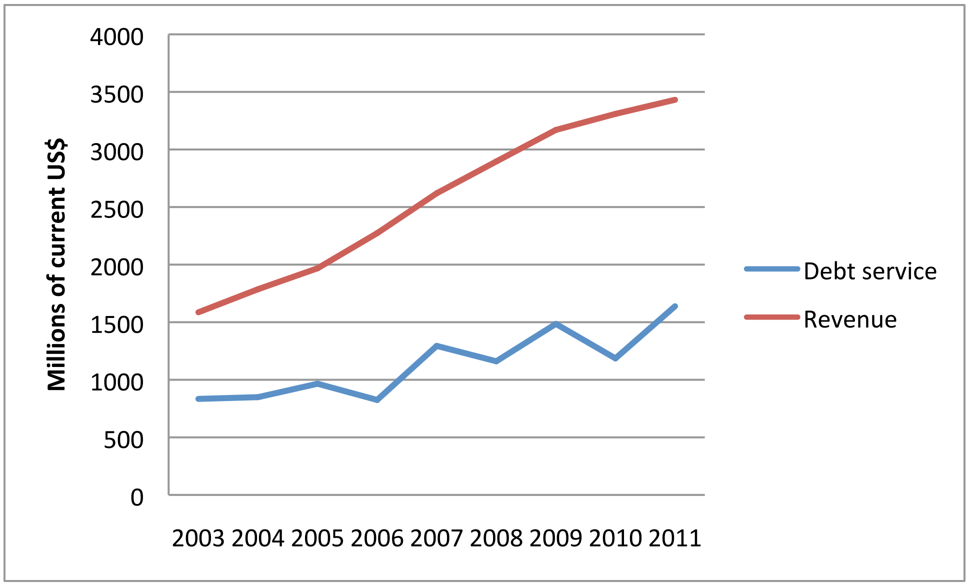


Figure 31. **Government Debt Service to Revenue, 2003-2011 (International Monetary Fund, 2014).**

Insufficient public financial capital undermines the performance of local public institutions that are vital to maintaining and increasing adaptive capacity. For example, lack of financial capital was seen as the main issue preventing enforcement of fishing regulations, particularly along Pedro Cays where 'pirates' from Central American countries were fishing illegally and stealing fish and lobsters from Jamaicans' fish pots. It also threatens to undermine operations of a series of nine marine protected areas (MPAs) that were established around the island in 2009, including the Bluefields Bay Special Fisheries Conservation Area, which is discussed in detail in 4.5.2.5.

4.5.1.2 Human Capital

While the population of Whitehouse possesses a wealth of knowledge surrounding fishing techniques and locations, ocean currents, soil types, local weather patterns, etc., a large portion lacks the type of human capital required to compete in a modern economy. In 2008, only 72.5% of individuals 15 years and older in Westmoreland were functionally literate. 12.2% had basic literacy and 15.3% were illiterate, the highest illiteracy rate in the country. Primary school was the highest level of education completed by 31.4% of those that were the heads of their households. 64.5% had attained secondary education, and only 4.1% had benefited from tertiary education. This situation was improving. Westmoreland achieved universal enrolment for those aged 3-14 in 2008, and the enrolment rate for those aged 17-18 was 40.8%, an increase of 19% over 2002 (PIOJ & SIOJ, 2013).

Employment opportunities in Whitehouse are in short supply, and with the downturn in the fishing industry, older fishers in particular have found limited employment. Most opportunities existed within the tourism industry, and most require formal education.

Recently, the Ministry of Education and Youth established a HEART Trust Vocational Training Centre in Whitehouse. The Centre has partnered with Sandals Whitehouse to match students with jobs once they complete their programme. However, given the limited number of employment opportunities in the area, many of those that graduate from high school or the HEART Trust Centre move to larger cities or overseas creating a brain drain.

Respondents explained that the lack of human capital in Whitehouse has not only reduced individual's adaptive capacity, it has also undermined the effectiveness of organisations, including the local government, and caused significant barriers in implementing adaptive strategies.

4.5.1.3 Natural Capital

Natural capital underpins each of the three industries examined in this project. Tourists are drawn to Whitehouse for its hospitable climate, its sandy beaches and to dive and snorkel along its coral reefs. Both tourism and agriculture rely on Whitehouse's reliable supply of freshwater. There are only a few sources of fresh water in the area, including Robin's River, Bluefields River, and Beeston Spring. Without irrigation, the vast majority of farms in Whitehouse and Bluefields are watered by hand with watering cans or rain-fed and depend on sufficient and predictable precipitation. Finally, the fishing industry in Whitehouse depends on a renewable stock of pelagic fish, conch, lobster, and near-shore fish populations that inhabit ecosystems based in coral reefs, sea grass beds, and mangroves.

Much of the natural capital that is vital to fisheries, agriculture and tourism is at risk from local human activity and climate change, and it is likely that without institutional or technical intervention, projected declines in natural capital will reduce Whitehouse's adaptive capacity. Downscaled RCMs based on the IPCC's higher emissions scenario project that mean annual temperatures in Jamaica will increase by between 2.9˚C and 3.4˚C by 2080 relative to the 1970-1999 mean. It is not yet possible to determine exactly what impact climate change will have on precipitation in Jamaica. Depending on what parameters are fed into GCMs, projections of the change in average monthly precipitation range from a dramatic decrease of 40 mm (–55%) to a moderate increase of 11 mm (+18%) by 2080. Models also disagree on which seasons will be most affected. Despite the uncertainty, most climate models point to a decrease in precipitation (CARIBSAVE, 2012a).

There was consensus among the respondents that rainfall patterns in Whitehouse have already been changing. Without the financial capital to invest in irrigation systems, changes in weather patterns have caused many farmers to leave their fields fallow when they could be producing:

> *Farmers in this general area don't do commercial irrigation. They depend on rain-fed irrigation. So when the dry periods become longer and the wet periods become more intense, you find out that it affects production. That affects the whole scheme of production and income into the farmer's pocket.*

As in Soufriere, the projected poleward shift in the distribution of pelagic fish species caused by climate change will likely cause a decrease in the pelagic fish stock in Jamaica, which is located at a latitude of 18° North (IPCC, 2014; Pauly, 2009). Currently, when the catch is poor offshore, fishers tend to rely on fishing in shallow waters. However, this adaptive strategy may not be an option in the future, because Whitehouse's coral reefs and associate fish species, as well as its lobster stocks, are also under threat. Much of the decline has been driven by overfishing and damaging fishing practices. Where possible, fishermen target larger fish, because they capture the highest market value. As a result, over the years, not only has the quantity of fish caught by fishers decrease, the average weight of the catch has also declined (Carroll, 2013). Schofield (2009) argues that a decline in large predatory fish has been an enabling factor in the most recent pressure on fish populations – a rapid invasion of the Indo-Pacific lionfish:

> *The lionfish! Almighty! They dominate the whole place. They dominate the whole Pedro bank. I have been fishing, over thirty years now. I have never seen those fish until recently. And right now, when you go to the sea and haul in a pot, if one hundred fish is in there, ninety of them are lionfish. […] Three and a half years now we have been noticing them.*

The lionfish has become an apex predator in local waters, feeding on large quantities of other species, particularly juveniles. Lionfish also have poisonous spines that can land victims in the hospital, creating a serious hazard for snorkelers and divers. The Ministry of Agriculture and Fisheries, along with numerous other institutions, has launched a campaign promoting the culling and eating of lionfish, but it is unclear whether these measures will have a significant impact.

Destruction of habitats and spawning grounds is a further threat to fish populations. Some of the depletion is driven by coastal development:

> *Uncontrolled beach development, housing in the mangroves, removal of mangroves wholesale for construction of hotels – not that that's a crime, but it's an ecological crime. […] A lot of the hotels are building in nursery areas. Some of them – to facilitate what they think the tourists need – clear the sea grass beds. They dig it up and dump it so you have this white sand, not realising that […] what is in there is fish and stuff that the tourists might want to snorkel and see.*

Coral reefs habitats are especially under threat. Respondents cited a variety of different pressures. Run-off during construction, particularly of limestone, which is used as a building material, has also been damaging for coral reefs. Some fishing practices have also been damaging, including nets being drawn along the corals and spear fishers breaking off coral to retrieve prey. In previous decades the most destructive fishing practice was dynamiting:

> *In the Belmont and Whitehouse area, before we introduced the protected areas, there was rampant dynamiting […] I used to scuba dive in that area. […] Some places between Whitehouse, Bluefields, and up to Sav-La-Mar […] look like a*

moonscape. Craters. […] Of course, there's no fish. No coral. Nothing! Just rubble and holes that look like the surface of the moon.

As explained in the section on Soufriere's natural capital, on top of these various pressures, ocean warming and ocean acidification represents perhaps the greatest challenge to coral reefs and near-shore fish stocks (IPCC, 2014; Pratchett, et al., 2011).

Beyond the decline in fish stocks, were the coral reefs to recede, Whitehouse would be at risk of losing its biggest tourist attractions. The quality of snorkelling and scuba diving would decline, and the beach would be more exposed to storm activity and more susceptible to erosion. As in Soufriere, there is risk that climate change will also cause Whitehouse's temperature and weather patterns to become less hospitable for tourism with increased frequency of heat waves, water shortages, flooding, intensity of storms, and risk of vector borne diseases such as dengue fever and malaria (CARIBSAVE, 2012a; Simpson, et al., 2008).

4.5.1.4 Physical Capital

Whitehouse is lacking in physical capital, and that which exists is of poor quality and ill-equipped to deal with current climate pressures. Moreover, there is risk that with climate change, Whitehouse's infrastructure will become increasingly maladapted. For example, Whitehouse currently experiences prolonged periods without precipitation, and as discussed in the previous section on natural capital, climate change is expected to cause average monthly precipitation to decrease. The majority of households in Westmoreland lack piped water and rely instead on rainwater catchments (see Figure 32). Currently during periods of low rainfall, those without water will either travel to Beeston Springs on their own to fill up drums of water, or they will pay for truckloads of water to be delivered to their empty catchments. In emergencies, the government will also provide water to households by truck. Lack of piped water is also a major challenge for farms, which will often lay unnecessarily fallow during periods without rain.

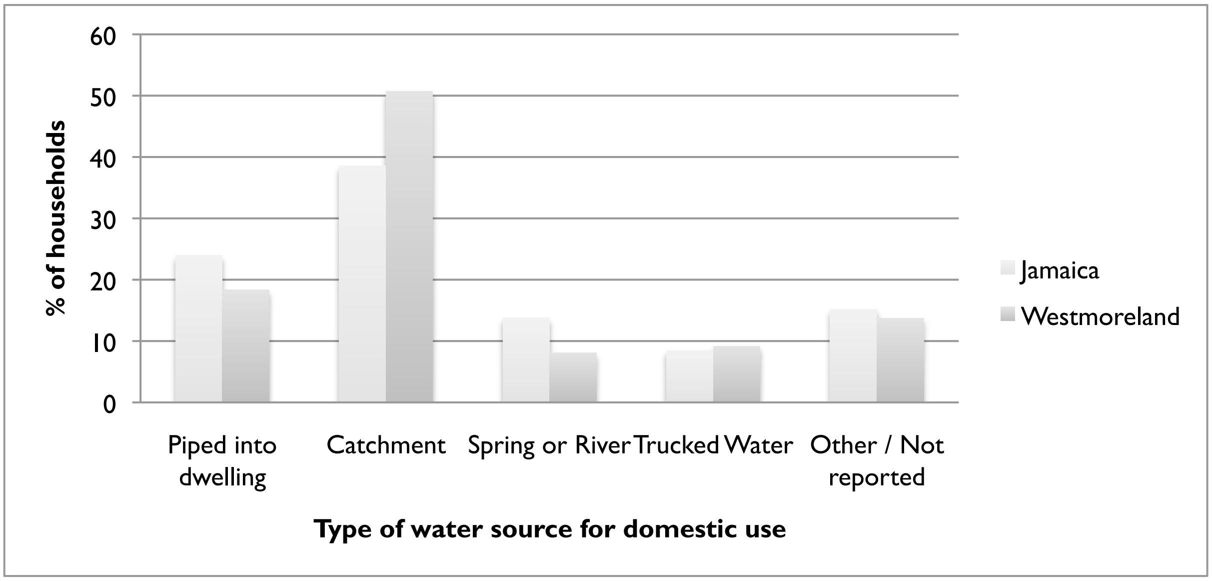


Figure 32. Type of water source for domestic use (Statistics Institute of Jamaica, 2011).

Whitehouse, located on the windward side of Jamaica, is also highly exposed to hurricanes. Historically, the mean hurricane strike rate in the northern Caribbean has been one per year (Campbell & Beckford, 2009; Spence, Katada, & Clerveaux, 2005). Figure 33 tracks the historical hurricanes and tropical storms in the vicinity of Jamaica, giving a further indication of frequency. The frequency of hurricanes and large tropical depressions has increased since the turn of the century with one hurricane striking in 2001, two in 2004, three in 2005, one in 2007, and one in 2012.

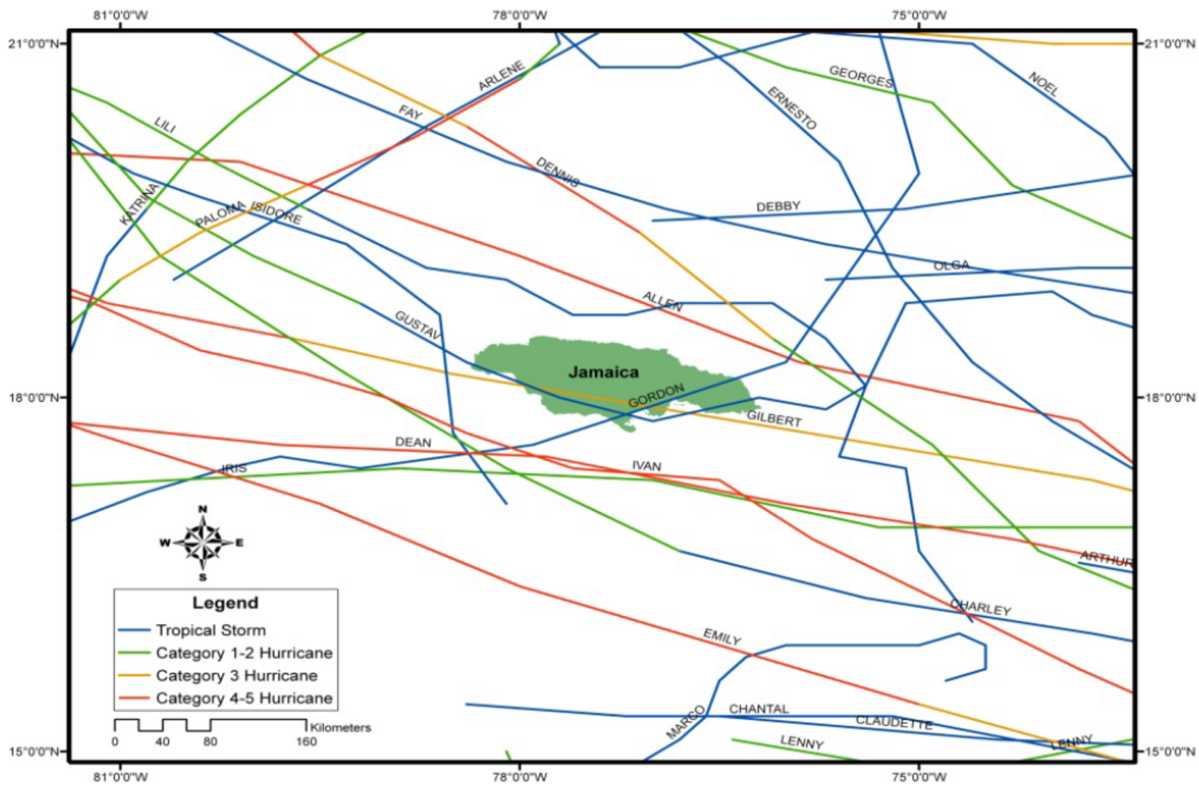


Figure 33. Hurricane and tropical storms that affected Jamaica, 1980 – 2008 (Campbell & Beckford, 2009)

It is currently unclear from climate models what effect climate change will have on the frequency of hurricanes, however climate change is predicted to cause an increase in the intensity of storms, and possibly an increase in frequency. These changes would lead to greater exposure of Whitehouse's physical capital to extreme wind and rainfall, storm surge, and erosion.

The infrastructure of Whitehouse is not well equipped to deal with the current frequencies and intensities of storms, nor the extreme levels of rainfall that they bring. The drainage system in particular is poorly constructed to prevent flooding:

> *One of the things [the government] would have to be able to address is to have all our drains concreted, because when you have the earthling drains the silt builds up,*

and we do not even have the funding to clean it. I believe that that money should be used to put in something more permanent so we can be able, in the long-term, to mitigate against flooding.

In 1979, a tropical depression dumped 865 mm of rain in an 8 to 10 hour period. Bluefields River and Robin's River flooded due to the high water table and impermeable underlying limestone. Parish-wide, the flood killed 41 individuals and caused J$100 million ($56 million) (Scolaro, 2013). Locally, the flood damaged roads and water infrastructure, devastated crops, rerouted the Bluefields River, and washed away much the sand on the Bluefields Fishing Beach (Carroll, 2013; Scolaro, 2013).

Increased storm surge from more intense storms also presents risks to Whitehouse Town and Bluefields. Respondents reported that waves regularly crash over the coastal road going through Bluefields and Belmont during storms in September and October. Following the category 4 Hurricane Ivan in September 2004, the Mines and Geology Division conducted a storm surge assessment that found that Bluefields and Cave areas experienced storm surge with heights of 1.5 meters that ran up to 50 meters inland (Carroll, 2013; Parish Council of Westmoreland, 2008). It predicted that a category 5 hurricane would cause sea waves of over 5 meters in height (Carroll, 2013).

As in Soufriere, climate change also threatens Whitehouse's coastal infrastructure through sea level rise. The Mona Geoinformatics Institute at the University of the West Indies (UWI) mapped the areas of the country that are at risk of being inundated by rising sea levels. As seen in Figure 34, some of the coastal road along Bluefields Bay as well as the waterfront location of Sandals Whitehouse would be underwater were the sea level to increase one meter above present level. The area is less exposed to sea level rise than other parts of the parish, especially the cities Negril and Savanna la Mar. However, given the importance of these two cities to the populations of Whitehouse in terms of services and employment, and that the four locations compete for public funds from the same government coffer, it is not hard to imagine that impacts from sea level rise on Negril and Savanna la Mar might have knock-on effects locally.

Figure 34. Topographically low-lying regions (adapted from Richards, 2008).

4.5.1.5 Social Capital

Most respondents felt that the communities of Whitehouse Town, Bluefields, and Beeston Springs had a high degree of social capital. Many discussed the low rates of crime relative to other parts of the country and reported that residents would regularly share the fruits of their labour with those less fortunate. Social capital was also seen as particularly important in the functioning of local organisations.

In some ways, high levels of social capital can alleviate the lacking physical and financial capital. The following response describing Bluefields' approach to dealing with hurricanes illustrates the importance that social capital has played in responding to extreme events:

> *We have an unwritten disaster plan. […] First thing, when there is a threat, all the equipment is secured. […] All the fishermen come together and pull the boats out of the water. Then all of the persons go and they batten up their windows as much as they can. Then we make sure that the senior citizens in the community that don't have anybody living with them, they are brought over to other homes. […] After the storm the first thing that we do is we try to clear the roads, our streets, and we remove any trees that have fallen on electricity wires. […] We assist as much as possible in terms of clearing all of the lanes and streets […] Some people who have family abroad, as soon as their phones get recharged they start getting calls to ensure everyone is ok and to send them money via Western Union. We want to have a disaster committee. […] We might put [a formal disaster management plan] down on paper, but the informal one has been working.*

One area where social capital appeared to be lacking was on Pedro Cay. Fishers unanimously agreed that illegal fishers coming from Nicaragua, Honduras, Columbia, and the Dominican Republic were a threat to their livelihood. Fishers reported that they commonly witnessed offshore trade in guns, marijuana, and cocaine. Many were concerned about the potential impact that these activities would have back on shore, for example on the tourism industry.

