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A review of adaptation to climate change through a development economics lens

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A review of adaptation to climate change through a development economics lens

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Abstract

This paper looks at adaptation to climate change from the point of view of (poor) households. Since the development literature has firmly established the role of weather risk as a source of income volatility for the poor, and climate change is expected to increase this risk, we review the range of risk-coping mechanisms available to poorer households, with a focus on possible barriers to adaptation. We ask both how government interventions affect the set of options available for adaptation and risk coping, and also what these adaptive responses imply for the prospects of sustainable development. Support for adaptation can involve efforts to make existing locations, livelihoods and forms of production more resilient to climate risk (*in-situ* adaptation), *or* reductions in vulnerability through the geographical and sectoral mobility of the poor (*transformational* adaptation). Our review shows how successful adaptation will need to strike a balance between the two forms of adaptation, avoiding locking-in unsustainable practices in locations that are already marginal from an economic perspective, and taking account of broader socio-economic trends already taking place in many developing countries (such as population growth and urbanisation). We also highlight important considerations for policy-makers, which to date have been relatively neglected in the literature, in particular related to the dynamic interaction between adaptation and sustainable development.

Key words: Sustainable development, climate change, risk, adaptation

JEL Codes: D9, I3, J6, O1, Q00, Q01, Q5

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1. Introduction

In this review article, we look at adaptation to climate change through the lens of development economics. Since the development literature has firmly established the role of weather risk as a source of income volatility for the poor, and climate change is expected to increase this risk, we review the range of risk-coping mechanisms available to poorer households, with a focus on possible barriers to adaptation and the interaction of adaptation to climate change with ongoing development trends. We focus on adaptation as an autonomous response to changing climatic conditions, and consider the appropriate role for government policy in fostering adaptation that is also conducive to sustainable economic development.

Concerns are regularly expressed about the potential for climate change to undermine progress towards economic development (e.g. Hallegatte et al., 2016a; FAO 2016), while a number of recent reports have also highlighted the effects of climate change on the poor and other vulnerable groups (Olsson et al., 2014; Oppenheimer et al., 2014; Hallegatte et al., 2016a).[1] More generally, the climate economy literature has expanded rapidly in recent years, and there are now a number of review articles that focus on particular climate impacts, for example in relation to agriculture (Aufhammer and Schlenker, 2014), health (Deschenes, 2014) and conflict (Burke et al., 2015a), as well as more general overviews of empirical findings from the literature (Dell et al., 2014; Carleton and Hsiang, 2016; Castells-Quintana et al., 2017).

Societies can adapt over time to limit the losses from climatic extremes and variability (e.g. Hsiang and Narita, 2012). A crucial outstanding question is why this has not occurred everywhere; why "adaptation gaps" or persistent differences in the socio-economic impacts of physically similar weather events remain across societies (Fankhauser and McDermott, 2014; Carleton and Hsiang, 2016). Explaining this macro-level finding in relation to adaptation gaps requires a better understanding of the specific mechanisms at a micro level that may prevent households from

[1] The latest report from Working Group II of the Intergovernmental Panel on Climate Change (Oppenheimer et al. 2014) identifies the direct threats posed by climate change for, amongst other things, ecosystems, human health, and agricultural productivity, and the potential knock-on effects for issues such as food security, rural livelihoods and migration.

adapting to current or future weather risk. This is precisely the aim of our review, which builds on, and complements the recent literature on adaptation to climate change by considering adaptation within a broader framework of long-run sustainable development, focusing on decisions faced by poor households, and analysing policy options facing the dual challenges of adaptation and development (not always aligned with each other).

Climate change involves a shift in the distribution of future weather, which is expected to manifest in more frequent extreme events and greater variability, or in other words an increase in weather risk. Extreme weather events have important human impacts, directly killing and injuring people and increasing spread of disease (McMichael et al., 2012), and impact on welfare indirectly, through the destruction of capital or run-down savings for example due to out-of-pocket health expenses. These effects occur predominantly in poorer countries, and impact disproportionately on poor people (Hallegatte et al., 2016a). Rather than rehearsing these threats, we focus instead on the household level capacity to adapt to an environment of increased risk due to climate change, drawing on the development economics literature to highlight constraints on adaptation and policy interventions with the potential to alleviate those constraints.

The existing literature on the economics of adaptation has tended to treat adaptation as a distinct set of activities, focusing for example on the challenges of project evaluation at the micro-level, particularly in the context of uncertain future impacts of climate change (see e.g. Markandya et al. 2014). Other recent reviews have focused on identifying and explaining barriers to adaptation as configurations of climate and non-climate factors (i.e., Biesbroeck et al., 2013 and Eisenack et al., 2014). We depart from this literature by treating adaptation to climate change not as a distinct set of activities, but as an additional consideration for the broader challenge of achieving climate resilient economic development (Fankhauser and McDermott 2016a). This approach recognises the essential interdependence between the dynamics of economic development and adaptation to climate change, acknowledging the micro-level constraints to adaptation (including e.g. risk-aversion, financial and other constraints) as well as the crucial role

of broader macro trends (economic growth, investment, structural change, demography and urbanisation) in determining vulnerability to climate risk. In particular, we focus on the micro-level constraints that prevent households from adapting efficiently, particularly in a developing country context, and how these constraints might be relaxed via policy interventions.[2]

The most negative effects of climate change from a socio-economic perspective are anticipated to occur in locations that are already economically marginal and where livelihoods are precarious (World Bank 2010, 2013a; Samson et al., 2011; IPCC 2014). Thus, climate change can be expected to reinforce existing location-based inequalities, and to give further momentum to the dynamics and incentives that drive economic migrants towards urban and coastal locations. We distinguish adaptation to climate change occurring along two broad dimensions; *in-situ* adaptation seeks to make existing locations, livelihoods and forms of production more resilient to climate change; *transformational* adaptation, on the other hand, seeks to reduce vulnerability or exposure to climate change through the movement of people and economic activity across sectors and across space.[3] This may be viewed as part of a longer-term process of economic development, involving for example a shift away from weather-dependent economic activities or the movement of population away from geographically isolated, less productive locations.[4]

While the two forms of adaptation we identify may appear distinct, they are in fact highly interconnected. Indeed, we argue they should be thought of as two dimensions on which a continuum of adaptation strategies might be mapped, rather than discrete policy options or alternatives. Some *in-situ* adaptation may be required to facilitate transformational change, and

[2] Addressing these challenges is particularly timely now, given policy momentum created by the Paris Agreement (COP21) and the renewed emphasis there on the need for adaptation to climate change, as well as the large-scale investments and other dramatic socio-economic and demographic trends currently underway in many developing countries (see Dietz et al. 2016; Fankhauser and McDermott 2016b).

[3] Kates et al. (2012) define transformational measures as those that meet at least one of the following three conditions: (1) the measures are pursued at a large scale; (2) they rely on novel approaches and tools; or (3) they involve deep structural changes to economic activity and/or location.

[4] If the productivity of some locations or activities suffers because of climate change, then an obvious response is to relocate capital and labour to relatively more productive or less risky locations and sectors (Collier et al., 2008). This is also part of the broader development agenda – the standard path of economic development involves structural transformation of the economy, with an accompanying shift from rural to urban locations (see e.g. Dercon, 2012; Lewis, 1954; Harris and Todaro, 1970). Such shifts of course are not without costs and frictions. We return to these themes in Section 4.

there are many intermediate cases. For example, seasonal migration has often been used as a coping mechanism for vulnerable households – a theme we return to in Section 4.

