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Climate Change and Poverty

An Analytical Framework

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Abstract

Climate change and climate policies will affect poverty reduction efforts through direct and immediate impacts on the poor and by affecting factors that condition poverty reduction, such as economic growth. This paper explores this relation between climate change and policies and poverty outcomes by examining three questions: the (static) impact on poor people's livelihood and well-being; the impact on the risk for non-poor individuals to fall into poverty; and the impact on the ability of poor people to escape poverty. The paper proposes four channels that determine household consumption and through which households may escape or fall into poverty (prices, assets, productivity, and opportunities). It then discusses whether and how these channels are affected by climate change and climate policies, focusing on the exposure, vulnerability, and ability to adapt of the poor (and those vulnerable to poverty). It reviews the existing literature and offers three major conclusions. First, climate change is likely to represent a major obstacle to a sustained eradication of poverty. Second, climate policies are compatible with poverty reduction provided that (i) poverty concerns are carefully taken into account in their design and (ii) they are accompanied by the appropriate set of social policies. Third, climate change does not modify how poverty policies should be designed, but it creates greater needs and more urgency. The scale issue is explained by the fact that climate will cause more frequent and more severe shocks; the urgency, by the need to exploit the window of opportunity given to us before climate impacts are likely to substantially increase.

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Climate Change and Poverty—An Analytical Framework[1]

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1 INTRODUCTION

Despite substantial progress in reducing poverty rates from some 42% 20 years ago to what is expected to be less than 15% in 2015, close to 1 billion people still live in poverty (Chen and Ravallion, 2010).[2] Many more hover just above the poverty line, vulnerable to shocks that could send them into poverty. At the same time, the post-2015 discussions on what will replace the Millennium Development Goals (MDGs) have reaffirmed the goal of ending extreme poverty, or as the World Bank has operationalized, reducing the share of the population living on less than USD $1.25/day to below 3% by 2030.

Climate change and climate policies will affect poverty reduction efforts both through direct impacts on the poor, such as those caused by natural disasters, and through factors that condition poverty reduction, such as economic growth. While the magnitude of climate change is likely to be relatively limited by 2030, localized impacts may still be important, for instance in already marginal areas (e.g., semi-arid areas) or in those regions where the intensity of climate-related weather extremes is increasing. And as the goal is not simply to eliminate poverty by 2030, but to eliminate it once for all, we need to ensure that short- to medium-term poverty reduction strategies take into account these long-term threats to the elimination of poverty.

This paper proposes an analytical framework to investigate the linkages between poverty and climate change and policies, seeking to answer three main questions:[3]

- How do climate change and climate policies affect the current welfare of poor people?
- Do climate change and climate policies make it more likely that non-poor, but vulnerable, people fall into poverty in the future?
- Will climate change and climate policies exacerbate poverty traps that make it harder to bring people out of poverty in the future?

The first question is about the current well-being of poor people, irrespective of their past and future conditions and poverty dynamics. The specific living conditions of poor people may indeed make them more vulnerable to climate and climate policy shocks such as natural disasters, a reduction in the ecosystem goods and services they rely upon, or an increase in energy prices.

In addition, a dynamic view is needed to investigate the impact of climate change on poverty. Over a 25-year period, 14% of households in 36 communities in Andhra Pradesh in India escaped poverty. Over the same period, 12% of non-poor households became poor, so that, overall, poverty was reduced by 2%. The net flow out of poverty is much smaller than the gross flows in and out of poverty (Krishna, 2007).[4] A relatively small change in the flows in and out of poverty can thus have a significant effect on net flows and overall poverty dynamics. In the case of these Andhra Pradesh communities, an increase by less than 10%

[2] Unless otherwise specified, poverty is measured using the USD $1.25/day line.

[3] The literature on social protection uses a similar framing when it classify social protection goals in three categories: protective (improving the well-being of the poor), preventive (preventing people from falling into poverty) and promotional (improving the chances for poor households to escape poverty) (e.g., Guhan, 1994).

[4] Similar findings exist in many countries and regions, see for instance data for four other countries in (Krishna, 2007), for Bangladesh in (Sen, 2003), and for South Africa in (Carter and May, 2001).

of the number of people falling into poverty every year (i.e., an increase from 12% to 13% per year) and a reduction by less than 10% of the number of households escaping poverty (i.e., a reduction from 14% to 13% per year) would reduce the pace of poverty reduction by 50%.

As to the second question, climate change affects flows into poverty, notably through its impact on weather events. For instance, among the 12% of households that fell into poverty in the Andhra Pradesh communities, 44% cite "drought, irrigation failure, or crop disease" as one of the reasons for their income losses. "*All else being the same, the odds of a non-poor household falling into poverty increase more than 15 times when drought is a significant feature of its event history"* (Krishna, 2006). Of nearly 400 Bangladeshi households falling into poverty, 15% cite natural disasters and 18% loss of natural assets as main reasons (Sen, 2003). More generally, results from household surveys often show that a larger share of poorer households report economic impacts from weather risks compared to richer households (e.g., Wodon et al., 2014). Changed weather patterns and modified rainfall may increase or decrease the frequency and intensity of such weather shocks and therefore change the flow of households into poverty.

As to the third question, there are a number of ways through which climate change or climate policies may lead to magnified "poverty traps" (at the household, regional, or country level) and thus reduce the flow out of poverty.[5] Higher energy costs due to mitigation policies could make access to energy and its many benefits more difficult. Increased natural risks may impair capital accumulation through more asset losses (e.g., due to floods), but also through reduced incentives to invest in a context of higher uncertainty and risk (Elbers et al., 2007). Climate and environmental degradation have been linked to such poverty traps (Carter et al., 2007; Barbier, 2010a; Dercon and Christiaensen, 2011). Climate change may also impact human capital accumulation: natural disasters are known to lead to reduced investment in children's education, nutrition and health, with large and quasi-irreversible effects on their prospects. Thus, more intense or frequent disasters brought by climate change could lead to worsened intergenerational transmission of poverty.

The framework developed to answer these questions follows the poverty literature by proposing four channels (prices, assets, productivity, and opportunities) that help understand changes in household consumption and movements in and out of poverty. The paper discusses whether and how these channels are affected by climate change and climate policies, and investigates the exposure, vulnerability, and adaptive capacity of the poor and those vulnerable to poverty.[6] It reviews the existing literature and investigates how the impact of climate change on poverty reduction depends on a combination of climate and non-climate policies as well as exogenous economic, social and environmental changes (e.g., in technologies or market integration).

[5] There is a debate on the existence of poverty traps at different scales. For instance, Kraay and McKenzie (2014) review evidence and mechanisms, mostly at national or regional level. Carter et al. (2007) and Carter and Barrett (2006) investigate household level poverty traps, linked to their asset stock.

[6] In this text, we use the classical formalization defining risk as the combination of hazard, exposure, and vulnerability following IPCC (2014). Note that previous IPCC reports used a different framework and definition of vulnerability.

This review leads us to three main conclusions:

- **Climate change is very likely to represent a major obstacle to the sustained eradication of poverty.** Climate change will not just negatively affect the welfare of poor people; it is also very likely to increase the flow of people who fall into poverty and make it more difficult to escape poverty. Climate change and climate policies may increase the price of basic goods and services such as food and energy -- which already account for a large share of poor people's expenditure— thus reducing their real income, hence their ability to invest in their future. Climate change impacts can also bring more people into poverty every year due to increased frequency and intensity of the events that destroy physical, human, social, and natural assets, such as floods and droughts. And if climate change leads to a general increase in real or perceived risk, it can push households toward low-risk activities that offer limited opportunity for income growth, thereby expanding poverty traps and reducing the number of households escaping poverty every year. These effects are largely independent of any impact on GDP because they tend to mostly fall upon people and regions too poor to materially affect such aggregate figures.

- **Climate policies – whether linked to adaptation or mitigation – are compatible with poverty reduction provided that (i) poverty concerns are carefully taken into account in their design and (ii) they are accompanied by the appropriate set of social policies.** Carbon taxes or the elimination of fossil fuel subsidies increase the cost of energy, but they also generate revenues that can be redeployed to finance programs that benefit the poor. Support for reduced deforestation can result in an increase in land prices that would tend to benefit landowners, particularly richer ones, better able to take advantage of opportunities. Similarly, adaptation policies such as flood zoning can limit the availability of cheap land accessible to poor households migrating to cities in search of better opportunities. Careful design and accompanying measures, however, can help ensure the impacts are not harmful to the poor and can help create new employment opportunities notably for traditional communities.

- **Managing the poverty impacts of climate change does not require different poverty and social protection policies; but it creates a need for more, sooner.** The basic policy prescriptions in terms of social protection do not change: with or without climate change, interventions are needed to reduce the exposure and vulnerability of the poor while increasing their capacity to adapt to shocks. This includes well-funded, and easily scaled-up social protection schemes; good targeting mechanisms to identify the transient poor; financial inclusion and multi-sectoral interventions such as flood zoning, information diffusion, targeted investments, notably to increase access to basic services; and universal health care. But climate change will result in more frequent and bigger shocks, and will therefore increase the frequency at which traditional coping mechanisms and informal safety nets fail, and the scale of the associated needs. The increased urgency springs from the fact that climate impacts remain limited today but are expected to increase significantly in the decades to come, regardless of global mitigation efforts: a window of opportunity therefore exists to significantly reduce poverty and to establish solid and far-reaching safety net systems before most of the impacts materialize.

The remainder of the paper is structured as follows. Section 2 provides the basic framework for examining the impact of climate change on poverty and outlines the four channels – consumption (prices), assets, productivity, and opportunities. Sections 3 through 6 discuss each channel in turn. Section 7 concludes.

2 A FRAMEWORK

We use the standard asset-based framework to represent poverty, income and consumption at the household level, inspired from those proposed in Attanasio and Székely (1999), Carter and Barrett (2006), and López-Calva and Rodríguez-Castelan (2014).

2.1 The basic framework and four intertwined channels

The instantaneous utility of a household can be written as:

$$Max\ u(c) \qquad \text{s.t. } p \cdot c \leq y, \tag{1}$$

Where c is the vector of consumption of the household (of different goods and services), p is the price vector, and y is the income of the household.

The income of the household is given by:[7]

$$y = \sum_{j \in J} a\beta_j, \tag{2}$$

Where J is the set of livelihood and income-generation activities, a is a vector of assets including human capital (health, education, etc.) and productive assets (land, equipment, livestock, etc.) and β_j is a vector of returns of the different types of capital in the activity j.[8] Time can also be considered as an asset, and in that case the return on time is the hourly wage or the labor productivity.

In this framework, household consumption (and thus consumption-related poverty) is determined by four components, which act as channels through which external factors can influence poverty.[9] The first channel relates to consumption, while the three latter are about income:

- *Consumption (and price) channel.* If prices p change, then consumption c_i can increase or decrease in real terms; the change in prices can be due to changes in the productivity of the rest of the economy, in the connection to markets, barriers to trade, or taxes. Climate change and policies may increase food, energy, or land prices and thus reduce consumption, therefore hurting the poor.

[7] Here we make the simplifying assumption that asset returns are independent. In fact, many assets are complementary. For instance, a tube well is only useful if land is available to grow crops. Time for work is more productive if manufacturing equipment (e.g., a sowing machine) is available. This simplification does not prevent the model from being a crude but useful framework to think about poverty reduction.

[8] This framework is also consistent with a "livelihood" view, in which a livelihood is the combination of activities (J), assets (a) and capability (mix of a and β) (Department for International Cooperation, 2000).

[9] This note uses a consumption-based definition of poverty, even though poverty is a multi-dimensional condition, including consumption but also access and inclusion.

- *Asset channel.* Households can accumulate assets a, by acquiring education or information, improving their health, and investing in productive assets such as livestock or manufacturing equipment. They can also lose assets following shocks such as floods or liquidation forced by reductions in income. Assets usually include financial, physical, human, social, and natural capital. They also include public goods, infrastructure, and institutions households have access to.

- *Productivity channel.* Households can increase the return on their asset (and their labor productivity) β_j by being more efficient and improving processes; the β_j can also increase through macro-intervention, for instance due to better infrastructure or a better functioning of markets (through smarter regulation). On the other hand, returns are often limited by economic inefficiencies (e.g., corruption, market failures, and inappropriate regulations), and can be reduced by changing economic or environmental conditions, including for instance the effect of climate change on labor productivity or agricultural yields.[10]

- *Opportunity channel.* Finally, households can increase their income by expanding their range of activities J; this can be done by the households themselves (e.g., through migration to cities), but it is also the result of aggregate economic growth and development that creates new opportunities in new sectors. On the other hand, the opportunities are often limited by exclusion (e.g., based on gender or ethnicity) and constraints on mobility.[11]

Positive (or negative) effects on each of these channels, permanent or temporary, affect the consumption and income of households.[12] Of course, these channels interact closely. For instance, increased productivity (3rd channel) could lead to reduced prices (1st channel), which can make it more attractive or even simply possible for some to save, allowing households to build their asset stock (2nd channel). Also, capturing new opportunities (4th channel) requires investments and sometimes migration, activities possible only with an appropriate asset base (2nd channel). Equally important is the fact that price changes will affect consumption (for net buyers) and income (for net sellers) simultaneously.[13]

As suggested in the introduction, poverty cannot be understood in a static framework, so we investigate the flows in and out of poverty, looking at the four "channels" as intertwined instruments for households to escape poverty, or causes of a fall into poverty.

