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Climate Change Adaptation

What Does the Evidence Say?

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Abstract

Adapting to climate change is an increasingly urgent policy priority in lower- and middle-income countries. This systematic review summarizes the current state of the literature on adaptation to climate change, and conducts a quantitative meta-analysis of the effectiveness of climate adaptation. The meta-analysis reveals that observed adaptations offset 46 percent of climate losses on average, with firms using more effective adaptation strategies than households and farmers. The review identifies several key lessons. First, purely private adaptations to climate shocks tend to be less effective than those from public infrastructure and services, although neither by itself is generally sufficient to fully offset the effects of climate change. Second, some adaptations may reduce climate losses in the present, but in the long-run, households, firms, and farmers might be better-served by reducing their climate exposure. Third, the literature tends to focus on adaptation by households and farmers, neglecting firms. Finally, productivity losses from climate shocks may be offset if capital and labor can adjust across sectors and locations, but constraints on these reallocations have not been sufficiently studied.

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Climate change adaptation: What does the evidence say? *

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1. Introduction

Climate change is leading to higher surface temperatures, acidifying oceans, and a rising global mean sea level. The consensus estimate is that the average global surface temperature has increased by 0.85 degree Celsius since the industrial revolution, with estimates of future increase ranging from 0.9 to 5.4 degrees Celsius by the end of this century (Hsiang and Kopp 2018, IPCC 2014). With long-term precipitation patterns changing in complex ways, some parts of the world are expected to get drier, while others get wetter (Hsiang and Kopp 2018). Droughts are expected to become more common in drier parts of the world (Collins et al. 2014). Climate change is also increasing the frequency and intensity of extreme weather events. For instance, the prevalence of intense tropical cyclones is expected to increase (Kossin et al. 2017).

These changes in the earth's climate are projected to reduce aggregate economic output because of their adverse effects on agricultural yields, industrial output, labor supply, productivity, and human capital, among other mechanisms (Auffhammer 2018, Carleton and Hsiang 2016, Dell, Jones, and Olken 2014, International Monetary Fund 2020). Recent econometric studies suggest that warming has a sizable adverse impact on GDP (Burke, Hsiang, and Miguel 2015, Dell, Jones, and Olken 2012, Hsiang 2010). Based on a review of such studies, Carleton and Hsiang (2016) estimate that future warming will reduce the global GDP growth rate by 0.28 percentage points per year during the coming century. Such estimates of aggregate GDP impacts are subject to uncertainty about the future path of climate change. However, when the economic impacts of both climate trends (such as rising temperatures) and climate-change-related extreme event risks (such as more frequent cyclones) are taken into account, even moderate future climate change scenarios imply sizable effects on GDP (Fernando, Liu, and McKibbin 2021).

Major storms have sizable negative impacts on such economic outcomes as per-capita income and output (Anttila-Hughes and Hsiang 2013, Cachon, Gallino, and Olivares 2012, Nordhaus 2010, Yang 2008). Storms also damage productive assets: in India, for example, the average cyclone destroys 2.2 percent of a firm's fixed assets (Pelli et al. 2023). Cyclones and droughts also increase infant mortality and worsen other health outcomes (Anttila-Hughes and Hsiang 2013, Currie and Rossin-Slater 2013, Kudamatsu 2016, Schmitt, Graham, and White 2016). As a result, extreme weather events not only reduce output in the short run, but also harm long-run economic growth: a 90th-percentile cyclone event is estimated to reduce per-capita incomes by 7.4 percent two decades later (Hsiang and Jina 2014).

The economic impacts of climate trends, such as rising temperatures, are also complex and sizable. Abnormal temperatures are associated with damages to agricultural yields (Guiteras 2009, Lobell, Schlenker, and Costa-Roberts 2011, Schlenker and Lobell 2010, Schlenker and Roberts 2009). For example, Guiteras (2009) estimates that in the long run (2070–2099), climate change will reduce farm yields in India by at least by 25 percent. Temperature also affects industrial output (Cachon, Gallino, and Olivares 2012, Dell, Jones, and Olken 2012, Hsiang 2010, Somanathan 2021, Zhang et al. 2018). Annual output is estimated to fall by about 2 percent per degree Celsius of warming in Indian manufacturing plants (Somanathan et al. 2021). Heat also reduces labor productivity (Niemelä et al. 2002) and labor supply (Zivin and Neidell 2014). In addition to these impacts on economic outcomes, exposure to abnormal temperatures has negative health consequences, for example, reduced birth weight and increased mortality among infants (Barreca 2012, Burgess et al. 2013, Deschenes and Greenstone 2011). Exposure of children to abnormal heat or rainfall at all stages of early development—in-utero, during infancy and at school-age—can have long-term impacts on human capital (Fishman et al. 2019, Garg et al. 2020, Maccini and Yang 2009).

Because projections of the adverse economic impacts of climate change are so large, it is important to better understand how firms and households adapt to a changing climate, and the extent to which adjustments can make economic activity more resilient to climate change. Households and firms can reduce their vulnerability to extreme weather in many ways. For example, farmers can adopt crop varieties better suited to adverse growing conditions, buy insurance, and diversify into non-farm activities that are less vulnerable to a changing climate. They can also migrate away from vulnerable locations. Understanding the drivers and impacts of such responses can help authorities devise more effective policies to address climate change.

A growing body of economic literature explores whether such adaptation occurs, how it occurs, and the extent to which it is successful in making economic activity less vulnerable to climate change. The purpose of this review is to generate a repository of this evidence base, with the goal of describing trends in the field and identifying gaps in the literature. The review is global and not restricted to any area of the world. However, because it is part of a regional work program on climate change adaptation at the World Bank's Office of the Chief Economist for South Asia, it pays particular attention to assessing the evidence on South Asia.

First, it builds a comprehensive database of studies on climate change adaptation. After filtering for relevance and quality, a database was built that consists of 324 studies from high-income countries and emerging market and developing economies (EMDEs). Second, the review systematically assesses these studies in terms of regional coverage, types of climate shock considered, type of adaptation mechanism being analyzed, and the agent whose adaptation behavior is being studied (firms, farmers and households). Third, it standardizes the quantitative estimates presented in 80 of the reviewed papers— those that permit such standardization— and conducts a meta regression analysis of the impact of adaptation. Finally, to inform policy dialogue and help set an agenda for policy-relevant research, the review identifies the main emerging messages and knowledge gaps in understanding when adaptation occurs, how it occurs, the constraints on it, and its effects.

There are several key points about the state of the literature on climate adaptation. This literature is large but shrinks substantially when journal quality is accounted for, because the top journals in economics have only recently begun to cover the subject. Although studies on agriculture and household behavior are well-represented, there are fewer studies on firm responses. Perhaps because of its high exposure to climate shocks, the South Asia region is well-represented in the literature. The most studied adaptation mechanisms differ by type of agent, but reallocations, technology adoption, and migration top the list.

The review finds that neither individual-level adaptation nor public investments in adaptation on their own are enough to recoup the full cost of climate shocks. Some commonly seen individual-level adaptations, such as crop diversification, are costly and limited in their impacts. This means there is a role for policy to facilitate more effective types of adaptations. Furthermore, while certain necessary adaptations can only occur through policy—for example, large infrastructure investments in sea walls (Husby et al. 2014) or irrigation canals, the impact of such policy interventions is not well-studied.

A quantitative meta-analysis of 118 estimates of the impact of adaptation shows that, on average, climate adaptation offsets 46 percent of the cost of climate shocks. Adaptations that involve public goods or technology adoption tend to be more effective than purely private adjustment strategies unaided by public goods or new technologies. The effectiveness of adaptation is higher for firms than households or farmers. This difference is primarily the result of the greater adoption of technology by firms. Households and farmers generally employ less effective strategies, such as labor or land market adjustments.