Achieving the optimal balance of adaptation policies presents an interesting dilemma for policymakers. *In-situ* adaptation may be easier to implement, and more suitable as a short-term response. However, in the extreme, any form of *in-situ* adaptation in locations that are already economically or agriculturally marginal, and where conditions are expected to deteriorate, might represent maladaptation. An important message from our analysis is that adaptation strategies need to recognize the opportunity of leveraging underlying dynamics of economic development, rather than simply trying to preserve existing practices – in a word, they need to become more *transformational* in nature.

The remainder of our review proceeds as follows: In Section 2 we review the reinforcing dynamics between poverty and vulnerability to climate change, with an emphasis on the barriers to optimal adaptation for poorer households. In particular, we highlight the challenges for credit-constrained households in coping with (environmental) risk, and engaging in productive (entrepreneurial) investments, including adaptive investments. In Section 3 we highlight the dynamic interactions between existing development trends and adaptive responses to climate change at the household level. Section 4 presents several mechanisms through which government policies can best manage the dual challenges of adaptation to climate change and economic development, to achieve sustainable, climate-resilient development. Section 5 concludes, highlighting some open research questions.

2. Barriers to adaptation at the household level

Climate change represents a change in the distribution of future weather (Daron and Stainforth, 2013), and economic activity will be sensitive to more than the mean of that distribution (Stainforth et al., 2007; Weitzman, 2009). Changes in weather variability and in the frequency of extremes are anticipated to have a stronger influence on impacts than changes in

average weather (Revesz et al., 2014), for example due to observed non-linear effects of weather on economic activity (Burke et al., 2015b) and on crop growth (Schlenker and Roberts, 2009). Such effects will be particularly important in determining how climate change affects development. While predicting changes in extremes is challenging, it is confidently expected that weather risk (both variability and extremes) will increase for many developing countries under most climate change scenarios (see e.g. SREX, 2012; Stainforth et al., 2013), exacerbating already challenging climatic conditions in developing countries (World Bank, 2010, 2013a; Samson et al., 2011; IPCC, 2014).

Why poorer households are more vulnerable to climate change

One reason the poor are more vulnerable to climate variability and shocks is their reliance on agriculture. In Appendix A, we present simple indicators of the link between poverty and climate vulnerability in countries highly dependent on agriculture, hinting at the dual challenge of development and adaptation to climate change. Poorer households in urban areas may also be vulnerable to climate risk because of settling in riskier locations (the poor are often priced out of safe areas), with little or no infrastructure and poorly constructed housing. In recent decades, exposure to climate risk has been increasing globally; while the world population grew by 87% between 1970 and 2010, the population in flood plains increased by 114% and in cyclone-prone coastlines by 192% (Hallegatte et al., 2016a). Recent work by the World Bank has also found that the poor are disproportionately exposed to flood risk, particularly in urban areas, including slums, based on evidence from Africa (Winsemius et al., 2015) and Vietnam (Bangalore et al., 2016).

Development and industrialisation mean that citizens in rich countries depend little on weather-contingent production activities and can also use more resources to protect themselves against the direct effects of adverse weather conditions (Fankhauser and McDermott, 2014). Not so for the poor, who aside from being more dependent on weather-sensitive economic activities, and residing in areas of higher climate risk, also tend to be financially constrained. Not only do

the poor lack own resources (by definition), but they are also often shut out of credit markets -- since they lack the collateral required to obtain a loan -- constraining their ability to cope with risk. In Appendix B, we present some simple descriptive statistics illustrating the relative gaps in access to credit and financial services in poorer countries. This represents another fundamental barrier for optimal adaptation. A lack of financial reserves makes the poor vulnerable to income shocks – with consequences for health, education, investment, productivity – and ultimately in danger of falling into poverty traps (see e.g. Skoufias et al., 2011; and further discussion in Section 3).

The climatic vulnerability of the poor is further compounded by marginalisation along various dimensions; including gender, ethnic, political and geographic discrimination. For example, the literature on climate impacts appears to show a greater income elasticity of female opportunities and wellbeing, including access to education and health (see e.g. Maccini and Yang, 2009; Henderson et al., 2014) indicating the potential for climate shocks to exacerbate existing gender inequalities.[5]

Political and geographic marginalisation can also play important roles in reducing or exacerbating the effects of climate stress. Globally, poverty is geographically concentrated in locations that are already marginal from a climate and agricultural productivity perspective. For example, a high proportion of Africa's rural poor live in pastoral and agro-pastoral drylands, with poverty in these regions attributed to climate variability and vulnerability to drought (FAO 2008). Various measures of human well-being have also been found to deteriorate with aridity; e.g. infant mortality, child malnutrition, maternal care, adult literacy and access to education (de Sherbinin, 2009). Political and geographic isolation is also likely to affect the provision of basic

[5] Existing patterns of discrimination against women can also be exacerbated by climatic stress, via income shocks (as noted in Dell et al., 2014). For example, the murder of "witches" – typically elderly women – in Tanzania has been found to increase in response to extreme rainfall events (Miguel, 2005); the frequency of witch trials also increased in response to cold weather in 16th-18th century Europe; and dowry killings were found to be higher during recent periods of low rainfall in India (Sekhri and Storeygard, 2011).

infrastructure, access to markets (transport), financial services, and the under-provision (by both public and private sectors) of basic services including health and education (Anbarci et al., 2005).

The anticipated impacts of climate change on the poor will depend on the interaction of the severity of the climatic stress and the exposure, vulnerability and adaptive capacity of the societies affected. For example, projections of climate change impacts on agricultural productivity depend heavily on assumptions about, among other things, the degree of future climate change and the local adaptive responses of affected people and societies. In agricultural settings, adaptation may be limited in part due to a lack of basic infrastructure. For example, one crucial type of infrastructure relates to irrigation, as optimal crop growth depends on the right combination of ambient temperatures and water availability.[6] Man-made (and natural) irrigation, and to a lesser extent temperature control techniques (e.g. using greenhouses) can reduce dependence on the weather.[7] Various studies have highlighted the problems due to under-provision of irrigation and other farm inputs (see Cooper et al., 2013). In Africa, the situation is particularly dramatic, with just four per cent of agricultural land irrigated, compared to 18 per cent globally (Yu et al., 2010).[8] Growth (or contraction) of agricultural production has a disproportionately large impact on poverty, compared with changes in output from other sectors in developing regions (Valdés and Foster, 2010; Dercon, 2012). The significance of irrigation in reducing vulnerability of agriculture to weather shocks, especially relevant in the context of climate change, highlights the role of basic infrastructure in enabling adaptation to climate risk, as demonstrated in recent empirical studies for the Indian case (i.e., Jayachandran, 2006; Burgess and Donaldson, 2010; Burgess et al., 2011). Beyond irrigation, and other agriculture-linked infrastructure, a lack of access to basic services (e.g. energy and sanitation) might represent

[6] Combined with soil quality and other inputs such as fertilizer, farm labour etc.
[7] The availability of irrigation depends on a combination of capital owned by farmers, e.g. small irrigation systems, and (public) water infrastructure, e.g. water reservoirs and irrigation canals. See e.g. Schlenker et al. (2005) and Fishman (2011), on the importance of the distinction between irrigated and rain-fed agriculture for anticipated climate impacts on yields.
[8] Low fertilizer use might represent a rational response to unreliable water supply, in the form of high rainfall variability and low provision of irrigation, since the returns to fertilizer use depend on the timing of watering during the cropping cycle (Henderson et al. 2014).

another critical infrastructure-related barrier to the adaptation options available to the poor – especially women and girls, since the burden of domestic activities tends to fall disproportionately on them (UNDP, 2011). Appendix C illustrates the gaps in basic infrastructure provision in many poorer countries, including those that are particularly vulnerable to climate change impacts.

