Climate Change and Firm Exposure to Political Risk*

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Abstract

We study the impact of climate shocks on firms' exposure to political risk–risk from government expropriation and political violence. Using a novel panel dataset of country-level Political Risk Insurance (PRI) ratings, we find that hotter and drier weather conditions increase the probability of rating downgrades, which are in turn associated with increases in actual expropriation and decreases in investment and income. The climate effects are stronger for low-income countries and for countries in colder and wetter climates. We find evidence suggesting that democratic institutions can reduce the impact of climate shocks.

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1 Introduction

Climate shocks such as droughts and heatwaves affect firms' financial performance by damaging physical assets and reducing worker productivity (Hong et al., 2019; Somanathan et al., 2021). A separate yet related issue is climate-induced *political risk*, in which the economic consequences of extreme weather can lead to armed conflict and violations of property rights. However, quantifying the impact of climate shocks on political risk is challenging, as concrete incidents of institutional degradation (e.g., expropriation) are seldom systematically documented. Further, focusing solely on such realized events only partially identifies the scope of climate-induced political risk for investors, since the *perception* of expropriation risk alone may be enough to discourage investment (Eaton and Gersovitz, 1984; Besley and Ghatak, 2010).

This study explores the effect of climate shocks on firm exposure to political risk using a novel global data set of Political Risk Insurance (PRI) ratings. PRIs are financial products devised specifically to hedge multinational investors against the risk of political violence and governmental expropriation, as this risk remains one of the "key obstacles to investment [...] in developing countries (United Nations, 2025)." The providers of PRI policies, who are largely private insurers, assign a "country risk rating" to each host country. Just as how corporate bond ratings reflect the investment market's perception on the risk of credit default, the PRI country ratings reflect the investors' perceived political risk in a given country. The ratings determine the insurance policies' premiums and coverage, and their accuracy is disciplined by actual occurrence of institutional breakdowns (Jensen, 2008). Our panel data set of PRI ratings, spanning 174 countries and 23 years, provide a unique opportunity to assess how climate shocks affect the perceived political risk of investors.

We assess the performance of PRI ratings as metrics of institutional quality by linking our data with independent data sets of actual PRI claims and country-level macroeconomic outcomes. Using event-study methods (Callaway and Sant'Anna, 2021), we find that the PRI rating downgrades are indeed associated with an increase in PRI claims and expropriation events. Further, the downgrades are associated with statistically significant drops in per capita real income, foreign direct investment, and domestic investment by 4%, 27%, and 14%, respectively. Such results are not only consistent with the prior literature on the importance of property-right institutions (Acemoglu, Johnson and Robinson, 2001), but also imply that investors both inside and outside the host country respond to its institutional degradation.

We then combine the ratings data with a gridded weather data set and estimate a fixed-effects panel model (Deschênes and Greenstone, 2007) to measure the effect of anomalously hot weather and droughts on PRI rating downgrades. The identification strategy hence relies on the quasi-experimental year-to-year variations in weather, holding country characteristics fixed. We follow prior studies (e.g., Carleton et al., 2022) to allow the effect of weather shocks to be a function of the country's average climate and its average income levels, hence accounting for climate adaptation and income effects. The model also allows for lagged effects of weather.

We find that the effects of warmer-than-average weather are larger in countries with *colder* climate, with countries of average temperature above 20°C (Spain and Australia) being less vulnerable to anomalously warm weather. Similarly, the effect of droughts are stronger for countries with a wetter climate. Low-income countries are more vulnerable to both temperature and precipitation shocks. The drought and warm weather's effects are largely nefarious (increasing downgrade probability), and estimates of beneficial effects (decreasing downgrade probability) are seldom statistically significant. On average, a standard deviation increase in temperature leads to a 0.5 percentage point increase in downgrade probability, versus an average downgrade probability of 5%. The results are robust to using actual realizations of expropriation events, or the proxies thereof, as the outcome variable.

Ostensibly, the effect of warmer weather being more harmful in colder climates stands in contrast to prior studies in the literature which have identified a "hill-shaped" relationship between economic productivity and temperature (Mendelsohn et al., 1994; Burke et al., 2015). Such studies have pointed to warm temperature shocks being detrimental for productivity in hotter-climate countries, while being beneficial in some cold-climate countries. Yet, previous theoretical analyses on the drivers of expropriation (Thomas and Worrall, 1994; Besley and Ghatak, 2010; Stroebel and Van Benthem, 2013) have suggested that *positive*, exogenous productivity shocks increase the incentive for the government to expropriate. Such studies suggest that the "windfall" characteristics of climate-induced productivity increases could be what's driving the observed PRI downgrade-climate relationship.

To investigate the potential of such productivity-related channel, we extend prior work by developing a stylized model of *perceived* expropriation risk. Unlike previous studies, which assume perfect observability of the true risk, we conceptualize the investors' decisions as being characterized by *beliefs* about expropriation risk, updated via Bayesian inference from actual expropriations. The empirical predictions suggest that positive pro-

ductivity shocks increase equilibrium expected expropriation risk, even under imperfect observability. The model also suggests that the nefarious effects of "positive" climate productivity shocks are weaker in countries with robust democratic institutions and where the government is subject to strong executive constraint–hence being *moderators* of the productivity channel. The same institutions can also be *mediators* of climate shocks' effects, with democratic institutions and executive constraint reducing investor-perceived risk of expropriation.

We test such empirical predictions by first, regressing indexes of economic productivity, democratic institutions, and executive constraint against year-to-year variations in weather. We find strong evidence in favor of the productivity channel as the mediator for the climate shock effect. In contrast, we find that the effect of climate shocks are muted for more democratic countries and for countries with strong executive constraint, suggesting that these political institutions play the role of moderators (instead of mediators) in translating the effect of climate shocks into changes in property-right institutions.