2.2 Falling into poverty

When aiming at poverty eradication, it is not only important to look at those that are currently classified as poor, but also at those at risk of falling into poverty. In multiple studies (e.g., Carter and May, 2001), a distinction is made between structural poverty where households have *assets* that are below a given asset

[10] López-Calva and Rodríguez-Castelan (2014) also includes the intensity of use of these assets, but this aspect is here included in the productivity of the asset, and measured through β_j.

[11] Exclusion can also act indirectly, for instance by preventing people discriminated against to access education.

[12] This framework does not include household demographics, such as new born or young adults leaving the household, despite the potential impact on poverty (Sen, 2003).

[13] This is of course the case for agricultural goods (see below), but Moser and Felton (2007) also report the example of how trade and imports from China decreased the price of clothing in Ecuador, increasing the ability of households to consume, but reducing wages and destroying jobs.

poverty line, and stochastic poverty characterized by *income* below an income poverty line. Structural poverty is considered more permanent than stochastic poverty, which may be due to the variability in asset returns. Moser and Felton (2007) show that households that have few assets (the structurally poor) but benefit from an income above the poverty line (stochastically non-poor) are particularly vulnerable.

Here, the stochasticity in income can be represented by transforming the returns from assets β_j and prices p into random variables with some variance. But we have to differentiate (1) temporary shocks that reduce the return on assets or affect prices (e.g., a bad year with low yields, a disease that reduces labor productivity), and (2) permanent shocks that affect long-term productivity (e.g., increased trade openness that increases competition and reduces prices of some production). Some temporary shocks (such as a hurricane that destroys houses and transport infrastructure, or a disease that leads to permanent consequences or to children dropping out of school) do not affect productivity so much but affect assets or opportunities (i.e. reduce a or the set J). A temporary shock on β_j can bring households into poverty in a temporary manner (i.e. stochastic poverty). A permanent shock on β_j or a shock on a or the set J can bring households into poverty in a more permanent way, and represent a challenge to poverty reduction.

Table 1: Reasons for the 'deterioration in economic well-being over the last decade' as perceived by respondents in rural Bangladesh

Reasons	Number of households	Percentage
Structural	**25**	**27**
Loss of natural assets	**17**	**18**
Loss of human assets	**-**	**-**
Loss of financial assets	**8**	**9**
Loss of social assets	**-**	**-**
Adverse market conditions	**-**	**-**
Life cycle	**33**	**35**
Negative change in household demography	**33**	**35**
Crisis	**36**	**38**
Ill-health	**17**	**18**
Natural disaster	**14**	**15**
Personal insecurity	**3**	**3**
Social ceremony	**2**	**2**

Source: Sen (2003)

Krishna (2006, 2007), Sen (2003) and others report on the shocks that explain why households fall into poverty, looking at structural changes and crises. In Bangladesh, Sen (2003) provides a list of reasons why households have seen their situation deteriorate (Table 1). This work identifies:

- Structural changes – for instance caused by technological change or trade liberalization – that are associated with a loss of assets, represented through the productivity and asset channels in our framework, i.e. on a_i and β, and are linked to long-term changes in economic and household-specific conditions.

- The major role of shocks in explaining why some households fall into poverty, in particular health shocks and natural disasters. These shocks reduce income (for instance through reduced

productivity of assets β), but, most importantly, they deplete assets a: disease may reduce human capital through permanent health consequences and financial assets through medical expenditures (especially in the presence of high borrowing costs, Krishna, 2006); and natural disasters destroy houses and productive capital, including livestock.

- Note that other shocks not listed in Table 1 can have a large impact on flows in and out of poverty: conflict, social unrest, and exclusion can reduce both assets and the opportunity set J. Also, global shocks such as the increase in food prices in 2007/08 affect prices and thus poverty through the first of our channels (World Bank, 2013, Ch. 4).

Natural disasters (including weather events) play a significant role in bringing households into poverty, which is a strong justification for investigating the interplay of climate change and poverty (Table 1). This is all the more important given that people in lower quintiles of the income distribution often appear more exposed and vulnerable to weather shocks than the rest of the population. For instance, Table 2 shows the percentage of the population in five countries in the Middle East and North Africa that report economic impacts from weather shocks in the previous five years, and suggests that the bottom three quintiles are more exposed than the top two.

Table 2: Percentage reporting economic impacts from weather shocks in the last 5 years by wealth quintile, five-country sample in MENA, 2011.

Percent	Quintiles					
	Poorest	Q2	Q3	Q4	Richest	All
Lost income	46.37	44.14	43.21	29.25	20.72	36.59
Lost crops	58.12	61.96	62.13	49.42	42.10	54.62
Lost livestock or cattle	23.81	25.19	30.11	23.17	15.23	23.43
Less fish caught	9.51	10.27	8.90	9.65	4.69	8.60

Source: Wodon et al. (2014)

2.3 Poverty traps and escapes

Asset accumulation can lead poor households out of poverty, often over several generations. In Moser and Felton (2007), for instance, asset-poor households in Guayaquil, Ecuador, are found to start by accumulating housing capital through improvement in their dwelling. This improves quality of life, but also helps build human capital through better health, safety and security. Then, households consume more durable goods and diversify their asset base by investing in productive assets, children's education as well as financial capital to become better able to cope with negative shocks such as illness or natural disasters. Barrett et al. (2013) present a similar story in Bangladesh where households that receive assets (such as livestock or a sewing machine, complete with income support and training) are found to build and diversify their asset portfolio to increase their income and make it less vulnerable to negative shocks, thereby becoming less poor and more resilient to adverse events.

But because the ability of the poor to save and invest is limited by their resources, living conditions and luck, poverty traps are possible.[14] Multiple explanations for poverty traps have been proposed, based on nutrition and labor productivity (Dasgupta, 1997; Jha et al., 2009), on the need for a "minimum" asset base (Carter and Barrett, 2006; Carter et al., 2007;), on natural capital and environmental conditions (Barbier, 2010a), on the combination of borrowing constraints and lumpy production technologies (Banerjee and Newman, 1993; Banerjee and Duflo, 2012), and on the choice by poor households of low-risk low-return strategies (World Bank, 2013). While Kraay and McKenzie (2014) suggest that income stagnation does not frequently happen at the national level, the existence of regional and household-level poverty traps is an important component to consider when investigating poverty dynamics.

To represent poverty traps, our basic framework needs to be expanded. In the previous section, we assumed that households have a given set of income-generating activities, that they do not face trade-offs in their choice of activity, and their assets are productive in all activities. In fact, they have to decide which activities they will invest in (within a set of possible options, exogenously given) and how much to invest in each. We therefore modify the framework to (1) consider multiple asset categories (Section 2.3.1), (2) include asset dynamics and the possibility of poverty traps (Section 2.3.2), and (3) the role of uncertainty and risk in the allocation of assets and income-generating activities (Section 2.3.3).

2.3.1 Asset categories

In asset-based frameworks, assets are usually allocated across five categories: (1) human capital including health and education; (2) physical capital including housing and productive assets; (3) financial capital (currency and savings in financial institutions); (4) natural capital (especially eco-systems and subsoil resources); and (5) social capital including formal and informal networks, institutions, and migrated household members who send remittances.[15] Other useful classifications are noted in Box 1.

In addition, for many poor people, escaping poverty may require access to public goods and social protection – which are determined through a collective decision-making process they may not control. Social protection and redistribution from the government, NGOs, or international actors are particularly important for (1) the elderly, who can be fully dependent on publicly-managed or publicly-regulated pension systems; (2) the unemployed/under-employed, who may temporarily depend on unemployment insurance and social safety nets or on redistribution schemes; and (3) the sick or disabled, who depend on a combination of informal social safety nets and social protection if they are unable to generate an income.

Box 1: Other asset classifications

Rival and non-rival assets. Some assets can be used in multiple activities independently. We will refer to them as "non-rival" assets. For instance using an education level in farming does not make education less useful for manufacturing. Other assets are rivals: use for one activity makes it unavailable for other activities. Examples include land (using land for farming makes it unavailable to build a shop) and time (spending work hours in farming makes them unavailable for manufacturing). Households do not have to make trade-offs in their use of non-rival assets, but their choice of activities will involve trade-offs in how they use their rival assets.

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[14] The existence of multiple equilibria (where asset-nonpoor households grow and recover; and asset-poor households become stuck in poverty traps) has been examined theoretically by Deaton (1992) and Zimmerman and Carter (2003).
[15] In some instances, especially in case of international migration, remittances can represent more than 50% of the income of a household (e.g., Moser and Felton, 2007).

Portable and non-portable assets. Non-portable assets are attached to a location and are usually useful only for a narrow set of activities. They include for instance land and corresponding equipment (e.g., irrigation canals) and many natural resources (e.g., forest). Portable assets – such as education and generic skills (e.g., numeracy) – can be "transported" with their owner and can often be used for many activities.

Transferrable and non-transferrable assets. Some assets are perfectly transferrable into other assets, such as financial savings. For these assets, there is perfect flexibility in the allocation of assets (and there is no useful distinction between portable and non-portable assets since any asset can be transformed into any other asset). Some assets could be sold and then transferred into other asset forms (e.g. selling livestock to buy land). Some assets are not transferable, however. For instance, education or job security cannot be easily transferred. Similarly, time cannot be transferred. And under informal tenure regimes land is also often impossible to sell or transfer, making it difficult to transform the right to use a land lot into another asset.

Public vs private goods. Public goods are assets whose use is non-rival and non-excludable, such as a clean environment, infrastructure for water and transport, schools and education, and security. Individuals have an incentive to under-invest in them, despite often having high returns. In that case, the allocation of assets made by individuals independently will be suboptimal, and only collective decision-making can increase investment levels to their optimal levels. The ability to make such collective decisions depends on institutions, governance, and the voice of the different population groups.

2.3.2 Asset dynamics

The assets available to a household to generate income have to be created or acquired through investment. To include asset dynamics and investment, Eq. (1) is replaced by an inter-temporal optimization:

$$Max\ w(c_i) = \int_0^{\infty} e^{-\delta t} u(c_i(t)) \quad \text{s.t. } p(t) \cdot c_i(t) \leq y_i(t) - i(t), \quad \text{s.t. } y_i = \sum_{j \in J} a_i \beta_j \tag{3}$$

Where $u(c)$ is a utility function, i_i is the total investment and asset accumulation of the household *i*, and δ is the utility discount rate (or pure rate of time preference for the present).

With investment, and noting a_i the i^{th} component of the vector of assets a, Eq. (3) is replaced by an asset dynamics as follows:

$$\frac{da_i}{dt} = i_i - \delta_i a_i \qquad \text{with} \qquad \sum_{i \in J} i_i = i, \tag{4}$$

Where i_i are the investments of the household in the non-rival and rival asset i, and δ_i is the depreciation (if any) of the asset i. For an asset a_i, the investment (i_i) can be negative if the asset is transferable or transformable (e.g., if the asset can be sold and the revenue used to invest in another asset), but remains positive or nil otherwise. In that case, J is not the set of activities actually carried out by the household, but the set of activities *available to the household*, among which the household has to allocate its resources (especially time and productive assets).

There are several dimensions that affect the ability and willingness of households to allocate their resources and invest in poverty-reducing assets. Because these dimensions depend on their assets – including human and social capital – they can therefore create poverty traps, as discussed below.

Exclusion. A first dimension is the existence of exclusion and the role of political voice. Income and consumption can indeed be reduced in the presence of exclusion based on gender, ethnicity, origin, or even income level. In some places, resources and opportunities are reserved for a subset of the population,

leaving the rest excluded from benefits. In our framework, exclusion is equivalent to a reduction in the opportunity set J to the subset J_e, reducing the optimization to a smaller domain, and leading to higher poverty. A negative shock to a community can increase competition for resources, damage social capital and increase exclusion, leading to a reduction in the ability of households to capture opportunities and increase income. If we include exclusion in social capital, then we create a feedback from the current asset base to the ability to save and accumulate assets: a poor household with little social capital is excluded and cannot capture some income generating opportunities and build its stock of other (physical and financial) assets, and is therefore trapped in poverty.

Voice and public goods. Public goods are an important part of household assets but households cannot decide individually to invest in them: it is a collective decision upon which poor households have more or less influence, depending on their social capital, and existing institutions and governance structures. As shown in Moser (2007:85), poor households sometimes invest a lot of time and effort lobbying local authorities to invest in their communities to provide basic infrastructure such as roads, piped water, and sanitation. Nevertheless, households with little social capital – for instance with little trust and organization in their community – will be unable to "invest" in public goods and increase their quality of life and income.

Willingness to save. "Willingness to save" is linked to time preference and behaviors. First, the poor generally exhibit high discount rates given the urgent needs linked to everyday survival, with such an emphasis on the short-term reducing the willingness to divert consumption for savings (Haushofer and Fehr, 2014). Second, the poor may have little time or energy to think about the future, as their day-to-day challenges and the stress and negative affective states caused by poverty are more consuming of cognitive control and may lead to short-sighted and risk-averse decision-making (Banerjee and Duflo, 2011; Haushofer and Fehr, 2014).[16] As a result, poor individuals find it difficult to exert self-control and resist the temptation of spending the money at hand (Ashraf et al., 2006; Duflo et al., 2006; Bernheim et al., 2012).