Most adaptation – and certainly the autonomous adaptation of private individuals and firms – will depend on informed decisions by individuals. Actors will respond appropriately to changing conditions when they have adequate information, appropriate incentives and an environment conducive to investing in required changes (Collier et al., 2008). Empirical work in Ethiopia confirms that farmers who are better informed about farming practices and climate change are more likely to adapt (successfully) and experience, on average, higher productivity and output (Di Falco et al., 2011). However, acquiring information may be costly for individuals, and the inability to access quality information may represent an important barrier to optimal adaptation. Weak property rights in many developing countries might represent a further barrier to adaptation for poorer households.

Why poor households might miss profitable opportunities to adapt

Climate change poses a direct threat to the livelihoods and wellbeing of the poor, via various channels, including its expected impacts on agricultural production (Aufhammer and Schlenker, 2014), health (Deschenes, 2014), and the ability to invest in long-term assets including education (Hallegatte et al., 2016b). More generally, climate change will involve an increase in weather risk, particularly in developing countries. The difficulty faced by poorer households in coping with risk has long been a central theme in development economics. As the work of Collier et al. (2008) suggests for the African case, informal coping mechanisms at the household or community level are often relatively well developed in poor, subsistence agriculture and pastoralist settings, enabling households to at least *survive* short-run shocks. The longer-term capacity for *sustained* adaptation to new circumstances (or the adoption of new technologies), by contrast, is often

limited in those same settings – in part because poorer households have less capital-intensive technologies; because their economic activities – whether farming or other – tend to operate at relatively small scales (with implications for management practices and the capacity to experiment with new technologies); due to an aversion to experimentation, deriving from precarious livelihoods; and also because they often lack access to credit and other financial services (as detailed further in Section 3 below).

The barriers to optimal adaptation that poor households face can be formalised in a simple way.[9] Consider a poor household that starts with assets A_t, and receives weather-dependent income y_{st}, which depends on state-of-nature $s \in S$ in period *t*. In any period, the household has cash on hand $x_t = A_t + y_{st}$. The household can save some portion of its cash on hand – to protect itself against uncertain future income flows – and earns interest at rate R on its savings. However, due to credit constraints, the household is unable to borrow to fund consumption. Consumption in any period must therefore be less than cash on hand $(c_t \leq x_t)$.[10] The household also has the option to invest in "adaptation"; which might include for example, the adoption of new technologies to reduce weather-dependence in agriculture (e.g. irrigation, new crop varieties or planting techniques), diversification of income streams away from weather-dependent activities, or migration away from areas adversely affected by a changing climate. We think of adaptation as being a risky activity for the household. If adaptation is successful, the household receives a positive (net) return of *m*. However, if adaptation is a failure, the household receives no return, and has to pay costs *F* for the failed experiment. With full information, and appropriate incentives, the household faces a simple choice about whether to experiment with adaptation (Collier et al., 2008). However, in a developing country context, these conditions are

[9] The aim is to clearly i) capture the different channels through which climate change might impact on the welfare of a credit-constrained household, which derives its main source of income from weather-dependent activities; ii) potential responses by households; and iii) opportunities for policy intervention to enhance optimal adaptation that is also conducive to sustainable economic development.

[10] The notation here draws on the model presented in Bryan et al. (2014), who analyse the propensity of income-constrained households to experiment with migration, which in turn builds on the classic Deaton (2001) buffer stock model and its applications for example in the poverty trap literature (e.g. Banerjee 2004).

often not met – particularly for the poorest and most vulnerable households.

With uncertainty about the success of the new technology, the household chooses in each period both whether to experiment with adaptation, and consumption/savings. If it decides to experiment, the new technology will be successful with probability π_p and has value P(x).[11] However, if the experiment fails, then it has paid the cost F and receives value B(x – F)[12]. The household with cash on hand x chooses to experiment if the expected utility is greater than not experimenting, and therefore solves

(1)

$$V(x) = \max\left\{ \max_{c \le x} \left[u(c) + \delta \int_S V(y_s + R(x-c)) d\mu(s) \right], \ \pi_p P(x) + (1-\pi_p) B(x-F) \right\}$$

where u is a standard strictly increasing, strictly concave utility function and δ is the household's discount factor.

As equation (1) illustrates, there are two specific sets of circumstances (with different policy implications) where the (private) household will not avail of potentially profitable adaptation opportunities. The first is when cash on hand, x, is so low such that aversion to experimentation prevents poorer households from engaging in risky (but productive) adaptation activities – since any failed experiment can have devastating consequences taking consumption below required levels for survival. The second is when the expected probability of success, π_p, is low.

In the first case, the household becomes infinitely risk averse and is unwilling to consider experimenting with risky adaptation even if expected returns are positive. The household is in a

[11] $P(x) = \max_{c \le x+m} \left[u(c) + \delta \int_S P(y_s + R(x+m-c)) d\mu(s) \right]$

[12] $B(x-F) = \max_{c \le (x-F)} \left[u(c) + \delta \int_S B(y_s + R(x-F-c)) d\mu(s) \right]$

type of poverty or vulnerability trap. There are several policy channels available to encourage more productive risk taking in this case. First, policy could aim to raise x, for example through a cash transfer programme or through initiatives aimed at improving agricultural yields (increasing the expected value of weather dependent income). Secondly, policy could aim to relax the credit constraint $(c \leq x)$, for example by improving access to financial services. A third option is to reduce the negative consequences of a failed experiment (reducing *F*), for example by offering some form of insurance or social safety net. Improved infrastructure might also reduce the costs associated with adaptation experiments. In Section 4, we explore the available evidence on how such policy options operate in practice.

In the second case, when expected probability of success is low, the household chooses not to experiment with adaptation, not because it cannot afford to, but because it does not consider that the expected returns are sufficient to warrant investment. There are two possibilities here: the first is that the household is correct in its belief, and the household specific returns to adaptation are insufficient to justify investment, for example because the household lacks the skills or experience required to make a success of adaptation, because available adaptation technologies are not appropriate to local conditions, or because property rights are insecure and the household will not be able to appropriate the full gains of its investment. Policy in these circumstances could target training in the skills required to successfully implement adaptation technologies, the development of locally-tailored adaptation options, or improvements to property rights. The second possibility is that the household has underestimated π_p. In this case, policy could aim to provide more or better information on available adaptation options and how they work, or to provide better information on future weather patterns and the need for (and likely benefits of) adaptation to new weather conditions. Again, we explore available evidence on the operation of these policy options in Section 4. First, we turn to the dynamic interaction of adaptation with underlying development trends from the perspective of poor households.

3. Household responses to climate risk in a developing country context

While most attention in the literature on adaptation has focused on policies undertaken by governments (Fankhauser and Soare, 2013), private agents – households, communities and firms – also undertake important initiatives that help to mitigate or adapt to climate change. Households will react autonomously to changing environmental conditions. However, as noted above, poorer households face various barriers that limit their ability to adapt efficiently, while some risk coping strategies may ultimately lead to maladaptation. For policy to be effective, and efficient, in pursuing optimal adaptation it is important to first understand how household responses to changing risk – mediated by the incentives and policy environment they face – can impact on their climate vulnerability. In this section, we review what the literature has identified as the main responses from poor household to the risks brought about by climate change. We do so analysing the pertinence of these responses not only in terms of adaptation (as traditional in the climate literature) but also in terms in of the process of economic development and poverty reduction.