This paper speaks to the broad literature that studies the risk posed by climate change on the firms' financial outcomes (Addoum et al., 2020; Krueger et al., 2020; Pankratz et al., 2023; Sautner et al., 2023). Government expropriation of capital pose real risks to firms considering large-scale investments in developing countries, as evidenced in the vibrancy of the PRI market itself. Our results suggest that the impacts of climate shocks are already observable in the PRI market's signals. The heterogeneous effects of warm weather, in turn, suggest that regions of the world that were traditionally thought to be safer from climate change impacts may not be so in their institutional resilience–hence adding to the urgency of climate action.

This study also contributes to the burgeoning "climate-conflict" literature (Hsiang et al., 2013; Burke et al., 2024), which identify the link between weather shocks and civil conflicts. While a few studies in the literature (Burke and Leigh, 2010; Brückner and Ciccone, 2011) have explored the impact of weather shocks on institutional quality, such studies were focused on non-market indexes of democratic institutions (e.g., Polity V index, Marshall and Gurr, 2020). In contrast, this paper's outcome measures property-right institutions and are direct results of the investment market's shifting evaluations–hence being a more convincing metric of firm exposure to political risk.

More broadly, the theoretical literature on political violence (Besley and Persson, 2009, 2011) have suggested that the weakening of institutions precedes civil violence, the subject of the climate-conflict literature. The results in this paper imply that this "middle step" between climate shocks and violence does exist. The mechanism results highlight the

importance of democratic institutions in preventing this chain reaction, from climate shocks to property-right institution degradation–and ultimately to violent conflicts.

The remainder of the paper is structured as follows. Section 2 discusses the PRI ratings in detail and presents the data that we use, followed by Section 3 on the empirical strategy. Section 4 presents the main empirical results, additional findings, and the potential mechanisms. Section 6 concludes.

2 Background and Data

2.1 Political Risk Insurance and its country-level risk ratings

This study uses country-level risk ratings of PRI policies to assess firms' exposure to climate-induced political risk. PRI products are offered by both governmental and private insurers to private investors aiming to hedge their investments against political risk.[1] Investors covered by PRI policies can file for claims when their assets or the returns thereof are subject to losses from political reasons, such as unilateral expropriation and destruction from violent conflicts. The insurers' country-level risk ratings, the source of this study's outcome variable, plays a crucial role in the setting of premium, coverage, and terms of contract of PRI policies. For example, some insurers stipulate that projects hosted in countries with the worst ratings are not eligible for insurance coverage.

We use PRI ratings from the Belgian governmental export credit agency (ECA), Credendo (formerly *Office National du Ducroire*). On top of being the source of data for prior cross-sectional studies using PRI ratings (Jensen, 2008; Jensen and Johnston, 2011), Credendo's ratings have several other properties that improve their representativeness and their usefulness. First, Credendo publicly discloses its most recent annual country-level ratings on its website. Such public disclosure of ratings, combined with the multinational nature of most purchasers of PRI policies, have meant that a considerable degree of parity has been established in the PRI market–such that premiums of other PRI products show similar variations to those of Credendo (Jensen, 2008).

Further, unlike other ECAs which capture a country's overall political risk with a single rating, Credendo breaks down a country's ratings into the different aspects of political risk. We focus on ratings for expropriation risk, which "encompasses all discriminatory measures taken by a host government which deprive the investor of its investment without

[1]Governmental insurers mostly consist of export credit agencies (ECAs) aiming to promote investments in developing countries, such as U.S. International Development Finance Corporation (DFC).

any adequate compensation (Credendo, 2024)." To compare our results with the studies in the climate-conflict literature (Burke et al., 2024), we also study rating changes for political violence risk, which include risk of damages from terrorism attacks or violent conflicts.

Every year, Credendo adjusts the countries' risk rating by combining results from its own propriety quantitative risk model, the investors' experiences, and regional experts' assessments. We use all Credendo ratings from 2002 to 2024, and define a dummy variable of "downgrades" from the changes in the country's ratings. Crucially, weather and climate characteristics are *not* part of the risk rating adjustment process–suggesting that our core results on the link between climate shocks and PRI ratings are not mere artifacts of the Credendo's assessment methods.

A first inspection into the PRI expropriation rating data reveals that upgrades and downgrades are pervasive, observed in more than half of the countries (113 out of 174) and with an average probability of 5% per country-year. Importantly, Appendix Figure B1 suggests that these shifts are not disproportionately focused on specific climate zones of the world. Most of the countries' records span 23 years (from 2002 onward), with global coverage (174 countries, Appendix Figure B2). Appendix Figure B3 presents the average expropriation risk rating over the sample period, where lower value means lower expropriation risk.

Notably, Appendix Figures B4 and B5 show that certain countries (e.g., non-OECD countries) have experienced multiple downgrades and upgrades, while a few countries (e.g., South Korea *and* North Korea) have not experienced any changes in their ratings.

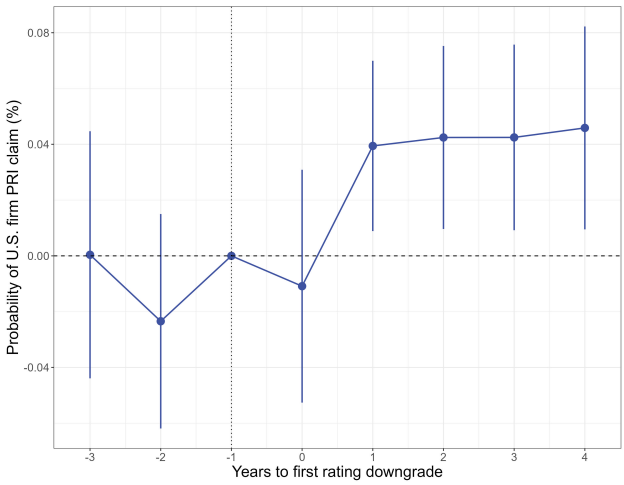
2.2 Risk rating, claim occurrence, and macroeconomic outcomes