4.5.2 Institutions and Entitlements

4.5.2.1 Historical institutions of a plantation economy

During the 17 and 18th centuries, Jamaica was England's leading sugar producing colony. By the 1770s, it produced more sugar than all of the other English islands combined. Historical maps show that during this period numerous sugar estates were established within the study area[21] (Scolaro, 2013). On these estates, imported slaves, primarily from West and Central Africa, worked the field and cut cane. It was not until the 1830s, that the British Parliament passed the 'Act for the abolition of slavery throughout the British colonies.'

Beyond the potential psychological and social legacy, which is difficult to measure, the pattern of land ownership is a concrete structural remnant of slavery that limits the adaptive capacity of the lowest income strata in Jamaica to this day. After Emancipation, many of the plantations in Jamaica continued to operate, and still controlled the most fertile agricultural land. To fill the gap in labour created by

[21] There were sugar estates along Bluefields Bay, Orange Grove, Beeston Spring, Lenox, Grand Vale, Bog, Content, Petersville, Culloden, Belmont, and along Bluefields River. There may also have been a cotton, indigo, and cocoa plantation along Bluefields Bay. Maps and archaeological evidence also show that there were waterwheels and watermills to process the cane on Robin's River, Sweet River, and Bluefields River, and cattle-powered mills in Content, Petersville, and Culloden (Scolaro, 2013).

Emancipation, many estates brought in indentured servants from India and China. Other estates maintained their labour force by hiring the newly freedmen as wage labourers, and providing them with land for subsistence farming and rent-free accommodation. Historical accounts suggest that this latter model existed in the estates surrounding Bluefields Bay.[22] Other newly freed men preferred to leave the estates and work as independent farmers and/or fishermen. Those who farmed were largely forced onto marginal lands in the interior.[23] In the absence of comprehensive land reform, the current land ownership pattern in Jamaica is very much a path-dependent product of slavery. In 1998, the Statistical Institute of Jamaica's Census of Agriculture revealed that 65% of Jamaica's agricultural land was controlled by only 4% of the landowners. The remaining 96% of landholders owned 35% the land, divided into small plots averaging 0.83 hectares (Weis, 2004). The farms observed within our study area fell exclusively into the latter variety. As in Soufriere, these land ownership patterns create severe structural impediments to adaptation and lead to unsafe conditions: "One hundred and sixty years after Emancipation, most small farmers continue to operate on small, steep hillside plots that severely constrain their production options and efficiency. In particular, the lack of irrigation limits the variety and timing of cropping patterns, and steep land gradients and poor infrastructure make labour less efficient, limit mechanized tillage, force more land clearance when soils get exhausted, make it difficult to get

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[22] During a trip to Bluefields in 1844, the British naturalist Philip Henry Gosse observed that Belmont had been "apportioned out in small […] allotments, and cultivated in gardens" (Gosse 1851:87 as cited in Scolaro 2013).

[23] In some areas, such as Beeston Springs[23], Christian missionaries bought large plots of land and established 'free villages' with schools, farms, and churches for the newly freed peasants. For example, In Beeston Springs, in 1860, a Moravian missionary named Alfred B. Lind purchased Salem Estate at Beeston Springs and founded a free village with a teacher's cottage (Scolaro 2013).

produce to the market, and simply increase the arduousness of everyday tasks" (Weis, 2004).

4.5.2.2 Structural adjustment programmes and international trade law

In the 1970s, under a government controlled by Michael Manley's leftist Peoples National Party (PNP), small-scale farmers enjoyed significant public support in the form of publicly leased land,[24] public investment in agricultural cooperatives, rural infrastructure, agricultural research and extension services, and government efforts to improve access to credit and tenure security. During this time, employment levels and domestic food production increased[25] (Weis 2004). However, in the late 1970s and early 1980s, Jamaica experienced an increasing balance-of-payments deficit driven by the rising cost of oil, and received a series of International Monetary Fund (IMF) stabilisation loans and World Bank Structural Adjustment Loans. These loans were conditional on spending cuts,[26] reductions in tariffs and the removal other barriers to imports. Structural adjustments continued through the 1990s with privatisation of state-run enterprises and further reductions in tariffs. The formation of the WTO entrenched these tariff reductions by creating tariff ceilings. It also limited 'trade-distorting' domestic price supports, while permitting so-called 'non-trade distorting' subsidies – a loophole that allowed developed countries to spend billions of dollars each year on agricultural subsidies that distorted trade in their favour. The result in Jamaica was a rapid increase

[24] 36 thousand hectares of (albeit marginal) public land was leased to 36 thousand small farmers (Weis, 2004).

[25] Domestic food production increased by 10–20 per cent between 1977 and 1979. Between 1977 and 1980 agriculture accounted for 36–39 per cent of employment (Weis 2004)

[26] Between 1981 and 1985, government expenditure on agriculture as a percentage of GDP declined fourfold. This was not only due to a shrinking overall budget associated with debt and austerity; agricultural spending was also de-prioritized – in 1974–5, agriculture received over 19 per cent of government expenditure, but by 1990–1 this had fallen to less than 4 per cent. (Weis, 2004).

in imports, especially food products,[27] and a mounting trade deficit (see Figure 35). In 2012, the value of Jamaica's imports equalled 175% of its exports.

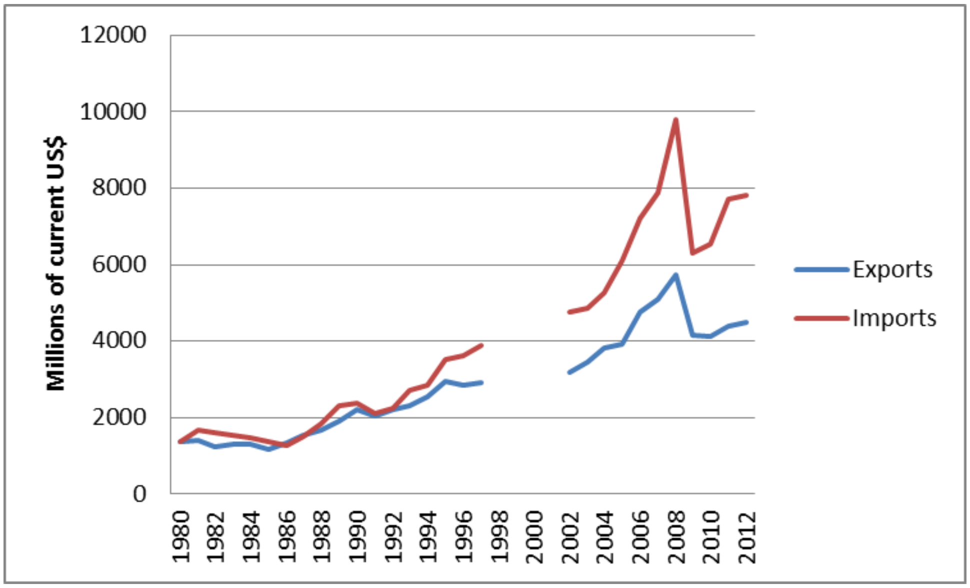

Figure 35. Jamaica's trade exports and imports, 1980-2012 (International Monetary Fund, 2014).[28]

As discussed earlier, respondents repeatedly explained that local markets were being undercut by cheaper imported products. However, WTO rules limit tariffs and subsidies, reducing the Government of Jamaica's flexibility to intervene in its agricultural markets (Weis, 2004). These limitations, in turn, reduce the capacity of small-scale farmers to adapt to changing market conditions, and the resulting lack of financial capital limits their capacity to adapt to climate change.

4.5.2.3 Fishing Regulations

Fishing regulations have significant implications for Whitehouse's adaptive capacity due to their impact on its natural capital. However, respondents explained that

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[27] Jamaica's food and beverage more than doubled between 1991 and 2001 from US$199m to US$503m (Weis 2004)

[28] Data not available from 2008 to 2002.

regulations were insufficient and that enforcement was poor, partly due to the limited financial capital of the government for monitoring personnel and equipment.

Historically, fishers used fish pots and fine mesh seine nets. Fine mesh seine nets are particularly harmful because they capture everything, i.e. they do not differentiate between large and small fish. They also damage the seabed, destroying breeding grounds. Many countries have banned fishing with seine nets, but Jamaica has not. Only recently did it institute a minimum mesh size on its nets and traps.

Regulations surrounding lobster and conch fishing are more stringent. Lobster fishing is open for nine-month seasons (August through July) and closed for three months (April through June). Harvesting of female lobsters, identified through the presence of eggs, is banned. Conch fishing is likewise regulated through closed seasons, as well as through export quotas. The driving force behind these regulations is partly pressure from the international Convention on International Trade in Endangered Species (CITES), which lists conch under Appendix II, meaning that it is considered not necessarily at risk of extinction, but may become at risk unless trade is closely controlled. Jamaica follows CITES guidelines voluntarily (Cartarci, 2004).

4.5.2.4 Access to decision-making structures and elite capture of institutes

There was evidence that elite capture of institutions in Whitehouse has further limited the adaptive capacity of lower-income groups. For example, with the limited government spending in the area, gated communities in Whitehouse have formed homeowners associations to invest in road improvements, and water and sewerage infrastructure. In doing so, the residents of the gated communities demonstrated a much higher degree of adaptive capacity than the other residents of Whitehouse and

Bluefields. A side effect of the homeowners associations is the institutionalisation and exacerbation of the inequalities that exist in the region.

Fishers in particular felt that they had little access to government decision-making structures:

> *One of the issues is that the fishing community is not as politically powerful as other economic communities. […] There are some in the larger companies, but by and large the fishers themselves don't have that sort of political clout.*

This lack of political power compared to other interest groups, such as tourism companies, has had significant influence in the outcome of political decisions:

> *What we observed is that the government is selling the wetland to developers. This is the habitat where the fish breed. […] Sandals Whitehouse is built on wetlands. What is happening is that the reef is being stifled, the mangrove destroyed. The breeding ground becomes obsolete, the fish stock becomes weaker, but you start to blame the fishermen. In fact, the fisherman has nothing to do with that. The industrial and commercial waste that goes into the sea daily, the fisherman doesn't contribute to that, but the fisherman is blamed.*

The SDC within the Ministry of Local Government and Community Development has made some progress in increasing local access to decision-making structures. The SDC is structured in a hierarchical order, with the national SDC broken into Parish Development Committees, which are broken into Development Area Committees and finally Community Development Committees (CDCs). The Bluefields CDC has been particularly active. The role of CDC was taken on by Bluefields People's

Community Association (BPCA), which acts as an umbrella organisation for community groups including the Bluefields Bay Fishermen Friendly Society (BBFFS) and the Jamaican Organic Agricultural Movement (JOAM).

4.5.2.5 Bluefields Bay Special Conservation Area

In 2008 a new government, led by the Jamaican Labour Party, announced a national target of protecting 20% of its marine and coastal habitats by 2020, and that it aimed to establish nine MPAs, five of which would be on the south coast. With the vast majority of local fishers in favour of establishing a fish sanctuary, the BBFFS quickly approached the government and established the largest conservation area in Jamaica. The Bluefields Bay Special Fisheries Conservation Area[29] encompasses 3054 acres and stretches 12 km along the coast (see Figure 29). The zone is patrolled 24 hours a day by wardens that have the authority to fine fishers for infringements and to seize their equipment.

The Conservation Area has enhanced Bluefields' adaptive capacity in multiple ways. First, early evidence suggests that the fish populations within the zone are recovering, enhancing natural capital (Rudolph, 2012). It is hoped that the 'spill-over' effect from the area will increase fishers' catch outside of it (Roberts, et al., 2001). Second, as a flagship conservation programme, it has attracted significant financial capital for Bluefields in the form of international grants,[30] which have been directed to operation expenses of the Conservation Area, as well as projects to create alternative

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[29] The designation was changed from MPA to a Special Fisheries Conservation Area to allow for research and culling of lionfish. Fishers are not allowed to enter the area without a permit.

[30] In November 2012, BBFFS signed a Memorandum of Agreement with the CARIBSAVE Partnership, from which BBFFS will receive US$91 thousand. These funds will go towards the purchase of a new patrol boat, the wages of three new wardens and a supervisor, and the construction of a floating platform to assist with enforcement and research.

livelihoods for local residents (discussed in 4.5.5). Third, community discussions prior to implementation of the Conservation Area worked to increase awareness of the harmful consequences of overfishing. Finally, it can be argued that the communal effort involved in establishing the Conservation Area has enhanced and reinforced social capital in Bluefields. The wardens explained that this communal effort continues as community members have occasionally reported infringements within the area that occurred beyond the sight of the warden's vantage point.

4.5.3 Knowledge and Information

A recent study carried out by the Planning Institute of Jamaica (PIOJ) assessed the population's knowledge of climate change through quantitative household and industry surveys and qualitative focus groups. It found that Jamaicans have a high understanding about climate change, and a moderately good understanding of its causes and potential impacts.[31] Our research corroborated these findings.

The Jamaican population's high-level of understanding about the risks of climate change is partly the result of various initiatives to generate and disseminate information. Research into the effects of climate change in Jamaica is driven by a network of international organisations, such as the World Meteorological Organisation and CARICOM's Caribbean Community Climate Change Centre; government agencies, including the Met Office and the Water Resources Authority; NGOs, including

[31] Over 80% of respondents in the household survey had heard of the term climate change. Most respondents identified hurricanes (83.7%), droughts (84.5%), floods (76.9%), and increases in air temperature (74.9%) as events related to climate change. The focus groups also found that Jamaicans have a high understanding about the impacts of climate change. Participants identified hotter days, stronger hurricanes, shorter growing seasons, and increased floods and droughts as potential consequences of climate change, and discussed how construction in hazard-prone areas increases potential impacts (PIOJ 2012).

CARIBSAVE; and universities, particularly the Climate Studies Group at the UWI.[32] The CARIBSAVE Partnership has been influential in disseminating the results of downscaled climate models through an easily interpreted Climate Change Risk Atlas (CARIBSAVE, 2012a). The National Environmental Protection Agency (NEPA) has also been influential in communicating information to the general population by hiring a community animator to liaison with community groups and by working with musicians and other popular culture figures. Nonetheless, respondents explained that the main reason why awareness is high amongst Jamaicans is that they have observed climate changes in their everyday lives and are receptive to explanations.

Despite the high-level of awareness about the risks of climate change, there is limited understanding about adaptive options. One important area where knowledge is lacking in Whitehouse is how agricultural practices mush shift to deal with climate change. One respondent from Jamaica's Rural Agricultural Development Agency (RADA), the government agency responsible for agricultural extension services, explained that to improve general understanding about adaptive options, extension officers would require specialised training and there would need to be an increase in the number extension officers per farmer.

[32] Regionally, the World Meteorological Organisation heads a Caribbean Hydrologic Cycle Observation System, which produces research on climate, weather, and water cycles. The Met Office of Jamaica is the country representative to the programme. Between 2004 and 2007, the World Bank and CARICOM's Caribbean Community Climate Change Centre carried out a project called Mainstreaming Adaptation to Climate Change (MACC), which produced downscaled climate models and scenarios regarding the impact of climate change on water resources, sea level rise, temperature, and movement of the seawater. The Climate Studies Group at UWI has produced further models of future hydrological scenarios, which use rainfall data collected by the Met Office and stream flow data collected by the Water Resources Authority. To ensure reliable and continuous data, the Water Resource Authority is installing additional rainfall gauges in the different areas across the country, including rainfall intensity gauges.

Respondents explained that knowledge is also lacking about proper management of coral reefs. Multiple agencies are involved in sensitising local residents and tourists about coral reef preservation. Sandals Whitehouse and the Natural Resources Conservational Authority have held workshops and community education programmes about fishing practices and protection of sea life and the coral reef. However, further education is required among decision-makers that are responsible for the non-direct sources of pressure on the reef including run-off from construction and agriculture.

An effective mechanism to disseminate information about environment management has been school programmes. Since 1997, the Jamaican Environment Trust has held workshops twice per year to train teachers to lead class sessions on subjects such as management of coral reefs, wetlands, and human waste. By 2003, the environment programme was operating in a third of Jamaican schools. A similar school programme, run by an American NGO, is Project WET, which trains teachers to lead class sessions on water resource management.

Respondents felt that Jamaica's early warning system for hurricanes was also effective at rapidly disseminating information, and that it had matured significantly as a result of having to deal with an increased number of storms since the turn of the century. The MET office monitors incoming storm systems and red flags any approach storms for the Office of Disaster Preparedness and Emergency Management (ODPEM). In the event of a storm warning, ODPEM disseminates information through Parish-level Disaster Coordinators, which contact community groups and leaders, shelter managers, and media outlets to get the word out to general public. In partnership with the Water Resources Authority, ODPEM has also developed early warning systems for flooding and produced maps of flood plains for use in land-use planning and flood hazard management.

4.5.4 Innovation

Innovativeness varied a great deal between industries in Whitehouse. The fishing industry demonstrated particularly little capacity to innovate to reduce its pressure on near-shore resources. When the catch was not sufficient, many would simply pull their boats up on shore and deplete their savings. Others would resort to a number of maladaptations. For example, respondents reported that fishers are keeping increasingly smaller fish:

> *Over the years, the fish stock has declined. You're also seeing smaller fish due to the fact that there is a lot more fishing effort due to unemployment, education, just the present state of the economy. Persons leaving high schools have no jobs and they see fishing as an easy way out. They don't have the experience. They don't have the discipline. So the proper fishing practices are not being taken. They'll just go to sea, and the easiest way they can catch a fish, they'll try and do that. The older fishers had more discipline; had more patience. […] Their practices and ways of fishing would be more environmentally friendly. Fishers now are not throwing back the smaller fish, the under size fish. They say, 'Listen, I have to make my money.'*

Many fishers also reported going further and further out to sea in search of a healthy catch, often with inadequate navigational equipment, putting their vessels and lives at risk. The most common maladaptation to deal with depleting fish stocks has been the conversion to spear fishing with air compressors. Compressors are mounted on boats and, through long tubes, provide multiple spear fishermen with oxygen at once. They allow the fisher to stay below longer than scuba tanks. However, the method is highly dangerous, as fishers are exposed to numerous hazards including sharks and poisonous fish, decompression sickness, and equipment malfunction:

> *The biggest implication that we have that indicates that we don't have a lot fish is now that more people are going into diving. […] They get the air compressor, long hose, mouth piece and they are gone. They're going deeper in the water. […] More and more people are going into spear fishing because the trap fishing is not working. […] Anytime you get to compressor diving you've got to the bottom of the barrel. […] The week before last a young man came in here with what they called 'the bends,' and his legs – I don't know if he can walk now. They had to rush him to the hospital, and unfortunately we only have two decompression chambers in Jamaica.*

Very few respondents that fished with a compressor had received proper training. Every one of them had known another fisher who had drowned or was crippled from decompression sickness. Few fishers had switched to alternative industries. As discussed earlier, this lack of adaptive capacity was partly a result of limited human and financial capital. However, respondents also cited other barriers, such as the deep-rooted nature of fishing in the culture of Whitehouse:

> *Too many people are going into fishing, so we are trying to move them away from that, though some are a bit stubborn because it seems as if salt water is in their blood.*

The few processes that existed within the fishing industry to 'search' for solutions to the dwindling natural capital were primarily driven by the government, and involved transferring technology from other countries. For example, the Fisheries Department recently partnered with a Cuban marine biologist that had designed lobster condominiums or 'lobster casitas' out of PVC pipe, and installed 16 of them within the Bluefields Bay Special Fisheries Conservation Area to trial the technology. The government had also contracted an American company, EcoReefs, Inc., to install 350 artificial reefs in Bluefields Bay. Pictured in Figure 36, the units are ceramic and anchored to the sea floor using rebar. They are designed to mimic staghorn coral, which, respondents explained, had been greatly depleted in the area by successive hurricanes since the 1980s. The artificial reefs facilitate the growth of coral reefs by slowing the water flow, stabilising sediment and providing a microporous surface for coral adhesion. In the process, they also increase fish populations. Rudolph (2012) conducted a baseline survey of fish populations in June 2011, and subsequent surveys in January 2012 and June 2012. The study showed that fish abundance and diversity increased significantly: "Once modules were emplaced, colonization occurred quickly by a number of species. A year later, 8195 individuals were documented over three fifteen minute transects compared to the original 115 individual fish noted at the artificial reef site" (Rudolph, 2012).