The review also finds that there are important tradeoffs across adaptive mechanisms. For example, the adoption of certain practices or technologies, such as drought- resistant crop varieties, might reduce climate losses in the present, but in the long-run, farming-dependent households in severely climate-exposed areas might be better-served by migrating to less exposed areas or working in less climate-sensitive sectors. Macro-level adjustments such as spatial reallocation and structural change toward less climate-exposed sectors can be efficiency-enhancing because climate-exposed sectors like agriculture tend to be less productive.

Another message emerging from this review is that there is limited understanding of the factors that constrain individuals' and firms' choice of adaptation mechanisms, especially the latter. Similarly, little is known about the constraints on sectoral and spatial reallocation, such as the role of integrated markets and factor mobility.

The rest of this paper is organized as follows. Section 2 describes the methodology of the systematic review and a summary description of the reviewed studies. Section 3 summarizes the main mechanisms of adaptation examined in the reviewed studies and key findings about adaptation responses by agent type. Section 4 presents the methodology and results of a meta-analysis of the estimates of the effectiveness of adaptation responses reported in the reviewed studies. Section 5 concludes.

2. Methodology and study sample description

2.1. Sampling methodology

The goal of this review is twofold: to build a repository of studies on the economics of climate change adaptation, and to review and categorize these studies along a set of relevant characteristics. In addition, Section 4 conducts a quantitative meta-analysis of the impact of adaptation on climate losses. This review defines studies pertaining to "adaptation" as those that consider any human behavioral response to climate or weather shocks that could be construed as attempting to mitigate losses from these shocks. Importantly, the review excludes studies that attempt solely to quantify the economic losses of climate change without considering behavioral responses.

To generate the sample of academic articles, the review first identified a set of 147 works cited in a recent review article on climate change adaptation (Balboni et al. 2023). Of these, 58 studies were identified as pertaining to adaptation according to the criteria. These serve as the basis for the sampling procedure. The review then conducted forward and backward citation chasing on these 58 studies, collecting all articles citing or cited by these studies. This generated a set of 5,881 studies. Restricting the sample to studies published after the year 2000 yields 5,340 studies. A set of key word restrictions was then imposed on the titles and abstracts to ensure the papers are relevant to climate change, broadly construed, further narrowing the sample to 3,074.[2] Finally, a quality constraint—in which only the 250 top-ranked economics journals on Research Papers in Economics (RePEc) were used—further narrowed the pool to 946 studies. These remaining studies were manually reviewed to identify their relevance to climate adaptation. In total, 324 studies were found relevant and comprise the final sample. Some analyses that follow impose the additional restriction that the studies must be published in a top economics journal, which reduces the sample to 101 studies.[3]

The 324 relevant climate change adaptation studies were grouped in a review matrix across several study characteristics. *Agents* were grouped into three categories: firms, households, and farmers. *Climate shocks were* grouped into rainfall anomalies, temperature (including extreme heat), drought, flooding, and other natural disasters. Study *outcomes* range substantially given the significant heterogeneity in topics studied. Some examples include crop yield, land use, flood insurance take-up, household income, firm sales, migration, and mortality. The matrix also includes the World Bank *region* of the study, and the *empirical methodology*—experimental, quasi-experimental, observational, or structural. Importantly, the review matrix classifies the primary *adaptation mechanism* by which agents in the study cope with climate change into the

[2] These are: environment; climate; adaptation; temperature; disaster; flood; rainfall; drought; weather shock; heat; groundwater.

[3] The top journals are: the American Economic Review, the Journal of Political Economy, the Quarterly Journal of Economics, Econometrica, the Review of Economic Studies (the Top 5); Journal of the European Economic Association, the Review of Economics and Statistics, the American Economic Journals, the Economic Journal (the Top 10); the Journal of Environmental Economics and Management, the Journal of Development Economics, the Journal of Public Economics, Management Science, and the Review of Financial Studies (the Top Fields).

following groups: financial markets, public policy, transfers, infrastructure, labor markets, migration, technology adoption, reallocation, and general adaptation.

2.2. Characteristics of the reviewed studies

The field of climate change adaptation has grown substantially over the past two decades. Figure 1 (left) plots the cumulative number of climate change adaptation articles over time, by journal ranking. Most of the increase in the literature is concentrated in lower-ranked journals; coverage in the most selective economics publications remains relatively low. The right panel focuses on the subset of 101 studies published in a top economics journal, plotting the trend over time by subject. The majority, 54 percent, of the studies focus on households, followed by farmers, 34 percents, and firms, 22 percent.[4] Not only are firms the least-represented in studies among top journal publications, they are even less represented overall, the subject of just 9 percent of studies in the non-top journal publications.

Studies on firms appear neglected in the aggregate, but that varies by region. Table 1 (left panel) shows the geographic distribution of publications in top journals by World Bank region. North America is the best-represented region, followed by South Asia (SAR) and Latin American and the Caribbean (LAC). SAR and East Asia and the Pacific (EAP) have the most even distribution of studies between firms, households, and farmers. Sub-Saharan Africa (SSA), in contrast, is less well-studied in top journals and contains no work at all on firms. In part, this reflects both the structure of the economy in SSA and the vulnerability to climate. However, the right panel of Table 1 shows that SSA is much better represented among non-top journals; it forms the largest grouping in the full sample but is among the smallest among top journals. The Middle East and North Africa (MENA) and Europe and Central Asia (ECA) regions are not represented at all in top journals and receive scant attention in the broader sample, even though MENA is highly vulnerable to climate change.

Table 2 (left panel) displays the distribution of climate shocks in top journal publications on adaptation, by agent type. Heat is by far the most well-studied form of climate stress, the subject of roughly 50 percent of the studies—followed by rainfall and natural disasters. Most studies on firms consider the impacts of heat and natural disasters. Studies on rainfall, drought, and flooding, in contrast, focus primarily on agriculture and household behavior. However, non-agricultural firms may be affected by these shocks indirectly, due to sectoral linkages (such as those in labor or input markets), and directly, particularly by flooding. More research is needed to understand firm responses to these shocks. More broadly, the literature is overwhelmingly tilted toward understanding the impact of rising temperatures. Other extreme weather events and changing weather patterns that may result from climate change are less well-studied. The sample of non-top journal publications (right panel) is also skewed toward heat studies, though research attention is somewhat more evenly distributed across climate shocks.

[4] Note that these categories are not mutually exclusive, and so their shares sum to more than 100 percent.

3. Mechanisms of adaptation

This section categorizes and describes the main mechanisms of adaptation identified in the reviewed studies. It also discusses some key observations about adaptation mechanisms by agent type.

3.1. Types of adaptation mechanisms in the reviewed studies

Economic agents—firms, households, and farmers—have a variety of strategies available to adapt to the negative effects of climate shocks. These adaptation mechanisms are grouped into nine categories, as shown in Table 3.[5]

Reallocation is the largest adaptation mechanism, comprising 17 percent of the top journal studies and 27 percent of the sample overall. Reallocation is a broad category, referring to any behavioral response that involves changing the composition of a portfolio in response to a shock. For example, farmers may reallocate cropland to less heat-sensitive crops, or households may reallocate labor supply in response to extreme heat. In the full sample, 15 percent of the studies on reallocation study firms, 35 percent study households, and 64 percent study farmers. Table 4 shows that most reallocation studies investigate responses to temperature rise, with other climate shocks less prominent.

Technology adoption can help agents adapt to climate change—16 percent of all studies involve adoption of some sort of technology to adjust to climate change, and the rate is similar for both top journals and lower-ranking ones. Some examples of technological adaptation include installation of air-conditioning by households or firms (Davis and Gertler 2015), or the use of improved seed varieties to enhance the climate resilience of agriculture. In top journals, 39 percent of the article on technology adoption study firms, 39 percent study households, and 33 percent study farmers (Table 3, left panel).