Coping with risk, and taking risks

Access to finance is still very limited in many poor and developing countries (see Appendix B). Limited access to financial products, such as credit, saving opportunities, transaction facilities and insurance, not only constrains economic growth and poverty reduction but also hinders adaptation to climate change. Financially constrained households cope with risk in non-efficient ways, both *ex-ante* and *ex-post*. *Ex-ante* they either hold low-return liquid assets (Rosenzweig and Binswanger, 1993) or diversify productive activities. Liquid financial assets often carry negative real interest rates, and real liquid assets either have high costs of storage, such as grain, or are themselves vulnerable to climatic shocks: notably, during a drought the price of livestock will decline owing to synchronised pressures to sell (Dercon, 2002). Engaging in several productive activities deprives households of the benefits from scope and specialisation. Empirical works on

Thailand and India have shown that *ex-post* financially constrained households adapt by drawing on savings (Paxson, 1992); selling productive assets (Deaton, 1992); increasing labour supply, which on aggregate reduces wages (Kochar, 1999); sending children to work rather than to school (Jacoby and Skoufias, 1997); or engaging in informal expensive borrowing (Banerjee and Duflo, 2011). These informal risk management strategies are associated with increased poverty, lower investment and lower growth (Elbers et al., 2007).

Another important constraint on adaptation to climate change – closely related to problems accessing finance -- may be aversion to experimentation, which is prominent especially amongst poor households (Bryan et al., 2014). An inherent obstacle for the poor in escaping poverty – especially for those living close to subsistence – is that any failed experiment can have devastating consequences for household finances and welfare. Clearly the aversion to experimentation problem presents a key challenge for climate change adaptation, and will affect both *in-situ* and *transformational* adaptation strategies. For example, adaptation in the case of agriculture may require the adoption of new technologies (e.g. drought resistant seed varieties, investment in irrigation or changes in production methods) and learning about new weather (growing) conditions. Similarly, diversification activities require entrepreneurial experimentation, while migration strategies often involve experimentation with seasonal migration or sending a household member to look for work in another location – often a nearby town or city, or even abroad. Bryan et al. (2014) make the point that this phenomenon can also explain the relatively low adoption and diffusion rates of 'Green revolution' technologies across South Asia.

Migration

Migration – particularly temporary or seasonal migration – has long been used as an important risk-coping strategy of poorer households facing uncertain income flows, resulting from adverse weather conditions and other external shocks (e.g. Laczko and Aghazarm, 2009; Wisner et al., 2004; Ellis, 2000; Marchiori et al., 2013) – a mechanism for household level income smoothing

(see also in this context the discussion of remittances below). Migration can also be a mechanism for raising average labour productivity -- as a result of permanent relocation of labour from less to more productive locations (e.g. from isolated, rural hinterlands, to high-productivity, coastal, urban locations). In either case, migration has the potential to generate significant welfare gains for migrants and their families (Dercon, 2012; Clemens, 2011).

It has been observed that some 90% of production and 72% of population occupies just 10% of land worldwide (Desmet and Rossi-Hansberg, 2015). This extreme concentration might render people and economic activity particularly vulnerable to threats posed by climate change. For example, recent research found striking evidence on the global exposure to urban flooding, and the concentration of economic activity in vulnerable locations (Kocornik-Mina et al., 2015). Of course, the relative abundance of unoccupied (or under-utilised) land globally, suggests a seemingly simple solution – moving people and their economic activity away from locations where risks are rising or productivity decreasing. Using a calibrated model, Desmet and Rossi-Hansberg (2015) show that climate damages are minimised by full mobility across space, but may be substantial if migration across borders is restricted. However, for the poor, an equally significant constraint may be the financial cost of migration and associated risk (see e.g. Abramitzky et al. 2013 in the case of the Norwegians during the Age of the Mass Migration (1850-1913) and more recently Bryan et al. 2014 in the case of Bangladesh), which creates an income or wealth threshold to migration.

While much of the literature on climate-migration has tended to focus on debates over the potential for mass waves of "climate refugees" (e.g. Myers and Kent, 1995; Gemenne, 2011; François, 2011), in reality it is often not the most vulnerable, or those directly affected by climate shocks, that are most likely to move as suggested by Gray and Mueller (2012) in the Ethiopian case and by Ó Gráda and O'Rourke (1997) in their historical work on the Great Irish famine during the 19th century. There appears to be relatively little evidence on *cross-border* migration in response to climate shocks (Beine and Parsons, 2013; Boustan et al., 2012; Drabo and Mbaye,

2011; Hornbeck, 2012). Instead most climate-induced migration is likely to occur within countries, and predominantly involving movements from rural to urban locations (see e.g. Barrios et al., 2006; Marchiori et al., 2012; Henderson et al., 2014).

Migration is costly and there are numerous barriers to migration, especially for poorer households who are often most vulnerable to climate risk. The inability to migrate – and the potential for populations to become trapped in marginal or vulnerable locations – thus represents an important, and relatively neglected, policy concern (Dercon, 2012). Constraints to migration are both financial, e.g. credit constraints and transport costs; and informational, e.g. knowledge, networks, and education (see e.g. Munshi, 2003; Hatton and Williamson, 2006; Gray and Mueller, 2012). Institutional factors will also affect both the ability to migrate (e.g. due to requirements for permits, e.g. in China), and the success of that migration. For example, Collier et al. (2008) point out that where tenure/land rights systems are based on traditional or ancestral claims, access to land may be problematic for newly arrived migrants. Policy barriers in destination countries also act as a major constraint to international migration – as evidenced by the 13.6 million applications for just 50,000 visas allocated by the US Diversity Visa Lottery (Clemens, 2011).

Climate change is likely to alter the character of migration patterns, and may even act as a further constraint on the migration opportunities of the most vulnerable populations, for example where the ability to accumulate the necessary resources is negatively affected (Gray and Mueller, 2012). In the context of climate change, migration also carries risks. For example, there is the risk of disorderly or reactive migration in response to climate shocks, potentially leading to disruptions of economic activity and in some cases conflict (see further discussion in Waldinger, 2016). A further risk is that internal migration – particularly the rapid urbanisation currently occurring in many developing countries – whether driven by economic or environmental forces, will place additional strain on scarce resources (e.g. infrastructure and housing) in receiving locations, potentially increasing the vulnerability of migrants to climate risk.

Remittances

An alternative source of finance for many developing countries and poorer households is remittances from family members living in domestic towns and cities or abroad. Remittances are increasingly used as a means of coping with climate shocks (Yang and Choi, 2007; Yang, 2008; Arezki and Brückner, 2012). International remittances have been on an increasing trajectory in recent years, gaining greater attention in the academic literature as a result (Clemens, 2011). International remittances represent significant sources of investment for many developing countries (up to a quarter in Sub-Saharan Africa, according to Arezki and Brückner, 2012). The scale of remittances now far exceeds aid flows to developing countries, and is equivalent to total private debt and portfolio equity flows, although to date there is little evidence of any effect of remittances on aggregate economic growth (Clemens and McKenzie, 2014).

Remittances can play a key role in providing finance alternatives when internal financial markets are underdeveloped, and appear to have first-order consequences for poverty at the origin as well as the welfare of migrants and their families (Clemens and McKenzie, 2014). Remittances can work either as an alternative source of credit for investment – and therefore react to productivity shocks – or as insurance to smooth income and consumption, and therefore react to income shocks. Arezki and Brückner (2012) show that when financial development is low, remittances react positively to productivity shocks, induced by improved rainfall, i.e. they are pro-cyclical, encouraged by high-return investment opportunities. However, when financial development increases, remittances seem to react in a counter-cyclical way to smooth consumption in the face of income shocks (also due to changes in rainfall). This finding suggests that although remittances potentially act to fill a financing gap in developing economies, they are most likely to play a complementary role to other sources of finance, and their effectiveness (and reach) is dependent on the development of the (domestic) financial sector.