Figure 36. Artificial Reef in Bluefields Bay Special Fisheries Conservation Area (Beckman, 2013; Carroll, 2013)

Within the farming population, innovativeness was more varied. Respondents explained that most farmers were risk averse, and would not adopt a new technology or practice until it had been proven to work. However, others would actively 'search' for new techniques and technologies. For example, one new and growing practice in Bluefields and Beeston Springs was apiculture. One beekeeper explained that the industry had great potential for growth in Whitehouse considering the size of the overseas market for honey, but that capitalising on the opportunity required government intervention to build knowledge and human capital. Another group of farmers in Bluefields recently joined JOAM. While the practice of organic farming is deeply rooted in Jamaica's Rastafarian community, training from JOAM had led to a variety new practices and enterprises. The farmers started an agroprocessing cooperative to produce jams and wine from sorrel and june plums, which they sold to local hotels. They also started a small demonstration plot to showcase organic practices. The motivations of organic farmers were primarily to produce healthier food in a more environmentally friendly manner. However, many felt that organic farming had advantages when it came to adapting to climate change:

> *The organic way contributes to how to deal with weather patterns. […] You have to organise your farm with shades to cover some of the plants from sun with other plants. You have to organise it for windbreaks, to [prevent] blow down of the crop when strong winds come in. And you have to organise it with contours, so that if there's a flood your farm can survive.*

Farmers were acutely aware of recently changing weather patterns. One technology that many felt would allow them to deal with these changes was greenhouses. A respondent from RADA explained how Jamaicans had made incremental innovations in the design of greenhouses to make them more fit for the local environment:

> *When you introduce a new technology sometimes you realize that you need to improve on it. […] It was after the experience of strong winds or a hurricane that we realized that it's best to install [greenhouses] in such a way where we can remove the roofs. I would imagine that all the greenhouses that are going up now would be constructed in such a way, because we have a greenhouse unit now throughout the island and they meet from time to time. They would pass on this information to the growers.*

Despite the improvement, financial barriers still prevented most farmers from obtaining greenhouses. Likewise, financial constraints were the primary barrier preventing diffusion of drip irrigation systems:

> *The only adaptation would be to look towards, in the drier periods, using irrigation techniques such as drip irrigation systems. It is quite expensive and most farmers cannot afford. They try their best to use innovative ways to ensure that the crop has water during that period. […] But sometimes what happens, it cuts people out of production during that period of time, because they cannot afford an irrigation system. So they wait on the rainfall period.*

An additional technology that some respondents felt could help farmers to cope with increasing dry spells was rainwater harvesting (with underground tanks significantly larger than the water catchment systems used my most households). One respondent explained that the barriers to this technology are cultural, rather than financial or technical, and that command-and-control regulation may be required to ensure that it is diffused:

> *We're looking at rainwater harvesting. […] I think the problem has always been more cultural than technical. Because people believe that you need to have piped water.*

The local tourism industry in Whitehouse also exhibited limited innovative capacity. Most entrepreneurship was driven by returning expatriates and foreign nationals that had more financial capital and technical training than local residents, and much of the recent development emulated Negril's all-inclusive beach resorts. In

Bluefields Bay, a few local respondents expressed the desire to launch ecotourism companies engaged in bird watching, hiking, spelunking, and snorkelling, and heritage tourism companies based on Bluefield's Bay historical significance as a one-time colonial centre and pirate stronghold and the birthplace of famous Reggae musicians. Nonetheless, like the fishing and agriculture industries, these innovative aspirations were largely constrained by limited financial and human capital.

4.5.5 Flexible forward-looking decision-making and governance

Flexible and forward-looking governance of land-use is particularly important due to the frequently myopic decision-making of private individuals and the slow changing and commonly irreversible nature of land-use. Jamaica already has a significant amount of infrastructure built along its coastline and in flood-prone areas. Flexible and forward-looking land-use planning would take into consideration the projected changes in climate and sea level. To this end, NEPA is in the process of creating a *National Spatial Plan* that will provide guidance for the layout of developments across the island. At the time of research, a committee in the Office of the Prime Minster was preparing legislation to submit to the Cabinet that would create coastal setbacks and no-build zones, particularly in flood-prone areas.

Given the projected increase in intensity of storm activity in the Caribbean, flexible forward-looking governance would entail improvements in disaster risk reduction, as well as disaster response systems. When ODPEM was established in 1980, its mandate focused on disaster response coordination and education about hazard risks. Over time, this mandate evolved to include the integration of disaster risk reduction into development planning as a whole. Parish Councils have employed Parish

Disaster Coordinators, whom act as a bridge between ODPEM and communities and whom are responsible for ensuring that communities are ready to respond to disasters. As was done in Whitehouse, Parish Disaster Coordinators and ODPEM host community meetings with local community members to identify vulnerabilities, increase awareness, establish storm shelters and shelter managers, and formulate community response plans. ODPEM has also worked with communities and other government departments to increase resilience of physical infrastructure through drainage systems and slope stabilisation mechanisms, and to rebuild important natural systems, for example, through mangrove replanting exercises.

Despite these (pending) improvements in governance of land-use and disaster risk reduction, flexible and forward-looking governance has been lacking in Jamaica's fishing industry. Given the severity of the threats imposed by climate change on Jamaica's fishing industry, it is highly likely that communities that specialise in fishing, such as Whitehouse Town, will need to undergo a transformative adaptation or face collapse. However, the policies necessary to support such a transformation have not been implemented. Jamaica's Fishing Industry Act, established in 1975, is severely outdated. A first draft of a new Fisheries Bill, with tougher regulations and penalties, was tabled in parliament in 1996. Since then, the bill has not reached a vote in Parliament. The bill would introduce a measure to reduce fishing effort through a moratorium on new fishing licenses:

> *We are going to look at a three-for-one system. Say, for argument sake, here in Whitehouse at least three fishermen have to come out of the sea before we put one in.*

One respondent estimated that 15-20% of fishers already fish without licenses, and stressed that were a moratorium to be successful, it must be accompanied by increased enforcement. Such top-down policies will likely need to be accompanied by bottom-up support for alternative livelihoods. The Climate Change Adaptation and Disaster Risk Reduction project, implemented between 2011 and 2013 by the Government of Jamaica, the European Union and the United Nations Environment Programme (UNEP), aimed to provide such support for alternative livelihoods.[33] Island-wide, J$15 million (US$133.6 thousand) in grant funding was provided to 14 enterprises (Jamaica Observer, 2013; Mcintosh, 2014). In Bluefields, three grants were awarded to projects promoting beekeeping, ecotourism, and organic farming (GCCA, 2012). The project demonstrates how international support can promote more flexible and forward-looking decision-making and governance at the local and national level.

4.6 Discussion and Conclusion

This paper set out to achieve three objectives. First, in Section 4.2, it aimed to demonstrate that the LAC framework corresponds with an evolutionary perspective on adaptive capacity. Second, in Sections 4.4 and 4.5, it aimed to provide thorough case studies of Soufriere and Whitehouse's adaptive capacity. This section will focus on the third aim – to critically assess whether the LAC framework fully captures the important elements of adaptive capacity across different geographical contexts.

The observations made in both case studies validated the LAC framework's inclusion of institutions, knowledge, innovation, and flexibility in decision-making and

[33] The EU Global Climate Change Alliance provided funding of EUR 4.13 million, and UNEP provided technical support.

governance in its characterisation of a system's adaptive capacity. An asset-oriented approach would have offered an incomplete understanding of the adaptive capacity of both communities. To illustrate, Soufriere's adaptive capacity is significantly curtailed by its inadequate stock of financial, human, physical, and social capital (though the distribution of each of these assets within the community is highly unequal). Conversely, its adaptive capacity is enhanced by the community's rich natural capital – its fertile soil, fresh water, coral reefs, near shore and pelagic fish populations, hospitable climate, and the Pitons. Much of this natural capital is at risk from pollution, overexploitation, as well as climate change, which threaten to undermine the very assets that are the foundation of Soufriere's economy. This rather crude assessment paints a stark picture of Soufriere's capacity to adapt to climate change. However, an assessment of Soufriere's adaptive capacity would be incomplete without an examination of factors such as the NEMO's early warning system for hurricanes, the Belle Vue Co-operative's trial nursery and the SMMA. The success of Soufriere in establishing an institution as innovative the SMMA to enhance social capital and to protect the biodiversity of Soufriere's near shore ecosystems demonstrates a high degree of adaptive capacity that would not be captured through an approach that focused exclusively on assets.

The adaptive capacity of Whitehouse is similarly limited by its inadequate stock of financial, human, and physical capital. Agriculture is becoming increasingly susceptible to increased dry spells and more variable weather patterns, and while greenhouses and drip irrigation could offer technical solutions to this problem by lengthening growing seasons and increasing production, most farmers lack the financial capital to invest in these adaptive technologies. The natural capital that underpins the economy of

Whitehouse is perhaps even more under threat from climate change and other stressors than that of Soufriere. Fish populations in Whitehouse are already under immense pressure from pollution, habitat destruction, and overfishing. Climate change will likely cause off-shore fish populations to migrate further northwards; and rising ocean temperatures and ocean acidification will likely cause widespread coral bleaching, which will severely impact near-shore fish populations. While an examination of Whitehouse's asset base did reveal that the fishing industry's adaptive capacity is inadequate, the severity of the circumstances would not have been clear without an analysis of Jamaica's insufficient and poorly enforced fishing regulations, or the industry's minimal capacity to innovate to reduce its pressure on near-shore resources. Our understanding was further enhanced through an examination of the novel institutions and technologies designed to conserve local marine resources in Bluefields. The Bluefields Bay Special Conservation Area, artificial reefs and lobster condominiums provided exceptions to an otherwise pessimistic evaluation of the adaptive capacity of Whitehouse's fishing industry.

Therefore, it was evident from each of the case studies that when assessing adaptive capacity it is important to consider not only the assets that agents have at their disposal to adapt, but also the processes whereby institutions guide private behaviour, knowledge is generated and disseminated, novel practices and technologies are introduced, and governance decisions are made. However, beyond these elements of the LAC framework, a number of themes prevalent in evolutionary literature emerged from the case studies that the framework does not explicitly take into account. For example, although the LAC framework does implicitly consider structures that constrain or enhance adaptive capacity through the category of institutions, it does not necessarily factor in how these structures have been shaped by each location's history. The case studies demonstrated that both Soufriere and Whitehouse's landownership patterns are path-dependent products of slavery and colonialism. Institutions, including clauses in St Lucia's Constitution that guarantee landowners' rights to determine the use of their land, reinforce this path-dependency of land-use by reducing the government's flexibility in instituting mandatory coastal setbacks or land reforms.

The case studies also revealed the importance of considering institutions and processes at different scales. For example, both Soufriere and Whitehouse's stock of financial capital has been heavily influenced by the institutions that govern trade at the national and international scale. At first, these institutions protected the markets for St Lucia's copra and banana industries; subsequently, they undermined them. Likewise, in Jamaica, the IMF and World Bank structural adjustment programmes that were forced onto the national government due to its mounting balance-of-payments deficit, combined with the WTO rules limiting tariffs and subsidies, reduced government support for small-scale agriculture and led to a rapid influx of cheap imports that undercut domestic markets. There is a danger that the '*Local*' Adaptive Capacity framework will fail to capture such higher-level factors that influence a locality's adaptive capacity if they are not explicitly included.

By factoring in innovation and flexible and forward-looking decision-making, the LAC framework implicitly considers the role of agency in fostering new adaptive options and shaping the institutional structures that guide private behaviour. However, the LAC framework does not explicitly consider the role of agency within the structured spectrum of adaptive options. For example, although seemingly irrational decisions – such as the continued harvesting of overexploited resources, the construction of homes in areas prone to landslides or flooding, and the use of weak building materials – could be partially attributed to structural root causes, human tendency to act heuristically and sometimes myopically must also be considered.

Lastly, although the LAC framework stresses the importance of innovation, and hence a system's capacity to foster diversity, it does not explicitly factor in a system's capacity to conserve diversity. In both locations, the institutions designed to conserve diversity, particularly biodiversity, proved to be essential in maintaining adaptive capacity. The case studies also demonstrated the perils of specialisation in one industry, a factor that is not explicitly negative within the LAC framework. Neither St Lucia's specialisation in bananas nor Whitehouse's specialisation in fishing would have necessarily factored poorly in an assessment using the LAC framework during boom times. Likewise, the increasing specialisation of Soufriere in tourism may have been interpreted as positive had this paper not portrayed it otherwise, given tourism's role in increasing financial and human capital.

These evolutionary themes – structure, history, path-dependency, scale, agency, conservation of diversity, and the perils of specialisation – should be explicitly taken into account in a framework for assessing adaptive capacity. Some of them, such as agency and conservation of diversity, could be included as new categories within the framework. However, it would likely be more practical to include these evolutionary themes as explicit considerations within the other categories as was done in this study.

Finally, this paper demonstrated the importance of using qualitative research methods in adaptive capacity assessments. While quantitative data, particularly about the asset base, is essential, in order to unearth the evolutionary themes discussed above, rich descriptive data is required that can only be captured through qualitative methods that place strong emphasis on the local context – the local culture, history, social dynamics, and institutions – and on how this context is shaped by forces at different scales. This case study captured a wealth of such data, which will be valuable to decision-makers in deciding which interventions are most appropriate in enhancing Soufriere and Whitehouse's adaptive capacity and how they can be effectively implemented.

5 An Evolutionary Perspective on Economic Change to Sustainable Pathways in Brazil

5.1 Introduction

Between 2005 and 2009, Brazil's annual GHG emissions fell by 25%. This level of reduction is usually reserved for economies undergoing recession or collapse. However, over the same time period, Brazil achieved an economic growth rate of 3.5% per year (Viola, 2013). The primary cause of the emission reductions was a rapid decline in deforestation rates in the Amazon. In 2010, with a successful record in hand, the Government of Brazil (GoB) submitted relatively ambitious NAMAs to the UNFCCC, which declared a GHG emission reduction target of 36.1-38.9% against a BAU trajectory with a baseline year of 2005. Although voluntary under international law, Brazil set precedence among non-Annex 1 countries by incorporating its emission reduction target into national law with the Federal Decree No. 7360. The Decree specifies a number of mitigation actions that will be deployed to achieve those reductions.

This paper will provide case studies of three of those mitigation actions: the expansion of no-till agriculture, the reduction of deforestation, and the increased displacement of gasoline with ethanol. Each of these actions is situated in a historical context spanning decades, and hence offers an illuminating case through which to study economic change towards sustainable pathways.

Much of the investigation into the mechanics of economic change to low-carbon economies, and how such change can be induced and managed, has been driven by neoclassical economics, and the related branches of environmental and welfare economics. These streams of microeconomic inquiry examine how rational economic agents – acting according to price-based market signals to maximise returns – drive economic change in a linear manner towards an equilibrium state in which supply matches demand. This thesis argues that a holistic understanding of the forces that drive and inhibit economic change requires a broader perspective that incorporates less tangible factors such as institutional evolution; domestic and international politics; leadership; and networks and power dynamics across government, the private sector, research institutions, and civil society.

This chapter will argue that the three economic changes in Brazil that are the focus of this paper loosely fit into Geels & Kemp (2006) three categories of economic change – reproduction, transformation, and transition – which were introduced in Section 2.3.2.2. It will demonstrate that an understanding of the mechanics of economic change is not possible through a lens that focuses exclusively on supply, demand, and price-based incentives. Due to the *bounded rationality* of economic agents and the importance of innovation, a holistic understanding also requires a close examination of the local knowledge flows and search process. Furthermore, given the importance of higher-level selection pressures and the inertia of established socio-technical regimes, the chapter will demonstrate that a holistic understanding can not only focus on the microeconomic processes at the level of the individual and firm; it must also consider the macroeconomic, ecological, and socio-political processes driving change at other scales – community, regional, national, and global.

The following section discusses the methodology used in the case studies. Section 5.3 examines the three mitigation actions that are the focus of this paper. For each action, the GHG emission and microeconomic implications are introduced, followed by an in-depth analysis of the forces that have driven and inhibited economic change over the previous four decades. Section 5.4 concludes with a discussion on the lessons that can be drawn from the empirical evidence for theories about economic change and policy prescriptions.

5.2 Methodology

In June and July 2013, fieldwork was conducted in Brazil with the aim of identifying the different drivers and barriers in the country's expansion of no-till agriculture, the reduction of deforestation, and the increased displacement of gasoline with ethanol. Eleven semi-structured interviews were conducted with key informants from the government, civil society, academia, and the private sector. Interview topics included (1) the history of emission producing practices in relevant sectors; (2) different structural pressures that are either promoting or inhibiting shifts to low-carbon practices and technologies; (3) niche markets for ethanol and no-till agricultural practices; (4) positive feedbacks within niche markets from learning effects and the development of a skill-base; (5) policies employed to promote innovation and foster niche markets; (6) policies employed to combat deforestation; (7) conflicting interests and power struggles involved in shaping policy; and (8) the way in which policies interact with local institutions to shape evolutionary trajectories.

The analysis of the interviews drew from evolutionary economic geography and transition management literature. Interviews were transcribed and 'coded' according to evolutionary themes using the software NVivo, and triangulated through third-party sources. The results were used to evaluate the degree to which different factors have influenced Brazil's low-carbon economic shifts, and to understand how these factors have changed and will likely change in the future.

5.3 Mitigation Actions

5.3.1 No-till agriculture

5.3.1.1 GHG Emissions

No-till agriculture, or direct planting, is a farming system whereby soil is undisturbed from harvest to planting, except for the application of fertiliser (Cerri, et al., 2009). Crop residue from the previous harvest is left on the surface. Estimates of the amount of land currently farmed using no-till agriculture in Brazil range from 23 to 26 million hectares (Mha), mostly located in the South and Centre-West regions of Brazil (Assunção, Bragança, & Hemsley, 2013; McKinsey, 2009a; Pinto, 2009). Direct planting increases the quantity of organic matter and water in the soil, thereby sequestering an estimated average 500kg of soil carbon per hectare annually, although the quantity varies with practice, climate, and soil type (Cerri, et al., 2009; Pinto, 2009). It is estimated that Brazil's current level of direct planting sequesters 12 million tonnes of soil carbon annually (Pinto, 2009). In addition, no-till agriculture consumes an estimated 60% to 70% less fuel than a conventional tillage system, resulting in further GHG emission reductions (Cerri, et al., 2009; EMBRAPA, 2006). As part of its NAMAs, the GoB aims to expand the practice to a further 8 Mha by 2020 to avoid 16 to 20 million tonnes CO_2e (tCO_2e) against BAU rates.[34]

5.3.1.2 A Microeconomic Analysis of the Diffusion of No-Till Agriculture

Direct planting has been shown produce higher and more reliable crop yields with fewer inputs (machinery, tractor fuel, pesticides, etc.). Other benefits include up to a 75% reduction in soil loss, control of soil temperature, enhanced water storage capacity, and better nutrient retention of plants (Assunção, et al., 2013; Gouvello, et al., 2010). Gouvello (2010) estimated that converting to no-till agriculture has a negative investment cost, at -US$0.33 per tCO_2e. Other studies observed greater economic benefits. For example, Sorrenson (1997) examined the performance of 18 farms in Paraguay that gradually converted to no-till agriculture in the 1990s. Over 10 years, crop yields declined under conventional cultivation by between 5% and 15% (depending on the crop), while they increased between by between 5% and 20% under no-tillage. No-till agriculture required 30% to 50% less spending on herbicide and fertiliser inputs, resulting in significant increases in net profit. Based on the time-series data collected, Sorrenson (1997) developed 10-year models of the financial performance of typical medium (45 ha) and large (135 ha) farms in two different regions. For the medium-sized farms, the average annual internal rate of return (IRR) ranged from -2.2% to -2.1% under conventional cultivation, and from 6.2% to 10.7% under no-tillage. For large farms, the average annual IRR ranged from 0.1% to 1.4% under conventional cultivation, and from 8.1% to 13.7% under no-tillage.