Migration is a common coping strategy for rural households, and a large literature has emerged identifying migration responses to climate shocks that reduce agricultural productivity or otherwise negatively affect rural economies. Migration studies comprise 15 percent of the literature on climate adaptation in top journals and 11 percent in the full sample. Table 3 shows that more than 90 percent of the journal articles on migration study households in both top and non-top journals. Table 4 shows that the migration studies in the top journals are also dominated by temperature, although a significant minority study flooding and drought.

Financial markets can provide insurance against climate-related losses or credit to businesses as part of disaster relief. As such, finance represents an important margin of adjustment to climate shocks. Studies on financial markets represent 15 percent of the adaptation literature and are similarly represented in the top journals and all journals. Financial markets studies are dominated

[5] Neither adaptation mechanisms nor agents are mutually exclusive categories, and, as a result, their shares add up to more than 100 percent.

by agricultural settings and rainfall, reflecting a substantial experimental literature on agricultural index insurance, which is discussed below.

Labor markets are another important release valve for climate stress, because climate change generates differential costs across sectors (Nath 2021). Labor reallocation is therefore an important way by which households can cope with climate shocks. Studies on labor markets comprise 10 percent of the economics literature on adaptation, with a primary focus on labor supply choices by households. Labor market studies cover all climate shocks, with the majority focusing on rainfall and temperature anomalies.

Public policy is a broad category capturing large-scale policy responses that aim to soften the costs of climate change—for example, through post-disaster relief transfers or infrastructure projects. Public policy is the subject of only 11 percent of the literature on climate change adaptation, with the remainder studying micro-behavioral responses by individual agents. Because of the scale of the adaptation challenge, individual adaptation is unlikely to be sufficient, requiring broader policy responses. More work is needed to evaluate the effectiveness of such responses.

Transfers constitute all public and private assistance that may help households or firms cope with climate shocks. Transfers are less well-studied, representing just 8 percent of the literature and mostly comprising studies on households. Because transfers often occur after disasters, roughly half of these papers study natural catastrophes.

Infrastructure projects—such as irrigation in drought-prone regions and flood protection systems in low-lying areas—are an important component of the global adaptive response to climate change. However, they comprise just 6 percent of the studies on climate change adaptation.

General adaptation studies typically estimate the extent of adaptation in a given setting without providing a specific mechanism. For example, a large literature on global agriculture interprets differential crop yield responses to weather variation in the long- and short-run as evidence of adaptation over time (Wing et al. 2021; Mérel and Gammans 2021). Similarly, several studies find evidence of nonlinear temperature effects on outcomes such as mortality (Barreca et al. 2015) and industrial output (Chen and Yang 2019), with smaller effects in hotter locations. These papers comprise 11 percent of the literature, although the proportion is higher (16 percent) among top journal studies.

3.2. Adaptation by firms

The small but growing literature on firm adaptation has primarily focused on three methods of adaptation: reallocation (30 percent of all firm studies), technology adoption (19 percent), and financial markets (14 percent).

Firms exposed to climate shocks reallocate both inputs and outputs to mitigate climate losses. On the inputs side, Xie (2022) shows that Indonesian firms employ more skilled labor and imported inputs as temperature rises, because heat disproportionately affects the productivity of unskilled workers. Balboni et al. (2023) demonstrate that manufacturing firms responded to flooding in Pakistan by diversifying towards suppliers located in less flood prone regions. Similarly, flood-affected firms in Tanzania adjusted their supply networks, and also reallocated resources toward inventory and backup capacity (Rentschler et al. 2021). Firms also reallocate their capital structure: using cross-country firm-level data. Javadi et al. (2023) show that climate change exposure is associated with an increase in firm-level cash holdings as a form of precautionary savings.

On the outputs side, firms tend to reallocate their sales to shield profits from climate risk. In the global automobile industry, Castro-Vincenzi (2023) found that manufacturers reallocated production across plants within a firm in response to flooding, leading to firm-level efficiency losses. Similar effects obtain across firms: Chinese manufacturers reallocated away from domestic buyers following typhoons (Elliott et al. 2019), while in Japan, transactions shifted away from firms in earthquake-affected regions (Carvalho et al. 2020).

Reallocation is costly, because such changes represent a deviation from what were optimal allocations before climate risk: holding cash has an opportunity cost, identifying new suppliers and buyers requires investment, and reallocation of output implies efficiency loss. Despite these challenges, evidence suggests that firms are remarkably resilient; for example, the negative effects of natural disasters appear short-lived (Elliott et al. 2019; Pelli et al. 2023) However, whether pre-emptive adaptation directly increases such resilience has not yet been studied.

Firm relocation is perhaps the costliest form of private adaptation. Both Indaco et al. (2021) and Balboni et al. (2023) find evidence for firm relocation following flooding events in the United States and Pakistan. Such relocations are an important form of adaptation and can reduce the costs of future climate events but may increase spatial inequality (Cruz and Rossi-Hansberg 2023).

Sectoral reallocation is an essential economy-wide adaptation, because climate change creates new patterns of comparative advantage both within and across countries. Because productivity in services and manufacturing are less affected by heat than is agriculture (Nath 2021), climate change will reallocate economic activity away from agriculture. These economy-wide adaptations can have dramatic effects; in India, reallocations away from agriculture reduced the losses from extreme heat by 69 percent from 2001–2007 (Colmer 2021). Indeed, climate-induced reallocations of firm activity may even *increase* aggregate productivity. Because less productive firms are more likely to exit, climate stresses and natural disasters can reallocate resources to the most efficient firms (Xie 2022) and better performing industries (Pelli et al. 2023). However, there may be allocation constraints, particularly in EMDEs, including both the ability of the manufacturing sector to absorb labor (Colmer 2021) and trade barriers (Nath 2021). Further research is needed on constraints on climate-induced reallocation, particularly the role of internal factor immobility and incomplete markets.

Technology adoption can mitigate the negative effects of climate shocks. In particular, rising global temperatures are likely to substantially increase the demand for cooling devices (Mansur et al. 2008). In India, cooling technologies have been shown to offer at least partial protection against heat-related losses, primarily by boosting labor productivity (Somanathan et al. 2021; Heyes and Saberian 2022). At the same time, Chen et al. (2023) find less support for a protective effect from climate control in a Chinese precision manufacturing firm. Other promising technological adaptations include shifting to LED lighting (Adhvaryu et al. 2020) and embracing better management practices on the factory floor (Adhvaryu et al. 2022). More broadly, technological diversity has also been shown to play a role in enhancing resilience to natural disasters among U.S. firms (Hsu et al. 2018). But the constraints on technology adoption are likely to be similar to those in non-climate contexts (Alfaro-Serrano et al. 2021), including credit constraints and information. Reliability of electricity supply is also likely to be an important constraint on adaptation in EMDEs because of the importance of cooling technology. Overall, more work is needed on the drivers and impacts of technology adoption for firm-level climate adaptation.

Financial markets can help firms smooth natural disaster shocks. Elliott et al. (2019) study the performance of Chinese firms following typhoons, showing that increases in debt serve as a buffer to allow for faster recovery. Similarly, Sri Lankan firms randomly assigned to receive capital grants recovered faster following the 2004 Indian Ocean tsunami (De Mel et al. 2012). Analyzing the same shock, Czura and Klonner (2023) found that savings and credit groups in India were able to channel funds to entrepreneurs in the wake of disaster. However, much more work is needed to extend this work to weather events other than disasters. Furthermore, more research is needed to understand how financial markets can facilitate both increased use of adaptive technology and reallocation across sectors.