4. How can governments best intervene: policies to foster optimal adaptation

So far, we have reviewed the main barriers to optimal adaptation (Section 2), and the expected response from households (Section 3), which includes potential for maladaptation. Building on this, a natural question is how government policies can best manage the dual challenges of adaptation to climate change and economic development to achieve sustainable development.

We have analysed optimal adaptation as reducing climate exposure without compromising prospects for poverty reduction and economic development. And we have made a distinction between *in-situ* and *transformational* adaptation (including sectoral and location mobility). The former is probably more relevant in the short run, and in many cases (not always) may be easier to implement. The latter, however, may be more desirable for poverty reduction and long-run economic development. But, as discussed before, several barriers exist that prevent transformational adaptation and therefore optimal long-run adaptation. It follows that one initial and main role for government intervention is to reduce these barriers to facilitate not only *in-situ* adaptation but also *transformational* adaptation, especially when the latter is most appropriate for poverty reduction and long-run economic development.

The different barriers that households face can be understood as traps; they keep households in poverty and more vulnerable to climate change. Relaxing these barriers can help poor households escape poverty traps, adapt better, and reduce their vulnerability to the risks brought about by climate change. Policy in this direction can therefore enhance at the same time adaptation and economic development. But one should not assume that the best form of adaptation is simply to pursue economic development. Certainly, many of the barriers to adaptation that we have identified have also long been recognised as barriers to escaping poverty. In one sense, this is a very positive message – that the goals of achieving economic development and of reducing vulnerability to climate change can coincide (as argued famously by Schelling, 1992, 1997). However, just as aggregate economic growth does not automatically translate into poverty reduction, economic development does not necessarily result in reduced vulnerability to

climate change. The shifting structure and location of economic activity that typically accompanies development will only result in reduced climate vulnerability to the extent that the expanding sectors and locations are not themselves subject to climate risks (Fankhauser and McDermott, 2016b). Many will be – for example, if economic development involves greater dependence on water-intensive production or if firms become more vulnerable through their (increasingly complex) supply chains (ASC, 2014). Household level decisions will also impact on vulnerability – for example, the large-scale movement of people towards coastal cities in Asia has been associated with a massive increase in flood risk exposure (Hansen et al., 2011).

Our analysis in Section 2 identified several policy channels to enhance the capacity of households to cope with climate risk and facilitate optimal adaptation. In the case of poor households living close to subsistence, the government can enhance productive risk taking through cash transfers, initiatives aimed at improving productivity - including the provision of infrastructure, and improving access to financial services and safety nets. Beyond these policies, the government can improve expected returns from adaptation (not only for poor households). In this case, policy options include technical training, the development of locally-tailored adaptation strategies, and the improvement of property rights and information available to households.

Providing infrastructure

As discussed above, the lack of adequate infrastructure is probably one of the most critical barriers for optimal adaptation, be it *in-situ* or *transformational*. Increasing resilience to changing rainfall patterns and weather conditions brought about by climate change is one important element of *in-situ* adaptation in agriculture. In this regard, providing irrigation infrastructure, or supporting investment to increase agricultural productivity, becomes an important policy option.

Beyond agriculture, the provision of basic infrastructure (e.g. energy, sanitation and transport) also represents an obvious role for government, and a first step in creating an 'enabling environment' for autonomous adaptation. However, public investment in infrastructure projects

raises the thorny issue of decision-making under (deeply) uncertain climate change (see e.g. Stainforth et al., 2007). Such uncertainty represents an additional motivation for policy-makers to prioritise building adaptive capacity, in particular economic flexibility of vulnerable groups, above defensive infrastructure investments (e.g. flood defences), which are much more subject to concerns about uncertainty (see e.g. Watkiss, 2016; McDermott, 2016).

Much of the basic infrastructure we refer to here (e.g. energy, sanitation and transport) will be required regardless of climate change to bridge the large gaps in basic infrastructure provision (illustrated in Appendix C) as well as to cater for rapidly growing population in many developing countries. Dietz et al. (2016), focusing on Africa, highlight the enormous anticipated investments in physical capital that will be required in many developing countries over the coming decades to meet these needs. Improved access to basic services will likely contribute to building resilience under a range of plausible climate scenarios. An important policy concern here should be the incorporation of climate risk into investment planning – acknowledging that any infrastructure provision represents a form of commitment to a specific location, with the risk of *increasing* vulnerability to climate change, if not planned with future climate conditions in mind. There is also a role for government in ensuring that capital intensive (and thus by definition, longer-term) investments are based on sustainable resource use (e.g. water), taking account of anticipated future climate trends. To this end, it is important that government policies do not distort information in the form of market signals. For example, government subsidies on scarce resources (including water) might deter vulnerable households from making timely and efficient adaptation decisions. Since information – e.g. on existing climate variability and anticipated climate change – is another form of public good, there is clearly a role for government in providing information as a further element of creating an enabling environment for (successful and efficient) adaptation. We return to this theme later in the section.

Access to (formal) financial services

i) Credit

Aside from the provision of infrastructure, governments can also enhance optimal adaptation (and risk taking) by relaxing credit or financial constraints faced by the poor. Relaxing credit/financial constraints on the poor could help them not only to cope better with exogenous risk, but also to take on riskier (and theoretically, more efficient) investments (e.g. Cai et al., 2009; Galarza and Carter, 2011; Hill and Viceisza, 2012; Mobarak and Rosenzweig, 2013). Several authors provide micro-evidence on the positive effects of financial expansion to increase households' income and consumption, and therefore to reduce poverty (Burgess and Pande, 2005; Karlan and Zinman, 2010; Kaboski and Townsend, 2012). Improved access to finance – as a means of coping with greater risk and escaping poverty – could therefore represent an important instrument for adapting to climate change (Hecht, 2008; Ward et al., 2008; Agrawala and Carraro, 2010; MCII, 2012, 2013; among others).

However, expanding access to finance for poor or vulnerable households is far from easy (Agrawala and Carraro, 2010; World Bank, 2013b). Microfinance can be a possible remedy. By definition, microfinance schemes rely on small-scale transactions but potentially for many customers; there is therefore a need for service providers to find cost effective means of reaching a broad customer base. Communications technology could facilitate such a process (see e.g. King, 2012). For financial services to be provided to the poor in a sustainable way, profitability for private providers has to be attained. For microfinance to make a real difference, it therefore has to become both attractive and affordable for poor individuals at the same time as profitable and financially sustainable for providers (Clarke and Grenham, 2013). From the user's perspective, there are also question marks over the usefulness of microfinance, since it may predominantly benefit those with an *a priori* propensity to become entrepreneurs (Banerjee et al., 2015). A second issue relates to the design of microfinance schemes; the commonly used joint liability schemes might have the benefit of delivering high repayment rates, but this could also discourage risk-taking, making investment in high-return activities less likely - see Fischer (2013) on a series of experiments with clients of a large microfinance institution in India.