To be a good proxy of the institutional environment that firms face in different countries, the Credendo expropriation risk ratings must be predictive of actual expropriation events. To empirically validate this, we combine the Credendo rating data with a firm-level panel data of expropriation events, from Arel-Bundock et al. (2020). The latter firm-level data set compiles PRI purchases and loss claims from a U.S. governmental PRI program run by the U.S. International Development Finance Corporation, and provides an albeit partial information on the extent of political risk-induced losses.[2] The unit of observation is at

[2]The following excerpt from a claim filed to OPIC (precursor of the U.S. DFC) on an expropriation event in Russia aptly illustrates the kind of incidents that are covered by DFC's PRI policies:

"On March 1, 2008, Terminal [Russian partner of GFMG] brought its own security service onto the Facility [owned by GFMG] and SGP [Facility's maintaining entity]'s security service resigned. (...) [W]ith the change in security services, Terminal took over all access into the Facility (the "Takeover"). (...) Following

(a) Political risk insurance claims, U.S. investors



(b) Income and investment per capita

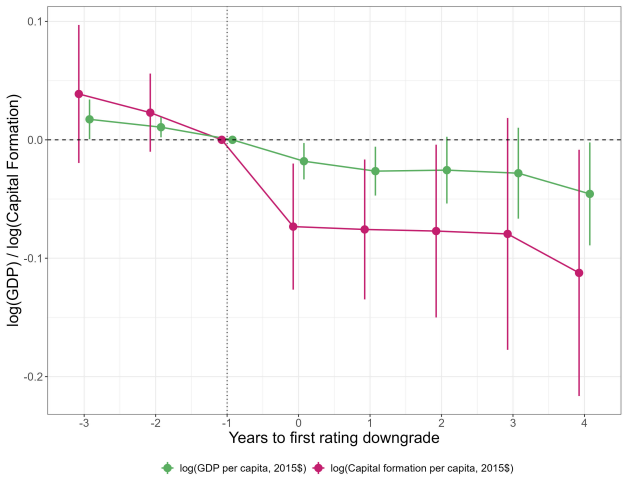


Figure 1. Country-level PRI rating, claim occurrence, and macroeconomic outcomes

Notes: Figure shows Callaway and Sant'Anna (2021) event study coefficients, with the treatment variable being "first Credendo expropriation risk rating downgrade." Credendo is the Belgian governmental export credit agency whose country-level risk ratings we use as primary outcome of interest. Figure 1a uses as outcome the investment project-level dummy of the project filing for a political risk-induced loss (losses from expropriation, war, and other political violence), while Figure 1b has macroeconomic variables of the country experiencing the downgrade. All standard error clustered at country level. Error bars represent 95% confidence intervals. See Appendix Figure B4 for coverage of Credendo ratings and country-level downgrade frequency.

the investment project-year level, and each investment project is linked with the Credendo data using the projects' host country and year.

We estimate an event study model (Callaway and Sant'Anna, 2021) using the combined data, with "first expropriation risk rating downgrade" as the treatment variable and an indicator variable of a firm filing for PRI claims as the outcome variable. The coefficient estimates measure the dynamic correlation between a country's downgrade in Credendo expropriation rating and the conditional probability of a U.S. company filing for PRI losses in that country. The model includes project- and year-fixed effects, and uses the "never treated" projects (i.e., projects in countries that have never experienced rating downgrade) used as the control group.

The results, shown in Figure 1a, suggest that Credendo's expropriation risk rating downgrades are indeed followed by persistent increases in the probability of a U.S. firm

the Takeover, GFMG, as 70% owner of SGP, immediately sought intervention from the Russian police, court, and local government authorities, but no action was taken against Terminal during the illegal occupation period... (Overseas Private Investment Corporation, 2011)"

filing for PRI losses in the country. While a firm files for PRI claims with a probability of 0.22%, the probability increases by 0.05%p following the downgrade. Interestingly, there is little noticeable pre-trend in PRI claims prior to the downgrade. These estimates indirectly suggest that the Credendo rating downgrades occur in anticipation of expropriation events, rather than as a mere responses to an actual expropriation occurrence.

Prior studies suggest that such deterioration of property-right institutions, as evidenced in the increase in expropriation events following the rating downgrade, likely discourages investment and hamper economic growth (Acemoglu et al., 2001; Besley and Ghatak, 2010). We empirically test this possibility by estimating event study coefficients on a data set combining the Credendo ratings with the countries' real GDP per capita and capital formation per capita, the latter defined as gross investment net of inventory changes. Both data are obtained from World Bank Development Indicators (World Bank Group, 2024).[3] We estimate the coefficients conditional on log of real GDP in year 2000 (prior to the first Credendo risk rating), in light of the differences in income levels of the countries that experience downgrades versus those who do not (Appendix Figure B4).

The event study coefficients in Figure 1b suggest that indeed, countries experience significant drops in income and capital accumulation following expropriation rating downgrade. The GDP and investment per capita drop by 4.1% and 14.0% respectively, while there are no obvious evidence of recession prior to the downgrade. Appendix Figure B6 suggests that the decreases are also observed in log of net FDI inflow (27% drop). Such results suggest that the infringement of property rights, as captured by the downgrades, affect investment incentives of both domestic and foreign investors, suppressing income growth. Further, Appendix Figure B7 implies that the downgrades are not driven by, or are followed with, deterioration of the countries' fiscal health–as measured through the ratio of external debt to currency reserves.