3.3. Adaptation by households

Migration in response to adverse weather events is a commonly studied phenomenon in the reviewed research. For example, in sub-Saharan Africa, temperature and rainfall anomalies were estimated to have caused a net displacement of 5 million people during the period 1960–2000 (Marchiori 2012). In Mexico, it is estimated that under a medium emissions scenario, climate change may increase migration (from rural to urban areas and to international destinations) by 1.4 percent (Jessoe 2017). The flood that hit Bangladesh in 2014 is estimated to have caused the internal migration rate to increase by 7 percentage points among low-wealth households, and the international migration rate by 3 percentage points for high-wealth households (Giannelli and Canessa 2022). Flexible labor markets are a critical mediator of the migratory response; the capacity of labor markets to absorb climate displacement is critical (Henderson et al. 2017).

Despite the attention paid to migration as a climate change response, quantitative evidence on this phenomenon is limited. This lack of data is particularly notable for South Asia, where existing evidence is not always robust to alternative empirical specifications (for example, Viswanathan 2015), and suggests that there is at a more heterogenous relationship between climate and migration, which depends on the type of adverse weather and the skill level of households (for example, Sedova 2020).

Migration in response to public goods investments intended to protect places or communities from weather shocks also can have unintended consequences. Infrastructural programs to protect against floods may have caused more in-migration into flood-prone areas in the United States (Boustan, Kahn, and Rhode 2012) and the Netherlands (Husby et al. 2014). Similarly, publicly subsidized flood insurance is found to have increased migration to flood-prone areas in the United States (Peralta 2023). More research on how migration responses can amplify or counteract the intended effects of public adaptation investment may be useful.

There is some evidence on the effect of social protection policy on household resilience to weather shocks. In Nicaragua, a program that combined a one-year conditional cash transfer with vocational training or a productive investment grant to weather-affected households helped smooth consumption and increase productive investment levels (Macours, Premand, and Vakis 2022). In Australia, a disaster relief program was found to be effective in aiding the economic recovery of flood-affected households (Akbulut-Yuksel 2023). In the United States, federal disaster aid may have reduced post-disaster debt among households (Gallagher 2023).

Technology adoption is also an important household response. Household-level adoption of cooling devices has risen dramatically in a warming world (Biardeau et al. 2019). Cooling has reduced the negative effects of heat on mortality (Barreca et al. 2016), on learning (Goodman et al. 2020), and on labor productivity (Heyes and Saberian 2022). But existing inequality can be exacerbated because high levels of poverty mean many households are unable to purchase needed cooling equipment, especially in EMDEs (Doremus et al. 2022; Yu et al. 2019).

3.4. Adaptation by farmers

Reallocating farmland to crops less sensitive to local climate change and adjusting other margins of farm investments is a common adaptation response among farmers. In India, farmers were found to adjust their irrigation investments and their crop portfolios in response to rainfall changes, with farmers who have faced dry years more likely to invest in irrigation and monsoon-season crop portfolios with lower average daily water needs (Taraz 2017). In China, farmers were found to have responded to changing temperature and precipitation patterns by shifting to earlier crop planting dates and shortening the growing season (Cui 2021). Areas with higher crop diversity are more drought resilient (Auffhammer and Carleton 2018).

Reallocation within the agricultural sector has considerable potential to reduce vulnerability to climate change. Using data on the productivity of each of 10 crops for each of 1.7 million fields, Costinot et al. (2016) simulate a model that suggests that the damage from climate change to world GDP is tripled when a farmer cannot relocate crops within each field, compared with a scenario in which such reallocation is costless. In practice, however, there appear to be limits to the impacts of such reallocation. For example, an adjustment of irrigation investment and crop portfolios was found to recover only a small fraction of the profits farmers lost to a drier climate in India (Taraz 2017). Similarly, in China, adjustments to crop planting dates and growing season prevented only 9 percent of the damages caused by climate change (Cui 2021).

Because agriculture is generally more sensitive to weather than is the non-farm sector, reallocation to non-farm activities may also be an important adaptation mechanism in rural areas. Indeed, the potential of crop diversification to help deal with long-term water scarcity appears to be more limited than diversification toward the non-farm sector (Blakeslee et al. 2020).

Access to markets plays an important role in determining relocation possibilities, because even as extreme weather increases the relative productivity of the non-farm sector, the negative income shock from extreme weather tends to dampen the local demand for non-farm products, increasing local crop prices in the absence of trade. This may explain why long-term rising temperatures are associated with *lower* shares of workers in nonagricultural sectors in rural India (Liu et al. 2023).

The adoption of newer, more climate-resilient agricultural technologies is another commonly examined adaptation mechanism among farmers. For example, a randomized field trial in India estimated that switching to a new flood-tolerant rice variety enabled an approximately 45 percent increase in yields over the prevailing variety when fields were submerged for 10 days in a year, with no penalty on yields when there is no flooding (Dar et al. 2013). The low adoption rate of such technologies suggests a role for policies to facilitate their use.

A relatively large literature examines the adoption and effect of weather insurance (largely, index-based rainfall insurance). Insurance has been found to enable faster recovery from shocks (Bertram-Huemmer 2017) and to induce greater investment in other agricultural activities (Stoeffler 2021). There is less work on understanding the role of savings and credit in agricultural adaptation than on weather insurance.

Studies also examine the choices between different adaptation technologies, which may involve tradeoffs between reducing productivity risks from adverse weather events and lowering average productivity, as seen in the case of "conservation agriculture" practices (Michler et al. 2019), or tradeoffs between short-run and long-run climate resilience, as seen in the choice between groundwater extraction technologies and drought-resistant practices in the water-scarce U.S. plains (Hornbeck 2014).

The literature highlights a potential negative effect from insurance as an adaptation mechanism: farmers with insurance may feel secure enough to invest in higher-return but rainfall-sensitive cash crops (Cole 2017) or more climate-sensitive varieties of the same crop (Annan and Schlenker 2015). The low take-up of insurance at market prices by farmers is also an issue, with studies exploring such factors as borrowing constraints (Giné et al. 2008), uncertainty about insurance (Giné et al. 2008), behavioral factors (Stein 2016), and social network-based diffusion (Cai 2015) in slowing the take-up of insurance.

4. Impact of adaptation

This section outlines a simple method of meta-analysis to estimate the average effectiveness of climate change adaptation. First, the sample is restricted to papers that study the impact of any climate adaptation on any final economic outcome. Then, the main estimates (and their variances) from each of these papers are transformed into a unit-free measure called the *adaptation ratio*, such that they are comparable across studies and contexts. Next, a random effects model is used to aggregate estimates across studies, accounting for within-study sampling variance and cross-study heterogeneity. Finally, aggregation of estimates by study characteristics as well as a meta-regression analysis are used to characterize impact heterogeneity.

4.1. Meta-analysis methodology

The sample of 324 empirical climate change adaptation papers can be broken down into two subgroups: studies that provide *evidence of adaptation* (192) and those that estimate *the impact of adaptation* (132). These studies can be distinguished on the basis of the primary outcome variables studied. The focus of our meta-analysis is on the latter group.

Papers that provide *evidence of adaptation* study the impact of some climate shock s_i on an adaptation activity a_i (for example, borrowing, irrigation, crop rotation, technology adoption) The primary specification takes the form of a reduced-form regression for some unit of analysis i:

$$a_i = \alpha + \beta s_i + \epsilon_i$$

There are, of course, many permutations of this basic specification in the literature. The climate shock may enter linearly or as a non-linear function. It may be defined contemporaneously or lagged, in levels or as a climate anomaly. Specifications may include fixed effects or leverage plausibly exogenous natural experiments. However, these studies all follow the same basic regression framework, which is to study the impact of climate shocks on adaptation behaviors. Studies of this form are excluded from the meta-analysis.