Ability to save. The poor's ability to save is often limited by the lack of a safe place to keep their money – savings at home can be easily stolen or grabbed by family members (Banerjee and Duflo, 2011). Indeed, creating a safe place to keep money can be an inexpensive way to increase savings – simply providing an account increased savings by 66 percent in an experiment in rural Kenya (Dupas and Robinson, 2013). Another reason, which is acute around the poverty line, is the fact that the ability to save depends on the difference between income $y(t)$, and basic needs or subsistence consumption, noted c_{basic}. This element creates a strong interaction between the first channel (consumption and prices), the third channel (income and productivity), and the asset channel. If a shock destroys household assets (a), then income y is

[16] Planning for contingencies (e.g. due to a shock), unpredictable income and constant worry about financial situation creates stress and depression for the poor, which reduces focus, lowers productivity and interferes with making long-term decisions (Banerjee and Duflo, 2011). Furthermore, there exists a strong association between the level of cortisol produced by the body, an indicator of stress, and poverty. Further, poverty-reduction programs, such as PROGRESA in Mexico, have been shown to reduce levels of cortisol in child beneficiaries, compared to children of the same age not included in the program (Fernald and Gunnar 2009). This is important, as cortisol has been shown to directly impair cognitive and decision-making ability (van den Bos et al., 2009).

reduced, and thus i becomes lower, possibly nil, possibly causing permanent impoverishment.[17] In the equation, these mechanisms can be represented as:

$$Max\ w(c) = \int_0^{\infty} e^{-\delta t} u(c(t)) \quad \text{s.t. } p(t) \cdot c(t) \leq y(t) - i(t), \qquad (5)$$

$$\text{s.t. } y = \sum_{j \in J} a_i \beta_j$$

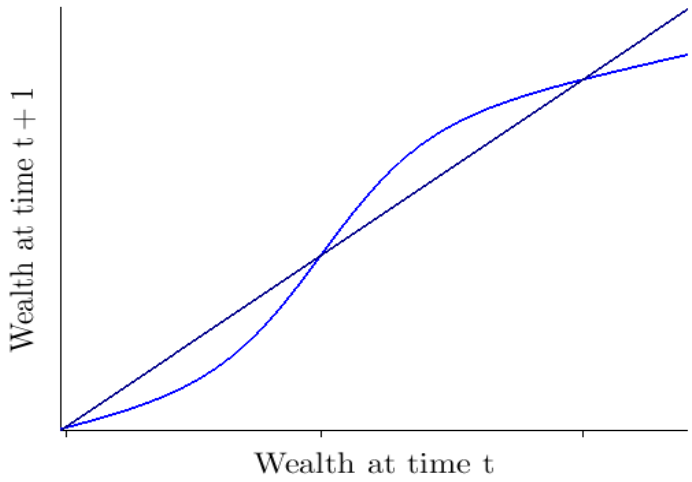
$$\text{s.t. } \sum_{i \in J} i_i = i(t) \leq f(y(t) - p(t) c_{\text{basic}})$$

With $\quad J_e \subseteq J$

And f is an increasing function (possibly increasing more rapidly than linearly).

Overall, these elements (exclusion, voice, willingness to save, ability to save) constrain investments, and thus can lead to poverty traps. These poverty traps can be represented with an S-shape relationship between wealth at one point in time and wealth in the future (Figure 1). Because the function crosses the 45° line at two levels of wealth, such a system has two equilibria, one at a low level of wealth and one at a high level of wealth. If climate change affects Equation (5) in a way that enlarges poverty traps, the long-term impact on poverty could be significant.

Figure 1: The relationship between wealth at time t and wealth at time t+1. If this relationship is not concave, then multiple equilibria are possible, and households can be locked into poverty.[18]



2.3.3 Risk taking, irreversible investment, and diversification

Household choices on risk-return trade-offs depend on their ability to cope with potential negative futures (e.g. bad rainfall, reduced consumption, lower demand). With less steady income, a larger percentage of

[17] This constraint can however be avoided in the presence of functioning capital markets, where financial inclusion is sufficient. In that case, borrowing makes it possible for $i(t)$ to exceed the saving capacity $y(t) - p(t)c_{\text{basic}}$. Debt can be represented as an asset with negative returns that is part of the optimization problem of households.

[18] A similar S-shaped graph for income today and in the future in the context of poverty traps is presented in Banerjee and Duflo (2011:12).

total assets exposed, and reduced insurance coverage, the poor generally have a lower ability to adapt to bad outcomes than the rich. As a result, low-income households disproportionately choose low-risk activities, which are also low-return, perpetuating poverty (Dercon, 1996; Elbers et al., 2007; Dercon and Christiaensen, 2011; Mobarak and Rosenzweig, 2013; Bandyopadhyay and Skoufias, 2013).

Most importantly in a context of rapid changes – including climate change – the reversibility of household investment matters. Investing in irreversible, non-transferable and non-portable assets makes households more vulnerable to changes in returns, and less able to adapt to and benefit from changes in J (the set of available livelihood and income-generating activities). Evidence suggests a large percentage of the poor's assets may be inflexible, which may (1) make households more vulnerable to a change in economic or environmental conditions, and (2) hinder asset accumulation (Barrett and McPeak, 2006; Hill, 2010).

Investment choices in Equation (6) depend on risk levels, access to information, the shape of the utility function, and the ability of households to cope with shocks (for instance from their ability to sell assets or to borrow to smooth consumption). The uncertainty can be represented by an uncertainty on the returns of different assets (the β_j) and uncertainty in the future set of possible opportunities (the set J). Changes in β_j and J can be due to technological, economic or environmental change. Irreversibility in investment and non-transferability and non-portability of assets can be represented in our model by sign constraints on a_i.

$$Max\ \mathbb{E}w(c) = \mathbb{E}\left[\int_0^\infty e^{-\delta t} u(c(t))\right]$$

$$\text{s.t.} \quad p(t) \cdot c(t) \leq y(t) - i(t), \tag{6}$$

$$\text{s.t.} \quad y = \sum_{j \in J} a_i \beta_j$$

$$\text{s.t.} \quad \sum_{i \in J} i_i = i(t) \leq f(y(t) - p(t) c_{\text{basic}})$$

$$\text{s.t.} \quad i_i > 0 \text{ for some i; } i_i < 0 \text{ for some i;}$$

$$\text{With} \quad J \subseteq J_0$$

$$\text{And} \quad \beta_j \text{ are random function of average } \overline{\beta_J} \text{ and variance } \sigma_j.$$

If risk taking is necessary for growth and poverty alleviation, then an improvement in the ability to manage risk, whether due to more and better information (which can be interpreted as a decrease in the variance of β_j, i.e. σ_j), financial instruments, social protection, or emergency response and crisis management can generate faster growth and more poverty reduction (World Bank, 2013).[19]

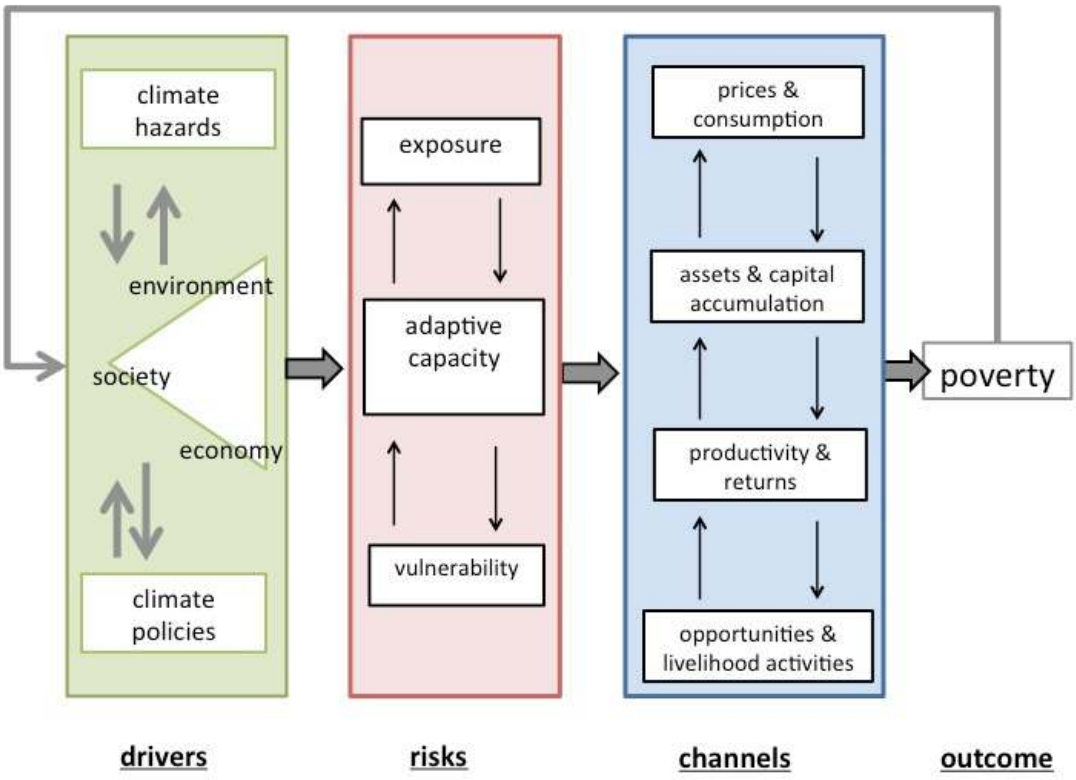
But since climate change is likely to lead to an increase in volatility and uncertainty (i.e., an increase in variance σ_j), it may also push households to increase diversification and reduce risk-taking, potentially reducing average incomes and income growth.

[19] In some domains, it is possible that households take too much risk instead of too little. This may be the case in the presence of externality and moral hazard (e.g., part of losses in case of bad outcomes is transferred to others). In that case, regulation or incentive-based policies should on the opposite try to reduce risk taking (see for example, World Bank, 2013: Ch. 2).

2.4 The impact of climate change on poverty alleviation

Climate change is hardly the only stressor that limits the ability of the poor to improve their condition. If households are poor, indeed, it is likely that the four channels to escape poverty are already impaired by some factors, mostly unrelated to climate and weather. As described earlier, limited access to infrastructure, inability to save, over-exploited natural resources, or exclusion, already represent significant challenges. Moreover, nonlinearity and thresholds (e.g. poverty trap) could lead a small climate-related increment in these obstacles to have a large impact on poverty reduction. Only the consideration of the full range of stressors can give a fair idea of the risks that climate change creates for poverty alleviation (Adger, 1999; O'Brien and Leichenko, 2000; Tschakert, 2007).

Figure 2: Channels from poverty to climate change vulnerability and back to poverty.



Source: Own elaboration.

Note: Climate hazards, climate policies and other economic, social and environmental stressors affect poor and vulnerable people. Depending on their exposure, vulnerability and adaptive capacity, these stressors translate into poverty outcomes through their impacts on consumption, assets, productivity, and opportunities. There is also a feedback relationship, whereby poverty outcomes can affect climate change.

To assess the impact of climate change on the four channels (Figure 2), we make use of the classical framework of risk management, which looks at risk as the combination of the hazard – here, climate change impacts – and (i) exposure to the hazard, (ii) vulnerability; and (iii) adaptive capacity and ability to adapt to changes (Figure 2). Following IPCC (2014), vulnerability includes prevention and preparation to reduce the sensitivity to hazards (from building dikes to precautionary savings), and coping elements (e.g., access to credit, health care, and social protection and safety nets after the shock) (see also Heltberg et al., 2009).

The following four sections examine each channel in turn. For each channel, we discuss the literature that describes the channel, and also review what we know of the exposure, vulnerability, and ability to adapt of the poor and vulnerable. Some determinants are very specific to a given channel; for instance, there is no reason for the exposure of the poor and vulnerable to food price changes to be similar to the exposure to asset losses from floods.

But some determinants are the same for all channels. For instance limited financial inclusion means that many poor people cannot save in a diversified portfolio and are more vulnerable to a single localized shock, regardless of its origin. According to the World Bank's FINDEX database (FINDEX, 2011), more than 20% of Indonesian households in the top 60% of the income distribution saved at a financial institution in 2011 vs. less than 8% for the bottom 40%.[20] This difference suggests poor households are likely to have more of their assets and savings localized in or around their dwelling, and thus lose a larger fraction of their income in case of an asset-damaging disaster such as floods.

In addition, poorer households often have more limited access than the non-poor to social protection and safety nets after disasters, which makes them more vulnerable to any sort of shock. According to the World Bank's ASPIRE database (ASPIRE, 2014), the average per capita transfer received by the extreme poor from social protection is much lower than the transfer received by the richest quintile. In Malawi, those in the poorest quintile receive on average 0.5 cents per day, while the richest 20% receive more than 17 cents. In Vietnam, transfers are respectively 9 cents and $1.6; in Colombia, the poorest receive 23 cents per day and the richest more than $4.6.[21] Poor households are therefore not only often more exposed to disasters, but also more vulnerable to them (in the sense that they lose more when affected).