[34] CO2e is a unit of measurement of the global warming potential of GHG emissions (carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons) over a given time period (generally 100 years). It is equal to the quantity of CO_2 emissions that it would take to equal the global warming potential of a given mixture of GHGs.

Given its cost-effectiveness, a general equilibrium model would predict rapid expansion of the technology through market forces without any need for price adjustments (Gouvello, et al., 2010). However, despite being introduced over 40 years ago, only about 10% of Brazil's cropland is currently cultivated using direct planting methods (Assunção, et al., 2013). The following section examines the various factors that have promoted or inhibited the diffusion of the technology.

5.3.1.3 The Diffusion of No-till Agriculture: Reproduction of the Agricultural Regime

The practice of sowing crops without tillage has, of course, existed far longer than the practice of tilling. However, tillage became the entrenched norm within 'modern' agricultural systems at the end of the 18th century after British, Dutch, and German innovations gave birth to an improved plough capable of inverting layers of soil. The modern plough allowed farmers to control the weed 'quack grass' which had spread throughout Europe threatening to cause famine, and was an integral component of increased agricultural productivity on the continent. As Europeans began cultivating land in the colonies in Asia, Africa, and the Americas, they brought the practice of tilling with them (Derpsch, 1998).

It was not until modern herbicides were invented in the 1940s that no-till agriculture could be practiced on a large-scale. While early attempts at modern no-till farming occurred in the United States and Europe soon after, the first no-tillage trials did not begin until 1971 in Brazil at IPEAME (Intituto de Pesuisas Agropecuarias Meridonal), which later became EMBRAPA (Brazilian Company of Agricultural Research). These niche-level trials were conducted in collaboration with the German aid agency, GTZ. The motivating factor behind the experiments was to control soil erosion, which had become widespread in the tropical southern states of Brazil - Rio Grande do Sul, Santa Catarina, and Paraná (Derpsch, 1998). Early pioneers of no-till agriculture assumed risks in adopting the technology, particularly as appropriate herbicide and machinery was not yet available in Brazil. Despite these risks, Derpsch (1998) estimates that no-till agriculture expanded from about 1000 ha in 1973/74 to about 400,000 ha in 1983/84 driven by its cost-effectiveness in controlling soil erosion.

Over time, the incremental innovations improved the yield of direct planting systems and allowed no-till agriculture to spread into regions with different climate and soil types. Relevant innovations included the invention of direct planting seeding machinery that was fit for local conditions and the development of local manufacturing base for this machinery; an increased variety of herbicides and increased understanding about their appropriate application; and improvements in the techniques of biological pest control, mulch cover, crop rotations, and green manure cover crops to replenish nutrients and suppress weed formation. These incremental innovations were driven both by research programmes funded by state government and state universities, as well as by simple trial and error by innovative farmers.

As yields improved, it became increasingly evident that the economic returns to no-till agriculture were 'immediate and substantial' (Derpsch, 1999). Upfront costs to switching to no-till agriculture were few, and as agriculture in Brazil had generally existed within competitive free-market conditions, with few subsidies, market forces were highly in favour of a rapid diffusion of the practice. Even in the first year of operation, the costs of no-till agriculture were generally lower and revenues higher than conventional tillage (Assunção, et al., 2013). There was also very little political or social resistance to the diffusion of the technology. As explained by Derpsch (1999): "The same consistent message, positive to no-tillage has generally been voiced by all sectors involved (public and private) without contradictions. […] No-tillage has been the only [soil] conservation tillage technology recommended to farmers. […] There have been no major forces against the system." Despite the favourable economic and political conditions for the diffusion of no-till agriculture, it was not until the 1990s that no-till agriculture started to diffuse rapidly.

The main resistance to widespread diffusion of direct planting revolved primarily around a lack of knowledge about site-specific implementation, inadequate flow of information to farmers, and farmers' behaviour based on heuristics. Sorrenson (1997) explained, "The adoption of no-tillage […] necessitates the learning and mastering of an array of new crop management skills." Importantly, the technique needs to be adapted to specific climate and soil conditions. The temperature and/or chemical composition of the soil will affect the optimal thickness of the layer of residue that will be spread on the soil or left from the previous harvest (Assunção, et al., 2013).

For these reasons, the rapid diffusion of no-till agriculture was delayed until there was sufficient site-specific know-how and flow of information. The foundation for this flow began as far back as 1973, when farmers established private institutes to co-operatively 'search' for solutions to their shared problem of soil erosion, such as the Agronomic Institute of Paraná (IAPAR). In 1975, IAPAR held the National Meeting of Research on Soil Erosion where direct planting was highlighted as a solution. In 1979, adopters of no-till agriculture in the Paraná State established the Club da Minhoca (CM), which aimed to spread the practice of direct planting. The CM began holding meetings between adopters and non-adopters to exchange information about the practice. In neighbouring states, farmers associations called Clubes Amigos da Terra (CATs) were modelled on the CM throughout the 1980s and 1990s. According to Derpsch (1999, p. 249), these farmer associations practiced "aggressive farmer-to-farmer extension." Assunção (2013, p. 10) argued that their meeting was and continues to be central to the diffusion of no-till agriculture: "…it is the basic cell where [direct planting systems] adopters coordinate efforts and exchange information." The early 1990s witnessed a flurry of activity that accelerated knowledge flows, including the establishment of the Direct Planting Association of the Cerrado and the over-arching Brazilian Federation of Direct Planting, which held six regional and two national meetings on direct planting between 1992 and 2001. Also relevant was the launch of *The Direct Planting System Journal* in 1990, which began disseminating practical information to farmers. This activity corresponded with a rapid increase in diffusion from approximately one million ha in 1990 to 18 million ha in 2000 (Assunção, et al., 2013).

Nonetheless, inadequate knowledge and information flows remain the primary barrier to further diffusion. Gouvello et al. (2010) explained that myths about soil compaction and increased likelihood of pests and disease have discouraged farmers from attempting direct planting. Furthermore, although direct planting is practiced widely in the South, there has been a lack of research on the benefits of direct planting in other regions where the climate is not as mild, for example on the necessary thickness of plant cover following the summer harvest to ensure that there is enough residue to cover the soil throughout the year (Gouvello, et al., 2010).

Assunção et al. (2013) demonstrated the importance of social learning in the spread of no-till agriculture through an econometric analysis that examined the relationship between adoption rates and soil heterogeneity. The study was premised on the observation that because direct planting needs to be adapted to specific climate and soil conditions, the practice spreads more easily in areas with relatively homogenous soil types where farmers can more easily learn best practice from their neighbours. In contrast, where soil is heterogeneous, best practice varies between farms, and knowledge does not spread as easily. Based on the correlation between adoption rates and soil heterogeneity, Assunção (2013) estimated that adoption rates of direct planting would be 7.1% higher if Brazil had completely homogenous soil.

As dramatic as the improvements from no-till agriculture have been, the diffusion of direct planting falls into the category of 'reproduction' within the agriculture regime. Unlike Geels & Kemp's (2006) description of reproduction, in which there is no activity present at the niche level, the niche-level was marginally important in the early 1970s while public funds were used to trial no-till agriculture. However, this technological niche was created by the regular 'search' processes established by the dominant actors of Brazil's agricultural regime, namely EMBRAPA, private agricultural institutes, public universities, state governments, and relatively wealthy farmers in the economically powerful southern region of the country. Once its cost-effectiveness was established, no-till agriculture became a 'disruptive technology' in that it threatened to compete with the widespread practice of conventional tillage and completely alter the established production process within Brazil's agricultural socio-technical regime. However, unlike many disruptive technologies, it was met with little political or social resistance because it did not threaten the position of any of the dominant actors within the socio-technical regime. As a result, the regime could be reproduced with the same function, same outputs, same core players, and same rules. The only change would be the replacement of one production process with another. This aspect of the emergence of no-till agriculture is much more characteristic of socio-technical reproduction than transition.

More recently, one might argue that a shift in landscape pressures in the form of increasing concern about GHG emissions may have created a 'window of opportunity' for increased diffusion of direct planting. The emergence of climate change as a global issue has certainly brought more international attention to the low-carbon aspects of Brazil's no-tillage system. Top-down landscape pressures combined with the bottom-up innovation would be characteristic of a socio-technical transition. However, given the private benefits of direct planting, downward pressure from the landscape on the regime has played and will likely continue to play a small role in the continued expansion. The primary the barrier to expansion of no-till agriculture is not its cost-effectiveness, but rather inadequate horizontal inheritance of information about how it can be applied in different soil types and regions and about the benefits that it brings.

5.3.2 Reduced Deforestation in the Amazon Rainforest

5.3.2.1 GHG Emissions

Brazil controls 70% of the Amazon Rainforest. The original forest cover of this area was 4000.0 x 10^3 km^2, almost half the size of continental Europe. Most of this area technically falls under some form of environmental protection. About 20% of the land is covered by territorial reserves of indigenous peoples and 25% is covered by federal and state protected areas (Arima, Barreto, Araúrjo, & Soares-Filho, 2014). Furthermore, the

Forest Code governing private land mandates that landowners in the Amazon keep 80% of their land as forest reserve. Nonetheless, since the 1970s, approximately 20% of the forest cover, an area almost the size of France (547.0×10^3 km^2), has been cleared, much of it illegally.

As the forest is converted, stored carbon is released to the atmosphere as CO_2 through fire and decomposition. Between 1990 and 2005, Brazil's lost six billion tonnes of stored carbon, an amount equivalent to two-thirds the current level of global annual emissions[35] (Olivier, Janssens-Maenhout, Muntean, & Peters, 2013). In 2005, emissions from deforestation in Brazil amounted to about 1.329 billion tCO_2e, 61% of the nation's total (MCT, 2010). However, deforestation rates in the Amazon declined by over 80% between 2005 and 2011 (INPE, 2012). As part of its NAMAs, the GoB (2009) aims to avoid 564 million tCO_2e against BAU trajectories by 2020 by reducing Amazon deforestation.

5.3.2.2 The Microeconomics of Deforestation

The primary driver of deforestation has been the clearing of land for cattle pasture, and, to a lesser extent, for agricultural land. Pasture accounts for approximately 80% of all deforested land; while planted crops, primarily soybeans, account for another 5% (Arima, et al., 2014). Given the relationship between agriculture and deforestation, there has traditionally been a strong correlation between deforestation rates and cattle and soybean prices. Between 1995 and 2007, over 75% of the variation in deforestation

[35] Note that one tonne of forest carbon in the Amazon represents approximately 3.66 tonnes of potential CO_2e emissions (Strassburg, Turner, Fisher, Schaeffer, & Lovett, 2009).

rates can be explained by changes in these prices. One interview respondent explained the microeconomic decision made by those who deforest the land:

> *Land is an asset. If you are a farmer on the margin in the Amazon, how do allocate your resources? Forestry does not provide any economic incentives. On the other hand, you can cut the forest and raise cattle. But there is a cost of cutting the trees. The cost is created by the operation and also the cost of policies. The calculation these guys are making is the cost of cutting the trees versus the price of cattle and crops.*

Many economists have observed that the profit gained from cutting land for pasture is relatively low, and argued that curbing deforestation would therefore be a relatively affordable way to reduce GHG emissions. A recent report on *The Economics of Climate Change in Brazil*, estimated that between 1997 and 2006, cattle ranching generated an average of US$402 per hectare of cleared land. Other uses of deforested land had much higher private returns. Soybean production was estimated to have a return of US$2,051 per hectare, while production of other crops was estimated to have a return of US$3,500 per hectare (Margulis, Schmidt Dubeux, & Marcovitch, 2011). The following section demonstrates that a microeconomic analysis based on price alone offers too narrow a perspective to interpret the causes of deforestation and to make policy recommendations for how to prevent it.

5.3.2.3 Reduced Deforestation as Transformative Economic Change

Deforestation in the Amazon only began in earnest in the 1970s with the construction of the Trans-Amazonian Highway, which enabled access to vast swaths of land that was previously unreachable. Up until that point, almost five centuries after the arrival of Europeans, the socio-technical regime(s) that had existed in the region resulted in a loss of an area only slightly larger than Portugal (Fearnside, 2005). While the Trans-Amazonian Highway was the trigger that spurred the 'modern era' of deforestation, the driving force was a shift in landscape pressures – the 'modernist' shift in the ideology of the military government. Landowners made microeconomic decisions to clear land for pasture. However, these decisions were heavily influenced by government decisions to provide tax incentives and subsidised agricultural credit, and to grant land title to those that converted forested land to productive functions. Much of the deforestation in the 1970s and 1980s was driven by land speculation as the price of land was increasing faster than the rate of inflation. Clearing for cattle pasture was simply the cheapest pathway to gaining tenure (Fearnside, 2005).

The transition from a military regime to a democracy in 1988 created the foundation for a gradual shift in landscape pressures that by the early 2000s would enable the GoB to implement the policies necessary to reduce deforestation. The transition coincided with the emergence of a free press, a politically independent judiciary, and a growing awareness within the Brazilian and international public about the environmental consequences of deforestation. The new constitution granted indigenous rights that paved the way for the creation of indigenous territories the following year (Arima, et al., 2014). In 1988, Brazil's Space Agency (INPE) began using satellite imagery to monitor deforestation, and 1989 the Brazilian government launched *Nossa Natureza* (Our Nature), its first major effort to control deforestation through protected areas (Arima, et al., 2014; Fearnside, 2005).

However, these initial efforts at conservation were undermined by a much more powerful countervailing force at the landscape level – the liberalisation of global trade. In the 1990s, major swings in the deforestation rate were highly correlated with the availability of capital and international prices for soybean and beef (Fearnside, 2005). In 1995, Brazil had its largest annual forest loss in history, at 29,059 km^2. Through executive action, President Fernando Henrique Cardoso increased the forest reserve from 50% to its current level of 80% (Arima, et al., 2014). According to Viola (2013), this law marked the greatest interference into private property ever seen in any capitalist country in the world. Yet, although the record high in 1995 was followed by two years of declining deforestation rates, between 1998-2004, the deforestation rate increased to 27,770 km^2 before plummeting to 5000 km^2 in 2011 (INPE, 2012).

During the 1990s and early-2000s, the GoB's policies were largely ineffective due to insufficient monitoring and enforcement. Implementation of the forest laws fell under the purview of the Ministry of Environment (MMA) and the Centre for Environmental Monitoring at the Brazilian Environmental and Renewable Natural Resource Institute (IBAMA), the agency charged with law enforcement. Fines were given for encroachment of protected areas and forest reserves, however surveillance was limited exclusively to denouncements of threatened areas and few of the fines that were issued were actually collected[36] (Assunção, Gandour, & Rocha, 2012). Though hard to quantify, it is evident that corruption also played a role in the lack of enforcement. One interview respondent explained that deforestation rates were connected to municipal elections, implying that municipal governments would ignore illegal deforestation in exchange for votes. The

[36] One respondent estimated that only one percent of all fines issued for illegal deforestation were collected.

Federal Prosecutor's Office (MPF) in Rondônia State even brought legal actions against IBAMA for alleged corruption (Arima, et al., 2014).

Another factor affecting deforestation rates was the construction of logging roads and highways to transport soybean crops. Roads greatly reduce the cost of cutting by increasing access to land (Fearnside, 2005). Prior to 2004, these decisions were made by government agencies with little or no coordination with MMA and with no mandate to prevent illegal deforestation.

A variety of changes at the landscape-level led to the reversal of deforestation trends in the mid-2000s. From about 1990 onwards, a multi-stakeholder coalition calling for an end to deforestation in the Amazon had been gaining momentum. Indigenous peoples, the scientific community, international environmental, and human rights organisations, and domestic NGOs gradually shifted public opinion by leveraging media and scientific evidence demonstrating the potential consequences of deforestation (Arima, et al., 2014, p. 471). An interview respondent explained that this shift in landscape pressures enabled the rise of two consecutive powerful Environment Ministers, Marina Silva (2003-2008) and Carlos Minc (2008-2010), each of whom had seats within President Lula da Silva's Cabinet.

Simultaneous to this political shift was a dramatic improvement in satellite monitoring technology that allowed for real time monitoring of deforestation hotspots. These two elements created a 'window-of-opportunity' for expansion of protected areas within the Amazon Biome, significant progress in recognising indigenous lands, and the implementation of the GoB's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) in 2004.

As part of the Action Plan, the government launched a programme called the Real-Time System for Detection of Deforestation (DETER). The Centre for Environmental Monitoring (CEMAM) began generating georeferenced imagery of changes to forest cover in 15-day intervals. These maps allowed IBAMA to more rapidly detect and penalise acts of illegal deforestation.

As explained by one respondent, the success of the PPCDAm's success was not only due to technological factors that improved monitoring and deforestation, but also institutional and political factors.

> *"I would say it's an innovation both in terms of technology, cause they're using satellites and things like that, but I would say that maybe more important than that was the institutional innovation, or the political momentum that was created around this. What we are estimating here was not only the effect of using satellite data, but the whole framework that was created around it."*

Between 2004 and 2009, over 180,000 km^2 of protected areas were created (Assunção, et al., 2012). Furthermore, the PPCDAm greatly improved coordination between agencies and levels of government. Whereas prior to 2004 the responsibility to control deforestation fell exclusively within the remits of MMA and IBAMA, the PPCDAm centralised the management of joint conservation efforts within the Executive Office at the highest level, the Chief of Staff of the Presidency. It also mobilised the INPE, the MPF, Federal Police and the Highway Police, and the Brazilian Army in monitoring and enforcement efforts. Moreover, IBAMA increased its enforcement capacity by investing in the improvement of its training programme, increasing its number of personnel and requiring a college degree in its recruitment process.

In December 2007, Presidential Decree 6.321 was signed, establishing the legal basis for differentially targeting the municipalities that had the highest rates of deforestation. A blacklist was created of the 36 municipalities (of a total of 547 in the Amazon) that together were responsible for 45% of the deforestation (Assunção & Rocha, 2014). Seven more municipalities were added to the list in 2009, and again in 2011. Econometric analyses that compared blacklisted and non-blacklisted municipalities within 300 km of the Amazon biome frontier demonstrated that the blacklisted group decreased deforestation more rapidly than non-listed municipalities (Assunção & Rocha, 2014).

Again, the success was achieved through an increase in monitoring and enforcement of command and control regulations. Private land titles in blacklisted municipalities were revised so as to identify fraudulent land titles and squatters, and the requirements for a cutting license were increased. IBAMA also increased the share of its resources dedicated to blacklisted municipalities. Using a counterfactual based on non-blacklisted communities, Assunção & Roacha (2014) estimated that, between 2008 and 2011, Presidential Decree 6.321 resulted in 10% more fines than there would have been in the absence of the policy. In two high profile cases, IBAMA confiscated 3000 heads of cattle in pasture on protected areas and 20,000 cubic meters of illegally harvested timber (Arima, et al., 2014). Importantly, the policy had no effect on the quantity of crops produced or credit granted within the municipalities.

Combined with IBAMA's intensification of field inspections, MPF intensified legal actions and embargoed farms. In the state of Pará, MPF brought civil actions against 20 farms found to be in non-compliance with environmental laws, and 11 further civil actions against meatpacking plants that purchased cattle from embargoed farms. Furthermore, it issued recommendations to actors further down the supply chain, including 69 supermarket chains, to avoid purchasing beef or leather from the charged meatpacking plants. Greenpeace complemented these efforts by launching its own campaign against the purchase of beef from noncompliant ranches. In response, the Brazilian Supermarket Association began requiring that its suppliers provide certificates of origin (Arima, et al., 2014).