Papers that provide *evidence on the impact of adaptation,* in contrast, examine whether climate adaptation strategies allow agents to offset the costs associated with climate shocks. Now, the climate adaptation a_i is on the right-hand side of the estimating equation, and the outcome is y_i, some economic outcome (such as crop yield, labor productivity, and household income). The intuition can be expressed in a simple interaction regression for some unit of analysis i:

$$y_i = \alpha + \beta_1 s_i * a_i + \beta_2 s_i + \beta_3 a_i + \epsilon_i$$

Note that the adaptation a_i is interacted with the shock s_i, so that the model estimates how adaptive behavior *moderates* the impact of climate shocks on economic outcomes. Let $a_i = 0$ be the no adaptation case. Then, β_2 estimates the impact of the shock *without* adaptation, while β_1 estimates the differential effect of the shock with adaptation. Define the *adaptation ratio* as $\theta = \beta_1/\beta_2$. This ratio measures the share of climate damages in the no-adaptation case that are recovered by the use of an adaptation. This ratio is unit-free and can therefore be compared across heterogeneous studies with different outcome variables, adaptations, climate shocks, and identification strategies. While θ is in theory unbounded, it should range from 0 to 1 if adaptations are at least partially effective. When $\theta > 1$, then climate shocks *improve* y_i under adaptation. If $\theta < 0$, then adaptation worsens the impact of shocks.

Several caveats are worth noting. First, the most straightforward case is when a_i is a binary indicator variable for adoption of an adaptation. However, a_i may be a continuous variable, such as the share of the population with air conditioning (Barreca et al. 2016). In these cases, the adaptation ratio is rescaled by the average adaptation level $E[a_i]$ as $\theta = \frac{\beta_1 E[a_i]}{\beta_2}$. Second, the case of $a_i = 0$ does not imply that no adaptation has taken place, just that the specific adaptation a_i is not active. The adaptation ratio in interaction models should be interpreted as a partial derivative with respect to one adaptive behavior in an equilibrium where many adaptations may occur simultaneously. As before, climate shocks may be defined in many ways and cover numerous different weather events. Furthermore, adaptation may be endogenous, and studies have a variety of methods of accounting for endogeneity. This meta-analysis abstracts from causal identification issues and pools all available estimates.

The adaptation ratio is obtained for 80 of the 132 papers classified as "impact of adaptation." Many articles do not report the estimates of climate losses with and without adaptation that are necessary to form θ. However, because authors may estimate several models with different y_i, s_i, a_i within one paper, studies often have multiple estimates. In total, the adaptation ratio can be formed for 183 θ_{ks} where k indexes estimates and s indexes studies.

It is important to note, however, that not all studies estimate the adaptation ratio using interaction models. For example, Bento (2023) use differentials between short-run and long-run estimates to infer adaptation, where the former represents the no adaptation case while the latter captures adaptive responses over time. Alternatively, authors may use nonlinear models, for example, to show that the marginal effect of temperature rise is lower in higher-temperature locations, indicating adaptation (Barreca et al. 2015). Note that these methods estimate the impact of *generalized* adaptation responses, while interaction models highlight specific adaptive mechanisms. In our sample of 183 estimates, 112 are from interaction models, 41 are from "scenario" models that extrapolate the parameters of some underlying regression model under different climate scenarios (such as the RCP45 or 85 emissions scenarios), 10 are from "short-run/long-run" models, five are from nonlinear models, and 15 are from assorted other models.

As a numerical illustration of the method for estimating the adaptation ratio in the interaction case, consider De Mel, McKenzie, and Woodruff (2012), which studied how cash grants aided Sri Lankan microenterprises in recovering from the December 2004 tsunami. Using an interaction regression, the study estimated that the tsunami reduced monthly firm profits by LKR 1252 and a randomly allocated grant offset that by LKR 1024. Hence, for this study, β_2 is 1252 and β_1 is 1024, implying an adaptation ratio of 0.8. In another example, Lee and Moschini (2022) studied how technology adoption has aided adaptation to warming in maize cultivation in the United States. The study estimated that an additional hot day reduces yield by 0.293 units (β_2) and the use of genetically engineered varieties offsets this yield loss by 0.0286 units (β_1). This implies an adaptation ratio of 0.1.

Carleton et al. (2022) is an example of a study of general adaptation responses with future scenario modelling based on estimated age-specific mortality-temperature relationships. This study estimates that without adaptation, the mortality effects of climate change under the Representative Concentration Pathway 8.5 scenario by 2100 are 104 additional deaths per 100,000 individuals (β_2). Adaptation reduces this total by 31 per 100,000 (β_1), yielding an adaptation ratio of 0.3.

An important issue is inference— that is, how to obtain standard errors for each θ_{ks}. This is non-trivial, because standard errors are rarely reported for the ratio itself, but only for the individual estimates that comprise it. In the case where $\theta = \frac{\beta_1}{\beta_2}$, then by the delta method, a second-order Taylor expansion gives:

$$Var[\theta] \approx \frac{Var[\beta_1]}{E[\beta_2]^2} - \frac{2E[\beta_1]}{E[\beta_2]^3} cov[\beta_1, \beta_2] + \frac{E[\beta_1]^2}{E[\beta_2]^4} var[\beta_2]$$

Each of these quantities are observable using the estimates and standard errors for β_1 and β_2, as reported in a given regression (k, s), with the exception of $cov[\beta_1, \beta_2]$. This is because articles typically do not report the full covariance matrix of regression estimates. As such, three different assumptions capture extreme and intermediate cases of covariance: $cov[\beta_1, \beta_2] \in \{-0.75, 0, 0.75\}$; Figure 2 tests sensitivity to these choices. In total, standard errors are available for 118 estimates of θ_{ks} across 52 studies.

Another important issue is aggregation. The issue of aggregating estimates across studies consists of finding the appropriate weighting scheme that incorporates both cross-study heterogeneity and within-study sampling variation. Assume a linear random effects setup (DerSimonian and Laird 1986; Nakagawa et al. 2023):

$$\theta_{ks} = \theta_0 + u_{ks} + \epsilon_{ks}$$

That is, the adaptation ratio can be additively decomposed into a common component θ_0, an estimate-specific effect $u_{k,s}$, and a sampling error ϵ_{ks}, with the distributional assumptions:

$$u_{ks} \sim N(0, \tau^2), \epsilon_{ks} \sim N(0, \sigma_{ks}^2)$$

The minimum-variance unbiased estimator of θ, the average effect across studies, is a variance-weighted average of the θ_{ks} (Hedges 1983);

$$\theta = \frac{\sum_{ks} w_{ks} \theta_{ks}}{\sum_{ks} w_{ks}}, \; w_{ks} = \frac{1}{\tau^2 + \sigma_{ks}^2}$$

4.2. Main estimates of the impact of adaptation

The baseline estimates of the aggregate adaptation ratio θ are presented in Figure 2 with 95 percent confidence intervals. The results are presented for five different estimators: *i)* the naïve unweighted mean of all 183 estimates, θ_{ks}, where the confidence interval accounts only for cross-study heterogeneity; *ii)* the naïve unweighted mean of all 118 estimates, θ_{ks} for which standard errors are available; *iii)* the random effects estimate when $cov[\beta_1, \beta_2] = 0$; *iv)* the random effects estimate when $cov[\beta_1, \beta_2] = -0.75$; and *v)* the random effects estimate when $cov[\beta_1, \beta_2] = 0.75$.

The naïve means are 0.57 for the full sample and 0.58 for the standard errors sample. This suggests the subsample is representative; there is unlikely to be sample selection bias in restricting to studies where enough information is reported to allow estimation of $var(\theta_{ks})$. However, the unweighted mean somewhat overestimates the average effectiveness of adaptation. For the random effects estimates, the variance-weighted average effect is 0.46. This is true regardless of the assumption about the covariance matrix between β_1, β_2, with these assumptions generating only minor changes in magnitude. Because the results are not sensitive to this choice, the zero-covariance assumption is maintained going forward. All confidence intervals are tight and exclude both 0 (useless adaptation) and 1 (perfectly effective adaptation). Overall, in our sample, adaptive responses mitigate just under 50 percent of the economic damages from climate shocks.