The Figure 1 results are robust to using "not-yet-treated" countries as the control group (Appendix Figures B9 and B10). Figure 1a results also stand when we limit the PRI claims to those related to expropriation (Appendix Figure B10). Lastly, Figure 1b results are robust to not conditioning the coefficients on income levels (Appendix Figure B11), although the coefficients become noisier.

[3]To be precise, World Bank provides the "share of capital formation in the GDP" data. We multiply this quantity with the inflation-adjusted GDP per capita to obtain domestic investment per capita.

2.3 Additional data

Actual expropriation cases. We obtain records of actual cases of government expropriation from United Nations Trade and Development's (UNCTAD) Investment Dispute Settlement Navigator (UNCTAD, 2023). The data set focuses on investors' international arbitrage attempts following alleged breaches of the investor right from a sovereign state, and includes information on the investor raising the claim, the state concerned, and a brief summary of the matter of contention.

Weather and climate. We collect data on experienced weather from two sources. First, temperature data come from National Oceanic and Atmospheric Administration (NOAA)'s GHCN CAMS gridded temperature data (NOAA, 2024b), which provides monthly temperature at 0.5 degree resolution from 1948 onward. We obtain precipitation data from NOAA's Global Unified Gauge-Based Analysis of Daily Precipitation (NOAA, 2024a), which provide daily precipitation at 0.5 degree scale from 1979.

We aggregate both data to calendar year level, by computing the annual average temperature and the yearlong average of monthly accumulated precipitation. We weight each grid by its population density to remove the effects of sparsely inhabited grids, where the population data come from NASA's Gridded Population of the World v4.11 product (NASA, 2024). We use gridded population density as of year 2010.

In order to make the weather shock terms more comparable, and to account for regional differences in variability of weather, we normalize the annual temperature and precipitation by the individual country's climatological average and standard deviation. The climatological averages are taken over the period 1991-2020.

Macroeconomic variables. On top of the real GDP per capita and capital formation data, we collect from World Bank (World Bank Group, 2024) the data on population, foreign direct investment per capita, ratio of total foreign reserve to external debt (in %), ratio of international trade to GDP (%). The latter two variables are winsorized at 2.5th and 97.5th percentiles.

We also collect information on country-level government annual balance sheet from the International Monetary Fund's (IMF) Investment and Capital Stock Dataset (International Monetary Fund, 2022), which present the value of government-owned and private-owned capital stock and yearly investment in purchasing power parity (PPP) dollars.

Governance data. We obtain data on time-varying levels of governance and other institu-

tions' qualities at the country-year level, from the World Bank's Worldwide Governance Index (World Bank Group, 2025). We also use Polity V index (Marshall and Gurr, 2020), an index of democratic institutions, at the country-year level. Such variables are used in understanding the role of other institutions in moderating the effect of climate shocks on firm exposure to political risk.

3 Empirical strategy

We estimate the effect of climate shocks on firm's exposure to property-right violations through a panel fixed-effects model of PRI ratings and country-level annual weather. Previous studies on the effect of climate on violence have pointed to the possibilities of lagged effects from weather shocks (Burke et al., 2024). We capture such dynamic effects by including lagged values of the weather shocks. We also account for adaptation and state-dependence of the weather effects by allowing them to vary with the climatological average temperature and precipitation (Heutel et al., 2021; Auffhammer, 2022; Nath et al., 2024). Lastly, in light of the global coverage of our observations, we follow previous studies (e.g., Carleton et al., 2022) in interacting the weather variables with the country's average real GDP per capita levels over the sample period, hence allowing responses to weather shocks to vary with income. The preferred reduced-form equation of interest is thus:

$$\begin{aligned} y_{it} = & \sum_{l \in \{0,1\}} \beta_{1l} T_{i,t-l} + \gamma_{1l} T_{i,t-l} \bar{T}_i + \zeta_{1l} T_{i,t-l} \bar{Y}_i + \beta_{2l} P_{i,t-l} + \gamma_{2l} P_{i,t-l} \bar{P}_i + \zeta_{3l} P_{i,t-l} \bar{Y}_i \\ & + \alpha_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{1}$$

where y_{it} is a dummy of country i experiencing the PRI rating downgrade in year t, $\bar{T}_i$ and $\bar{P}_i$ the average temperature and precipitation over the years 1991-2020, $\bar{Y}_i$ the log of average real GDP per capita of country i, and $T_{i,t-l}$ and $P_{i,t-l}$ the temperature and precipitation of year $t-l$. α_i and δ_t capture country- and year-fixed characteristics, respectively. The error term ε_{it} is clustered at the country level to account for correlation of errors across time.

Notably, our preferred specification uses *locally* normalized T_{it} and P_{it} values using country-level average and standard deviation of T_{it} and P_{it} for years 1991 to 2020. While such normalization improves their across-country comparisons and allows the comparison of T_{it} coefficients with P_{it} coefficients, we test the robustness of our results to using raw

temperature and precipitation, in which case the coefficients would represent the effect of 1°C increase in annual temperature and 1cm increase in monthly precipitation (versus a standard deviation increase in temperature and precipitation in the original definition).

The model (1) identifies the effect of weather shocks on PRI rating downgrade using quasi-experimental variations in intertemporal weather (Deschênes and Greenstone, 2007). Under this model, the cumulative effect of a standard deviation increase in temperature on the probability of PRI rating downgrade, for country i, is:

$$\beta_{10} + \beta_{11} + (\gamma_{10} + \gamma_{11})\bar{T}_i + (\zeta_{10} + \zeta_{11})\bar{Y}_i \tag{2}$$

Our estimand of interest is (2) and its equivalent for precipitation, for different countries i. The coefficients β capture the cumulative effect of weather shocks, while γ and ζ coefficients measure the effect of adaptation and income in moderating climate shocks' effect on PRI rating downgrade probability. Standard errors are computed using the Delta method.