The driving force behind the decline in deforestation rates came almost exclusively from landscape pressures. Not only did the shift in landscape pressures alter the microeconomic calculation of farmers by increasing the risk of fines, it also shifted the local political and cultural climate towards conservation. For example, in some municipalities, being blacklisted triggered local governments, civil society groups, and local producers associations to sign pacts to achieve zero deforestation and develop plans for sustainable production (Arima, et al., 2014; Assunção & Rocha, 2014).

Technological innovation in satellite monitoring technology did play an important role in enabling improvements in monitoring and enforcement of conservation laws, and hence, the enhancement of landscape pressures. However, it did not involve innovation in alternative technologies or routines at the niche-level, as is characteristic of a socio-technical transition. Therefore, the rapid decline in deforestation rates can be interpreted as a transformation.

5.3.3 Ethanol Displacing Domestic Gasoline

5.3.3.1 GHG Emissions

Brazil has one of the most advanced biofuels programmes in the world. All gasoline used for transport in the country is blended with a portion of ethanol produced from sugar cane. In its NAMAs, the GoB (2009) stated that it aims to reduce 48 to 60 million tonnes CO_2e through its biofuels programme against a BAU trajectory by 2020.

The relationship between Brazil's ethanol programme and GHG emissions is highly contested. Measuring its net emissions requires a lifecycle analysis, because although GHGs are released during the production (fertilising, harvesting, and refining) and burning of biofuels, growing the feedstock removes carbon dioxide from the atmosphere. As a result, replacing fossil fuels with biofuels can theoretically reduce GHG emissions. Macedo et al. (2004) found that replacing gasoline with ethanol produced from sugarcane will result in an 86% reduction of GHGs *excluding* land-use changes.

Land-use changes can contribute significantly to the total lifecycle emissions of biofuels. The vast majority of recent sugarcane expansion has occurred (and will likely continue to occur) on land previously use as rangeland, and this will likely continue to be the case for the foreseeable future. Searchinger (2008) argued that if the sugarcane displaces tropical grazing land, then the carbon released into the atmosphere during conversion of the land will be 'paid back' in only four years from displaced burning of gasoline, and further avoided emissions will be net gains. Less understood is the cascade effect of expanded sugarcane plantations pushing cattle ranching into forested areas. Lapola et al**.** (2010) projected that the indirect land-use changes caused by expanding

Brazil's ethanol production to the level needed to meet the goals stated in its NAMAs will cause the payback period to increase to 44 years.

A better understanding of the relationship between the cattle ranching, forestry, and biofuels sector is needed to determine the actual GHG emission reductions of Brazil's biofuels programme. Nonetheless, the primary concern of this paper is the forces driving and inhibiting a biofuels transition in Brazil.

5.3.3.2 Microeconomics of Ethanol Production

The microeconomics of ethanol as a transport fuel is intrinsically linked with the prices of gasoline and sugar. The GoB mandates that all gasoline used in Brazil be blended with 20% to 25% ethanol. Beyond that point, given that the majority of vehicles in Brazil are flex-fuel, capable of using any combination of ethanol and gasoline, the two fuels are in direct competition. Gouvello (2010) estimated that the price of ethanol for domestic consumption breaks even with gasoline when crude oil reaches approximately US$49 per barrel. Above that price, ethanol becomes more attractive than gasoline.

Ethanol's share of the transport fuel market in Brazil fell from its peak of 55% in 2008 to 35% in 2012. The decline was partly due to an increase in the price of sugar, as well as two consecutive poor harvests due to unfavourable weather and a lack of investment during the financial crisis. These factors caused a supply shortage and an increase in the price of ethanol. However, the decline ethanol's market share was also caused by the GoB's actions to freeze the price of petrol (Angelo, 2012). As a result of the freeze, although the global annual average price of crude oil fluctuated from US$62 per barrel in 2009 to a high of U$105 in 2012, ethanol has not been attractive to flex-fuel vehicle owners (World Bank, 2014).

Given the importance of Brazil's policies in both promoting and inhibiting the ethanol market, it is necessary to take a broader perspective that takes into account the history of the ethanol industry and the changing political landscape in the country.

5.3.3.3 The Emergence of Biofuels as a Socio-Technical Transition

Although Brazil has centuries of experience in sugarcane production, it only began converting it to ethanol on a large scale in the 1970s. Prior to that, ethanol occupied a small niche in the transport fuel matrix, but the purpose was primarily to stabilise against fluctuations in the global sugar price. Brazil's sugar production capacity had nearly doubled in the first half of the 1970s due to government subsidies (Lehtonen, 2007).

Brazil's transport system at the time was relying increasingly on automobiles, the number of which increased tenfold between 1960 and 1976 (Borges, Freitag, Hurtienne, & Nitsche, 1985 as cited in Lehtonen, 2007). These were fuelled primarily by oil, 80% of which was imported (Winfield, 2008). Two major shifts in landscape pressures triggered the shift to ethanol fuels: first, the oil price shock in 1973 caused oil prices to quadruple, threatening economic growth and the legitimacy of the military government; and second, the global sugar price collapsed in 1975, threatening the politically powerful sugar lobby (Lehtonen, 2007; Nass, Pereira, & Ellis, 2007). Therefore, mandating that the role of ethanol be increased within the energy matrix was politically expedient. It solved problems for both the politically powerful transport and agricultural industries, and it played to the ideology of national independence and sovereignty that predominated at the time. However, there was pushback to the plan from the state-led oil company

Petrobras, which at the time lacked significant political power because the country's oil reserves had not yet been discovered (Lehtonen, 2007).

In 1975, the GoB launched Phase I of the Proalcool Programme with the goal of increasing ethanol production five-fold and increasing the ethanol blend in all transport fuel from approximately 10% to 20% by 1980 (Gee & McMeekin, 2011; Rico, 2007). A 20% blend of ethanol was the maximum limit at the time given the existing stock of cars. Petrobras was tasked with purchasing a guaranteed quantity of ethanol, blending it, and distributing the mix. According to Gee & McMeekin (2011), this far reaching government intervention into the energy and agricultural markets was enabled by the State's ownership of Petrobras and the centralization of the sugar cane industry under the Instituto de Azucar e Alcool (IAA) of the Ministry of Industry and Trade. To rapidly increase and modernise production, the central bank and regional development banks provided credit guarantees and low-interest loans to actors throughout the ethanol production chain. By 1979, 104 distilleries were in operation (Gee & McMeekin, 2011). Ethanol imports were restricted to ensure a guaranteed market for domestic ethanol, and ethanol prices were guaranteed at a level lower than petrol prices, but above the average cost of production to insulate producers from fluctuations (Gee & McMeekin, 2011; Lehtonen, 2007). Large public investments were made into R&D. The IAA launched a national agricultural research programme into crop biotechnology to develop higher yield sugar cane varieties, and the state research-institute Centro de Tecnologia Aeronautica (CTA) in São Paulo conducted research into improving the engines using pure ethanol (Gee & McMeekin, 2011; Goldemberg, 2008; Lehtonen, 2007; Puppim de Oliveira, 2002) Finally, a public relations campaign was launched under the banner 'Let's

Unite, Make Alcohol.' Ultimately, the goal of increasing production 500% was achieved by 1980 (Sandalow, 2006).

By the time the second oil crisis hit in 1979, the main bottleneck to expansion of the programme was the maximum ethanol capacity of the existing fleet of cars. Phase II of the Proalcool Programme was launched in 1979 with the goal was of tripling production by 1985. The GoB contracted major car manufacturers (Volkswagen, Fiat, Mercedes-Benz, General Motors, and Toyota) to commercialise the engine technology capable of running on pure ethanol that had been developed at CTA. Targets were set at 250,000 cars by 1980 and 350,000 by 1982 (Sandalow, 2006). Most service stations were outfitted with a second reservoir for a pure ethanol pump (Goldemberg, 2008). The GoB also promoted the uptake of pure ethanol cars through government procurement programmes, tax incentives, and a policy capping the consumer price of ethanol at 64.5% of the petrol price (Goldemberg, 2008). By the mid-1980s, pure ethanol vehicles represented more than 80% of all vehicle sales and ethanol represented approximately 50% of Brazil's transport fuel matrix (Sandalow, 2006; Ueki, 2007).

Landscape pressures shifted against ethanol in the late-1980s with the decline in oil prices, the mounting public debt and economic crisis, and the transition to a civilian government. According to Lehtonen (2007), "Proalcool began to be seen increasingly as a 'monster' created by the military regime, out of phase with the prevailing spirit of the times emphasizing economic liberalism." In efforts to balance the budget, the new government removed subsidies to producers and all but dismantled the administrative structure of the ethanol programme. However, it maintained the fixed consumer price below that of petrol, and as a result, supply shortages emerged. In response, the government temporarily reduced the ethanol blend to 13% throughout the country from 1989 to 1993[37] (Lehtonen, 2007; Rico, 2007).

In the 1990s, ethanol was reduced to a niche-level energy source due to subsidy cuts, and its purpose was largely seen as creating employment and combating air pollution (Lehtonen, 2007). Attention was focused on increasing its competitiveness. As explained by one respondent, substantial government support was provided to the Copersucar Technology Centre to develop strains of sugar cane that would maximize ethanol production, which are different from those geared towards sugar production. The learning curve of the industry was impressive. Between 1990 and 2003 production per hectare increased from under 4000 litres to almost 6000 litres per hectare. Simultaneously, the price paid to ethanol producers fell from US$0.70 per litre in the 1980s to US$0.20 per litre in 2004, at which point it became competitive with gasoline (based on the prevailing international oil price of US$40 per barrel). Furthermore, positive feedbacks were created through the development of co-products including sugarcane bagasse for power generation (Goldemberg, 2008).

In the early 2000s, a niche-level innovation emerged that dramatically altered Brazil's transportation fuel market dynamics, because it allowed ethanol to compete directly with gasoline. In 2002, Ford introduced a prototype of the flex-fuel car. Volkswagen and General Motors followed suit in 2003. The government offered a marginally preferential sales tax rate[38] for flex-fuel vehicles. Sales were rapid. Between

[37] Except for São Paulo where it was maintained to curb air pollution (Lehtonen, 2007).

[38] 14% sales tax for flex-fuel vehicles compared to a standard 16% rate (Lehtonen, 2007).

2003 and 2012, flex-fuel vehicles represented 62.9% of all light vehicles sold (ANFAVEA, 2012). Cumulative production reached 20 million units in 2013 (Calmon, 2013).

These niche-level innovations combined with shifting landscape pressures – including increasing public concern about climate change and the dramatic increase in global oil prices – created a window-of-opportunity for a resurgence of ethanol within Brazil's energy matrix. By 2008, the country was producing over 27 million litres of ethanol per year, second only to the United States (Gee & McMeekin, 2011; Reis, 2012), and ethanol once again reached over 50% of transport fuel consumed, the highest level in the world (Angelo, 2012).

As discussed previously, the subsequent decline of ethanol's share of the fuel matrix was partly the result of the GoB's actions to freeze the price of petrol in the country. This policy was largely in response to macroeconomic factors in that it aimed to curb inflation (Angelo, 2012). However, one respondent explained that the decision to implement the price freeze was also highly political in that it was favourable to the automotive industry and auto workers' unions, powerful players within the base of the ruling Workers' Party. Other powerful forces opposed the measure, including Petrobras, which was forced to sell its product at a reduced rate domestically. During the price freeze, the company was concurrently making unprecedented capital investments to extract Brazil's offshore oil reserves. It developed severe capital flow constraints and debt trying to keep its operations afloat (Blount, 2012; Spinetto, 2014).

The evolution of ethanol as a transport fuel in Brazil has been heavily influenced by major shifts in landscape pressures including oil and sugar price shocks, the transition to a civilian government, economic liberalisation, and increasing public concern about climate change. It has also been shaped by dramatic innovation in sugar cane yield, variety, and processing, as well as in pure ethanol and flex-fuel engine technology. Much of this innovation was driven by large-scale public research programmes and public investment in R&D. Given the combination of landscape pressures from above and niche-level innovation from below, the evolution of ethanol represents a socio-technical transition. Microeconomic analyses offer much too narrow a lens to understand the historical development of this transition, and offer us relatively little information about the likely future trajectory of the industry because they fail to capture the role of politics and innovation. According to Goldemberg (2008), potential exists to increase the productivity of sugarcane plantations to perhaps as high as 9000 litres per hectare. There is also enormous potential for Brazil to increase its export of ethanol to other countries. However, this opportunity is highly dependent on the evolution of landscape pressures including global oil production and foreign government's policies on trade GHG emissions and mandatory ethanol blends.

5.4 Discussion and Conclusion: The Policy Implications of an Evolutionary Perspective on Economic Change

Empirical evidence on Brazil's success in reducing deforestation rates, and promoting of no-till agriculture and biofuels provides support for an evolutionary perspective on economic change, rather than one based on neoclassical economics. Within neoclassical and environmental economics, climate change is viewed as a market failure in that private actors that invest in emission-intensive activities are able to offload, or externalise the negative costs onto society. These *negative externalities* lead to an over-investment in carbon-intensive activities, such as deforestation, than is socially optimal. The inverse is true for those deciding on whether or not to invest in activities that will reduce carbon emissions. Although the global benefits of such investments often outweigh the costs, the private benefits may not. The *positive externalities* of low carbon activities typically lead to less investment than is socially optimal in renewable energy, low-carbon agriculture, etc. The textbook solution to address this market failure is for government to align private and social costs and benefits through regulations and fiscal measures. By "getting the price right" it is thought that market forces will drive a transition to a low-carbon equilibrium.

These theories have been highly prominent in debates, both internationally and within Brazil, about which policies are necessary to manage a transition to climate change. For example, based on the low estimates of the returns from historical uses of deforested land, the *Economics of Climate Change in Brazil* report proposed a payments-for-ecosystem-services (PES) programme whereby farmers would be reimbursed for not conducting farming and livestock activities. It argued that 70% of deforestation could be discouraged if farmers were paid US$3 per tonne of forest carbon, about US$450 per hectare; and 95% of deforestation could be discouraged if landowners were paid US$50 per tonne of carbon, about US$7500 per hectare (Margulis, et al., 2011).

However, empirical evidence shows that Brazil's success in transformative reduction in deforestation rates in the last decade was not driven by policies that change the microeconomic calculation of farmers at margin. Rather, it was driven by aggressive top-down command-and-control policies led by the Federal Government that struck at the heart of the profitability of illegal deforestation. Underlying these policies were shifts in landscape pressures including ideological changes and the emergence of climate change as an international concern that led to fierce political battles at the national and international scales – factors that would not be captured through a microeconomic lens. Similar shifts in landscape pressures and political battles were highly influential throughout the history of Brazil's ethanol programme. From an evolutionary perspective, shifting the landscape pressures in the direction necessary to induce socio-technical transformations or transitions is much more of a political project than a technocratic one.

This chapter also demonstrated that even where economic change does not necessitate a shift in landscape pressures, and can occur during reproduction of the socio-technical regime, it is unlikely to play out as predicted by equilibrium models which fail to take into account factors such as social learning and the bounded rationality of economic agents. The diffusion of no-till agriculture in Brazil illustrates that, beyond cost-effectiveness, social learning and flows of information play an important role in determining the rate of horizontal inheritance of novel routines. The GoB's primary policy to promote no-till agriculture is the Low-Carbon Agriculture program, which extends subsidised credit to those farms that apply low-carbon techniques. However, after three years, the uptake of credit from the programme for the implementation of no-till agriculture has been low. Given that inadequate knowledge-flows rather than capital constraints are the primary barrier to uptake of the method, an evolutionary perspective would concur with Assunção (2013), which argues that knowledge-management through extension services is a more appropriate policy intervention.

Finally, this chapter demonstrated the necessity of considering innovation as endogenous in any model of economic change. It took three decades of innovation for ethanol to become a cost-effective alternative to gasoline and for the flex-fuel engine to be developed that would allow the two fuels to compete directly. An equilibrium model would not have projected this outcome. It was only possible due to the guaranteed niche markets for ethanol and pure ethanol vehicles created by the government mandated blend and public procurement programmes, as well as substantial government investment in R&D. For this reason, while neoclassical economics generally prescribes measures that will increase competition in order to maximise productivity and efficiency, evolutionary perspectives stress the importance of strategic niche management – policies that reduce competition to the degree necessary to foster new innovations.

6 The Role of Climate Finance in a Sustainable Innovation Policy Regime

6.1 Introduction

With the impending 2015 UNFCCC Conference of the Parties (CoP) in Paris, the financial pledges of the Copenhagen Accord, and the creation of the Green Climate Fund (GCF), we are at a pivotal moment in (re-) designing the institutional architecture governing climate finance. The design will be an important component of efforts to promote transitions in developing countries towards low-carbon and climate-resilient economies. This chapter will address the question of what function climate finance should play in the transition, and how the architecture that governs climate finance should be designed to facilitate that function.

The Copenhagen Accord, and subsequently the Cancun Agreements, committed developed countries to mobilise US$100 billion per year in climate finance for developing nations by 2020 from a mix of public and private resources. These funds are to be split evenly between adaptation and mitigation, and a 'significant proportion' will be channelled through the GCF. The extent to which private finance is deemed compliant with this pledge makes a drastic difference in its ambition. The eventual decision of what qualifies as 'climate finance' will need to be a political decision made by the Conference of the Parties.

A small but growing body of literature has begun weighing in on how climate finance should be mobilised, managed and disbursed. Two broad streams can be identified. One stream, made up of literature from the disciplines of international relations, law, and philosophy, considers the ethics of climate finance. It views the primary function of climate finance as one of equity and restitution (Grasso, 2010; Müller, Rook, & Chandani, 2010). Climate funds are seen as reparation for a *climate debt* resulting from, one, the loss and damages from climate change caused by industrialised countries' historically emitted GHGs, and two, an over-occupation of the limited atmospheric space by industrialised countries' emissions that prevents developing countries from emitting their fair share. As compensation for a climate debt, this stream of literature argues that most, if not all, of the pledged US$100 billion per year by 2020 should be public funds (Oxfam, 2010). It pushes for climate finance to be managed separately from official development assistance (ODA) through a new entity, such as the GCF, to ensure that the funds are 'new and additional,' rather than redirected development funding (Müller, et al., 2010), and it wants the funds to be split evenly between mitigation and adaptation. Further, it advocates for developing countries to have greater control over funding decisions, for example, through the creation of national climate change funds (Gomez-Echeverri, 2010; Horstmann, 2011; Müller, 2009).[39] Despite providing perspective on how climate funds should be managed, this stream of literature offers little insight into how the money should be deployed.

The second stream, comprised of literature from business, economics, and finance, considers the economics of climate finance. It argues that the primary function of climate finance is to create the incentives necessary to attract private finance towards low-carbon initiatives. The role of climate finance in promoting 'adaptation' – processes

[39] Bangladesh, Brazil, China, Ecuador, Ethiopia, Guyana, India, Indonesia, Maldives, Philippines, Thailand, and Rwanda have each established, or are in the process of establishing, some form of a National Climate Change Funds.

or actions that increase the capacity of societies to cope with, manage or adjust to changing climatic conditions (Smit & Wandel, 2005) – has generally been downplayed by literature on the economics of climate finance. This is largely because unlike mitigation, in which the incentives must be created through regulatory and fiscal policy, the incentives to adapt exist naturally, and need not be created by government (Tol, 2005). Thus, it is argued, the majority of funds promoting adaptation will not come from international climate finance, but from private companies and households making economic decisions in a changing environment (Forstater, Huq, & Zadek, 2009).