However, there is substantial variation in estimates both across and within agent types. Figure 3 plots the unweighted density of θ_{ks} for the estimation sample with standard errors available, by agent type. Though there is a spread of estimates, the majority fall between zero and one, which is a reasonable range. The distributions for estimates from households and farmers largely overlap. Household density peaks at 0.34, while farmer density peaks around 0.63. Still, the farmer distribution has more mass in the left tail, implying a larger share of ineffective or even counterproductive adaptations. The household distribution is more tightly centered around its peak. The firm distribution, instead, is shifted substantially right, with a peak around 1 (full effectiveness). This suggests that firms are more capable of adapting to climate shocks. However, firm studies may differ in composition of climate shocks, methods, or adaptations—all of which may drive differential adaptation effectiveness.

4.3. Heterogeneity in the impacts of adaptation

Figure 3 suggests that there is substantial heterogeneity across studies. This is perhaps unsurprising, given that the meta-analysis pools many different settings, climate shocks, outcomes, and adaptations. An alternative visualization of both the within and cross-study heterogeneity in our sample is in Figure 4, which plots 110 estimates of the adaptation ratio with 95 percent confidence intervals, arranged in ascending order.[6] The results underscore two important points. First, 74 percent of these estimates fall between 0 and 1, the reasonable range for the adaptation ratio. Furthermore, the estimates that fall outside this range are typically do not exclude 0 or 1 from the confidence interval. Second, there is substantial within-study noise in the estimates. Confidence intervals are often wide and the estimates themselves not significantly different from zero. In fact, 67 percent of the confidence intervals contain 0, 66 percent contain 1, and 48 percent contain both 0 and 1. However, aggregation of many noisy studies using random effects weighting produces tight confidence intervals, underscoring the value of such an exercise.

[6] For visual clarity, we drop eight estimates with very large confidence intervals.

The results also exhibit substantial group-level heterogeneity. Figure 5 (left panel) estimates the average adaptation ratio via random effects for each subgroup—firms, households, and farmers. Among firms, adaptation recoups 72 percent [CI: 0.43, 1.01] of climate damages, with a relatively tight CI, even though this group only contains 13 estimates. But adaptive behaviors are less effective for other agents: households (n=56) only recoup 49 percent [CI: 0.36, 0.61] of climate losses while farmer adaptations (n=59) offset 38 percent [CI: 0.25, 0.51] of the impact of climate shocks. The firm effect is significantly different from the household and agriculture effects.

There are many reasons why firm studies may generate larger adaptation ratios, but the most important one may be that firms have access to more effective adaptation strategies. The larger adaptation ratios in firms may reflect compositional effects: firms are studied in different regions and climate shocks (see Figures 2 and 3), as well as potentially with different methods. However, the key factor behind this finding may be that firms have access to more effective adaptation strategies, such as technology adoption.

Consider the right panel of Figure 5, which estimates group-specific aggregate effects for different adaptation mechanisms.[7] In general, the results indicate substantial variation in the effectiveness of adaptation mechanisms. The most effective ones are those that leverage either government policy or technology. Public goods such as infrastructure (Burgess and Donaldson 2010; Brooks and Donovan 2020), effective health systems (Abiona and Ajefu 2023), and piped water (Costa, Sant'Anna, and Young 2023) are the most effective methods of blunting the costs of climate change, with an adaptation ratio of 0.64 [CI: 0.27, 1.00]. Next are technological solutions such as climate control (Barreca et al. 2016; Goodman et al. 2020; Somanathan et al. 2021), improved seeds (Dar et al. 2013; Lee et al. 2022), and management practices (Adhvaryu, Kala, and Nyshadham 2022), which offset 62 percent [CI: 0.41, 0.83] of the losses from climate shocks. Somewhat less effective, though still above average at 53 percent [CI: 0.39, 0.68], are transfers, which are particularly important in supporting resiliency following disasters (Kosec and Mo 2017; Premand and Stoeffler 2022). Many of these constitute government-supported social protection programs, which have the benefit of ameliorating climate losses for the poorest (Arouri 2015; Macours 2022; Premand and Stoeffler 2022).

The least effective mechanisms, in contrast, are private adjustments without the aid of finance, technology, or government assistance. In particular, labor market adjustments, most commonly migration (Giles 2006) and off-farm work (Gao and Bradford 2018), recover only 14 percent [CI: 0.06, 0.22] of climate losses. Similarly, climate-smart agriculture (CSA)—typically the adoption of improved farming practices (Michler et al. 2019; Alfani 2021; McCarthy 2021)—has below-average effectiveness, with an average adaptation ratio of 0.42 [CI: 0.21, 0.63].

[7] Note that these categories are defined slightly differently than those in Figure 4 because of the smaller sample of articles. Climate smart agriculture (CSA) now forms its own category (previously it was under either reallocation or technology), while public goods now combines both public policy and infrastructure categories.

The results of a meta-regression analysis in Table 5 are consistent with the hypothesis that firms have access to more effective adaptation strategies. In the baseline regression with no controls, the average adaptation ratio is higher for firms than for households and farmers by 0.28 (column 1)—as indicated by the positive coefficient on the firm study dummy, which is statistically significant at the 10 percent level. Controlling for the type of shock studied increases the point estimate of the firm study coefficient (column 2) while controlling for the type of econometric model used in the study does not affect it (column 3). However, the firm coefficient drops in magnitude and is no longer statistically significant after controlling for the type of mechanism (column 4). Controlling for mechanism reduces the firm coefficient by 37 percent relative to the unconditional specification.

Similarly, once both shocks and model specification are controlled for (column 5), the addition of controls for mechanism reduces the magnitude of the firm coefficient by 15 percent (column 6), and also reduces the significance from 5 percent to 10 percent. Taken together, these results suggest that the firm advantage in adaptation is not explained by composition of shocks or specification choice. Rather, the larger firm adaptation ratio is at least partly explained by firms employing more effective adaptation strategies.

5. Conclusion

A rapidly growing literature finds that households, farmers and firms can adapt to climate change in many ways. The two most common forms of climate change adaptation studied in this literature involve private action in the context of markets: reallocation of inputs and outputs, and technology adoption. Financial instruments and labor market adjustments also feature prominently in studies of climate change adaptation. Government policy—such as disaster relief programs and public infrastructure—also matters for adaptation, though the policy share in the number of studies is relatively small. If their share in the number of studies is indicative of their actual prevalence, then private climate change adaption mechanisms are relatively common.

A key message of the meta-analysis conducted in this study is that a combination of approaches will be needed to adapt to climate change. Most adaptation mechanisms are found to be effective at reversing part of the economic loss from climate change, but none are found to fully undo the loss by themselves. On average, the adaptation responses in the study sample reverse about 46 percent of the economic damages from climate shocks.

Identifying policies to spur the adoption of climate-resilient technologies is important, considering the relatively limited impact of purely private adjustment mechanisms. The meta-analysis suggests that there is heterogeneity in the impact of different types of adaptation mechanisms, with the least effective mechanisms being those that involve private adjustments without the aid of technology, finance, or public support. Notably, migration and shifting from farm to non-farm activities are common adaptation mechanisms, but they have limited impact on climate damage recovery. In contrast, adaptation mechanisms that leverage new technologies such as climate control, improved seeds, and adaptive business management practices are more effective.

Understanding how public policies can improve the resilience of connective infrastructure, essential public services and water supply is also important because of their relatively large impact. After technologies, the most effective adaptation mechanisms identified by the meta-analysis involve public goods such as infrastructure, effective health systems and access to water. Such public goods appear to have sizable effects on adaptation, not only by shielding economic activities and human capital from climate damage, but also by aiding private adaptation responses (such as economic reallocation). Connective infrastructure preserves access to labor and goods markets in the face of climate shocks, which opens possibilities for reallocation and other private adaptation mechanisms. For example, bridges are effective at protecting incomes from the impact of floods because they reduce uncertainty about market access and encourage greater investment (Brooks and Donovan 2020). Access to publicly provided inputs and services helps preserve productivity and human capital. For example, public access to water is effective at reducing the impact of droughts on farm incomes (Mukherjee and Schwabe 2015).