Similarly, households that are poor in terms of social capital may also be more vulnerable to all sorts of shocks; for natural hazards, social capital has been stressed in the literature as having an impact on vulnerability (Tompkins & Adger, 2004; Helgeson et al., 2013). While difficult to measure, examples from drought in Ethiopia and Hurricane Katrina in the US suggest low-income households rely on social capital for individual and family survival post-disaster (Little et al. 2006; Hawkins and Maurer, 2010)[22] and that higher levels of social capital are associated with shorter recovery time (Moore et al., 2004; Mogues, 2006; Bin and Edwards, 2009). In addition to higher vulnerability, households with little social capital may find it difficult to adapt to changes after shocks.

[20] This pattern is consistent across countries. In 159 out of 164 countries with data in 2011, the top 40% had higher proportion of households saving at a financial institution compared to the bottom 60%, with the average difference 10%.

[21] In these three countries, the difference does not arise from the coverage, since as many or even more households of the first quintile are covered than the richest households. Further, based on latest available data, the finding that the rich receive larger support is consistent across 49/52 countries, with the average difference $2.85.

[22] Hawkins and Maurer (2010), in an analysis of 40 families following Hurricane Katrina, find that residents, especially those with low incomes relied on social capital for individual, family and community survival. Bonding social capital was relevant in day-to-day activities (e.g. childcare) and following the storm; bridging social capital (connections across geographic and socio-economic lines) also provided access to essential resources. Little et al. (2006) find social mechanisms played a significant role in the recovery period in Ethiopia following the 1999-2000 drought. Wealthier members loaned considerable numbers of livestock, food, and cash to the poor, but such assistance drops off as conditions deteriorate, and are not enough to prevent asset depletion and suffering.

3 CONSUMPTION CHANNEL

Climate change and climate policies will affect relative prices, including food, energy, and land prices. The effect will not only be on the *level* of prices, but also on their *volatility*. And the impact will also depend on the context and the climate and non-climate policies implemented in the next decades.

3.1 Food prices

Food prices may increase under climate change due to a decline in crop yields and climate policies that constrain land uses for food production. Even with adaptation to changing conditions, food prices will be affected by climate change impacts on agricultural productivity, including through extreme events (droughts, extreme temperature), disease and pests (Knox et al., 2012; Bondeau et al., 2013). According to the last IPCC report (Porter et al., 2014), climate change could lead to increases in food prices by 3 to 84% by 2050, if the effect of CO_2 fertilization is disregarded. With the fertilization effect, the uncertainty is much larger and the modelled increase ranges from –30% to +45% by 2050. These results are based on models that ignore the effects of ozone, pests and disease, and therefore underestimate the uncertainty, and also very likely the possible increase in food prices. These are also global estimates, with the possibility of much larger (or lower) local changes, especially in places that are not well connected to global markets (because of institutional barriers or lack of infrastructure). Additionally, land-use based climate policies, that aim to expand use of bioenergy or to reduce emissions from deforestation and forest degradation and other forest-based activities (also known as REDD+) would lead to an increased scarcity of land and thus increase the domestic market prices of food crops and decrease food consumption (Wise et al., 2009; Chen et al., 2011; Golub et al., 2013; Kuik, 2013).

Everybody is exposed to changes in food prices, but the food budget of poor households is one significant source of vulnerability. The poor spend a significantly larger percentage of their budget on food in all regions – on average, 62% compared to 44% for the non-poor (Table 3). In certain cases (Cambodia, Malawi, Sierra Leone), the poor spend as much as three-quarters of their income on food.

Table 3: Food budgets of poor and non-poor households by region.

Region	Food share among poor (% of total income)	Food share among non-poor (% of total income)
East Asia and Pacific	65	52
Eastern Europe and Central Asia	63	45
Latin America and the Caribbean	59	33
Middle East and North Africa	66	49
South Asia	59	41
Sub-Saharan Africa	64	48
Developing World	**62**	**44**

Source: Ivanic and Martin (2014).

Note: Table is based on 31 household surveys covering half the population in developing countries.

The net impact on the poor will vary however, based on their individual circumstances and vulnerability – notably whether they are net food consumers or producers (Ahmed et al., 2009; Devarajan et. al., 2013; Section 5.1). It will also depend on their connection to larger (possibly international) food markets; and on

their ability to adapt for instance by modifying their diets toward cheaper crops or relying more on imports than local production. Note that not all impacts will be mitigated by markets: some food consumed by the poor is not bought on a market (e.g., non-timber products provided by forests, self-production of crops, or small fishery catches).

Without changes in productivity and returns, a rise in food prices could increase poverty rates significantly. Ivanic and Martin (2014) find food price increases unrelated to changes in productivity and wages raise poverty in most developing countries in the short-run: a 10% price increase leads to a 0.8 percentage point increase in poverty headcount rates; a 50% price increase, 5.8 percentage points; a 100% price increase, 13 percentage points. In countries where most of the poor are wage earners or urban laborers, large productivity losses in agriculture can increase poverty dramatically via the consumption channel – by 20–50% in these income groups in parts of Africa and Asia (Hertel et al., 2010). Productivity shocks due to the rising incidence of weather extremes could increase poverty across developing countries — particularly in Bangladesh, Mexico, and Indonesia – with urban wage earners the most vulnerable group (Ahmed et al., 2009).

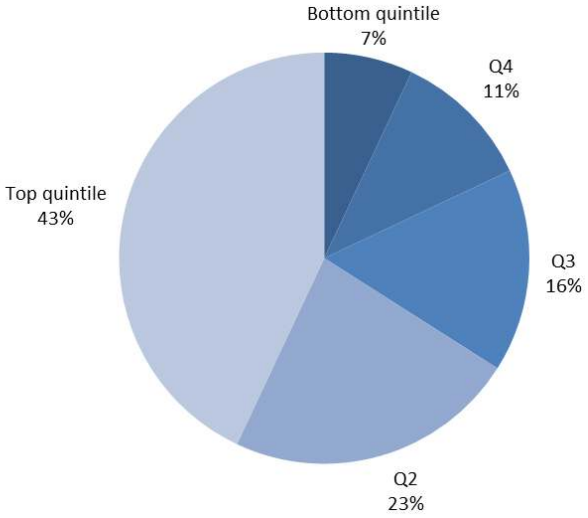
3.2 Energy prices

Energy prices may be affected through physical impacts (e.g., through a reduced availability of water for thermal and hydro energy generation), but also by climate mitigation policies (e.g., a carbon price). Individuals are affected by changing energy pricing and taxation directly as consumers, but also as tax payers/recipients of public spending and as workers (if energy pricing affects competitiveness and job creation, see Sections 5.1 and 6.2 for a discussion). Poverty is likely to increase if the rise in energy prices is not offset by an increase in energy efficiency (Ürge-Vorsatz and Tirado Herrero, 2012). Impacts on poverty will also depend on household exposure and vulnerability, measured by the share of income spent on energy, the need for energy consumption (which depends on the climate and economic activity), and the ability to shift from one fuel to another. There are many analyses of distributional impacts of a carbon tax, but mostly in developed countries (Dinan and Rogers, 2002; Callan et al., 2009; Fullerton, 2011). In developing countries, studies have focused on the reform of fossil fuel and energy subsidies, which pose similar distributional challenges (e.g., Vagliasindi, 2012; Clements et al., 2013).

Although both energy subsidy reforms and carbon taxation could hurt the poor, they can also generate resources that can be used to provide compensation to the poor, either by policies to provide in-kind benefits or through cash transfers (World Bank, 2014a). As the poor generally benefit less than the non-poor from energy subsidies (Figure 3), compensatory policies can more than offset negative impacts from reform. For example, Ghana‘s 2005 subsidy reforms increased the price of transport fuels by 50% but included in-kind benefits for the poor: an expansion of primary health care and electrification in poor and rural areas, large-scale distribution of efficient light-bulbs, public transport improvements, and immediate elimination of school fees at government-run primary and secondary schools (Coady et al., 2006; Vagliasindi, 2012; Clements et al., 2013). These mitigation policies (on health, education, and energy

access) were well-targeted to the poor and contributed to the success of the reform (Clements et al., 2013; World Bank, 2014a). Indonesia is another example of efforts to ensure the poor are protected.[23]

Figure 3: Share of benefits from energy subsidy by income quintile, average across 20 countries, various years.



Source: Arze del Granado et al. (2012)

3.3 Land prices

Land prices may also increase due to climate hazards or climate policies that constrain land availability. For instance, flood zoning policies in big cities may reduce the area available for development, leading to increased land – and thus housing – costs (Burby, 2001; Viguie and Hallegatte, 2012). For Paris, it was estimated that a strict flood zoning policy preventing all new development in the flood plain would increase rents, although by a small amount. In places that are growing faster and have a larger fraction of land exposed to flood, this effect could become much more significant. An increase in housing and land costs could have a direct (static) impact on the welfare of the poor. But more importantly, it can have a dynamic impact on poverty reduction, if it slows down rural-urban migration through which so many poor people access better salaries, health care, and education for their children (Section 6.3).

Land use-based mitigation policies could also increase land values through subsidies for certain activities (e.g. production of bioenergy) or payment for ecosystem service like mechanisms for carbon sequestration (e.g. through REDD+). In addition to increasing food prices, this could spur competition for land in which wealthier and more powerful land users oust the poor, who often lack secure of formal land titles (Redford and Adams, 2009; Larson et al., 2013). Increases in land prices may challenge the ability of the poor to access land, whether by buying (a path out of poverty that is important in some contexts, see for instance Barrett et al., 2013) or renting or using it illegally, for instance when they migrate to cities.

[23] To compensate for an increase in energy prices, Indonesia deployed a program of unconditional cash transfers which provided 1/3 of the population USD $30 per quarter, significantly more than the increase in energy costs (Vagliasindi, 2012; Clements et al., 2013). By covering the bottom 2 income quintiles, the program reduced the burden on the extreme poor and helped prevent vulnerable populations from falling into poverty (Bacon and Kojima, 2006). Despite leakage and targeting errors, the program was largely successful in reaching the poor (World Bank, 2014a).

3.4 Other sectors and price interactions

Food, energy, and land prices are affected by macroeconomic policies such as trade policies (e.g., export bans implemented after a disaster), the provision of infrastructure (e.g., better market access can help avoid price crisis in case of local production shock), and market regulations. Further, many markets in poor countries are hampered by a large array of market incompleteness and failures, potentially worsening consumption and price impacts of climate change relative to what models suggest. In general, a more open economy will be less exposed to local shocks (e.g., a local drought that drives food prices up), but more exposed to imported shocks, such as the 2007/08 food and fuel price crisis. The net impact (for instance on total volatility) will be dependent on the local context and the type of shock (local vs. global shock).

Finally, other prices matter too. In particular, most green technologies imply higher upfront costs and lower operational costs. Even when green options are less expensive when capital and operational costs are taken into account (e.g., energy-efficient buildings with low heating and air conditioning costs; energy efficient light bulbs), the increase in upfront costs may represent a barrier for poor households with cash constraints and limited access to credit. Introducing greener technologies without poverty impacts may thus require the development of specific financing instruments or fiscal policies (World Bank, 2012). In Tunisia, the government put in place, since 1995, exemptions from VAT and minimum customs duty on the import and production of compact fluorescent lamps and a range of other energy efficiency equipment materials.

4 ASSET CHANNEL

By affecting assets and their returns, climate change can affect households' ability to accumulate capital. It can do so through two main channels. First, climate change impacts or policies can lead to asset losses. For instance, natural disasters can destroy physical and natural assets. Also, changes in regulations can affect the use of some polluting assets that provide a service to the poor. Households holding less transferrable, less portable, and/or less diversified assets will be disproportionally hit by rapid changes in environmental conditions and disasters, as adaptation may require unaffordable investment in new assets.

Climate impacts and policies can also affect investment choices, even before a shock occurs or an environmental change takes place. Increased risk perceptions of asset losses (e.g., from natural disasters) or uncertainty on future returns can disincentivize capital accumulation, while greater income volatility can provide a rationale for larger savings and thus investment. These ex-ante impacts – in the sense that they occur even if the risk never materializes into actual losses – cannot be disregarded: in some analyses, ex ante impacts explain half of the reduction in income due to risk (Elbers et al., 2007). The next two sub-sections explore first the role of asset losses and then the ex-ante impacts on investment choices.

4.1 Asset losses

Given the critical importance of asset accumulation and portfolio diversification for poverty reduction, disasters that affect asset holdings can prevent households from escaping poverty, or bring non-poor households into poverty (Carter and Barrett, 2006; Moser, 2008; Barrett et al., 2013; Hallegatte, 2014a). For example it took an average of 10 years after the 1984-85 famine in Ethiopia for asset-poor households to bring livestock holdings back to their pre-famine levels (Dercon, 2004). Also in Ethiopia, Tesso et al. (2012)

find households who have not liquidated productive assets during a shock have a 17.8% higher likelihood of moving to the next-better category compared to those that liquidate assets.