The stream of literature examining the economics of climate finance argues that, due to the fiscal constraints faced by developed countries, transfers of 'new and additional' public funds will fall well short of US$100 billion per year (De Nevers, 2011; Liebreich, 2011). To ensure efficient management, it wants public climate funds to be mainstreamed with development assistance (De Nevers, 2011; R. Klein, 2010; Miller, 2008; J. Smith, et al., 2011), and used to *leverage* private investment (Brown & Jacobs, 2011). To maximise leverage, it pushes for a large portion of the funds to flow through IFIs, such as the World Bank, and stresses that climate funds should be deployed in a manner that crowds in further private investment. Finally, this stream of literature advocates scaling-up and including new industries in emission offset markets, like the Clean Development Mechanism (CDM), which award tradable carbon credits to project developers for each tCO_2e reduced relative to a BAU baseline. Discourse on the economics of climate finance emphasises that, by optimising market forces, offset markets will turn tackling climate change into a financial opportunity, galvanising private investment and driving low-carbon economic growth (Haigh, 2011).

There is general consensus on the importance of leveraging private investment. The International Energy Agency (2009) estimated that to achieve the goal of limiting global warming to less than 2° C, the capital investments required by developing and emerging economies will amount to an additional $197 billion in 2020 over and above the investments that would be required without consideration of climate change. However, this paper argues that the barriers to innovation and economic change are much more pervasive than a lack of incentives, and that, to overcome these barriers, climate finance will need to perform a variety of functions often overlooked by literature on the economics of climate finance. It posits that questions concerning the function of climate finance, and how it should be managed and deployed, are best addressed through an evolutionary economic geography approach that incorporates Geels (2002) MLP model of economic change and transition management literature, as discussed in Section 2.3.2.2.

Sections 6.2 and 6.3 examine the barriers preventing developing countries from transitioning to low-carbon and climate-resilient economies, respectively, as well as the interventions necessary to overcome those barriers. Section 6.4 argues that climate finance must play a variety of functions beyond incentivising private investment, and it explores the consequences that these further functions have regarding the institutional arrangements that govern how it is managed and deployed. Section 6.5 summarises the key findings and arguments of the chapter.

6.2 Barriers and Solutions to Low-Carbon Socio-Technical Transitions

A useful tool to contemplate the innovations required to transition low-carbon economies is McKinsey & Co.'s Global MAC Curve, presented in Figure 14 (on page 63). MAC curves have been used to estimate the total financing needed to support developing countries in mitigating climate change by adding up the incremental costs (Project Catalyst, 2010). As discussed in Section 2.1.2.2, implicit in such analysis is the idea that by 'getting the price right' market forces will drive the diffusion of these GHG abatement options. However, as is evident from the cost-effective, yet unexploited initiatives on the left of the curve, it is unlikely that subsidizing the incremental costs of low-carbon technologies will be enough to promote their diffusion. Metz (2009) noted that the emission abatement opportunities in the Global MAC Curve can be divided into three nearly equal categories – energy efficiency in buildings and industry; agriculture and forestry; and energy generation. Evolutionary economic geography and transition management literature, combined with empirical evidence, reveals a great deal about the barriers preventing socio-technical change in each of these categories, and about the interventions required to overcome them.

6.2.1 Energy Efficiency

The most cost-effective emission abatement opportunities, those on the left of the Global MAC curve, relate mostly to energy efficiency in buildings and industry. The failure of market actors to exploit these opportunities can be attributed to a number of factors. Within the buildings sector, there are often split incentives in that those making decisions about a building's design, whom would have to pay the upfront costs associated with more efficient construction, are typically not those that would benefit from energy efficiency gains or be in a position to monitor a carbon credit project that would last decades after the buildings construction. Only 10-20% of a building's lifetime energy use occurs during construction, manufacturing of materials, and demolition. The majority, approximately 80-90% is for heating, ventilation, and air conditioning (HVAC), lighting, and appliances. Numerous technologies, some of which can be retrofitted, are available to save on these energy costs including insulation, windows, natural ventilation, heat sinks, solar water heaters, natural lighting, and efficient lighting technology (Cheng, 2008). However, there is a general lack of awareness, both among those designing and constructing buildings and those using buildings, about energy-use and potential cost-savings.

Closing this knowledge gap will be a critical step in promoting an energy efficiency transition. First, workforces must be trained in energy efficient building design, construction, electricity distribution, and appliances. Training programmes must be developed that award certifications and accreditations in energy efficiency. Second, information concerning energy use must be made more available and transparent. Improvements must be made in building intelligence through investment in energy monitoring technologies and feedback systems. Voluntary labels and standards, like ENERGY STAR, can be developed for all appliances and buildings. As the European Union did in 2006, governments could mandate the disclosure of buildings' energy use, enabling investors and tenants to make more rational choices (Lovins, 2011).

For many small-scale measures like residential energy efficiency retrofits, a barrier to diffusion is not the cost of the initiative, but the purchasing power of the consumer. Consumer finance for upfront costs needs to have lower interest rates than the return on investment. However, financial institutions often perceive small investors as risky and are reluctant to extend the necessary loans at an affordable rate. Loan guarantee schemes can be effective in encouraging microfinance institutions, savings and credit cooperatives (SACCOs), and banks to extend consumer loans. For example, a loan guarantee scheme launched in China in 2006 by the International Financial Corporation (IFC) was able to develop a pipeline of energy efficiency projects worth over US$650 million in six months by taking a 'first loss' position for up to 75% of loans offered to energy service companies or industrial groups by Chinese financial institutions. The IFC has begun training these institutions in risk-based lending so that China can self-finance its energy efficiency requirements (Chandler & Gwin, 2008).

Energy efficiency measures in industry are generally cost-effective from a societal perspective; however, the economic signal is often inadequate or distorted by energy subsidies. Private finance for these measures will not be available without the appropriate risk-adjusted returns. A potential subsidy is available through the CDM, but the price of carbon credits has been extremely volatile. Emission reduction underwriting mechanisms (ERUMs) could be used to guarantee a revenue stream for project developers contingent on the mitigation of GHG emissions (Gray & Tatrallyay, 2012). However, a more efficient means of establishing the appropriate price signals would be carbon pricing through a carbon tax or cap-and-trade system. Unlike subsidisation through offset crediting or ERUMs, carbon pricing will directly induce energy demand management, thereby increasing the receptiveness of the socio-technical regime to more efficient alternatives.

There are also problems with the economic incentives facing utilities. "Utilities are uniquely positioned to become highly effective players in building efficiency. They're the only service provider with universal existing customer and billing relationships, knowledge of their clients' energy use, large scale, and access to major, low-cost financing" (Lovins, 2011, p. 115). However, with their revenues tied to the amount of energy that they sell, energy efficiency is often viewed not as an opportunity, but as a threat to their financial success. It is necessary to alter the price signals facing utilities by *decoupling* their earnings from total energy sold. Governments can achieve decoupling through two measures: first, periodically adjusting electricity prices so that the utility's revenues are consistent with what is authorised (Lovins, 2011); and second, rewarding utilities for cutting clients' bills by allowing them to adjust prices so that they can share in energy savings that they make possible. For example, in California, regulators allow utilities to share up 12% of gains made through energy savings, and penalise utilities that fail to achieve at least 65% of their efficiency targets. Such reforms reward utilities for buying *negawatts* (saved watts) instead of building costlier new generation (Lovins, 2011).

However, due to actors' bounded rationality, such information- and incentive-based instruments may not be sufficient. Ultimately, it may be necessary for governments to implement mandatory energy efficiency targets for industry, appliances, and buildings. Targets should begin relatively modest, and be reduced predictably over time as energy efficient technologies and practices improve and diffuse. Importantly, standards and building codes must be enforced, and continually re-evaluated (Lovins, 2011).

6.2.2 Agriculture and Forestry

The middle third of emission abatement opportunities in Figure 14 relates mostly to agriculture and forestry, and could be achieved at a very cheap cost to society. The main solution put forth in the literature on the economics of climate finance for these abatement opportunities is to expand emission offset markets to include projects that reduce emissions from deforestation and forest degradation (REDD) and from agriculture.[40] Considering that many of these opportunities are not particularly expensive, subsidising the carbon embodied in forests, plants, and soil in perpetuity through offset markets is an excessively capital intensive solution.

Moreover, due to the complexity of the socio-economic forces leading to deforestation, offset markets for REDD may lead to unanticipated consequences such as *carbon leakage*, i.e. an increase in deforestation outside of the project boundary, or the displacement of low-income households relying on forests for fuelwood. Offsets markets also do not generally value the other ecosystem services provided by forests, and thus could also lead to the undervaluation and harvesting of land vital to watershed maintenance, hillside stability, and biodiversity preservation. Successful cases of reduced deforestation are highly context specific, but usually involve multifaceted policy regimes that include clarification of land tenure, moratoriums on agricultural land expansion, protected areas, mandatory minimum forest reserves on private land, certification of legal wood products, and improvements in monitoring and law enforcement. Support for alternative industries for local communities, such as ecotourism and non-timber forest products, can help make forest conservation more politically and socially

[40] Currently REDD projects and agricultural projects are not eligible in the CDM, but are eligible in some voluntary carbon markets.

palatable; as can interventions to increase the intensity of farming practices and the fuel efficiency of charcoal production and cooking practices. In some cases, PES act as an effective supplement to command-and-control regulation to create the appropriate economic signals for private landowners to conserve standing forests. However, not even in the case of Costa Rica's renowned *Pago por Servicios Ambientales* has PES acted as a substitute for a well-managed system of protected areas. In contrast to REDD, it will always be necessary to create the appropriate economic signals to induce tree planting. Emission offset markets or ERUMs can be effective in leveraging private finance for afforestation and agroforestry. Private investment in reforestation can be leveraged through policies that require private companies to replant the land they harvest.

Strong short-term private interests that conflict with forest conservation, for example, from agribusiness and logging industries, make ratifying and implementing the necessary regulations hard fought political battles. These battles are often led by local *environmental policy entrepreneurs* that possess "the expansive social networks, an intricate knowledge of institutional relationships and tacit rules of political engagement, and a decades-long presence needed to take advantage of sporadic opportunities for agenda setting and to ensure long-term program success" (Steinberg, 2003, p. 16). This is not to say that international support does not play a role. When these windows of opportunity arise, timely delivery of international financial support for the design and implementation of policies and programmes could be vital to their success. Environmental policies and programmes of developing countries are often reliant on international financial resources. For example, many government conservation agencies receive more than 50% of their budget from foreign sources (Steinberg, 2003).

International technical support can also be crucial. For example, the UN-REDD programme provides both financial and technical support to national governments for the development and implementation of national REDD strategies. It supports the establishment of national forest inventories and monitoring systems that use satellite imagery and 'ground-truthing' through field-based sampling; and it ensures that strategies include stakeholder engagement with Indigenous Peoples and local communities. No pilot project has reached the crediting stage, but continued implementation of their national REDD strategies will result in payments for verified emission reductions and sequestration.

By treating the nation as the unit of analysis, the UN-REDD programme recognises that multipronged policy regimes are necessary to combat deforestation and that the composition of these policy regimes will vary across different national circumstances. Moreover, responsibility for deforestation from non-human causes, such as forest fires, is placed squarely on the shoulders of those that have the ability to take preventative action – governments.

In many cases, the measures in the Global MAC Curve relating to agriculture – like organic soil restoration and tillage residue management – are cost-effective. Where these measures are implemented, the incentive is generally not climate change mitigation, but rather the high costs of emission-intensive inputs and increased production from reducing those inputs. Brazil experience with no-till agriculture discussed in Section 5.3.1 provides an example. Another example from Brazil is the practice of integrating land used for animal husbandry with planting and/or forestry. Integrated forestry and pasture reduces erosion, recycles nutrients, and increases the production of biomass, thereby increasing the support capacity of the land from 0.5 to 2.5 animals/ha. The fact that the practice sequesters an estimated 2.5 tCO_2 per hectare annually is a side benefit (Pinto, 2009).

The main barrier that prevents diffusion of such emission abatement measures elsewhere is often path dependency – farmers are locked into practices that involve heavy use of nitrogen-based fertiliser. Efforts to alter the incentive structure of these farmers are often problematic. Policies like emissions trading or pricing that require the quantification of emissions levels based on practices like tillage and composting are cumbersome and costly to implement. The monitoring and verification requirements of emission offset markets have also proven inhibiting to projects that tackle small-scale and widely dispersed emission sources, like those of the agricultural sector. In some countries, reducing subsidies on fertilisers would be an obvious first step to creating an incentive framework in favour of organic soil restoration and tillage residue management. However, in many cases, removal of such subsidies would be a political dead-end, and, considering that the recovery of degraded soils can be a slow process, could have dangerous repercussions in food markets if done too quickly.

Promoting such practices is often a matter of forming networks for knowledge sharing and collective action, for example, through demonstration projects and agriculture extension services. A successful example is offered in Ghana. In the 1990s, the Crop Research Institute of the Ghanaian government's Council for Scientific and Industrial Research collaborated with the international NGO Sasakawa-Global 2000 and the multinational corporation Monsanto to conduct research on the potential for no-till agriculture with mulch to replace increasingly unsustainable slash-and-burn practices in the Forest, Transition, and Guinea Savannah Zones. It funded the doctoral dissertation of a soil scientist who worked with a group of innovative farmers to pilot a weed and mulch management system that responded to their needs, and then developed an extension program to disseminate the package widely. By 2005, an estimated 300,000 small-scale farmers were using no-till (Ekboir, Boa, & Dankyi, 2002).

6.2.3 Energy Generation

The final third of global emission abatement opportunities relates mostly to energy generation – nuclear, geothermal, co-firing of biomass in power plants, wind, solar PV, and concentrated solar power. These opportunities have relatively higher costs than their emission-intensive alternatives. In order to attract private finance, policies such as emission offset markets or pricing, feed-in tariffs, and/or risk financing will be needed to adequately increase risk-adjusted returns (Gray & Tatrallyay, 2012).

However, a number of non-financial barriers also inhibit private investment. Many of these technologies are in an early stage of development, rendering investment highly risky (Bowen, 2011), and many developing countries lack a workforce with the technical capacity to implement such technologies on a wide-scale. Neither R&D nor diffusion of these nascent energy technologies is likely to be driven by the private sector without well-targeted public support.

A successful example of the policy regime required to support innovation in renewable energy is provided by the Kenyan geothermal industry. Kenya currently generates 202 MW of electricity, or 17% of its total installed generating capacity, from geothermal energy (Kisero, 2010). Estimates of the total potential to produce geothermal electricity in Kenya range from 2000 to over 3000 MW (World Energy Council, 2010).

From the outset, private sector development of the geothermal industry was prevented by a series of barriers: high upfront costs and risk associated with exploration and drilling; a lack of technical capacity in the country; insufficient information on the competitiveness of geothermal relative to other sources of energy; a scarcity of funds in the country; a lack of creditworthiness, collateral, and equity amongst potential project developers; and the lack of geothermal development targets within national and regional energy plans (Mwangi, 2010). Successful development was contingent on the long-term support of the Government of Kenya and international organisations, spanning three decades, which served to build the confidence of private investors and developers (Karekezi, Kithyoma, & Muzee, 2007).

Drilling of deep exploratory wells began in 1973 with funds from the United Nations Development Programme (UNDP). Capital constraints impeded resource development, even after the resource was proven, until 1981, when KenGen, a state-owned power generation utility, installed the 15 MW plant Olkaria I. The project was supported with funds from the Global Environment Facility (GEF) (Karekezi, et al., 2007). Since then, KenGen has continued to develop the resource with co-financing from the World Bank, the European Investment Bank, and KfW of Germany, bringing its total generating capacity to 150 MW (African Energy Policy Research Network, 2008).

With the increase in production, the Government of Kenya fully integrated geothermal targets into its national power master plan and its main planning documents, Vision 2030 and the Medium Term Plan 2008-2012. It also invested considerably in developing a local technical skill base, specialised in undertaking geothermal resource assessment and development (African Energy Policy Research Network, 2008; Karekezi, et al., 2007).[41] The government's strong support for the geothermal industry was offered in spite of the fact that coal, at 0.407 US cents per kilowatt hour compared to 0.708 cents for geothermal, is a cheaper option (Kisero, 2010). Its motivation lay instead in the potential for geothermal to be a secure source of domestic energy that is not susceptible to global price fluctuations; anticipation that future innovation and successful exploration will drive the price down further; and its expectation of continued external support.

Over the last decade, interest in geothermal development from the private sector has increased. In 2000, construction began on the first and only private geothermal electricity plant in the country – the 52 MW Olkaria III, owned and operated by the company Orpower4 (Kisero, 2010; World Energy Council, 2010). In 2006, the government offered 30% of its shareholding in KenGen through an initial public offering, which was oversubscribed 236%. Private Chinese companies, financed by Chinese banks, have come to dominate geothermal exploration to such an extent that in 2009 the Government of Kenya established the state-owned Geothermal Development Company to compete with them, reportedly in efforts to bring down the cost of drilling and ensure jobs are created for Kenyan nationals (Kisero, 2010).

With increased interest from the private sector, international organisations have changed tactics. The United Nations Environment Programme, GEF, and World Bank

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[41] Interestingly, geothermal experts from Kenya are now providing technical assistance to neighbouring countries in the African Rift Valley through a short training course and professional work placements.

have established the US$17.75 million African Rift Geothermal Facility (ARGeo) to accelerate private investment and/or public-private partnerships in the geothermal industry. ARGeo will provide guarantees that will cover up to 85% of drilling expenses in the case of failure. Importantly, ARGeo is not only aiming to create incentives for private investment. It will also develop a regional network of geothermal experts to exchange information, a capacity building programme, and a programme to promote regulatory frameworks supportive of geothermal development (Mwangi, 2010).

6.3 Barriers and Solutions to Climate-Resilient Socio-Technical Transitions

As discussed in the Literature Review, and corroborated in the case studies on Soufriere and Whitehouse, the barriers to adaptation are highly context specific. However, they rarely involve a lack of economic incentive. Rather, they have to do with insufficient adaptive capacity arising from inadequate information on the potential impacts of climate change and on adaptive strategies to deal with the impacts; limited technical capacity and finance to implement those strategies; myopia or a lack of flexible, forward-thinking planning on the part of individuals, governments, and organisations; and additional stresses beyond those related to climate. As argued by Smit & Pilifosova (2001b, p. 907), "Adaptive capacity varies considerably among regions, countries, and socioeconomic groups. The ability to adapt and cope with climate change impacts is a function of wealth, technology, information, skills, infrastructure, institutions, and equity."

One example of a comprehensive policy regime employed to enhance adaptive capacity is offered by Brazil. Brazil's agricultural sector represents 30 percent of its GDP and is particularly vulnerable to climate change. Of the nine cultivated plants that are collectively responsible for 85 percent of its agribusiness – cotton, rice, coffee, sugarcane, beans, sunflowers, cassava, corn, and soybeans – it is predicted that by 2020 the potential cultivation area for all except sugarcane will decrease (Pinto, 2009). To address the lack of information on the potential local impacts of climate change, the Federal Government promoted modelling of regional climate change scenarios and hydro-climatic systems for large river basins, and it developed a climatic risk zoning programme that produces municipal maps that demonstrate the appropriate cultivation area for major crops, as well as the potential shifts in these areas due to increases in temperature (Government of Brazil, 2008; Pinto, 2009). In recognition of individuals' bounded rationality, this programme not only indicates to farmers 'what to plant, where to plant and when to plant'; the National Monetary Council has mandated that only farmers from municipalities that opt to grow crops deemed appropriate for their area are eligible for rural credit and insurance. The government has strengthened the nation's network of climate change-related research institutions, both public and private, many of which have and continue to develop genetically enhanced crops with improved tolerance to dry spells and temperatures (Pinto, 2009). Finally, it is establishing early warning systems for droughts and desertification (Government of Brazil, 2008).

6.4 A Transition Management Perspective on the Function and Institutional Arrangements of Climate Finance

The previous section revealed a number of insights that are important to consider in designing the institutional arrangements for climate finance. First, individuals, organisations, and governments rarely make decisions to implement mitigation actions or adaptive strategies for climate reasons alone. There are generally multiple factors influencing their decisions ranging from energy costs and energy security, to agricultural yield and input costs, to current weather variability and environmental tolerance levels. An transition management perspective would thus agree with the literature on the economics of climate finance that "mitigation and adaptation actions, and thus planning for climate investment, need to be fully integrated with development planning and not 'ghettoized'" (De Nevers, 2011, p. 4). The previous section also revealed that the barriers preventing transitions to more climate-resilient and low-carbon economies are much more pervasive than inadequate incentives. To overcome these barriers, climate finance will need to perform a variety of functions beyond creating the necessary economic incentives to attract private investment.