While our main outcome y_{it} is obtained from Credendo's risk rating data, we also test whether similar effects of climate and income are observed for the occurrence of actual investment disputes involving government expropriation. We also gather indirect evidence by assessing whether climate shocks are associated with sudden growths in government-owned capital stock, conditional on the general economy's growth patterns.

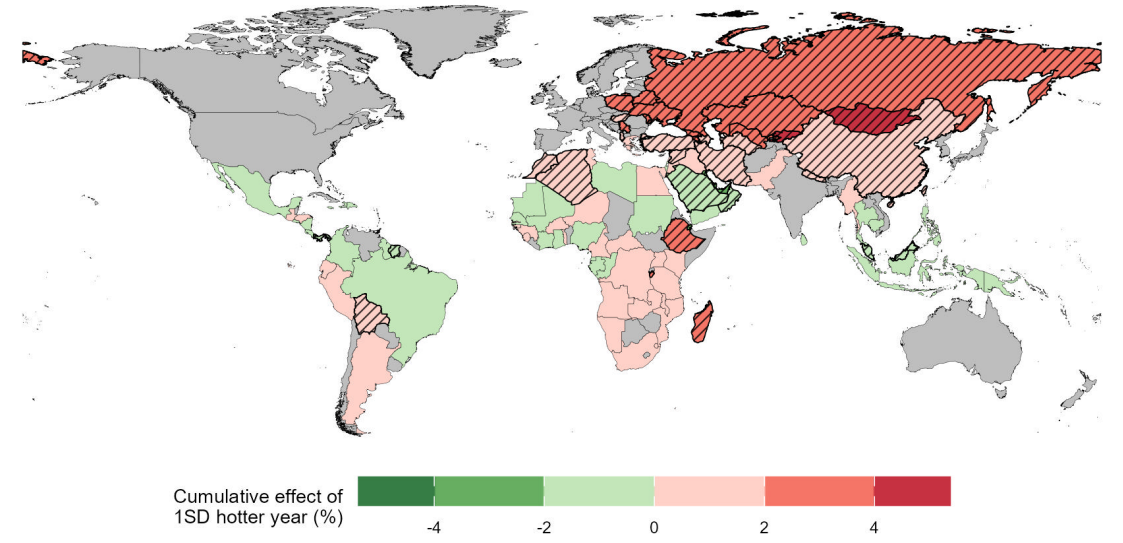
Finally, we evaluate potential mechanisms that drive the climate shocks' effects by inspecting the role of democratic institutions and anti-corruption institutions. We take the country-level average of the indexes pertaining to such institutions and divide the sample into two groups using the median of the country-level averages.

4 Results

4.1 Main results

Figure 2a present the estimates of cumulative effects of temperature, from the panel OLS model (1), with dummy variable of "experienced PRI risk rating downgrade" as the outcome. Positive marginal effects (i.e., *increases* in the risk of rating downgrade) are shown in red, versus green for negative estimates (*decreases* in downgrade probability). Countries with estimates significant at 95% level are shown with hatches. We do not show the marginal estimates for countries that did not experience any downgrades, and hence

(a) Marginal effect of temperature



(b) Heterogeneity with average temperature

(c) Heterogeneity with income

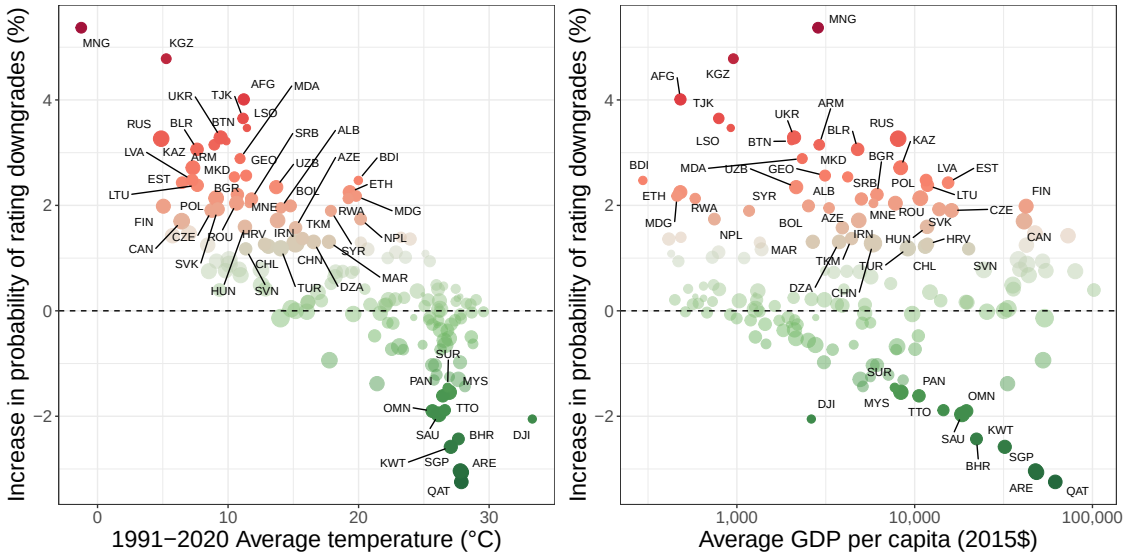


Figure 2. Temperature and political risk

Notes: Figure shows the effect of temperature shocks on country-level political risk insurance rating downgrade (equation (2)). Figure 3a plots the marginal effects, with increases (decreases) in downgrade probability from warmer weather shown in red (green). Countries with statistically significant marginals (at 95% level) shown in hatched fill, while countries that did not experience any downgrades are shown in grey. Figure 2b plots the marginals against the countries' climatological average temperature, while Figure 2b does the same but for average GDP per capita over the sample period (log-scaled). Three-character ISO codes for countries only shown when their marginals are statistically significant. Larger and darker dots mean larger gross GDP and higher significance.