Why might asset-poor households take longer to recover? One hypothesis is that households above and below a critical asset threshold have divergent fortunes. Households with enough assets are expected to smooth consumption following a shock while asset-poor households may smooth assets and destabilize consumption in an attempt to preserve the small productive resources they still have, as evidenced in case studies (Barrett et al., 2006; Carter and Barrett, 2006; Hoddinott, 2006; Carter et al., 2007). Vulnerability assessments by the World Food Programme and Save the Children also report reduced consumption and asset smoothing by the poor (Clarke and Hill, 2013). This literature suggests asset impacts from natural disasters are different for the poor and non-poor, with dynamic effects of asset-reduction possibly keeping households in poverty and pulling down vulnerable populations. This is especially true for households that have limited access to credit, social protection and smoothing instruments, since a one-time drop in income may force them to sell assets in a rush, often at a low price with long term consequences.

It therefore becomes a policy priority to keep households from losing their asset base below a certain threshold, and to likewise ensure consumption is not destabilized after a disaster (Carter et al., 2007; Heltberg et al., 2009). Doing so is only possible if social protection interventions can be scaled up or introduced rapidly after a shock: Clarke and Hill (2013) investigate the case of Ethiopia and Malawi and find that the cost of a drought to households increases from zero to about $50 per household if support is delayed by 4 months after harvest and to about $1,300 if support is delayed by 6 months or more. This rapid increase is due to irreversible impacts on children and on distress sales and loss of assets (especially livestock). Acting rapidly implies (i) scaling up social protection immediately after a disaster; (ii) targeting the affected population; (iii) enhancing livelihoods to make them more resilient to shocks, and (iv) having stronger institutions for managing risks and crises (Kuriakose et al., 2013; World Bank, 2013). In a world in which climate change makes such disasters more frequent or intense (IPCC, 2014), the effect on poverty could increase significantly, making policies to support affected households even more important.

The following sections explore different types of assets and the impact of weather events on them. They show that all asset categories are at risk from extreme weather events, with consequences for poverty. These risks may be magnified by climate change, due to increased intensity of heavy rainfall and storms, more frequent and intense heat waves, and sea level rise (Hallegatte 2014b, Chapter 4).

4.1.1 Physical asset losses

The weather events and natural disasters that are likely to increase with climate change cause large-scale destruction of assets with a strong impact on poverty. In Ethiopia where cattle account for more than 90% of household wealth (Dercon, 2004), Lybbert et al. (2004) find poor rainfall years result in increases of livestock mortality of 25%-35%. Similar findings of livestock loss after drought were also found more recently in Kenya (Government of Kenya, 2012; Clarke and Hill, 2013). And even when livestock survive, it may have to be liquidated to maintain consumption above subsistence levels: Hoddinott (2006), analyzing the 1994-95 drought in Zimbabwe, find that 15% of households with 1-2 livestock sold a fraction of their herd, while some 50% of those with more than 2 livestock did so.

Studies have also examined impacts from floods. A survey of households following the 2005 floods in Mumbai finds losses averaged more than four times the mean monthly income (Patankar and Patwardhan, 2014). Somanathan and Somanathan (2009) find the Kosi floods in 2008 in Bihar (India) reduced household savings by more than two-thirds: pre-flood, median savings of those who held bank accounts was Rs. 3400; post-flood, Rs. 1380. For cash at home (a category more relevant for the poor), a similar trend emerged: median savings decreased from Rs. 1370 to Rs. 360. Brouer et al. (2007) survey losses to annual flooding of 700 floodplain residents in southeast Bangladesh. Almost all (95%) report that housing area gets inundated, with average flood damage USD $198, or 21% of annual household income.

The impact on the poor depends on their exposure and vulnerability to the shocks that destroy assets, such as storms and floods. One major reason why the poor may be particularly exposed to such natural disasters is the role of formal and informal land markets: if natural risks are included in land price valuation (or desirability), poor households should be more likely to live in risky areas where land is cheaper (Fay, 2005). This explains why slums are typically located in floodplains or in areas at risk of mudslides, and why the poor are more likely to be exposed to disasters. For example, in Mumbai, by combining household data on income and household location with outputs from flood models of a 100-year event (one model using historical data and another considering climate change[24]), it is found that the poor are disproportionately exposed to these floods, today and in the future (Table 4). On the other hand, potentially dangerous locations may be sufficiently desirable to attract richer populations: coastal cities are often very exposed to flood risk, but they host households that are generally richer than those from rural and inland regions. Thus, data on exposure suggest very scale- and context-specific results. For instance, Carter et al. (2007) find that only 22% of households in the poorest quintile of a panel in Honduras were affected by Hurricane Mitch in 1998, as opposed to 68% in the richest quintile.

Table 4. Differential exposure of the poor to flood hazard in the Mithi River Basin, Mumbai

Income (Rs./month)	Share of households in survey (%)	Share exposed historically (%)	Share exposed with climate change impacts (%)
<5,000	27	44	43
5,001-7,500	28	33	34
7,501-10,000	22	16	17
10,001-15,000	12	5	5
15,001-20,000	6	1	1
>20,000	6	1	1
	n=4972	**n=210**	**n=347**

Sources: Baker et al. (2005); Hallegatte et al. (2010); World Bank (2014b)

While the poor may not always be the most exposed to shocks that destroy assets, evidence suggests that when hit, they lose a greater percentage of their assets. Carter et al. (2007), after Hurricane Mitch in Honduras, find that the poor lost 31% of their assets while the rich only 8%. Brouer et al. (2007) find poor coastal Bangladeshis have 25% higher levels of inundation, and lose more as a percentage of household income (41.6% compared to 16.6%). Also in coastal Bangladesh, Rabbani et al. (2013) find the extreme poor

[24] Based on the SRES/A2 scenario in the 2080's, using only one climate model, downscaling technique, and hydrological model (see Hallegatte et al, 2010).

lose more as a share of income due to the decrease in rice production from cyclone-induced saline intrusion. In 2009 (year of the event), the extreme poor lost 74%, the poor 43%, and the non-poor 45%; similar trends were present in 2010 and 2011. This is also supported by Patankar and Patwardhan's (2014) analysis of households affected by the 2005 floods in Mumbai (Table 5). A large share of disaster losses for poor households consists of housing losses (Patankar and Patwardhan 2014). The fact that housing investments are the first that poor households make before other categories of investments (Moser and Felton, 2007) suggests that housing losses have particularly large impacts on well-being and on the ability to generate an income and accumulate assets.

Table 5. Total losses per assets and expenditures by quintiles affected by 2005 Mumbai floods.

Quintile	Income and asset losses (Rs.)	Average of losses / cost of selected assets	Average of losses / total monthly expenditures	No.
1	43,794	4.74	13.45	249
2	59,931	3.17	10.12	163
3	61,916	3.03	8.16	205
4	67,038	3.26	6.74	263
5	83,760	2.50	5.92	148

Source: Patankar and Patwardhan (2014).

Note: In the absence of data on the total amount of assets owned by households pre-flood, we proxy using cost of some assets (household appliances, furniture, and vehicles) and total expenditure. Using both metrics, poorer quintiles have higher ratios of losses per cost of assets and losses per expenditure than richer quintiles. Quintiles are calculated based on monthly expenditure of the household.

The assets used by the poor to generate their income tend to be more vulnerable to climate change impacts for two reasons. First, assets used by the poor are usually more vulnerable (e.g., lower quality houses that can be completely wiped out, Fay, 2005). Second, the non-poor usually have more assets in non-physical forms such as financial savings, which are less vulnerable to disasters (as financial savings are usually diversified geographically). So while there is mixed evidence regarding the exposure of the poor when compared with the non-poor, we find a consensus regarding the higher vulnerability of the poor, i.e. when they are affected, poor households lose a larger fraction of their assets than the non-poor.

Considering the exposure and vulnerability of poor households to physical asset losses due to natural disasters, and the demonstrated impact on poverty (Sanchez and Calderon, 2014), an increase in disaster economic losses due to climate change may magnify this challenge to poverty reduction and bring more households back into poverty every year. For instance, Bouwer (2013) reviews the published studies looking at the impact of climate change on asset losses due to natural disasters and finds that the economic losses due to tropical cyclones are expected to experience changes between -27% and 1,365% (with a median at +30%); extra-tropical cyclones between -33% and 160% (median +15%); and river floods between +3% and +514% (median at 83%). These large ranges are explained by regional differences and by the use of different models. They underestimate the variance because most of the available studies focus on developed countries alone. In a study that includes developing countries and looks at storm surges in coastal cities of more than one million inhabitants, Hallegatte et al. (2013a) show that losses can react

nonlinearly and increase rapidly if appropriate adaptation measures are not (or imperfectly) implemented.[25]

4.1.2 Human capital and health

Building human capital through better health and education is an important component of escaping poverty. Moreover, it is one way for parents to help their children improve their condition, and reduce the intergenerational transmission of poverty. Further, health shocks are consistently mentioned as one of the main reasons why households become poor.[26] So even a small effect of climate change on health could have a significant impact on poverty dynamics, and result in a large increase in the number of households falling back into poverty every year.

Evidence suggests acute impacts on health from lower post-disaster consumption, especially after droughts. Following weather shocks in Sub-Saharan Africa, asset-poor households provide children with lower-quality nutrition (Yamano et al., 2005; Alderman et al., 2006; Hoddinott, 2006; Dercon and Porter, 2010) and are less likely to take sick children for medical consultations (Jensen, 2000). These behaviors have short- and long-term impacts particularly for children younger than two. Among this group, households reducing nutrition lowered growth by 0.9 cm in six months post-disaster (Yamano et al., 2005) and were more likely to suffer recent illness (Dercon and Porter, 2010). In the long term, asset-smoothing households permanently lowered stature by 2.3 cm (Dercon and Porter, 2010) and 3 cm (Alderman et al., 2006). Hoddinott (2006) also observes the body mass index (BMI) of women reduced 3%; while this recovered the following year, impacts on children are long-lasting.

Impacts on education are also prevalent. Jensen (2000) finds enrollment rates declined 20% in exposed regions, Alderman et al. (2006) find drought-affected households delayed starting school of children on average 3.7 months, and this sample completed 0.4 fewer grades. Dercon and Porter (2010) find those younger than 36 months at the apex of the famine were less likely to have completed primary school, with calculations suggesting this leads to income losses of 3% per year (Dercon and Porter, 2010). Such findings are not restricted to Africa; similar impacts on health and education post-disaster have been found for instance in Asia, Latin America and elsewhere (see Maccini and Yang, 2009; Baez et al., 2011).

Health challenges are not limited to shocks: malnutrition can be a chronic condition linked to usual economic and climate conditions. Climate change may reduce future agricultural yields and threaten food security, thus increasing the risk of malnutrition and stunting. Lloyd et al. (2011) develop a model for estimating future patterns of malnutrition that accounts for climate and non-climate causes. They estimate that climate change will lead to an increase in moderate stunting of 1-29% in 2050 compared to a future with no climate change while severe stunting could increase by up to 23% in Sub-Saharan Africa, and 62% in South Asia – even when accounting for economic growth.

[25] They find that without adaptation, losses would rise from $6 billion per year today to unacceptable losses (in excess of $1 trillion per year) in 2050, even with only 20 cm of sea level rise. And even with adaptation, losses would still rise to more than $50 billion, and hard protection increases the vulnerability to defenses failure. The non-linearity in disaster frequency is also visible in Church et al. (2013): their Figure 13.25 shows that a 50 cm rise in sea level could multiply by between 100 and 1000 the frequency of coastal floods in some locations, if defenses are not upgraded.

[26] Health issues reduce the ability of households to earn an income, but it also deplete their financial assets because of health expenditures, especially when households have to borrow at high interest rates.

Considering the importance of child health and education for long-term prospects, productivity and income, even a moderate impact of climate change on these dimensions could affect poverty visibly over the long-term. Moreover, since poor households are suffering disproportionally from impacts, it would increase the poverty legacy and reduce the chance for children from poor families to escape poverty, reducing further social mobility.

Avoiding irreversible losses of human capital should thus be a priority of social protection systems and safety nets, and doing so is only possible if these systems can be scaled up or introduced rapidly after a shock (Clarke and Hill, 2013). Doing so requires that safety nets are designed to be easy to scale up both in terms of amount per beneficiary and in number of beneficiaries, creating issues related to the targeting and identification of affected population, as well as method and type of service delivery. Furthermore, the literature shows that health shocks are more likely to bring households into poverty where households can only borrow at high interest rates (e.g., Krishna, 2006). It suggests that health shocks create poverty not only by reducing income, but also through health care expenditures and excess borrowing. Financial inclusion and universal health care insurance could therefore be powerful instruments to reduce the poverty impact of health shocks and therefore the impact of climate change through this channel.

4.1.3 Social capital and conflict

Social capital comprising networks and connections between people and the norms and preferences underlying social behavior can be harmed by stressors, such as conflict. By creating forced migrations (e.g., due to disasters or permanent changes), local conflict and violence over resources, climate change could reduce the social capital of households, and make it more difficult for households to generate income. The impact of environmental and climate conditions on conflicts is an open research area, with many new analyses being published every year (Burke et al., 2014). These studies look at interpersonal conflicts (e.g., crime, assaults, rape, and road rage) and intergroup conflicts (e.g., civil conflicts, wars, and riots).

On interpersonal conflicts, Ranson (2014) finds a strong correlation in the US between crime and violence and temperature and suggests that climate change will increase murders, assaults, rape and other violence. In developed countries, this increase is usually explained by psychological factors, and seems robust to climate conditions.[27] In less developed countries, such as India, it has been suggested that the channel is from weather to income and from income to crime (Iyer and Topalova, 2014).