As outlined in Figure 37, different types of interventions will be required at different levels of the MLP model. *Technology-push policies* will be required in the R&D phase to develop a pipeline of innovations and bring down their cost. Climate finance could be invested directly in R&D, as UNEP invested in geothermal exploration in Kenya or as the Government of Brazil invested in climatic risk zoning; or it could be awarded as innovation prizes to project developers that achieve a pre-determined goal. Importantly, climate finance may also need to be invested in the delivery of non-financial support. To help develop the networks and technical capacities in science and engineering that are required for R&D, climate finance could support *innovation platforms* such as the Ghanaian Crop Research Institute, Sasakawa-Global 2000 or ARGeo.

To support innovations during the early stages of diffusion, climate finance should be employed in *strategic niche management*. For example, public procurement schemes, such as feed-in tariffs, can secure a market for innovations while market infrastructure and distribution outlets are established. Investment in demonstration projects, such as Kenya's Olkaria I geothermal well, can help build a track record for new innovations, opening up access to future risk capital. Again, non-financial support will be critical at the pre-commercialisation phase. Investment in on-the-job technical training or mentoring or *business incubators* can provide the combination of business and technical skill sets required to attract investors and bring viable innovations to the market. Network building around value chains is essential during this pre-commercialisation phase. To this end, investments in public-private partnerships or farmer associations can be effective in facilitating the necessary relationships.

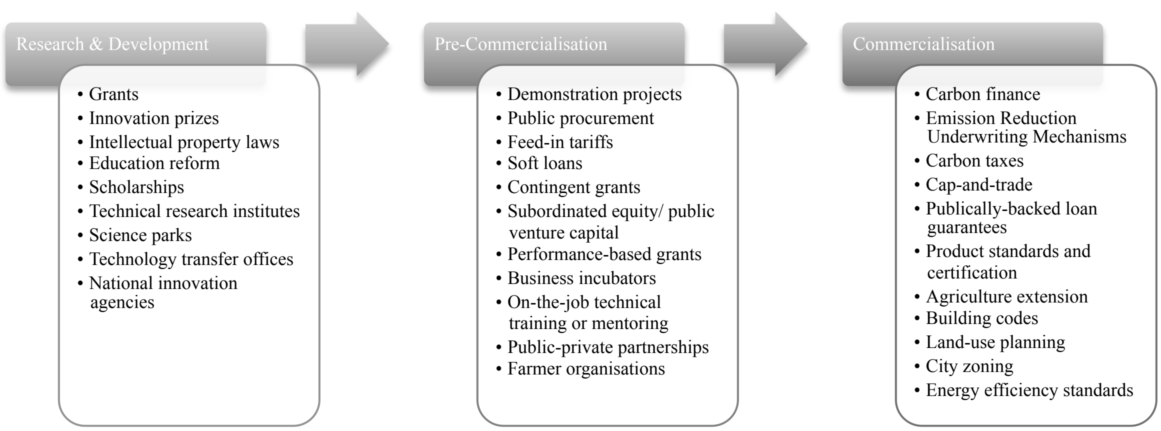

Figure 37. Interventions for different stages of the innovation process (author's own)

As innovations become embedded in the socio-technical regime, more private capital can be leveraged until the market is fully privatised. Public investment in innovations should be gradually phased-out, as demonstrated by ARGeo's change in tactics to support private investment and public-private partnerships once the geothermal resource was proven. Policies that aim to optimise price signals, such as emission offset markets or ERUMs, may be most effective at the commercialisation stage. However, depending on the main barriers to diffusion, investment of climate finance in the implementation of other *demand-pull policies* may be more effective such as energy efficiency certification schemes for appliances or extension services promoting no-till agriculture.

Perhaps most importantly, the previous section revealed that comprehensive policy regimes are necessary to guide transitions to climate-resilient and low-carbon economies. Thus, climate finance will need to contribute to a political environment in which developing country leaders are incentivised, and can secure the mandate, to implement SI policy regimes. Furthermore, it will need to support developing country governments to build the technical capacity and secure the financial resources necessary to implement such regimes. SI policy regimes will have various compositions depending on the context, but will comprise policies like energy efficiency standards, building codes, land-use zoning, protected areas, the elimination of fossil fuel subsidies, emissions pricing, and decoupling utilities revenues from energy sales.

As demonstrated by the Government of Brazil, proactive policies and programmes will be needed to increase the adaptive capacity of socio-technical regimes. While Brazil is a wealthy enough country to afford such public initiatives without support from climate finance, since 2005, 47 least developed countries have developed and submitted a National Adaptation Plan of Action (NAPA) to the UNFCCC. They did so with the support of the Least Developed Country (LDC) Fund, and while some further funding has been made available through various channels, NAPA-implementation remains chronically underfunded (Fankhauser & Burton, 2011; Flam & Skjaerseth, 2009).

Current literature exploring the economics of climate finance has neglected the role that it can play in shaping domestic public policy in developing countries. As a result, the institutional arrangements envisioned for climate finance are not fit for purpose. Two recommendations are thematic in this literature: one, for GHG emission offset markets to be scaled-up and for their remit to be expanded to REDD and agriculture; and two, for public climate finance to be channelled through IFIs.

Emission offset markets can be instrumental in tilting economic incentives in favour of low-carbon options. However, as our previous analysis demonstrated, tackling most GHG emission abatement opportunities, particularly those related to REDD and agriculture, will require a multifaceted policy regime. As project- or programme-based mechanisms, offset markets inherently fail to provide sufficient incentives to governments to implement the broader policy regimes necessary to guide socio-technical transitions.

IFIs are favoured because they can issue bonds on the back of paid-in public funds to generate additional flows of private capital (UN High-level Advisory Group, 2010), and they have a wealth of experience in providing concessional investment capital or guarantees to crowd in private investment. It is also argued that channelling funds through multilateral development banks is the simplest way of integrating adaptation and mitigation into development planning (Fankhauser & Burton, 2011). However, critics contend that projects and programmes supported by international institutions have been fragmented and had little impact on government policy and activities. Moreover, as argued by Gomez-Echeverri (2010, p. 4), "The complexity of financing requirements are too varied to be addressed by the global institutions demanding standard formulas. […] Decisions on how to address these differences, and with what instruments, can best be addressed by those who have the knowledge on the local needs and conditions." This critique is corroborated by our previous analysis, which revealed that the barriers to innovation and economic change, and their solutions, are highly context specific.

This is not to suggest that IFIs should not play an integral role in implementing developing countries' transitions. On the contrary, many developing countries lack functioning capital markets, causing large-scale measures to rely primarily on IFIs for financial services. Furthermore, as demonstrated by the case of geothermal in Kenya and the loan guarantee scheme in China, climate finance channelled through IFIs could play a central role strategic niche management. However, even where the primary barrier to innovation is inadequate economic signals, government policies that induce demand management such as carbon taxes or cap-and-trade systems, or that decouple utilities revenues from energy sales will often be more effective and efficient than emission offset markets or any tools available to IFIs.

A transition management approach would therefore argue that mainstreaming should occur at the domestic level, rather than at the international level. Like the literature on the ethics of climate finance, a transition management approach would push for a significant portion of climate finance to flow through national funding entities. National funding entities would enable governments to formulate clear, long-term goals; establish a diverse mix of policy instruments necessary to guide socio-technical transitions; and align and mainstream climate change programmes into development strategies. IFIs could play an important role as a trustee of national funds where the fiduciary responsibility of governments is in question.

However, climate finance should not be granted outright to national funding entities. It should be made conditional on the implementation of SI regimes as is the case with the UN-REDD programme. One option that has been proposed is for the UNFCCC to adopt a crediting-mechanism for either the implementation of NAMAs or Sectoral No-Lose Targets (SNLTs). This could either be a standalone mechanism or it could be implemented through a reformed CDM.

NAMAs were submitted by developing countries to the UNFCCC under the Copenhagen Accord. Rather than crediting emission reductions at the project or programme-level, a NAMA-crediting mechanism would grant a pre-negotiated payment or carbon credits to developing countries that comply with the actions laid out in their strategies (Chung, 2009). Credible measures could include compliance with voluntary national emission reduction targets and/or implementation of SI policy regimes (Kraiem, 2009). SNLTs would be similar, except that individual sectors would adopt voluntary emissions reduction actions or targets. A country would not be penalised for failing to achieve its target or implement its actions, but would receive payments or carbon credits for meeting or beating the target (Ward, 2009).

Regardless of the design, the intention would be to incentivise developing country governments to implement SI policy regimes, and the bottom up submission process would allow for these regimes to have various compositions. Crucially, the mechanism must be nimble enough to deliver support in a timely fashion when windows of opportunity to shape agendas open up. Technical support will also often be required to build the capacity of developing country governments to design and implement such actions.

6.5 Conclusion

This paper addressed questions of the function and institutional arrangements of climate finance from a transition management perspective. It examined the barriers that prevent developing countries from transitioning to low-carbon and climate-resilient economies, and the interventions necessary to overcome those barriers. It argued that the barriers to innovation and economic change are much more pervasive than a lack of incentives. They include issues like insufficient knowledge flows and technical capacity in R&D and business; inadequate network formation around value chains; capital constraints due to undeveloped capital markets; and unstable and inappropriate policy regimes.

To overcome these barriers, climate finance will need to perform a variety of functions beyond creating the necessary economic incentives to attract private investment. It will need to be deployed through a wide variety of technology-push policies, such as investment in R&D, innovation prizes and innovation platforms to develop a pipeline of new innovations and bring down their cost. It will need to contribute to strategic niche management to help secure a market for innovations in the pre-commercialisation phase while market infrastructure and distribution outlets, networks around value chains, and the technical skill-base are developed to bring viable innovations to the market. Climate finance will also need to support demand-pull policies like energy efficiency certification schemes.

Perhaps most importantly, climate finance will need to be used to incentivise and enable developing country leaders to implement the SI policy regimes necessary to increase the adaptive capacity of socio-technical regimes and guide transitions to low-carbon and climate-resilient economies. Many of the barriers to such transitions can only be overcome by governments, which can define long-term national targets and strategies for achieving them, and which have the authority to implement regulations like energy efficiency standards, building codes, land-use zoning, protected areas, emissions pricing, and policies to decouple utilities revenues from energy sales. A crediting-mechanism for NAMAs or SNLTs could be instrumental in creating incentives for the governments to implement such policies. Sustainable private investment for innovation and economic change will only be forthcoming if developing countries implement comprehensive and predictable SI policy regimes.

7 Conclusion

7.1 Restatement of objectives and questions

As I think back on the experiences that I had while conducting research for this thesis, admittedly, much of it is troubling. I cannot help but draw connections, even parallels, between Petrobras's deep sea drilling for pre-salt oil at unprecedented depths and the young fishermen in Jamaica that, without seeing any alternative options, would turn to spear fishing with compressors in increasingly deeper and more dangerous waters.[42] Likewise, I cannot help but contemplate about the whereabouts of the elderly Jamaican woman that I spoke to whom frequently could not afford to purchase food supplies prior to the onset of a hurricane; or about the fortunes of an elderly man whose house teetered on the edge of a landslide in St Lucia, but whom could not afford to move. These are the most vulnerable to climate change. And yet, in the same communities I spoke to people with entirely different, even uplifting stories to tell – individuals that were actively mobilising their communities to create institutions to protect vital local ecosystems, or to establish novel, more profitable, and more sustainable industries. Moreover, in Brazil, within the same government that was enabling Petrobras to drill thousands of metres below the surface – driving the technological innovation that will open up vast swaths of previously unreachable oil reserves and sequestered carbon around the world – I found profound and largely successful leadership in the fight to mitigate GHG emissions. These are only a few of the

[42] Research on the former topic did not make the final manuscript.

contradictions and complexities that I aimed to understand and explain in my data analysis and thesis.

As I argued in Chapter 1, knowledge building is a see-saw process whereby theory is drawn from complex empirical observations, and then corroborated and/or revised based on further observation. Empirical evidence accumulated over decades has demonstrated numerous problems associated with the application of neoclassical equilibrium models to develop and analyse questions about wide scale and long-term economic change. This thesis corroborated their inadequacy. Yet, these tools have been highly influential in the body of environmental and neoclassical economics' research geared towards predicting how economies will respond to climate change, assessing the future costs of climate change, and designing policy measures aimed at reducing GHG emissions. The weaknesses of current economic modelling techniques beg for more nuanced theories about economic change, and for policy prescriptions based on empirical observations rather than abstract models.

This thesis argued that evolutionary economic geography offers a number of advantages over neoclassical and environmental economics in explaining why GHG emissions and vulnerability to climate change vary across space and time:

- Its focus on evolutionary factors, such as diversity, selection, and retention, helps to explain the dynamics of adaptation and the processes of innovation and diffusion of low-carbon and climate-resilient technologies and practices.
- Its more realistic assumptions about human behaviour – that it is based on heuristics and bounded rationality, and that it is constrained by historical, institutional, and socio-cultural factors – offer a more realistic understanding of

the way in which structure and agency interact to inhibit or promote shifts to low-carbon and climate-resilient pathways.

- Its emphasis on contextual factors, such as local culture, institutions, and politics, helps to provide a more nuanced understanding of why some places evolve to have a higher adaptive capacity than others, or why some locations are more liable than others to get locked into emission-intensive pathways.
- Its consideration of innovation as an endogenous (rather than exogenous) phenomenon helps to explain why economies never are, and never can be, in perfect equilibrium. This understanding discredits policy frameworks that rely excessively on 'getting the price right', and provides theoretical justification for substantial public support for innovation in low-carbon and climate-resilient technologies and practices.
- Its understanding that higher-level structural change can cause selection pressures to shift highlights the importance of innovation and conservation of diversity in order to enhance adaptive capacity, and provides justification for policies that uphold the precautionary principle rather than strive to maximise efficiency.

The aim of this thesis was to provide an evolutionary economic geography perspective on three of the central debates surrounding economic change in response to climate change:

1) What factors influence human systems' capacity to adapt to climate change, and how can these factors be assessed?

2) What forces drive and inhibit economic change towards low-carbon economies? How should governments induce and manage such shifts?
3) What role should climate finance play in promoting developing countries' shifts to low-emitting and climate-resilient economies? How should the institutional architecture governing climate finance be designed?

This following section will review the findings pertaining to each of these debates.

7.2 Summary of findings

1) What factors influence human systems' capacity to adapt to climate change, and how can these factors be assessed?

The future economic costs of climate change will depend a great deal on human systems' capacity to adapt. From a neoclassical economics perspective, adaptation will be driven by market forces. Rational, self-interested agents will choose each course of action based on the expected utility that they will gain, driving economies towards optimal equilibria in which production is maximised. Based on this theory, any government intervention to promote adaptation will necessarily lead to a less than optimal outcome.

Climate impact assessments are often based on neoclassical economics assumptions about market-driven adaptation (although sometimes the models do not factor in adaptation at all). Economic agents are often considered to have perfect foresight and ability to adapt to climate change, and this adaptive capacity is considered to be uniform across space. Hence, the vulnerability of a human system is not influenced by its adaptive capacity. It is determined exclusively by exogenous forces, rather than endogenous characteristics of the system itself.

These assumptions are of course gross oversimplifications that are adopted to enable rapid assessments, and a rich body of literature exists that is devoted to the empirical analysis of adaptation and vulnerability. Chapter 3 identified two alternative perspectives within this literature: the behavioural approach, which emphasises the role of irrational human behaviour in producing vulnerability; and the structural approach, which emphasises the role of deep-rooted and historical socio-economic structures in producing vulnerability by limiting human agents' adaptive options. Both of these perspectives observe that adaptive capacity varies across space, but they attribute the variance to different causes – structure vs. agency. Chapter 3 drew on case studies of the famine in the Sahel in the early-1970s and the earthquakes in Chile and Haiti to demonstrate that structural factors do influence adaptive capacity and produce vulnerability. Nonetheless, it concluded that a complete understanding must not only give weight to the structural factors that limit adaptive capacity; it must also consider agents' capacities to adapt within those structures, as well as their capacities to alter the structures through political processes, etc.

From an evolutionary perspective, adaptation is driven by human agents' innovation and adoption of behaviours and technologies that are more suited to local selection pressures. However, agents' abilities to adapt are structured by socio-cultural, ecological, and historical elements – factors that are highly context specific. As increasingly competitive features are selected and retained, adaptation is thought to progress towards an optimal state in which no potential features exist that are more competitive. However, at best, optima can only exist within local selection environments and can only be temporary, because climatic, ecological or socio-economic changes can lead to a different selection environment in which current routines and technologies are less well adapted or even *maladapted*, resulting in an increase in vulnerability.

Given the context-specific and structured nature of adaptive capacity, as well as the inherent uncertainty in climate models, it is not possible to understand the landscape of vulnerability to climate change using large-scale regional or global integrated assessment models. Instead, understanding the landscape of vulnerability will require the accumulation of local vulnerability assessments to enable comparisons between places. In some ways, vulnerability assessment is the reverse of impact assessment because the starting point is an examination of the endogenous characteristics of the human system in question, rather than exogenous climatic factors.

The accumulation of vulnerability assessments has been ongoing over the last decade, however significant research remains to be done. The assessments have used numerous different methodologies, ranging from highly quantitative to qualitative, and characterised adaptive capacity using a variety of different frameworks. Chapter 3 argued that the LAC framework, which characterises a systems adaptive capacity based on its asset base, institutions, knowledge and information, innovation, and flexible- and forward-looking decision-making processes, aligns well with an evolutionary perspective on adaptation. It argued that the descriptive data necessary to identify the locally specific processes involved in adaptation – as well as the deep-rooted structural and historical factors that constrain these processes – can only be unearthed through qualitative research methods, such as those used in community-based vulnerability assessments.

Chapter 4 set out to empirically test the evolutionary perspective on vulnerability and adaptive capacity shaped in Chapter 3 through CBVAs in two island communities: Soufriere, Saint Lucia and Whitehouse, Jamaica. The results of the CBVAs were analysed using the LAC framework. The case studies validated that the elements of the LAC framework do influence a human systems adaptive capacity.

To illustrate, the adaptive capacities of both Soufriere and Whitehouse were limited by inadequate stocks of financial, human, and physical capital. Respondents explained that a lack of these capitals limited their adaptive options and prevented effective implementation of adaptive measures. Both economies were underpinned by rich natural capital. However, much of this natural capital was at risk from human activity and climate change, which threatened to further undermine adaptive capacity. It was found that, in general, Whitehouse had a larger stock of social capital than Soufriere. Based on discussions with interview respondents, the chapter concluded that, in some ways, a high level of social capital can alleviate a lack of physical and/or financial capital. For example, in Bluefields Bay and Fond St Jacques social capital proved highly important in coping with extreme events when the community provided shelter for those most vulnerable. However, the degree to which one form of capital could be substituted with another was unclear.

The case studies further corroborated the LAC framework's inclusion of non-capital-based elements in its characterisation of a system's adaptive capacity. It was argued that an approach focused exclusively on different forms of capital would have offered an incomplete understanding of the adaptive capacity of both communities. For example, although the Whitehouse fishing industry's inadequate adaptive capacity would have been hinted at through an assessment of the region's declining natural capital, the severity of the problem would not have been clear without an examination of Jamaica's insufficient and poorly enforced fishing regulations, or the industry's minimal capacity to innovate to reduce its pressure on near-shore resources. Moreover, an assessment of neither location's adaptive capacity would have been complete without an examination of the novel institutions and innovations implemented to conserve and enhance near-shore biodiversity, such as the SMMA, the Bluefields Bay Special Conservation Area, artificial reefs, and lobster condominiums.