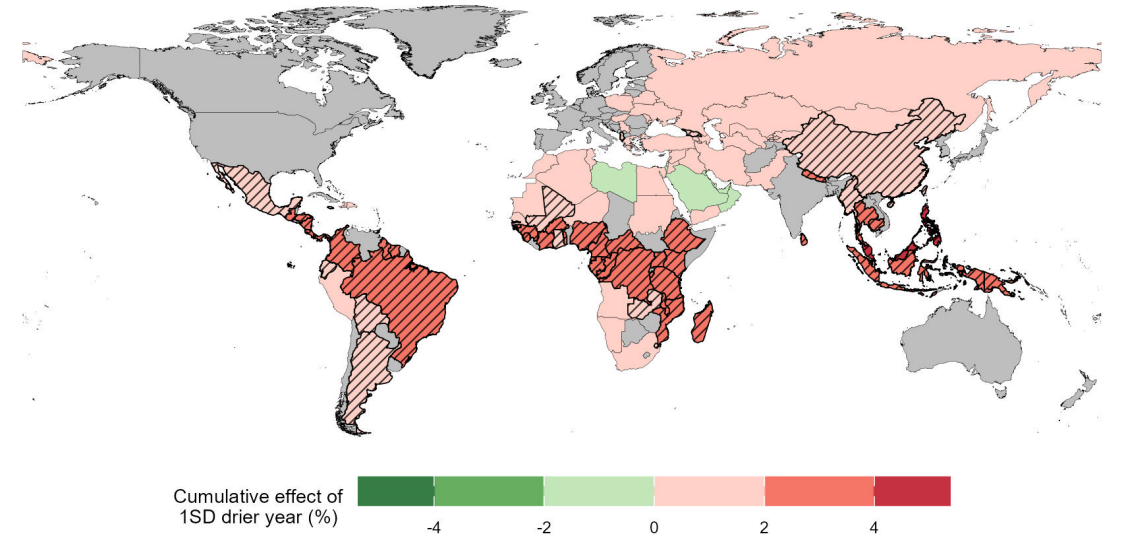
did not have their variations included in the estimation of the coefficients.

The results suggest that it is the countries that are in colder climates, such as Mongolia (MNG) and Russia (RUS), that are more vulnerable to anomalously hot weather. This is highlighted in Figure 2b, which plot the marginal effects against the country's average temperature. There is, however, a strong heterogeneity in the marginal effects within countries with similar average temperature. Figure 2c suggests that this heterogeneity is driven by income per capita, where developing countries are more vulnerable to warm anomalies; even relatively hot-climate countries, such as Ethiopia (ETH), still have statistically significant positive effects from warm weather. In general, the statistically significant estimates are largely negative, and are positive only in hot, high-income countries such as Saudi Arabia (SAU). The size of the marginal effects are economically significant, in that the average probability of downgrade for a country-year is 5%.

Figure 3 presents the results for precipitation shocks, where we show the results of a one standard deviation *drier* weather (i.e., inverse of the marginal (2)). Contrary to temperature, it is the countries with *wetter* climate that are more vulnerable to droughts (Figure 3b), with exceptionally dry countries (e.g., central Asian countries) showing statistically insignificant effects, versus wet countries such as Philippines (PHL) and Malaysia (MSY) predicting increases in rating downgrade probability from droughts. Further, low-income countries show stronger responses to droughts (Figure 3c), although the income-associated heterogeneity is less salient than in temperature. All statistically significant marginal estimates are *positive* (increasing downgrade risk). The effect of droughts in sub-Saharan Africa are consistent with prior climate-conflict studies that point to the importance of precipitation in violent conflicts and institutional breakdowns in the region (McGuirk and Nunn, 2025; Eberle et al., 2025).

Taken together, the results suggest the importance of adaptation, as droughts and hot weathers are more detrimental to countries that are wetter and colder in climate. Importantly, while the experience of on-site investor corporations and regional experts' evaluations factor into Credendo's rating evaluations, climate shocks *per se* are not part of the input variables–suggesting that the results identified here are not artifacts of Credendo's rating policy. We now present additional results that confirm similar trends in a separate data set and provide important insights on the role of dynamics.

(a) Marginal effect of precipitation



(b) Heterogeneity with average precipitation

(c) Heterogeneity with income

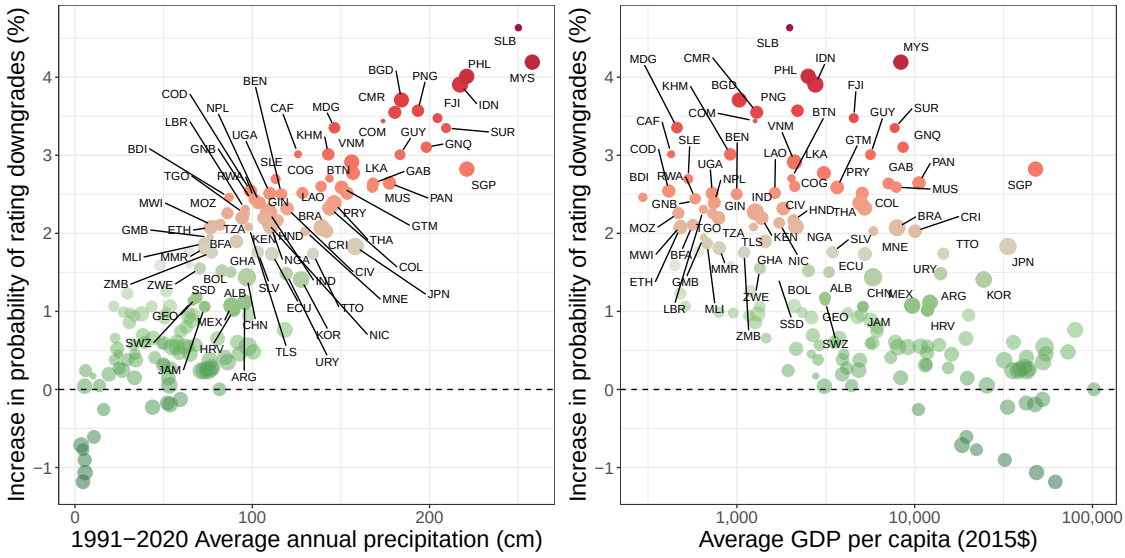


Figure 3. Precipitation and political risk

Notes: Figure shows the effect of drought on the probability of country-level political risk insurance rating downgrade. Visualization of panels (a), (b), and (c) identical to that of Figure 2.