On intergroup conflict, the large literature reviewed in Burke et al. (2014) also suggests an impact of weather and climate on conflict, for temperature and precipitation, and especially in low-income areas. Their meta-analysis suggests that interpersonal conflicts increase by 1.2% and intergroup conflicts increase by 4.5% when temperature deviates by one standard deviation, and the cumulative effect of rainfall on intergroup conflicts is also notable, with an increase by 3.5% for one standard deviation. But a vigorous debate has emerged around the robustness of these results (Buhaug et al., 2014 and Hsiang et al., 2014), with the IPCC taking the position that “collectively the research does not conclude that there is a strong positive relationship between warming and armed conflict” (Adger et al., 2014).

Social capital can be related to increased well-being as it enables collective action, which can be used to overcome markets and government failures (Putnam, 1993; Bowles and Gintis, 2002). In the absence of

[27] At least for the climates that can be found in the US.

other safety nets, these are also important means to manage climate risk (Adger 1999; Tompkins and Adger, 2004; Rodima-Taylor, 2011). As such, poor households are likely to be more vulnerable to loss of social capital than richer households, who are more integrated in markets and more protected by formal safety nets provided by the government (see, e.g., Fay, 2005, for examples in Latin America). Lack of security is a fundamental threat to poverty reduction and the well-being of the poor. This is illustrated by the increasing share of the poor living in conflict environments. In the 33 countries (representing half a billion people) classified by the World Bank as fragile and conflict-affected states, the poverty headcount is 51%. Poverty reduction is impaired by conflict and fragility (World Bank, 2011), and an increase in conflict would likely translate into a slowing of poverty reduction.

4.1.4 Natural capital and ecosystem services

Many livelihood activities of the poor – especially in rural areas – depend on climate-sensitive ecosystems and natural capital, which can be affected by climate change. Ecosystem services play an important role in the livelihoods of the rural poor through agricultural incomes from activities that require intensive ecosystem management (i.e. cropping, livestock, forestry and aquaculture) and other ecosystem-based incomes from the extraction of non-cultivated ecosystem goods, such as timber, plants, and animals. A systematic analysis of a 28-country data set shows that the share from other ecosystem-based incomes in forest-based communities is higher for low-income quintiles but not dramatically so[28] (approximately 24% in the bottom quintile versus 18% in the top quintile) (Angelsen et al., 2014).

Climate change may affect stocks of natural capital, and hence flows of ecosystem services, which will change ecosystem-based income. There is increasing evidence that climate change alters the structure of ecological processes and supply of ecosystem goods (Chapin et al., 2004; Mooney et al., 2009; Warren et al., 2013). A review of the literature finds climate change has an effect on poverty through hazard regulation, soil and water regulation with ecosystem services most vulnerable in the Mediterranean, low elevation coastal zones and small island states, and dryland margins (Howe et al., 2013). Tropical forests can also suffer from die-back and forest fires (Malhi et al., 2009; Russell et al., 2012; Good et al., 2013).

The effect of climate change on the relationship between poverty and ecosystems depends on the role of ecosystem-based incomes in rural livelihoods. First, ecosystems can provide additional regular income that significantly lowers poverty – nearly two-thirds of the poverty reduction associated with the establishment of Costa Rican protected areas is causally attributable to tourism-based incomes (Ferraro and Hanauer, 2014). Second, ecosystem-based incomes often play a role in consumption smoothing between seasons or as a coping mechanism when other incomes fail – also due to climatic variability (Russell et al., 2012). Although this safety net role may be overestimated as argued in a recent global study (Wunder et al., 2014), climate change could undermine one of the only safety nets poor households can build on. Third, many rural poor are concentrated in ecologically fragile and remote locations and thus resort to overexploiting natural resources (e.g., timber, fish or grassland) for short-term survival – a strategy that can cause poverty traps (Barbier, 2010a; Barrett et al., 2011). In these circumstances, climate change can exacerbate the downward spiral of fragility and over-exploitation and make ecosystem-dependent households even more vulnerable (Munang et al., 2013).

[28] Prior case studies generally find a larger difference between poor and non-poor, although methodologies across studies are not standardized with differences in data collection/analysis, sampling, and definition of poor/non-poor.

4.2 Ex ante impact and risk taking

Low-income households are often risk averse and in the presence of climate-related risks they apply safety-first strategies, whereby they choose lower-risk, lower-return strategies. Accordingly, poor households are often found to diversify their income portfolios to manage risks, which comes at the cost of lower welfare: (Reardon et al., 1992, 2000; Barrett et al., 2001; Lay et al., 2008; Bandyopadhyay and Skoufias, 2013). Poor farmers, who lack other insurance mechanisms, disproportionately choose to grow low-risk, low-return crops, thereby perpetuating poverty (Rosenzweig and Binswanger, 1992; Dercon, 1996). These results suggest an increase in price and yield volatility (even with unchanged or improving averages) may lead to reduced average incomes for farmers, by causing them to focus more on low-return, low-risk activities. The literature on resilience stresses the importance of income diversification to reduce the vulnerability of poor households (e.g., Ellis, 2000), but there may be a trade-off between resilience and income growth for households in poverty, and an increase in risk due to climate change may push households toward more resilient options that offer less opportunity for income growth.

Evidence suggests that climate hazards can also impact risk preferences (Abreha, 2007; Cassar et al., 2011; Dang, 2012). Higher risk aversion due to natural disasters may in turn reduce risk taking in other domains such as innovation and entrepreneurship, reducing income and growth. For instance Cassar et al. (2011), through risk experiments of 334 subjects from Thai villages affected in different degrees by the 2004 Asian tsunami, find that individuals hit hardest exhibit strong risk aversion 4.5 years after the disaster.[29] Such an increase in risk aversion can lead to less innovation and investment in (non-climate-related) risky but high-yield activities (such as switching to new technologies and practices) (World Bank, 2013). In that case, higher risks from climate change can affect poverty reduction not through the losses from disasters, but from less risk taking in non-climate-related domains. This would result in reduced average income and possibly reduced income growth through slower innovation.

The problem is magnified by lack of information, cognitive failure and behavioral bias. A variety of studies have shown how inconsistent and incomplete people can be in their evaluation of risk (Tversky and Kahneman, 1979; Banerjee and Duflo, 2011; Weber and Johnson, 2012). When climate change is modifying environmental conditions – and thus the optimal allocation of assets and resources – lack of adaptation can occur due to the bias toward the status quo or the use of heuristics that are no longer valid. As the poor have less access to information and scientific knowledge, they are particularly exposed to this problem.

Where rapid changes occur, either climate conditions, policy shocks (a carbon price) or technology changes, the distribution of assets can become suboptimal, especially when asset portfolio structures cannot be adjusted rapidly. It is the case for physical assets (e.g., farm equipment) but also human capital if skills become inappropriate. The literature on mitigation policies is increasingly referring to these risks as "stranded assets" – that is, assets that cannot be used because of changes in regulations or relative prices. But stranded assets are also possible due to changes in climate conditions, e.g. if reduced water availability makes hydro dams or water resources useless (or at least in excess capacity, Nassopoulos et al., 2012).

[29] Not all studies confirm these results. Bchir and Willinger (2013), in a field experiment of lahars risk in Peru, finds no significant difference at the whole sample level for measures of risk aversion comparing exposed and non-exposed households. It should also be noted that this is a nascent literature and all above studies are in manuscript stage.

5 PRODUCTIVITY CHANNEL

Climate change can alter productivity in different sectors, which may translate into adjustments of returns to land and labor, thereby affecting incomes. Distributional impacts will vary depending on the role of earnings from agricultural self-employment and wages in the income portfolios of the poor.

5.1 Agricultural productivity, profit and wages

This channel is the "other side of the coin" of the food price discussion covered in Section 3.1. Changes in agricultural productivity, with gains in some places (even where yields decrease, prices may increase more and lead to high profits) and losses in others will affect the income of workers in the agricultural sector, and therefore poverty. In countries such as Burundi, Burkina Faso, Ethiopia, Mozambique, Sierra Leone, and Tanzania, World Bank household survey data indicate that more than 75% of workers are in the agricultural sector and between 75 and 95% of poor adults are farmers. The income growth of workers in the agricultural sector is therefore a key determinant of poverty eradication.

Crop productivity will be affected by temperature increases, changes in rainfall patterns, carbon fertilization from higher CO_2 concentrations, diseases/pests, water run-off/regulation, and soil erosion. Globally under a high emissions pathway scenario, the expected mean biophysical yield effect (without CO_2 fertilization) is a 17% reduction in crop productivity by 2050 relative to a scenario with unchanging climate (Nelson et al., 2014). However, impacts will vary across countries and crops – even within regions (Knox et al., 2012): recent findings from Latin America and the Caribbean indicate climate impacts on agriculture could be significant even by 2020, with rising risks to maize, soybean, and wheat in most producing countries by 2050 (Fernandes et al., 2012). In Bangladesh, climate variability is estimated to reduce long-term rice production by an average 7.4% each year through 2050, with the potential to lower GDP by an average of 1.15% each year (Yu et al., 2010).

Climate change may affect fisheries and the biomass and production of marine communities. Climate change could increase the productivity of freshwater ecosystems, while reducing it in coral reef fisheries and coastal aquaculture (Bell et al., 2013). National economies and fishing societies in tropical countries, especially in South Asia and East Asia and the Pacific could experience a significant loss in production potential (Allison et al., 2009; Cheung et al., 2010; Blanchard et al., 2012; Barange et al., 2014). As many subsistence households depend on fishing, management of fisheries under increasing pressures plays a key role in poverty reduction (Allison and Ellis, 2001; Béné, 2003; Béné et al., 2009).

The distributional impact of reduced productivity in farming and fishing depends on their impacts on agricultural profits and rural wages. Impacts on agricultural profits are determined by the integration of rural producers in markets. If farmers are price-takers, the farm-level price elasticity of demand facing producers will be crucial: when demand is inelastic, a reduction in supply will boost prices and profits and vice-versa (Hertel and Rosch 2010).

Wage earnings will also be affected. Yu et al. (2010) estimate that 80% of the total economic losses in Bangladesh occur primarily in the upstream and downstream agriculture value-added processing sectors. Wage response depends on the elasticity of rural wages with respect to productivity. The larger agriculture

is in relation to non-agriculture, the less elastic is the supply of labor to agriculture and hence the more responsive is the agricultural wage to price shock, as seen in India (Jacoby et al., 2014). These price-induced earning changes can be a more important driver of household poverty than the commodity price changes themselves (Ahmed et al., 2009; Hertel et al., 2010; Ivanic and Martin, 2014).

The poverty impacts of changes in agricultural profits and wages depends very much on where impoverished households earn their income. In countries where the bulk of the poor are self-employed in agriculture, moderate productivity losses can boost factor returns and reduce overall poverty (Hertel et al., 2010). Skoufias et al. (2011b) analyze how changes in the prices of land, labor, and food induced by modest temperature increases over the next three decades will affect household-level welfare in India, taking into account only agricultural impacts. Overall, the welfare costs of climate change are limited but fall disproportionately on the poor and the results suggest that poverty in India will be roughly 3-4 percentage points higher after 30 years of rising temperatures than it would have been had this warming not occurred.

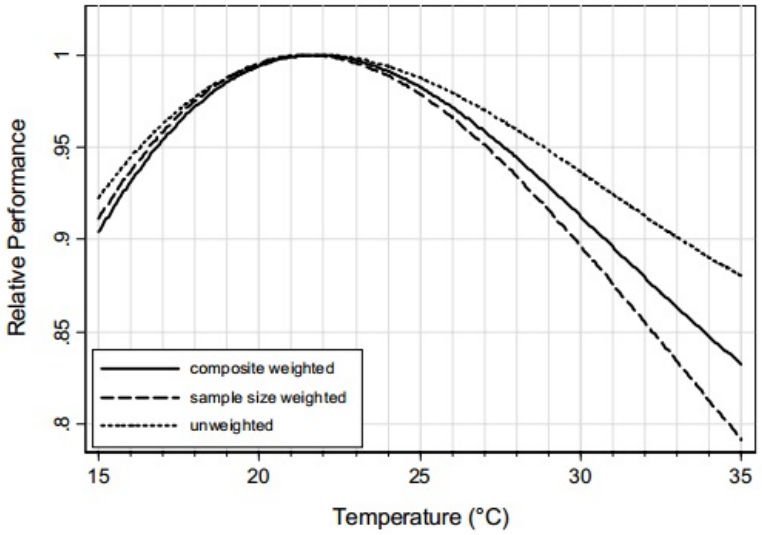
Adaptation options exist to help farmers manage impacts on productivity and respond to changing prices. These include improved seed varieties, technology adoption, crop and livestock diversification, changes in intensity and sequencing of production, and improved nutrient and pest management (Dinar and Mendelsohn, 2011). However, a farmer's adaptation decisions generally result from the interaction of a number of factors. Critical factors include access to credit and extension services (Nhemachena et al., 2014); access to key markets, tenure and plot characteristics (Pattanayak et al., 2003; Barbier, 2012), soil quality and farm size (Pattanayak et al, 2003). In Mozambique, Nepal, and Ethiopia, market access through an adequate road network was found to be crucial for the adoption of new technologies, and to help compensate for poor environmental characteristics (Dercon et al., 2009; Cunguara and Darnhofer, 2011; Dillon et al., 2011). Moreover, it is important to consider that, as mentioned earlier, poor farmers may be more risk averse and thus less likely to pursue adaptation options.