There are also limitations to the effectiveness of financial instruments in coping with risks, particularly when shocks recur with relative frequency, repeated borrowing could simply result in greater indebtedness.[13] Differences in the nature, reach, frequency and impact of climate shocks, call for different strategies (see e.g. Hallegatte et al., 2010; Mechler et al. 2014). Access to finance can be a useful tool for adaptation to some, but not all, climate-related shocks (MCII, 2012). When shocks have low frequency but high impact, financial services, such as credit, savings and insurance, can play a key role in poor households' adaptation to climate change. When shocks have higher frequency the need for large-scale intervention, for instance investments in infrastructure, may become necessary.

A final question mark relates to the external validity of existing findings in relation to microfinance schemes; can the success stories be scaled up and replicated in other settings? Further research is required, in particular on the specifics of how microfinance can best be implemented to deliver maximum benefits for the poor.

ii) Insurance

One instrument for dealing with income shocks resulting from climate variability and change is insurance. In the absence of transaction costs, insurance offers an efficient response to climate risk (Collier et al., 2008), particularly where combined with risk mitigation. Microinsurance, in particular, not only allows for better risk management but, by increasing creditworthiness of individuals, it can also promote investments in productive assets that might be riskier but also of higher return (MCII, 2013).[14] An additional feature of insurance schemes might be a commitment effect, which for example savings schemes generally lack; that is, insurance would only pay out following a weather shock (or loss of output) whereas savings might be drawn down to cover

[13] Frequent shocks that affect large numbers of households, depressing the local economy, could also result in micro-finance initiatives themselves becoming indebted or even bankrupt, particularly where these schemes are not well diversified geographically.

[14] The MCII (2013) report describes the major components of a risk management framework including risk identification, risk reduction, financial protection, preparedness, and post-disaster reconstruction.

other fluctuations in income or household expenses.[15] However, there are numerous challenges to implementation of an effective weather insurance scheme. Aside from the standard insurance problems of moral hazard and adverse selection, insuring against weather risk also faces the additional challenge of coping with covariant (regional) as opposed to individual shocks. From the demand side, there are also challenges to deal with (see e.g. Hecht, 2008): For example, limits on time and other resources necessary to obtain or use information (e.g. about climate risk) may cause people to disregard those risks. Perceived or real budget constraints may also deter poorer households from paying for insurance, while people also tend to view insurance as an investment rather than as a hedge against loss, leading to underinsurance.

Providing traditional *indemnity insurance*, in which the claim payment depends on the policyholder's loss, against weather risk faces the familiar moral hazard problem, which might be particularly strong in the context of the type of business activities engaged in by many poorer households. For example, in a rural agriculture setting, observing the effort of many small policyholders can become very expensive. Similarly, in urban areas many poorer households depend on small-scale activities and the informal economy – where business is often not conducted at a fixed location – observing effort and loss assessment may become virtually impossible. An alternative might therefore be *indexed insurance* products (Clarke and Grenham, 2013), where claim payments are triggered by for example rainfall dropping below some predefined threshold, which is expected to cause agricultural output losses. Indexed insurance can overcome the problems of moral hazard and adverse selection, while reducing the cost of monitoring. It can also be sold to many households relatively easily, increasing the customer base for the insurer, and facilitating accelerated claim payments, which can be of major importance for poor households. However, there are a few drawbacks to indexed insurance. For one thing, indexed insurance is simply a hedge against risk and does not necessarily foster adaptation. Furthermore, indexed insurance schemes require good historical data on climate (and its impacts

[15] Of course, it is debatable whether this should be viewed as an advantage or disadvantage of insurance schemes in the context of credit-constrained households.

on output) and that these data are a good guide to future weather distribution and associated losses (Collier et al., 2008) – which is a challenge in the best of circumstances, but particularly so under uncertain climate change and using the spotty climate data available in many developing countries.

According to Clarke and Grenham (2013), a combination of indemnity and indexed insurance can offer a solution. Local community indemnity-based mutual insurance groups can provide protection from individual shocks (with the community playing the role of controlling moral hazard and adverse selection), while indexed insurance can provide protection to the mutual against aggregate shocks (like climate-related shocks) by transferring the risk to reinsurers.

Providing access to insurance is more complex and difficult than providing other financial services, such as credit (MCII, 2013). To date, successful (micro) insurance schemes that have been implemented have mostly relied on government funding. The challenge for government then becomes one of attempting to facilitate, but not substitute, (micro) insurance provision by private insurance providers. There is also a question mark over the cost of insuring against climate risk, particularly in low-income environments.

It has been suggested that insurers can help society to adapt to the impacts of climate change, by promoting the effective limitation and management of risks from extreme weather-related hazards (Wilbanks and Romero Lankao, 2007) and by facilitating "the creation of new markets and services that will help to solve the climate change problem" (Hecht, 2008, p. 1585). However, the effect of insurance on risk-taking behaviour is unclear. Ward et al. (2008) suggest three main channels through which insurance can help to promote efforts to adapt. The first of these relates to the provision of information about reducing vulnerability, and therefore improving insurability, of properties. The second relates to financial incentives, whereby insurers can provide discounts or make insurance conditional on efforts to mitigate the impacts of extreme weather. The final channel emphasises the role of partnerships with policy-makers to establish maximum thresholds of acceptable risk, and actions to remain below those thresholds.

Despite the theoretical benefits, empirical evidence remains limited; for example, Surminski and Oramas-Dorta (2013), in a study of 27 flood insurance schemes in developing countries, find that only a small proportion (less than 40 per cent of the schemes studied) have either a direct or indirect association with risk reduction beyond risk transfer.

An important question is; does insurance lead to more or less risk taking? Perhaps more important again is the normative question; *should* insurance lead to more or less risk-taking? If paying actuarially fair premiums, then insurance is "efficient" in the sense of providing a risk-coping mechanism, while still ensuring that agents internalise risks (and their costs). Subsidised insurance schemes, on the other hand, could lead to inefficient risk-taking behaviour and sub-optimal levels of adaptation. Both the positive and normative questions raised here appear deserving of further attention from researchers.

Cash transfers and social safety nets

For those most vulnerable to climate risk, inadequate access to market services is likely to be particularly acute. Beyond the provision of infrastructure and financial services, social safety nets may therefore form an important part of a broader poverty reduction strategy that helps among other things to redistribute income to the poorest and most vulnerable, to enable households to make better investments and to help them to manage risk, particularly when faced with unexpected shocks (Grosh et al., 2008). In fact, the 2010 World Development report argued that the creation and reinforcement of social safety nets is critical to adapting to the impacts of climate change (World Bank, 2010). One important caveat to the use of social safety net schemes as (public) insurance against climate risk is that their availability might reduce incentives to adapt or reduce vulnerability. This concern reinforces the importance of the careful design of such schemes, so that they support efficient risk-taking – i.e. risks and investments that are productivity enhancing.

Although for emergencies the most common type of transfer is the in-kind programme, their effects seem to be small and in the very short-run. Yet, there is evidence that in-cash safety

net programmes, e.g. those implemented in Somalia and Swaziland, have had a positive impact during emergencies (Pelham et al., 2011). Even during conflict periods in Somalia, evidence shows that cash could be delivered and distributed safely and is less prone to diversion than food transfers (Majid, 2007). Cash payments have often been used in social welfare programmes and in emergency responses (as insurance and as relief) in developed countries. However, their implementation in developing countries may take time and more regulation and monitoring due to weaker institutions and enforceable laws.