4.2 Additional results

While our main outcome of interest relies on Credendo's country-level ratings, Figure 4 identifies similar patterns in the role of climate shocks in *realized* outcomes. Figure 4a refers to Investor-State Dispute Settlement (IDSDS) cases, where investors engage their

host country in an international arbitrage process for an alleged breach of their investment rights. In particular, we focus on the existence of newly initiated cases where the arbitrators mention "expropriation" in their settlement rulings for each country-year. Figure 4a plots the country-level marginals from fitting this outcome in the model (1). While the difficulty in pinpointing the exact date of results are less precise the trend of lower average temperature and low income being associated with higher vulnerability to temperature shocks.

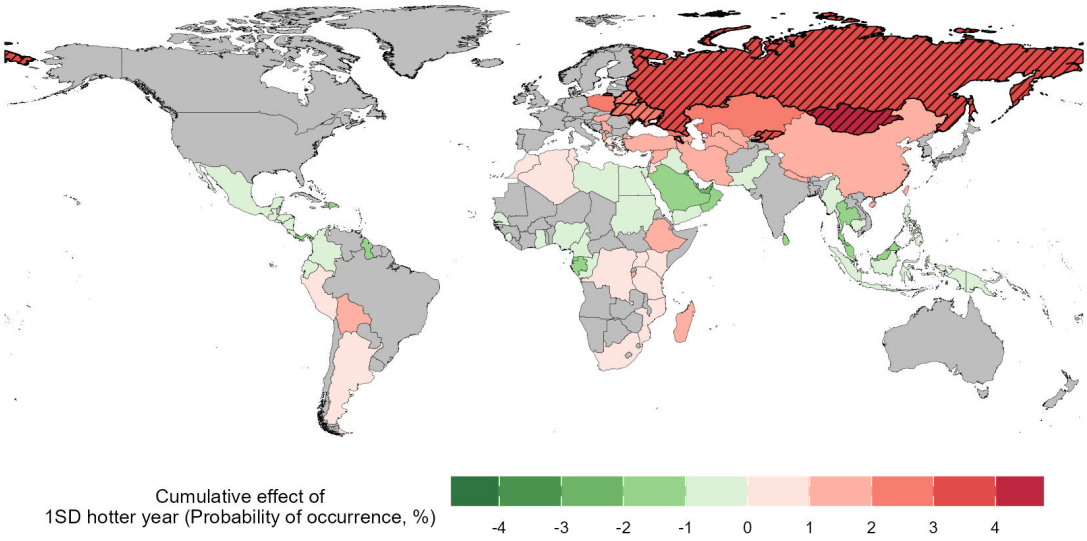
A more indirect way to identify the occurrence of expropriation is through sharp increases in government-owned capital stock. Using data from the IMF Investment and Capital Stock Dataset, Figure 4b estimates the effect of warm weather on the *growth* of government capital stock. We control for growth rates of GDP per capita and private capital stock, in light of the effect of temperature on economic productivity (Burke et al., 2015). The results once again suggest that government capital stock follows the pattern in Figure 2a. A separate regression that uses the *share* of government capital stock over total capital stock also finds a similar pattern (Appendix Figure B12). In contrast, the effects of precipitation shocks are less precise and statistically insignificant (Appendix Figures B13 to B12).

To be clear, the impact of climate on expropriation risk, does *not* have to be materialized for it to affect investor incentives and hamper economic growth; a mere increase in the *expected* probability of expropriation suffices (Eaton and Gersovitz, 1984). This investor belief in expropriation risk is what the PRI risk rating captures. Nevertheless, the results in Figure 4 do suggest that the effect of temperature shocks are also observed in macroeconomic outcomes and in investor actions against sovereign states.

We now return to Credendo risk rating to explore the role of lagged effects in our results. To this end, we estimate a new model after dropping the lagged terms ($l = 1$ terms) on the right-hand side of (1). Under "harvesting" effects where weather shocks simply triggers a downgrade that would have occurred anyway, the more parsimonious model would lead to *larger* estimates (Hsiang, 2016). The results, shown in Appendix Figures B15 and B16, are smaller in size–pointing to the absence of strong harvesting effects. The lagged terms are particularly large in size for precipitation marginals, pointing to the importance of lagged effects in drought effects.