One important gap in the academic literature on adapting to climate change is the limited study of the adaptative role of certain public goods and programs that are relatively prominent in the policy discourse. In EMDEs, national policy documents on climate change adaptation often emphasize public disaster preparedness programs and protection investments, such as flood protection infrastructure (for example, Government of Bangladesh 2018). But public policy represents only 13 percent and infrastructure just 6 percent of the academic literature on climate change adaptation. The rest of the literature mainly studies private adaptation responses by individual agents.

More attention could also be given to studying how public goods and programs interact with private adaptation response—and its policy implications. Although policy documents on climate change adaptation emphasize public goods and programs, they also recognize the role of private and community level responses to climate change and how governments can support them. For example, Pakistan's National Climate Change Policy mentions support to building the adaptive capacity of communities and farmers as part of an overarching policy agenda on climate change adaptation (Government of Pakistan 2021). Research on how public policy can support private adaptation responses would help inform such national strategies.

This review also finds that researchers have focused more on studying adaptation to heat than other aspects of climate change. Other slow-moving climate change trends and their resource implications, such as changing precipitation patterns and falling groundwater levels, are less studied, as are extreme weather events.

Finally, perhaps the most notable gap in the economic literature on climate change adaptation is the limited study of firms (that is, non-farm enterprises). This review indicates that firms may have better access to effective adaptation mechanisms than farmers and households. But among the papers we identified, firms are the least studied of the three types of economic agents. Research may uncover more effective pathways to adaptation by paying more attention to studying how firms adjust to climate change and what factors hinder their adaptation.

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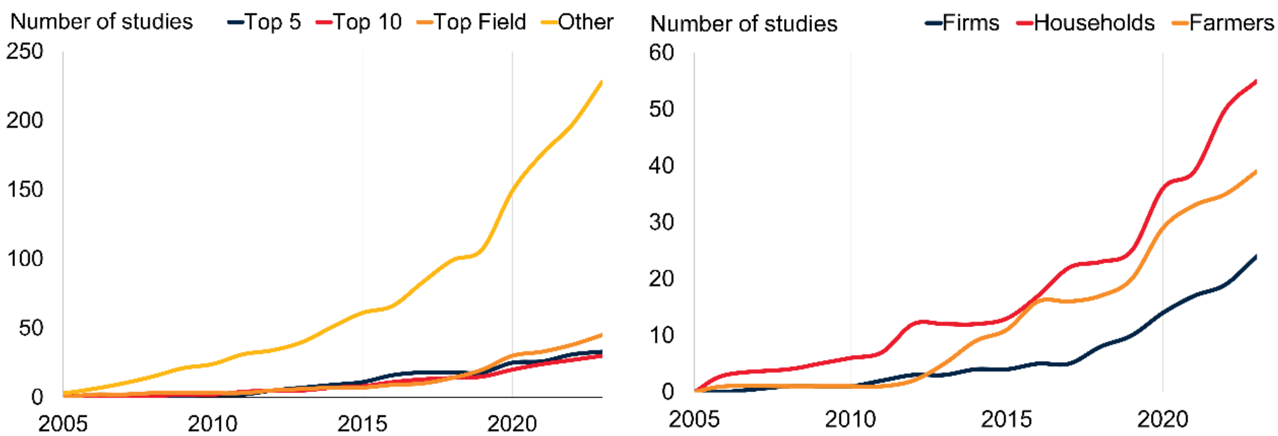
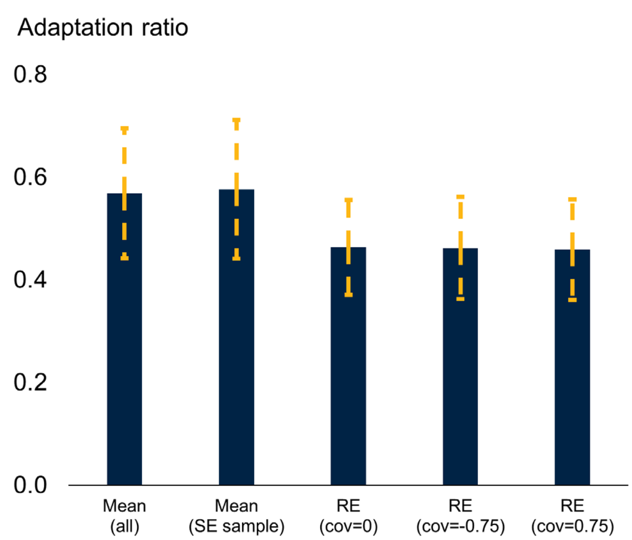
Figures

Figure 1: Studies over time



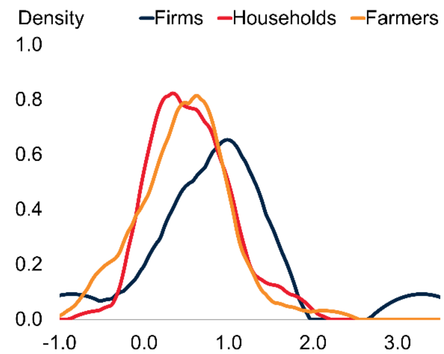
Source: Authors' calculations. Figure shows total cumulative count of articles on climate change adaptation for by journal type the full sample of 324 articles (left) and by agent for the subsample of 101 top journal studies (right). The top journals are: the American Economic Review, the Journal of Political Economy, the Quarterly Journal of Economics, Econometrica, the Review of Economic Studies (the Top 5); Journal of the European Economic Association, the Review of Economics and Statistics, the American Economic Journals, the Economic Journal (the Top 10); the Journal of Environmental Economics and Management, the Journal of Development Economics, the Journal of Public Economics, Management Science, and the Review of Financial Studies (the Top Fields).

Figure 2: Estimates of the aggregate adaptation ratio



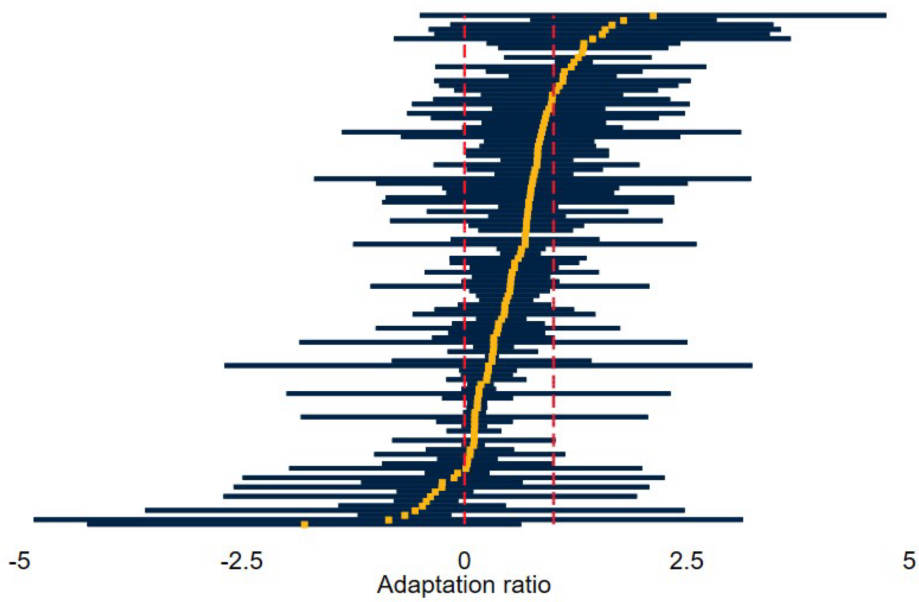
Source: Authors' calculations. Figure shows estimated adaptation ratios by meta-analysis aggregation method. Mean (all) refers to the raw mean of all 183 available estimates. Mean (SE sample) calculates the raw mean only of the 118 estimates for which standard errors can be estimated. RE (cov = 0) estimates the random effects model in which the correlation between coefficient estimates in the adaptation ratio is assumed to be zero. Similarly, RE (cov=-0.75) and (cov=0.75) assume correlation coefficients of -0.75 and 0.75.