The advantages of cash transfers are related to their potential positive externalities in terms of stimulating local markets whereas the negative side is that cash is particularly susceptible to changes in the market and increases the risk of inflation (Pelham et al., 2011). Cash provides more flexibility and choices to participants whereas transfers in-kind are more rigid and have a limited use. Cash transfers can help to build assets or provide households with contingency finance for mitigating climate-related risks. In-kind transfers such as food have a more direct impact on consumption, whereas cash has a direct impact on asset accumulation. Cash is also more empowering since decision-making power is transferred directly to households. This benefit can be magnified when disadvantaged groups, such as women or the elderly, receive the cash directly. This has been the case in Swaziland, where women have benefited directly from cash transfers (Pelham et al., 2011). In terms of maximising household choice, cash gives more decision options and allows households to decide how best to allocate their resources. However, it is common to observe that households decide to meet other urgent needs (e.g. paying debts), with the result that programme objectives, such as health and education, remain unaffected (Bailey, 2008). A further drawback of cash payments during a period of crisis – e.g. following a natural disaster – is that markets may be (temporarily) disrupted so that providing cash is not sufficient to ensure that affected people are able to access food and other essential supplies.

In terms of the applicability of cash transfer to climate risk, there is evidence that conditional cash transfer programmes in Central America have been able to help participants and

to protect children from being taken out of school and used as a risk coping strategy after a shock (de Janvry et al., 2006). Ethiopia has also implemented a productive safety net programme since 2008, which aims to meet transient food insecurity as well as responding to longer-term needs. In this programme, more than eight million employees are paid with food and/or cash in return for work on community-based public works activities for up to 6 months (Pelham et al., 2011).[16]

Providing information, correcting incentives, and defining property rights

As discussed above, access to reliable information, appropriate incentives, and well-defined property rights, are fundamental for optimal adaptation. Understanding information as a public good, and consequently the lack of it as an important market failure, justifies a role for policy. Relevant information for adaptation decisions might also go beyond making existing modes of production more resilient, to include information that facilitates *transformative* adaptation; for example, information on job opportunities for migrants and on local opportunities for diversification and entrepreneurial activities for those who wish to remain. Governments might also intervene to encourage long-term investment (e.g. in education, health and productive assets) or to improve access to credit for small borrowers, since imperfect information may prevent small borrowers from obtaining credit to finance adaptive investments (Fankhauser et al., 1999).

In addition to providing information, a key role for governments in creating an enabling environment for adaptation is to ensure that private sector actors have the incentive to adapt. In many cases, this means that governments commit *not* to act, to avoid creating moral hazard by for example trying to insulate households and firms from risk. Governments that react quickly to any adverse shock may produce perverse incentives for private actors, weakening the incentive to reduce exposure to risk, as suggested by Deressa and Hassan (2010) in the Ethiopian context. However, getting incentives right is not just a matter of committing not to act.

[16] In the Supplementary Online Materials (available at [include url here]), we discuss further examples of social safety net schemes in operation in several semi-arid countries, which are the focus of the PRISE research project. In particular, we discuss schemes that may be relevant for responding to climate shocks and for improving the resilience of poorer households.

Another crucial component in creating the right incentives for adaptation is the allocation and enforcement of property rights. Several studies show how better definition of property rights improve investment incentives in agriculture (see for instance the studies about Ghana of Besley, 1995, and Goldstein and Udry, 2008). This suggests the importance of property rights in adapting to climate change, given that successful adaptation will require consideration of the long-term sustainability of investments and resource use. Moreover, the evolution of property rights and their effect on important variables like productivity, investment, output, and access to credit among others is an important issue in development economics and has been seen as a key precondition for economic growth (Furubotn and Pejovich, 1972; Locke, 2012). Consequently, improving property rights could have important benefits for poorer households, creating new economic opportunities, but also helping them to adapt to the risks brought about by climate change.

6. Conclusions

Climate change represents a threat to the livelihoods and wellbeing of the poor, and as such, a threat to the prospects for sustainable economic development. In this review, we have studied adaptation from the point of view of (poor) households. In contrast to the standard approach in the economics literature on adaptation to climate change, we analysed adaptation through the lens of development economics, considering the dual challenges of optimal adaptation and sustainable economic development.

Our review identifies several important barriers to optimal adaptation for the poor – from problems accessing financial resources, to informational and institutional barriers, as well as more basic problems of inadequate infrastructure and (both physical and social) marginalisation. Many of these barriers coincide with standard and well-established problems of development – and, as such, sustained economic development may well help to alleviate some if not all the constraints that we have identified. However, the dynamics of development – and the constrained risk-

coping strategies of poorer households – can often lead in the longer term to *increased* vulnerability to climate risk, especially where investment plans and development strategies are made without due consideration of future climate risk.

Building on a simple conceptual framework that captures the impact of climate change on the (weather-dependent) income of poor households, as well as the barriers to optimal adaptation that these households often face, we have illustrated several important mechanisms for policy intervention. In general, policy intervention can act to relax constraints on poor households' adaptation strategies, leading to more efficient adaptation choices and ultimately more sustainable forms of development. In particular, we have discussed the provision of adequate infrastructure, information, and direct assistance (i.e., cash transfers and safety nets), the expansion of access to (formal) finance, and the development of property rights. Identifying which of these mechanisms is at play in specific circumstances is an important task for future empirical research in this area.

Finally, we have also interrogated the practicalities of these policy interventions and identified related open questions calling for further research. Regarding formal finance, we have highlighted the challenges associated with expanding access to financial products like credit and insurance. Micro-credit and indexed insurance schemes, for example, are often championed as potential silver bullets for climate change adaptation. While not discounting their potential as tools to facilitate more efficient adaptation by the poor, our review shows that the implementation of these schemes in the context of climate change needs to be carefully considered. Further research is needed in relation to the additional informational burden that may be required to operationalize such schemes, as well as their potential influence on risk-taking behaviour of the target populations.

Regarding infrastructure, policy interventions have to weigh the benefits of providing infrastructure that facilitates *in-situ* adaptation, like irrigation infrastructure, against providing infrastructure that enhances *transformational* adaptation, for instance easing geographical and sectoral mobility. Regarding direct policy intervention (for instance through cash transfers and

safety nets), caution is warranted to avoid introducing perverse incentives (moral hazard), while at the same time preparing for urgent interventions, when required. These are issues that require careful planning, where specific circumstances limit *one-size-fits-all* policy suggestions. Nevertheless, further research can be important to guide policy interventions; for instance, helping to identify best practices and analysing their external validity and replicability. Similarly, further research is required to understand the optimal balance between private and public adaptation, and potential conflicts between the two. Finally, and more generally, our review highlights the need to consider adaptation and development policies together. In this line, our review demonstrates that further research on adaptation needs to be framed in the broader context of sustainable development, and therefore consider how specific adaptation policies may affect the interplay between on-going development trends, including for example internal migration patterns and urbanisation. Likewise, research on development policies needs to consider the challenge of adaptation to climate change, and how households respond to a world of increasing climate risk.

Rapid economic, social and demographic change in many developing countries is altering dramatically their vulnerability to climate change. In the face of these large-scale trends, most current adaptation strategies still tend to be relatively static – aimed at preserving current modes of production, and protecting existing patterns of development. We have termed this *in-situ* adaptation. Successful adaptation strategies will need to recognize the opportunities of *transformational* approaches that attempt to leverage the underlying dynamics of economic development, rather than trying to stem them. There is a window of opportunity now to avoid locking-in future vulnerability to climate change by incorporating climate risk into broader development strategies, to shape these wider trends towards more sustainable and climate-resilient pathways.