5.2 Labor productivity and wages

Excessive heat in the workplace reduces labor capacity and productivity due to the limits of human physiology in adapting to high temperature (Kjellstrom et al. 2014, and Figure 4). A recent report estimated this could account for up to 56% of the total economic costs due to climate change in 2030 (DARA, 2012). Heal and Park (2013) show that labor productivity is a key link between climate and economic outcomes at the macro-level, with hotter-than-average years associated with lower income and total factor productivity for countries in hot climates but higher output for countries in cold climates. They quantified this variation of productivity to be approximately 2-4% of output per capita per °C in both directions, noting that temperature inside the workplace matters for economic productivity. The ability to provide adequate thermoregulatory infrastructure is thus crucial for the economic development of hotter countries.

Labor productivity can also be affected indirectly, through complementary inputs into the production process. For instance, an increase in energy prices (e.g. through energy subsidy reform) can threaten the competitiveness of energy-intensive industries, thereby reducing labor productivity and wages (Section 6.2). It can also make it more costly to protect workers against climate conditions, for instance by making air conditioning more expensive, especially in low-quality buildings.

Figure 4: Task performance vs temperature. Maximum performance is normalized to 1 at 22°C.



Source: Seppanen et al. (2006)

6 OPPORTUNITY CHANNEL

Historically, poverty alleviation has mostly taken place through structural change, with people moving from rural to urban areas, and from informal traditional activities to formal modern ones such as manufacturing and services. Maximizing these opportunities, and the ability of households to capture them, is therefore a critical component of poverty reduction (Fay, 2005). In OECD countries, industrialization provided new opportunities for agricultural workers just as mechanization increased agricultural productivity, creating surplus labor. If observed in developing countries, this virtuous circle would lead to poverty eradication via increased wages in agriculture and a modernization of the economy (Lewis, 1954, Timmer, 1988; 2009).

However, migration to cities is not always driven by better opportunities in urban modern sectors. The driving force may be the push of declining returns to agriculture, due to high population growth and land constraints, insecurity, or the lack of services in rural areas (Dorin et al., 2012; Wodon et al., 2014). Climate change impacts in rural areas may thus lead to more rapid changes in the rural-urban and economic structures without reducing poverty. However, Henderson et al. (2014) find that in Africa at least, the drying conditions of the last 50 years induced employment change out of agriculture but only increased urbanization in places that already had an industrial base; the only impact in those without such an industrial base, was a reduction in both rural and urban incomes.

There are many channels through which opportunities in modern sectors are affected by climate change. And where these opportunities do exist, climate change can affect the ability of poor households to capture them. It is especially important to note that this opportunity channel interacts closely with the asset channel; indeed, assets are critical to allow households to migrate or shift toward other activities (e.g., formal land tenure allows migration without losing rights to use land; savings help meet upfront costs; social networks help reduce uncertainty and find a job in a city). Reciprocally, the ability to capture opportunities helps to accumulate assets, through higher and more diversified incomes, but also through remittances from migration (e.g., Adams, 1998).

6.1 Climate change and economic growth

Given the critical role of economic growth in reducing poverty (Dollar and Kraay, 2002; Dollar et al., 2013), a key concern is that of the impact of climate change and policies on growth (and thus on the pace at which new sectors and jobs appear, affecting the set of opportunities *J*).[30]

The existence of a relation between climate and economic growth is now well established. Reduced rainfall in the 20th century partly explains Sub-Saharan Africa's slow growth (Barrios et al., 2010, Brown et al., 2011). High temperatures in the second half of the 20th century may have slowed down growth in poor countries in both the agricultural and industrial sectors (Dell et al., 2012) with one degree of warming found to reduce income by 1.2% in the short run, and by 0.5% in the long run (Dell et al., 2009). Other studies have found an even larger impact. For instance, Horowitz (2009) finds a 3.8% drop in income in the long run for one degree of warming. Such a reduction in aggregate growth would have a major impact on poverty.

Most studies of the aggregate economic impact of climate change find relatively limited impact on GDP,[31] hence modest poverty impacts through this channel (Table 6 is an example). However, these efforts suffer from a number of limitations. First, studies of the impact of climate change on growth have well-identified gaps and methodological limits, and the confidence in their results is limited, especially at warming levels that exceed 2°C (IPCC 2014); second, studies such as Anderson (2006) and Skoufias et al. (2011a) assume the GDP-poverty elasticity remains constant so that growth is the only channel through which climate change affects poverty reduction.[32] The discussion in Sections 3, 4 and 5 suggest the poor are more exposed to climate risks than the non-poor; thus the GDP-poverty elasticity is unlikely to remain unchanged.

Table 6. Impact of climate change on poverty (at the $2 line) assuming no changes in the poverty elasticity of growth

Scenarios	Number of poor (millions)			Headcount poverty rate (%)		
	2005	2055	Change	2005	2055	Change
Baseline	2,069.4	1,259.1	(810.3)	32.3	14.1	(18.2)
BAU	2,069.4	1,269.2	(800.2)	32.3	14.2	(18.1)
Difference from baseline	..	10.1	10.1	..	0.12	0.12
Optimal abatement	2,069.4	1,268.5	(800.9)	32.3	14.2	(18.1)
Difference from BAU	..	(0.7)	(0.7)	..	(0.01)	(0.01)

Source: Skoufias et al. (2011a)

Note: Baseline amounts to no climate change, BAU is business as usual (unmitigated climate change), and optimal abatement is a scenario with mitigation. The authors assume unchanged elasticity of growth with respect to poverty. In the BAU scenario, climate change impacts reduce global GDP by 1.5% in 2055. Growth

[30] At the macroeconomic level, Hallegatte (2012) provides a framework to assess the impact of sea level rise on economic growth, looking at the permanent and temporary impacts on four capitals (natural, human, social, and physical capitals) and on the efficiency of the economic system.

[31] On this issue, the latest Synthesis Report of the IPCC states "*Incomplete estimates of global annual economic losses for additional temperature increases of ~2.5°C above pre-industrial levels are between 0.2 and 2.0% of income (medium evidence, medium agreement). Losses are more likely than not to be greater, rather than smaller, than this range (limited evidence, high agreement).*"

[32] This however, does not imply impacts will be evenly distributed.

impacts are based on Nordhaus (2010)'s RICE model, in which climate change impacts in the scenario without mitigation reduce global GDP by 1.5% in 2055 compared with the baseline.

As to the impacts of climate policies on growth, the IPCC (2014) summarizes results as follows: "*… mitigation scenarios that reach atmospheric concentrations of about 450 ppm CO2eq by 2100 entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation—of 1 % to 4 % (median: 1.7 %) in 2030, 2 % to 6 % (median: 3.4 %) in 2050, and 3 % to 11 % (median: 4.8 %) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300 % to more than 900 % over the century.*" Overall the impacts of climate policies on growth are expected to have limited aggregate impacts although this could hide large shocks on vulnerable countries/ industries.

Finally, another question is what a reduction in poverty entails for climate change. The answer is that it depends on how poverty reduction is achieved. Providing universal access to infrastructure services for the poor, as needed to help eradicate poverty, would most likely not result in much of an increase in emissions (Pachauri et al., 2013; Rao et al., 2014). However, if poverty eradication is achieved through growth rather than targeted policies and redistribution, the economic growth required would lead to large increases in emissions in the absence of ambitious climate policies (IPCC, 2014). This is especially true for low-income countries, as the carbon intensity of GDP is found to increase with GDP per capita from low-income to upper middle income categories (Edenhofer et al., 2014). Climate polices able to limit climate change without impairing economic growth and poverty alleviation will therefore require rapid and large improvements in the efficiency of production and an unprecedented decrease in carbon intensity (Guivarch and Hallegatte, 2013; Audoly et al 2014; Clarke et al., 2014).

The conclusion then is that mitigation compatible with poverty reduction will require well-designed policies that target technological development and dissemination, increase efficiency thorough the economic system, catalyze smart investment in efficient and low-carbon infrastructure, and include strong distributional policies to support the weakest and most vulnerable (World Bank, 2012).[33] Experience from energy and fossil fuel subsidy reform efforts fortunately offers lessons on how to protect the poor from the consequences of such policies (see below).

6.2 Impact on structural change

Climate change and policies will affect relative prices, the comparative advantage of many regions, and influence structural change, even for an unchanged aggregate growth. This will affect some activities negatively and others positively. This is similar to other technological or policy shocks (e.g., trade openness and liberalization, development of ICT), affecting the set of available activities J, and making it critical for households to be able to shift activities (favoring households with portable and transferable assets).

Structural change is a major component of development and economic growth (Rodrik, 2011; McMillan et al., 2014). Policies implemented to mitigate climate change could negatively affect structural change and the ability of the "modern" sector (industry or service) to create enough higher-wage jobs to eradicate extreme poverty. Examples of such impacts can be found in episodes of energy subsidy reforms and price

[33] An important consideration is the existence of international transfers to support the transition to low-carbon development without affecting the poorest. This difficult issue is left out of this analysis.

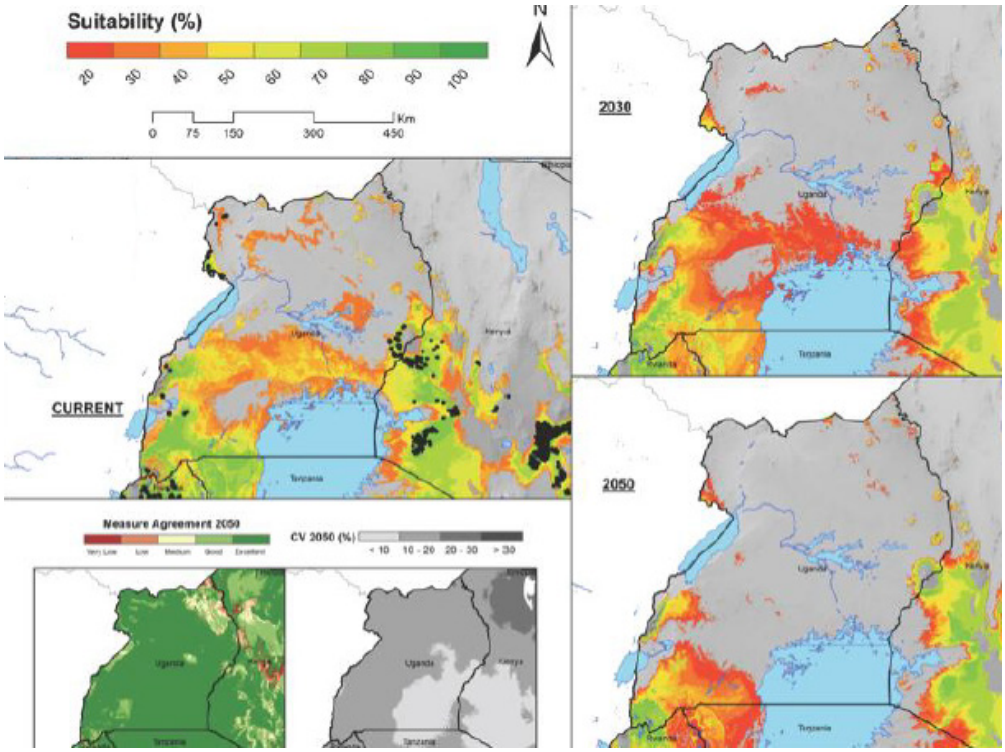
increases (see Bazilian and Onyeji, 2012 and Okafor, 2008 for a discussion of Nigeria's experience). Where poverty reduction is carried out largely through structural change and a shift from low-productivity agriculture to manufacturing, a negative impact of climate policies on industries could slow down poverty reduction, and reduce the elasticity of poverty to GDP (i.e. make economic growth less efficient to reduce poverty). Local context and conditions make this effect more or less important, as the shift to manufacturing plays a differential role in poverty reduction in different countries and regions.

There is mixed evidence on the employment impact of climate policies, and the impact depends on the considered timescale, as short term effects are most likely negative while longer term substitution and reallocation across sectors can offset those losses. While climate policies will destroy jobs in polluting industries, it will create jobs in cleaner ones and the net results will depend on substitution options and demand elasticity (Morgenstern et al., 2002). At the firm level, the impact of environmental regulation on productivity and competitiveness is found to be modest (and sometimes even positive), thanks to innovation (Ambec et al., 2013). Recent evidence further suggests switching to green technologies can have economy-wide benefits, as low-carbon innovations generate more knowledge in the economy than dirty technologies (Dechezleprêtre and Sato, 2014). World Bank (2012) provides a review of evidence and concludes that climate policies are unlikely to significantly affect employment opportunities, at least if policies are progressive enough not to cause a large drop in GDP growth.