Despite the case studies' validation of the existing elements of the LAC framework, a number of other evolutionary themes were unearthed that also influence adaptive capacity, but that are not explicitly taken into account. These include structure, history, path-dependency, scale, agency, conservation of diversity, and the perils of specialisation. It was argued that these themes should be explicitly taken into a framework for assessing adaptive capacity, either as additional elements in the LAC framework, or, more pragmatically, as elements to consider within the existing categories.

2) What forces drive and inhibit economic change towards low-carbon economies? How should governments induce and manage such shifts?

From a neoclassical economics perspective, climate change is the result of an environmental externality. Private actors are able to produce GHG emissions without paying for the social costs that they cause. As a result, there is an overinvestment in GHG-intensive activities than is socially optimal. The best solution to address this market failure is for governments to implement policies, such as a carbon tax or cap-and-trade system, that require polluters to pay a price on emissions equal to the SCC. With a price on emissions equal to the SCC (and provided that there are not further market failures), it is predicted that markets will trend in a linear manner towards an equilibrium state with an optimal level of GHG emissions, i.e. a state with the lowest net cost to society from climate change and climate change policies.

Evolutionary economic geography questions many of the assumptions inherent in the neoclassical economics models used to assess how an economy will respond to emissions pricing. It argues that a holistic understanding of the forces that drive and inhibit economic change requires a broader perspective that incorporates non-price-based factors such as innovation, knowledge-flows, leadership, institutional evolution, and domestic and international politics. As a result of these factors, it argues that economic change is path-dependent and non-linear.

To assess this theory, Chapter 5 empirically examined three cases of successful economic changes towards lower emitting technologies and practices in Brazil: the expansion of no-till agriculture, the reduction of deforestation, and the increased displacement of gasoline with ethanol. Drawing largely on transition management, discussed in Chapter 2, it categorised these changes, respectively, as reproduction, transformation, and transition of the socio-technical regime. The chapter found that in each of the three economic shifts in question, the driving forces were far more varied and complex than the price-based market dynamics analysed in neoclassical economics.

For example, Brazil's success reducing deforestation rates, classified as economic transformation, was not driven by policies that changed the microeconomic calculation of farmers at margin. It was driven by aggressive top-down command-and-control policies led by the Federal Government. Behind these command-and-control policies were shifts in landscape pressures including the shift to a civilian government with an independent judiciary and free press, and the emergence of biodiversity protection and climate change as international concerns. Likewise, the changing fortunes of Brazil's ethanol industry – classified as a transition of Brazil's transportation fuel regime – were only partially tied to price-based factors. They were also highly influenced by shifts in landscape pressures, such as the oil price shocks in the 1970s and political pressure to reduce GHGs. Based on the importance of shifting landscape pressures in directing economic change, the chapter concluded that inducing transitions and transformations towards low-carbon socio-technical regimes is much more of a political project than a technocratic one.

Even in the case of the diffusion of no-till agriculture (which was classified as reproduction because it is more cost-effective than alternative practices and does not threaten the position of any elements of the agriculture socio-technical regime) it was found that market signals were not the only important factors determining diffusion. Social learning, the flows of information, and the bounded rationality of economic agents also played an important role in determining the rate of uptake. It was therefore concluded that knowledge-management through extension services, workshops, etc., would be more appropriate policy interventions than those that aim to get the price right.

Finally, Chapter 5 demonstrated the importance of innovation in driving economic change, a factor considered only exogenously in equilibrium models. Ethanol only became a cost-effective alternative to gasoline after three decades of innovation in production and processing methods, as well as the invention of the flex-fuel vehicle, which allowed the two fuels to compete directly. These innovations were enabled by the guaranteed niche markets for ethanol and pure ethanol vehicles created by the government-mandated blend and public procurement programmes, as well as substantial government investment in R&D. For this reason, while neoclassical economics generally prescribes measures that will increase competition in order to maximise productivity and efficiency, Chapter 5 stressed the importance of strategic niche management – policies that reduce competition to the degree necessary to foster new innovations.

3) What role should climate finance play in promoting developing countries' shifts to low-emitting and climate-resilient economies? How should the institutional architecture governing climate finance be designed?

From a neoclassical economics perspective, the function of climate finance is to help correct the environmental externalities that cause excessive GHG emissions and to create the incentives necessary to attract private finance towards low-carbon initiatives. The role of climate finance in promoting adaptation is generally downplayed, because, barring any further market failure, the incentives to adapt exist naturally and need not be created by government. Literature on the economics of climate finance promotes the use of emissions offset markets and PES, arguing that with the application of such price-based incentives, market forces will drive transitions to low-carbon economies.

As argued throughout this thesis, it is not clear that government intervention can recreate optimal market conditions. Building on previous chapters' discussions about the mechanics of adaptation and mitigation, Chapter 6 examined the barriers that prevent developing countries from deploying the low-carbon measures identified in McKinsey's Global MAC Curve (Figure 14), and it provided empirical examples of interventions that have overcome those barriers. It also examined the factors that contribute to vulnerability to climate change. The chapter concluded that the barriers to mitigation and adaptation to climate change are much more pervasive than a lack of price-based incentives. They include issues like insufficient knowledge flows and technical capacity in R&D and business; inadequate network formation around value chains; capital constraints due to undeveloped capital markets; and unstable and inappropriate policy regimes.

Therefore, contrary to neoclassical economics arguments, Chapter 6 argued that climate finance should perform a variety of functions beyond creating the necessary economic incentives to attract low-carbon private investment. It should be deployed through a wide variety of technology-push and demand-pull policies to promote strategic niche management. Moreover, it should be used to promote structural change by incentivising and enabling developing country leaders to implement SI policy regimes.

The chapter concluded that in order to achieve these aims, the institutional structures governing climate finance should more closely resemble those being promoted by developing countries in the UNFCCC negotiations than those being promoted by neoclassical economists and most developed nations. Rather than policies that aim 'to get the price right,' such as carbon crediting schemes and PES, the chapter called for the creation of national climate change funds and crediting-mechanism for NAMAs or SNLTs to incentivise governments to implement the long-term economic planning, and SI policy regimes necessary to drive the shift towards low-carbon and climate-resilient economies.

7.3 Contributions to literature

Besides neoclassical economics research, most literature pertaining to economic change in response to climate change has been more narrowly focused than this thesis – concentrating on either adaptation or mitigation, or on much more specific issues such as politics in the UNFCCC or at the country-level, technology diffusion or the impact of a specific policy. As far as I am aware, this thesis is the first time that literature on both mitigation and adaptation has been brought under the umbrella of evolutionary economic geography, although other studies have made similar propositions for an evolutionary approach (Foxon, 2011; Howarth, 2012; Patchell & Hayter, 2013). Perhaps the most valuable contribution of this thesis is the proposition that evolutionary economic geography offers an alternative to neoclassical economics as an overarching theory of economic change within which more narrowly focused studies on climate change adaptation and mitigation can be embedded.

The broader theory of evolutionary economic geography is informed primarily by evolutionary economics (Gowdy, 1992; Nelson & Winter, 1982, 2002; Rammel & van den Bergh, 2003; Schumpeter, 1942) and economic geography (Clark, et al., 2000; Coe, et al., 2013). As a new theory, the maturation of evolutionary economic geography requires grounding in empirical evidence in order to test its usefulness in explaining real-world phenomenon (Boschma & Martin, 2010). This thesis contributed to this process by applying evolutionary economic geography to case studies on the vulnerability of Soufriere and Whitehouse, and on the forces driving and inhibiting economic shifts towards no-till agriculture, reduced deforestation and ethanol biofuels in Brazil. In each of these case studies, the thesis demonstrated that evolutionary economic geography offers a more nuanced perspective than neoclassical economics on economic change by incorporating more realistic views on human behaviour, innovation, politics, institutions, local contexts and histories, and higher-level structural forces. Questions pertaining to economic change in response to climate change are particularly fertile ground for further theoretical development in evolutionary economic geography due to critical importance of considering contextual, spatial, scalar, and temporal factors in answering them.

The development of an evolutionary economic geography of climate change need not start from scratch. A variety of rich, multi-disciplinary, and growing bodies of literature already exist that empirically examine aspects of why the impacts of climate change and/or the production of GHG emissions vary over space and time. Each of these bodies of literature can inform the future development of an evolutionary economic geography of climate change as they have done in this thesis.

Specifically, this thesis has drawn from literature focused on hazards (Burton, et al., 1978; Eiser, et al., 2012; K. Smith & Petley, 2009; White, 1945), disasters (Glantz, 1977; Hewitt, 1980; Torry, 1979; Wisner, et al., 2004), climate change vulnerability assessment (Brooks, Adger, & Kelly, 2005; Füssel & Klein, 2006; Smit & Pilifosova, 2001a, 2003; Smit & Wandel, 2006), innovation systems theory (Foxon & Pearson, 2008; Lundvall, 2007, 1992; K. Smith, 2000), and sustainable transitions and transition management (Foxon, 2007; Geels, 2002; Geels & Kemp, 2006; Geels & Schot, 2007). Beyond providing an overarching framework for studying issues relating to economic change in response to climate change, this thesis has made specific contributions to each of these bodies of literature.

The evolutionary perspective on adaptation and vulnerability developed in Chapter 3 offers a potential resolution to debates within hazards and disasters literature about whether the causes of human vulnerability are due primarily to structural factors or irrational behaviour. The chapter argued that adaptation is driven by agents with imperfect information and bounded rationality, and that the adaptive options open to these agents are limited by structural factors. The evolutionary concept that higher-level structural change can cause selection environments to shift provided a theoretical explanation for why building flexibility into institutions and maintaining a diversity of options is important in enhancing adaptive capacity and reducing vulnerability. It also provided justification for policies that aim to foster innovation and conserve diversity by reducing market competition – a policy goal that is antithetical to neoclassical economic thought.

As discussed in the previous section, the thesis also contributed to the literature on adaptation and vulnerability by applying insights from an evolutionary perspective to questions concerning the methodology of climate change vulnerability assessments. Literature on vulnerability assessment had not adequately engaged with broader theories about economic change. The connections that this thesis made between this literature and evolutionary economic geography provided broader theoretical justification for some of the arguments being made concerning the importance of qualitative data and the local context (Smit & Wandel, 2006), and the consideration of innovation and institutions in adaptive capacity assessments (Jones, et al., 2010).

Literature on innovation systems, sustainability transitions, and transition management offered a relatively well-established evolutionary theory on climate change mitigation that reflects many of the same ideas of evolutionary economic geography (e.g. selection of routines and technologies, lock-in, and path-dependence). The case studies provided by this thesis on the economic shifts in Brazil towards no-till agriculture, reduced deforestation, and ethanol biofuels, as well as the empirical examples of successful GHG abatement measures offered in Chapter 6, provided further theoretical evidence in support of arguments made by transition management literature.

7.4 Contributions to policy

As discussed in the Literature Review, one difference between evolutionary economic geography and transition management literature is that the latter, like neoclassical economics, gives more weight to 'stylised facts.' As such, it is less considerate of context, and quicker to recommend normative policy prescriptions. This thesis argues that there has to be a middle ground between universality and context, and that this balance can be arrived at through the 'see-saw' process between theory and empirical observation.

Transition management's policy prescriptions to reduce GHG emissions, referred to in this thesis as a SI policy regime (Foxon & Pearson, 2008), align closely with this thesis's analysis of the GoB's policies used in reducing deforestation and promoting no-till agriculture and ethanol biofuels. In each case, the government played a relatively hands on role in guiding economic change. Rather than relying exclusively on market-based policies designed to 'get the price right,' the GoB implemented a plethora of policies with aims ranging from knowledge creation (through public research or direct investment in private R&D), to knowledge management (through conferences and campaigns), to niche management (through mandatory blends and public procurement programmes), to command-and-control (through protected areas and forest reserves combined with aggressive monitoring and enforcement).

Based on the empirical observations made in this thesis, ten broad policy conclusions can be drawn:

1. SI policy regimes should be context specific, both in design and enforcement, taking account the local culture, politics, human capacities, ecology, history, state of industries and technologies, etc., as well as prevailing prices.
2. These contextual factors are liable to change, as they did, for example, throughout the history of Brazil's ethanol industry. Policies should be designed to be flexible to allow them to adjust.
3. The effect that policies will have on local economies will vary across time and different contexts. For example, much of the deforestation of the Brazilian Amazon had been technically illegal for decades. It was only after the context shifted to include a favourable political economy and a technological capacity for enforcement that the policies had their desired effect. Therefore, policy design is only one step in the governance process. Effective governance necessitates ongoing monitoring of policies' interactions with local contexts.
4. Given that selection pressures can shift, it is desirable to promote diversity in the economy. Diversity can be achieved through policies that promote conservation, such as the SMMA, and policies that foster novelty in practices and technologies, such as the Climate Change Adaptation and Disaster Risk

Reduction project's investments in apiculture, ecotourism, and agroprocessing in Bluefields Bay.

5. Policies are often justifiable that are contrary to perfect competition. For example, the GoB was able to maintain a niche with lax selection pressures for ethanol biofuel by implementing mandatory blends of ethanol with gasoline.
6. It is frequently necessary for policies to address non-price-based barriers. Policies that aimed to promote flows of information, including extension services and workshops, were central to the diffusion of no-till agriculture in Brazil and Ghana; and policies to develop the local skill base, such as publicly-funded training programmes, were necessary to develop the geothermal industry in Kenya. Public investment in research was also necessary to generate much of our understanding about the future impacts of climate change in the Caribbean, such as Mona's map of areas that will be impacted by sea-level rise in Jamaica and CARIBSAVE's downscaled regional climate models.
7. It is often preferable to remove entire segments of the economy from market competition, as done in the cases of protected areas of forest and coral reef. Sometimes, this may be achieved by nationalising nascent industries that are desirable from a societal perspective, but are not yet competitive. This latter point may be the most contradictory to neoclassical economic thought. As evidence of its importance, the Government of Kenya's ownership of the utility KenGen was essential to the early development of the country's geothermal resources. Similarly, the GoB's ownership of Petrobras was critical in the early days of the ethanol industry, as its monopoly over the automobile fuel industry

allowed it to centralise the process of procuring the ethanol, blending it with gasoline and distributing the mix. Moreover, the GoB's near monopoly over agricultural finance has allowed it to be extraordinarily influential in directing economic change by withholding credit in municipalities that do not comply with forestry regulations, and providing concessional loans to farmers that apply desirable practices, such as no-till and climate-resilient agriculture. The advantage of nationalised industries is their ability to operate in manner that is contradictory to profit-maximisation, even if it means operating at a loss, if it is to the betterment of the population.

8. Policies may need to target the underlying structural factors that prevent adaptation or mitigation. For example, in Brazil, the creation of a free press, indigenous rights, and an independent judiciary during the shift to a civilian government in the late-1980s was an essential prerequisite to the country's future success in reducing deforestation rates.
9. Long-term vision and planning on the part of the government can help guide economic change by enabling coordination and signalling stability to investors. The long-term vision and centralised planning on the part of the Kenyan government was critical in sourcing the finance and generating private interest in the development of its geothermal resources.
10. Given that both economic and ecological changes are frequently unpredictable, path-dependent, and irreversible, it is generally appropriate to apply the precautionary principle, rather than aim to produce at the maximum sustainable yield or the optimal emissions levels. Had the Government of Jamaica applied the

precautionary principle to the regulation of its fishing industry, the industry would likely be much more resilient and capable of supporting more fishermen than it is today.

Many of these conclusions are not novel contributions to policy discussions. Some echo transition management and innovation system literature (Foxon, 2007; Foxon & Pearson, 2008; Loorbach, 2007; K. Smith, 2000). Others draw from evolutionary and ecological economics (Rammel & van den Bergh, 2003), or literature on reducing vulnerability (Smit & Pilifosova, 2003; Wisner, et al., 2004). However, they are worth reiterating as many of them contradict neoclassical economics policy prescriptions and prevailing common practice.

7.5 Limitations and directions for future research

A feature of evolutionary economic geography that is both limitation and strength is its emphasis on careful empirical research. This emphasis is a limitation, because it means that the process of knowledge building is slower and more expensive than neoclassical economic modelling methods, and the knowledge produced is not fully applicable beyond the context being studied. It is a strength, because the rich and holistic data produced can enable a deep understanding of that context. Furthermore, the theoretical grounding of evolutionary economic geography through real-world observation means that it can offer powerful insights into debates concerning economic change and policy design.

Substantial room remains for the application of an evolutionary economic geography to questions about the landscapes of vulnerability and GHG emissions. Given the context-specific and structured nature of adaptive capacity, as well as the inherent uncertainty in climate models, it is not possible to understand the landscape of vulnerability to climate change using large-scale regional or global integrated assessment models. Instead, as argued, understanding the landscape of vulnerability will require the accumulation of local vulnerability assessments to enable comparisons between places (Smit & Wandel, 2006).

Vulnerability assessments using different methodologies and perspectives have been accumulating over the last decade, but significant research remains to be done. The evolutionary perspective on vulnerability and adaptive capacity offered in this thesis can contribute to this ongoing process of mapping vulnerability to climate change. This thesis examined vulnerability from an evolutionary perspective in two coastal communities in the Caribbean. A useful direction for further research would be to examine, from an evolutionary perspective, how their vulnerabilities compare to other regions and landscapes, such as areas at risk of desertification, urban areas, or polar regions.

Evolutionary economic geography can also contribute to other questions about the spatial and economic aspects of adaptation and vulnerability. Leichenko & Thomas (2012, p. 328) provided a useful agenda setting paper for potential contributions of economic geography, in general, to research on climate change impacts: "[…] fundamental questions remain about how climate change impacts and adaptation responses may affect patterns of regional growth and development, which types of local and regional economies are most vulnerable to the impacts of climate change, and what the prospect of climate change implies for theoretical understandings of regional economic growth and change." To these questions we can add numerous others: What factors cause vulnerability to specific climatic shocks and stressors to vary across space? How do the costs of adaptation vary across space? How will climate change affect spatial inequality? What policies can effectively enhance adaptive capacity at different scales, and how do these change across regions? Can specific successful adaptations in one region be applied in another, and if so, what factors will influence their diffusion? Evolutionary economic geography is well position to contribute to all of these discussions.

It is also well placed to continue to contribute to discussions concerning the landscape of GHG emissions. On the mitigation front, Foxon (2011, p. 2259) provided a valuable agenda setting paper that argued that a coevolutionary framework could be applied to research and policy challenges in four areas: "(1) detailed empirical analyses of the challenges relating to the innovation and adoption of particular low-carbon technologies; (2) as a framework for analysing the multi-level interaction of social and technological elements within potential transition pathways to a low carbon energy system; (3) to inform assessments of the implications for economic growth of a transition to a low carbon economy; and (4) to assist in the development of more formal, multi-level evolutionary economic models." I argue that this research agenda can equally be applied to evolutionary economic geography. However, evolutionary economic geography should also aim to inform questions with a spatial element: How do processes of innovation of technologies and practices vary across space? How do local business strategies shape those processes, and which strategies are most successful? Which policies have worked best to guide economic changes in different contexts, and what underlying factors created the windows of opportunity for implementation of those policies? What types of economic and political systems are best able to transition to low-carbon economies?

This thesis focused on relatively successful examples of shifts towards low-carbon technologies and practices. There are many other examples of such shifts that offer fruitful areas of research to help answer unresolved questions. However, there are also areas where shifts have been unsuccessful. Research into partial or failed shifts could offer perhaps even more valuable insights into questions surrounding how lock-in, vested interests, political opposition, consumer behaviour, etc. shapes the landscape of GHG emissions.

A fundamental difference between neoclassical economics and evolutionary economic geography is that the latter does not presume to be a hard science. In other words, evolutionary economic geography does not seek to identify universal laws about how economies function. Instead, it celebrates complexity, context and change. For this reason, the task of forming an evolutionary economic geography of climate change can never be complete. Further research can always advance a more nuanced understanding about the factors that influence the evolution of GHG emissions and vulnerability to climate change in different places. As the see-saw sways between theoretical inquiry and empirical observation, *The Evolutionary Economic Geography of Climate Change* will evolve alongside the topics of its inquiry.

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