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Appendix A: Poverty and climate vulnerability

Climate vulnerability is strongly associated with poverty. This is especially true in still largely rural/agricultural societies. Table A.1 shows some selected indicators comparing averages for the Low-Income-countries group, as well as Sub-Saharan Africa (being the poorest region in the world), and world averages. As expected, a much larger percentage of national income (and people) depends on agriculture in poor countries. But furthermore, in the Low-Income-countries group, as well as in Sub-Saharan Africa, agricultural productivity is significantly lower than world averages. And this is partly due to a lower availability of (fresh) water per capita. Climate change is expected to increase climatic stress in most of these poor countries (especially in SSA), reinforcing the negative feedback loop between poverty and climate vulnerability.

The reinforcing dynamics of poverty and climate vulnerability are even clearer in semiarid countries. In fact, many of the world's poorest people live in areas that are already marginal from a climate and agricultural productivity perspective (with very low levels of rainfall), and many of these areas are precisely those suffering more from climate change. Table A.2 shows selected indicators for six selected semiarid countries (Burkina Faso, Kenya, Pakistan, Senegal, Tajikistan and Tanzania).[17]

[17] These six countries are the subject of the *Pathways to Resilience in Semi-arid Economies* (PRISE) research project, from which this review article was originally developed.

Table A.1. Selected indicators for Sub-Saharan Africa (SSA), Low income countries, and the World

	Agriculture (% of GDP)	Water per capita (m3/yr)	Cereal yield (kg/ha)	Rural Pop (%)	Poverty rate (% of total pop.)
SS Africa	14.3	4417.5	1214.5	63	47
Low Income	26.4	5095.8	1882.9	69	46
World	3.9	6123.7	3333.5	47	14.5

Note: Averages for the 2001-2010 period. Data from World Bank - World Development Indicators. Data for poverty rates (headcount ratio at $1.25) for 2013 or closest available year.

Table A.2. Selected indicators for selected semiarid countries

	Agriculture (% of GDP)	Water per capita (m3/yr)	Cereal yield (kg/ha)	Rural Pop (%)	Poverty rate (% of total pop.)
Burkina Faso	35.3	781.5	1021.9	71.81	44.46
Kenya	29.9	492.5	1596.6	75.22	43.37
Pakistan	24.4	312.2	2650.0	62.14	12.74
Senegal	16.7	1935.4	1064.2	59.92	34.06
Tajikistan	27.2	8120.4	2456.8	73.38	5.92
Tanzania	27.6	1812.1	1289.3	69.80	43.48

Note: Averages 2001-2010 period. Data from World Bank - World Development Indicators. Data for poverty rates (headcount ratio at $1.25) for 2013 or closest available year.

Appendix B: Access to (formal) finance

Access to finance is still very limited in many poor and developing countries. Limited access to financial products, such as credit, saving opportunities, transaction facilities and insurance, not only constrains economic growth and poverty reduction but also hinders adaptation to climate change, as discussed in the main text. Tables B.1 and B.2 display some basic indicators on formal finance penetration in two groups (Sub-Saharan Africa and low income countries) and in six semi-arid countries: Senegal, Burkina Faso, Tanzania, Kenya, Tajikistan and Pakistan.

As the figures show, the percentage of population with an account at a formal financial institution remains very limited (even compared with regional averages). Only in Kenya more than 40% of the adult population have an account (but still significantly below the world average of around 50%). In all remaining countries, the figure does not reach the 20% mark. Regarding commercial bank branches, in the best case (Pakistan) the number is still very low, with less than 9.7 branches per 100,000 adults and compared with a world average of more than 12.5.

In terms of getting credit the situation does not appear much better, although Kenya scores relatively highly on this indicator. New technologies arise as an interesting tool to provide financial services including transaction facilities. The mobile phone to pay bills seems already quite well developed in Kenya and Tanzania, but remains an almost unexplored opportunity in Burkina Faso and Senegal.

When looking at small firms, Sub-Saharan Africa countries display relatively high values of small firms having an account in formal institutions – over 96% in the case of Burkina Faso. By contrast, in Pakistan just over half of small firms have a formal bank account. In Tanzania, the government has undertaken an effort to formalise property rights aimed at among other things, increasing access to credit by poor/rural households, which would allow farmers to utilise their land as collateral to buy new seeds, fertilizers and so on, and therefore help them to adapt to climate change.

Table B.1. Selected indicators for Sub-Saharan Africa, South Asia and the World

	Accounts at a formal institution (%)	Commercial bank branches	Getting private credit (%)	Mobile phone use to pay bills (%)	% of Small enterprises with account
Low Income	22.3	3.1	1.8	3.1	
SS Africa	24.0	4.3	6.3		84.47
World	60.7	12.5	28.3	2.0	75.83

Note: Accounts are % of population aged 15+. Commercial bank branches are per 100,000 adults. Getting private credit refers to the % of adult population that is listed by a private credit bureau with some information about credit history. Mobile phone use to pay bills as a % of population aged 15+. Small enterprises are defined as from 5 to 9 employees. Data for 2014-2015 or closest year. Data from World Bank –Development Indicators.

Table B.2. Selected indicators for selected semiarid countries.

	Accounts at a formal institution (%)	Commercial bank branches	Getting private credit (%)	Mobile phone use to pay bills (%)	% of Small enterprises with account
Burkina Faso	13.4	2.7		3.1	96.78
Kenya	55.2	5.7	4.9	58.4	84.96
Pakistan	8.7	9.7	4.5	5.8	54.02
Senegal	11.9	4.6		6.2	80.78
Tajikistan	11.5	6.6	7.0	2.0	81.06
Tanzania	19.0	2.5	5.0	32.4	84.64

Note: Accounts are % of population aged 15+. Commercial bank branches are per 100,000 adults. Getting private credit refers to the % of adult population that is listed by a private credit bureau with some

information about credit history. Mobile phone use to pay bills as a % of population aged 15+. Small enterprises are defined as from 5 to 9 employees. Data for 2014-2015 or closest year. Data from World Bank –Development Indicators.

Appendix C: Access to (basic) infrastructure

The lack of adequate infrastructure is probably one of the most critical barriers for optimal adaptation and for sustainable development. In poor countries, access to basic infrastructure is still very limited. Tables C.1 and C.2 show some data on access to basic services, like access to improved water source, access to improved sanitation facilities, and access to electricity. Table C.1 shows values for the Low-Income-countries group, as well as for Sub-Saharan Africa (SSA) and the world. Compared to world averages, access to basic services in low-income countries is still very deficient. In particular, improved sanitation facilities and electricity cover less than a third of total population in these countries.

Looking at some semi-arid countries - those more challenged by climate change – we see that the situation in some cases is critical. For instance, in Burkina Faso and Tanzania fewer than one out in five people has access to electricity.

Table C.1. Basic Infrastructure: Selected indicators for SSA, Low income countries, and the World

	water (% of pop)	sanitation (% of pop)	electricity (% of pop)
SS Africa	66.5	29.3	35.3
Low Income	65.1	27.9	25.4
World	90.6	67.0	84.6

Note: Values for water and sanitation refer to access to an improved source and facilities (respectively). Values for 2014. Values for electricity refer to 2012. Data from World Bank - World Development Indicators.

Table C.2. Basic infrastructure: Selected indicators for selected semiarid countries

	water (% of pop)	sanitation (% of pop)	electricity (% of pop)
Burkina Faso	82.1	19.4	13.1
Kenya	63.1	30.1	23.0
Pakistan	91.3	61.8	93.6
Senegal	77.8	47.1	56.5
Tajikistan	73.7	95.0	100.0
Tanzania	55.5	15.0	15.3

Note: Values for water and sanitation refer to access to an improved source and facilities (respectively). Values for 2014. Values for electricity refer to 2012. Data from World Bank - World Development Indicators.