Climate change impacts will also affect structural change with impacts on poverty. A classic example is the impact of climatic changes on areas suitable to grow coffee in Uganda, the leading coffee producer in Africa. Under a business as usual emissions scenario, estimates of future climate from the IPCC were paired with data on suitability of Arabica coffee in Uganda (Jassogne et al., 2013). Results suggest significant declines in most areas by 2030 (top right map in Figure 5); by 2050, much of the area currently under production becomes unsuitable (bottom right). This would strongly affect Uganda's economy, where agriculture accounts for 80% of the jobs and 90% of export, and the coffee industry employs more than 2 million people and contributed close to US $400 million to the national economy in 2012.[34] Since coffee production will be affected slowly, a well-prepared transition toward other production – in agriculture or manufacturing or services – could of course avoid the negative economic impacts. But history suggests that managing such transitions is difficult and often leads to prolonged periods of underactivity.

[34] http://www.undp.org/content/undp/en/home/ourwork/crisispreventionandrecovery/successstories/saving-ugandan-coffee-from-climate-change/.

Figure 5: Impact of climate change on predicted suitability of coffee production in Arabica coffee-producing areas in Uganda today, in 2030, and in 2050.



Sources: Läderach and van Asten (2012); Jassogne et al. (2013).

Notes: The coefficient of variation (CV) and measure of agreement (ME) is shown for the study area with the points (black dots) representing the sampled Arabica farms (large map).

Past examples of negative sectoral shocks have triggered long periods of depressed activity at the macro level. For instance, Hornbeck (2009) shows the slow adjustment to changing environmental conditions during the Dust Bowl in the US in the 1930s. Agricultural adjustment toward better adapted production recovered only 14 to 28% of the initial cost, and most adjustment took place through outmigration toward other areas. Hanlon (2014) looks at the impact of the US Civil War and the resulting increase in cotton prices on the UK textile industry. The shock had large negative impacts on the UK cities specialized in the textile sector (and reliant on cotton supply), and these impacts persisted with no recovery for at least 35 years. Moreover, the impact on the textile sector propagated into the rest of the regional economy, with visible impacts on the main suppliers of the textile industry, especially machinery and metal-good producers. These results demonstrate the vulnerability of specialized economies when their main industry is affected by a shock, even a temporary one.

Labor markets are seldom very flexible and structural changes or trade liberalization often lead to a rise in unemployment, with skill and institutional issues preventing workers shifting from sunset to sunrise sectors. For instance, (Muendler, 2010) and (Menezes-Filho and Muendler, 2011) show that trade

liberalization displaced workers from the de-protected industries in Brazil, and that it took several years for these workers to be absorbed by growth sectors (see a review in Porto, 2012). This is particularly true in places with limited access to markets for credit, capital, land, insurance and labor. As discussed in Barbier (2010a; 2012) poor households in remote places that lack connection with major markets cannot access employment opportunities out of the affected areas/sectors and may turn toward over-exploitation of common resources (e.g., deforestation) to compensate for losses, threatening natural capital and the sustainability of the local economy.

Policies have however been introduced to smooth economic transitions (trade liberalization, oil shock). This experience can provide lessons to improve the ability of economic systems to adjust to climate change and policy impacts without affecting negatively the poor. The social costs of such a transition may indeed justify transient support to declining industries to allow time for retraining and shifting workers toward growing sectors (Hallegatte et al., 2013b). This was the approach used by Japanese industries to make the transition toward high-productivity high-skill industries more socially acceptable (Peck et al., 1987). In parallel, support can be offered to the sunrise sector, to enable it to more rapidly absorb workers from declining sectors, or more directly to the workers themselves through social safety nets and retraining schemes.

A climate change adaptation strategy may therefore include structural policies aiming to accelerate the transition from sectors that are negatively affected to unaffected sectors (or to sectors and activities that benefit from climate change and policies). Similarly a low-carbon strategy may need to include some transient support to energy-intensive industries. Such support would aim to smooth the transition, helping businesses adjust their production technologies and workers adapt by moving to other sectors. Often, there is also a regional component, when a region is particularly dependent on an energy-intensive sector. Direct support creates a significant risk if policies cannot be progressively phased out, making it preferable to use sector-neutral safety nets when possible.[35]

6.3 Climate change and migration

Migration can be seen as either an adaptation option, or the result of a failure to adapt. Independently of climate change, migration plays a key role in the ability of poor households to escape poverty by capturing opportunities for better jobs, higher pay, and improved access to services and education. Migrants typically benefit, as do their family and area of origin, through remittances and enhanced social networks and access to information (Adger et al., 2002; Moser and Felton, 2007; Bryan et al., 2012). In our framework, the set of income-generating opportunities J is therefore linked to the ability to migrate.

Migration can be a way of adapting to weather events and climate change impacts, and thus of reducing welfare impacts (Jülich, 2011; Black et al., 2011b; Adger et al., 2014). In that case, migration increases the set of opportunities available to an individual or household, improving well-being and prospects. However, there is some evidence that the poorest households have lower capacity to migrate, and may therefore be unable to use this option (Black et al., 2011a). This is also the case for households in conflict and fragile areas, or those facing exclusion.

[35] Public support has been found difficult to remove (for instance in the agricultural sector) even in industrialized countries with strong institutional capacity, high level of transparency and strong civil society. The need for such complementary policies depends on the availability of safety nets and retraining programs.

Climate change can trigger more migration, especially out of heavily affected areas, as opportunities disappear because of climate impacts (see a review of regional studies in Adger et al., 2014). Climate change can affect drivers directly – through environmental factors – or indirectly – through socio-economic factors. However, migration is driven by a multiplicity of pull and push drivers, both environmental and socio-economic (Adger et al., 2014; Black et al., 2011a). Today, direct environmental factors generally play a minor role (Black et al., 2011a), except in rare cases such as large natural disasters. The most important factor remains the socio-economic context in the originating and destination area (Wodon et al., 2014). Climate change could nevertheless induce more migration, even though no robust estimates at the global scale is available (Adger et al., 2014). Wodon et al. (2014) investigate this question in five countries in North Africa and the Middle East and conclude that a significant deterioration of climatic conditions would lead to an increase of about 1.5 percentage points for temporary and permanent migration or about one-tenth to one-fifth of current migration levels.

But climate change could also impair migration, for instance through (1) constraints on urban development and higher housing costs linked to natural risk (e.g., higher construction costs due to better building norms, or restrictive flood zoning, see Section 3.3) and (2) increased conflict and exclusion (crime and violence, civil unrest, see Section 4.2). In that case, climate change would reduce the set of opportunities that individuals and households can capture. The ability to migrate also depends on household assets, including land tenure, the ability to sell assets, information and social capital, financial resources, and human capital. As a result, the effect of climate change through the asset channels may have an important secondary effect on migration and therefore on the ability for households to capture the opportunities they need to escape poverty.

Given the importance of mobility as an instrument for poverty reduction, climate change then adds another argument to support portable social protection benefits (Holzmann et al., 2005; Kuriakose et al., 2013): adaptation support or safety nets that are linked to particular locations could tie poor populations to places that may no longer support livelihoods given climate change, thus reducing their ability to escape poverty. This may create a trade-off between improving the life of poor people today, and maximizing the flow of households out of poverty.

6.4 Income opportunities from climate policies

Climate policies can potentially provide new income opportunities for the poor. Many ecosystem-based adaptation and mitigation measures require labor-intensive activities, such as re/afforestation, land restoration, and protection of land. Such activities are often undertaken by the poor and can be an important element of their income portfolio. In South Africa, for example, the unemployed can participate in land-restoration activities through a government-funded Working for Water (WfW) program (Turpie et al., 2008).

However, such climate policies could also restrict land use, thereby constraining the livelihood activities of the poor (see also Section 3.3). Ecosystem-based adaptation and mitigation policies could involve the protection of natural areas which could limit the use of land for agriculture, timber and firewood collection. As many of the poor depend on such activities, this could have detrimental impacts on poverty reduction.

Implementing climate policies through results-based payments for forest conservation, land restoration or more sustainable land use can also provide new income opportunities for the poor. So-called payment for ecosystem services (PES) can reward poor land users for mitigation or adaptation-based activities and add to the incomes of the poor (Pagiola et al., 2005; Wertz-Kanounnikoff et al., 2011; Pokorny et al., 2013). Pfaff et al. (2007), van Noordwijk and Leimona (2010), and Bremer et al. (2014) document cases in which PES schemes have benefited the poor. Simulation exercises in Bolivia calculate that REDD+ payments could lead to a 7.2% increase in the per capita income of poor municipalities (Andersen et al., 2012). Overall it is estimated that by the year 2030, mitigation-related PES for carbon could benefit 25-50 million low-income households in developing countries, while adaptation-related payments for watershed protection could benefit 80-100 million (Milder et al., 2010).

Such "win-win" situations are not an automatic outcome (e.g. Muradian et al., 2013). In many circumstances, the design of PES schemes actually allows a few, powerful land users to reap most of the benefits (Kosoy et al., 2007; Börner et al., 2010; Sommerville et al., 2010; Jindal et al., 2013). The poor are generally constrained in participating in such schemes, as they either face high transaction costs (e.g. for administrative work) or do not fulfill the participation requirements (e.g. secure land titles) (Zbinden and Lee, 2005; Jindal et al., 2013). Yet in some contexts, such as Colombia and Nicaragua, the poor are able to participate in PES notwithstanding technically difficult and costly investments (Pagiola et al., 2008; 2010).

Designing pro-poor benefit sharing mechanisms, land tenure regimes and social safeguards can help avoid negative impacts on the poor. In communities characterized by low inequality, benefit distribution should be based on proportionality and equality of opportunity, whereas in more unequal contexts benefit distribution would need to positively discriminate in favor of the poor (Mohammed, 2011). The role of land tenure and the importance of considering local contexts for forest carbon projects has attracted attention in the literature (Larson et al., 2013; Naughton-Treves and Wendland, 2014; Sunderlin et al., 2014). Implementing social safeguards and standards underpin the design of pro-poor benefit sharing and land tenure regimes and improve chances for success (Chhattre et al., 2012; McDermott et al., 2012).

World Bank (2012) also reviews the potential for green policies to generate jobs. Green policies can create jobs in sectors such as renewable energy and building retrofitting. In China, measures to save energy, reduce pollution, and replace polluting industries with high-tech firms could lead to the net creation of some 10 million jobs over the next 5-10 years, and that exports of green goods could create some 4-8 million jobs (World Bank, 2012). Experiences from green stimulus packages show some employment benefits, but with a large variability. In the Republic of Korea, forest restoration generated nearly eight times as many jobs per dollar as the least labor-intensive green objective, "vehicles and clean energy" (Barbier, 2010b). In Latin America, water network rehabilitation and expansion in Honduras is much more effective (by a factor of more than 10) in creating jobs than hydroelectric schemes in Brazil, with rural electrification in Peru falling in between (Schwartz et al., 2009). Overall, and taking into account job destruction in carbon-intensive sectors, it is unlikely that climate policies will lead to large job creation at the national level. But the impact at the local level or for some categories of skills can still be significant.

7 CONCLUSION

This paper explores the many channels through which climate change and climate policies can affect poverty. It highlights the multiplicity of transmission channels and the fact that they interact with each other and with other non-climate-related stressors such as structural transformation, technological change, population growth, and international trade in determining the eventual impact. Impacts through these channels are already observable, and their effect on poverty is documented. For instance natural disasters increase poverty when they hit a given country or community, with significant and long lasting impacts. These effects are also observed when non-climate events have impacts similar to what is expected from climate change, for instance when food prices increase or when exogenous events affect the productivity of an economic sector that is important for the local economy.

This paper has three major findings. First, climate change is a major challenge for poverty reduction. Second, climate policies are compatible with poverty reduction provided that they (i) incorporate poverty concerns into adaptation and mitigation policies and (ii) are accompanied with the appropriate complementary policies. Third, climate change does not modify how poverty policies should be designed. But it creates greater needs and more urgency. The scale issue is explained by the fact that climate will cause more frequent and more severe shocks; the urgency, by the need to exploit the window of opportunity given to us before climate impacts are likely to substantially increase.

Quantifying the magnitude of the additional challenge that climate change and policies will represent for poverty eradication requires accounting for all these effects in a consistent and common framework, a task that is likely to remain out of reach. However, the multiplicity of adverse effects, their visible impact on poverty, and their expected magnitude suggest that climate change and policies will slow down poverty eradication, by making poverty reduction more difficult and by bringing non-poor people into poverty.

Most importantly, the poorest are generally the most exposed to climate impacts and the least equipped to adapt to changes in climate and economic conditions. Extreme poverty may therefore be particularly affected by climate change and policies, and it is very likely that household and local-level poverty traps will be exacerbated by climate change in the future. If the extreme poor are most at risk of such climate-related poverty traps, then climate change provides an additional rationale for eradicating extreme poverty as soon as possible, preferably before climate change impacts are expected to increase rapidly.

But even if extreme poverty is eradicated, the impact of climate change on poverty will not disappear. An important consideration is that poverty is a dynamic phenomenon, with households moving in and out of poverty. Investigating the reasons why households fall into poverty highlights the importance of the kind of extreme weather events that will be become more frequent with climate change. Beyond the existence of poverty traps, therefore, climate change could increase the flow of households into poverty following a shock, raise transient poverty, and increase the need for the safety nets and social protection systems that households need to manage their risk and cope with negative shocks.

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