Figure 3: Distribution of adaptation ratios by agent type



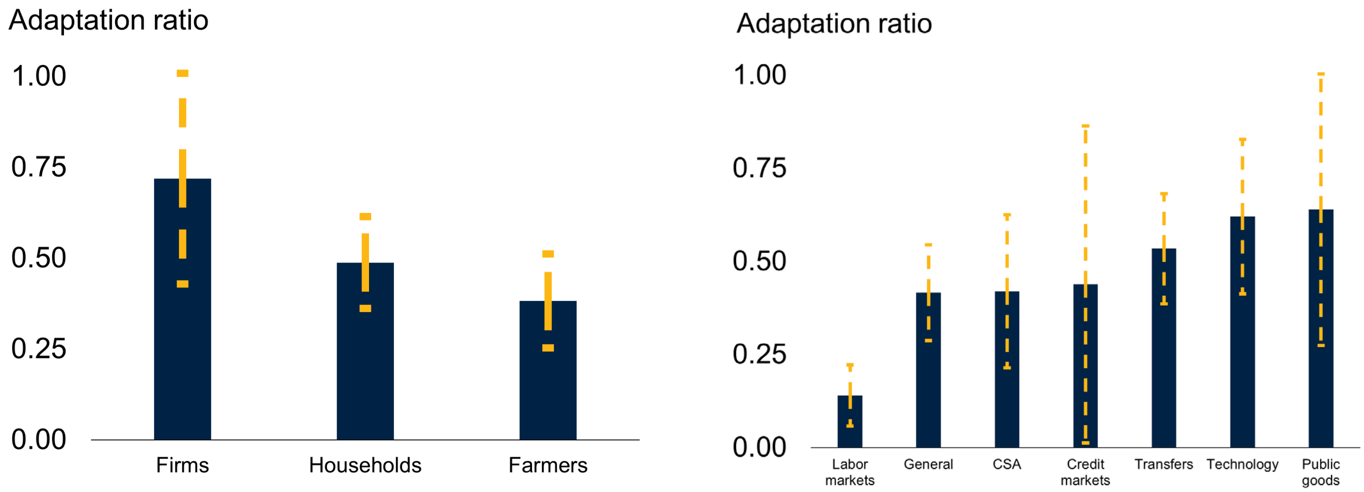
Source: Authors' calculations. Figure shows the density of estimated adaptation ratios across studies by agent type for households, firms, and farmers.

Figure 4: All study adaptation ratios



Source: Authors' calculations. Yellow squares indicate estimated adaptation ratios for each of 110 estimates in the study sample. Blue bars indicate 95% confidence intervals around the adaptation ratio. For visual clarity, 8 estimates are omitted because of overly wide confidence intervals. Red lines indicate adaptation ratios of 0 and 1.

Figure 5: Average adaptation ratios by agent type and adaptation mechanism



Source: Authors' calculations. Figure shows estimated adaptation ratio by agent type (left) and by adaptation mechanism (right). Adaptation ratios are defined in-text.

Tables

Table 1: Adaptation studies by region, agent, and journal type

	Top journals				Other journals			
Region	Firms	Households	Farmers	Total	Firms	Households	Farmers	Total
East Asia & Pacific	4	5	5	14	5	17	6	29
Europe & Central Asia	0	0	0	0	0	2	4	6
Global	3	7	4	11	5	8	8	19
Latin America & Caribbean	1	12	3	15	0	9	7	15
Middle East & North Africa	0	0	0	0	0	0	2	2
North America	6	14	9	28	6	14	20	39
South Asia	8	12	9	24	4	22	25	47
Sub-Saharan Africa	0	5	4	9	0	27	46	64
Total	22	55	34	101	20	99	118	221

Note: Table shows counts of the number of studies by region and agent type for top journals (left) and tother journals (right). The top journals are: the American Economic Review, the Journal of Political Economy, the Quarterly Journal of Economics, Econometrica, the Review of Economic Studies (the Top 5); Journal of the European Economic Association, the Review of Economics and Statistics, the American Economic Journals, the Economic Journal (the Top 10); the Journal of Environmental Economics and Management, the Journal of Development Economics, the Journal of Public Economics, Management Science, and the Review of Financial Studies (the Top Fields).

Table 2: Adaptation studies by climate shock, agent, and journal type

	Top journals				Other journals			
Climate shock	Firms	Households	Farmers	Total	Firms	Households	Farmers	Total
Drought	0	9	5	12	1	12	25	34
Flood	1	5	3	8	6	15	7	26
Natural disaster	7	8	0	15	6	10	0	16
Other	2	1	5	8	3	7	15	24
Rainfall	2	9	11	20	0	27	50	71
Temperature	10	30	14	49	5	40	48	92

Note: Table shows counts of the number of studies by climate shock and agent type for top journals (left) and tother journals (right).

Table 3: Adaptation studies by adaptation mechanism, agent, and journal type

	Top journals				Other journals			
Adaptation	Firms	Households	Farmers	Total	Firms	Households	Farmers	Total
Financial market	3	3	10	14	3	13	20	33
General	4	4	7	16	2	6	10	21
Infrastructure	0	3	3	6	0	3	13	15
Labor market	2	10	2	12	1	13	12	21
Migration	2	14	3	15	1	21	2	22
Public policy	2	10	2	14	2	16	4	21
Reallocation	5	10	8	17	8	21	48	71
Technology	7	7	6	18	1	14	19	34
Transfer	1	7	0	8	2	15	3	18

Note: Table shows counts of the number of studies by adaptation mechanism and agent type for top journals (left) and tother journals (right).

Table 4: Adaptation studies by adaptation mechanism and agent for top journals

Adaptation	Flood	Rainfall	Temperature	Drought	Natural Disaster	Other
Financial market	1	5	1	2	3	2
General	0	3	16	0	0	0
Infrastructure	1	1	1	3	1	0
Labor market	1	4	5	1	1	1
Migration	4	1	7	3	3	1
Public policy	0	3	7	1	4	1
Reallocation	2	1	10	2	2	1
Technology	2	3	10	1	1	1
Transfer	0	2	3	2	3	0

Note: Table shows counts of the number of studies by adaptation mechanism and climate shock for top journals (left) and tother journals (right).

Table 5: Meta-regression estimates of firm effects

	(1)	(2)	(3)	(4)	(5)	(6)
Firm study	0.278*	0.419**	0.269*	0.174	0.410**	0.346*
	(0.143)	(0.164)	(0.145)	(0.160)	(0.176)	(0.182)
Shock	No	Yes	No	No	Yes	Yes
Model FE	No	No	Yes	No	Yes	Yes
Mechanism	No	No	No	Yes	No	Yes
Observations	118	118	118	118	118	118

*Note: Table shows estimates from a meta-regression analysis of firm adaptation effects using a random effects specification. Standard errors are in parentheses. Firm study is an indicator variable equal to one if the study covers firms. Shock indicates dummy variables for temperature, rainfall/drought, and flood studies. Model FE are fixed effects for model type, comprised of the following categories: interaction, nonlinear, short-long-run, and scenario models. Mechanism indicates dummy variables for technology, transfers, financial markets, labor markets, and public goods. *** $p<0.01$, ** $p<0.05$, * $p<0.1$*