Lastly, while we have been focused on Credendo's expropriation risk rating downgrades, we assess whether political violence ratings, which evaluate risk of war and terrorism, are also affected by weather shocks. Appendix Figures B17 and B18 suggest that warm weather and droughts do have adverse effects on risks of political violence,

(a) Occurrence of expropriation cases



(b) Growth in government-owned capital

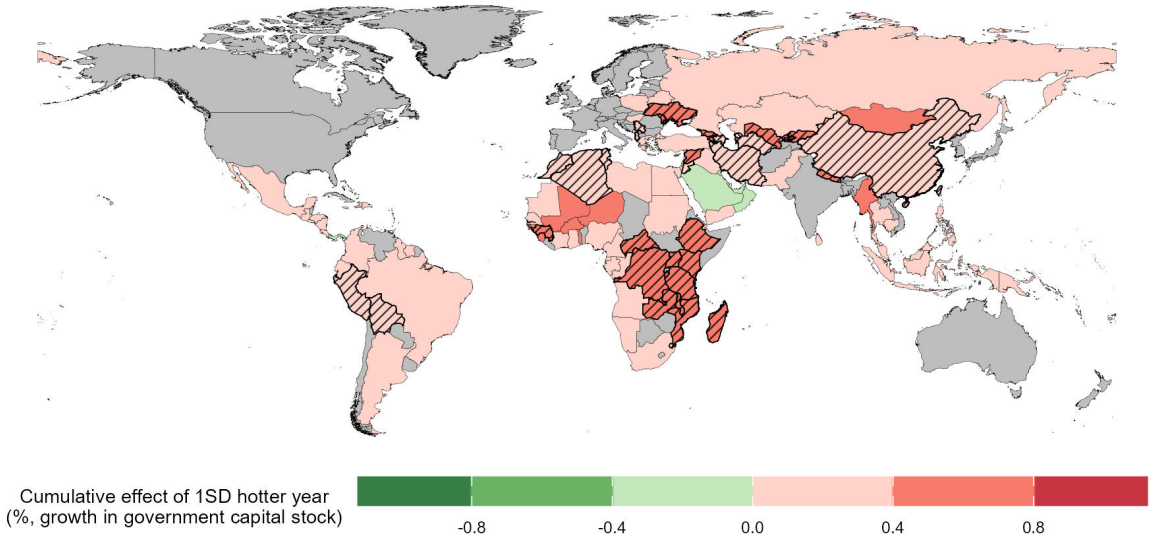


Figure 4. Temperature, realized expropriation cases, and government-owned capital

Notes: Figure shows the effect of temperature on proxies of *realized* expropriation. Figure 4a uses the number of investor-state dispute cases involving government expropriation, and Figure 4b focuses on % growth in government capital, controlling for growth in GDP per capita and in private capital. Countries without investor-state dispute cases shown in grey for Figure 4a.

particularly in countries with *drier* climate and low income. Such results are consistent with the climate-conflict literature (Burke et al., 2024).

5 Mechanisms

5.1 A stylized model of government expropriation

What drives the effect of climate shocks on property-right institutions? To answer this question, we present a stylized model of state-led expropriation consisting of a unitary expropriating agent ("government") and multiple investors. Crucially, while we consider a dynamic game with investors and governments (Besley and Ghatak, 2010), we allow uncertainty in the investors' *beliefs* in the probability of expropriation, which are in turn updated following actual expropriation using Bayes' rule. We also assume that investors are risk-averse, in light of their involvement in the PRI market.

We assess the comparative statics of the equilibrium probability of expropriation, with respect to shocks to the investment return (i.e., productivity). We present the model set-up and main empirical predictions here, while the full model, derivations, and extensions can be found in the Appendix.

5.1.1 Model environment and timing

The model consists of three time steps. At time 0, the N symmetric and non-cooperating investors are endowed with a capital of k_0. The investors have an exponential utility function $u(x) = 1 - \exp(-\lambda x)$, where λ is the risk aversion coefficient and x the (expected) profit. The capital stock follows the standard law of motion $k_{t+1} = (1-\delta)k_t + i_{t+1}$, where δ is the depreciation rate and i_{t+1} the investment to the future capital stock. The investors possess a risk-free asset with a known return r_f. At each time period, the investors allocate a fixed cash flow of CF to either the risk-free asset, with return r_f, or the investment to capital i_1. The production technology is linear in capital, $y_t = Ak_t, t \in \{0, 1, 2\}$.

At period 0, the investors hold a prior belief on the probability of expropriation, $p_0 \overset{\text{iid}}{\sim} \text{Beta}(\kappa\tau_0, \kappa(1-\tau_0))$. As $\mathbb{E}[p_0] = \tau_0$, the investors set the capital for period 1, k_1, to maximize their expected utility conditional on τ, A, and r_f. That is, the investors at time 0 maximize

$$(1-\tau_0)u\left(Ak_1 + (CF_0 - (k_1 - (1-\delta)k_0))r_f\right) + \tau_0 u\left((CF_0 - (k_1 - (1-\delta)k_0))r_f\right) \tag{3}$$

where the first term refers to the expected utility under non-expropriation, and the second term under expropriation.

At time 1, the government chooses the actual probability of expropriation, τ_1. For

simplicity, we assume that the all N investors are applied the same risk of expropriation (no preferential treatment). This leads the investors to update their beliefs, with posterior $p_1 \overset{\text{iid}}{\sim} \text{Beta}\left(\kappa\tau_0 + N\tau_1, \kappa(1-\tau_0) + N(1-\tau_1)\right)$, with $\mathbb{E}[p_1] = \frac{\kappa}{\kappa+N}\tau_0 + \frac{N}{\kappa+N}\tau_1$. The posterior in turn shapes the investors' investment for period 2, i_2.

The government sets the τ_1 in a forward-looking manner, in that it maximizes a weighted sum of expropriation rent from period 1 and the investor's expected profit from period 2. The optimal τ_1 hence maximizes the following:

$$N\tau_1 A k_1^*(p_0) + \alpha N\left[(1 - \mathbb{E}[p_1(\tau_1; p_0)])Ak_2^*(p_1(\tau_1; p_0))\right] \tag{4}$$

where $k_1^*(p_0)$ is the investors' optimal capital given their prior p_0, and $k_2^*(p_1)$ the optimal investment for period 2 given the posterior p_1. The term α captures the extent to which the government measures the importance of the investors' future profit, and is required to avoid total expropriation in period 1 (i.e., $\tau_1 = 1$). We follow Besley and Ghatak (2010) to conceptualize α as a metric of "voice," with larger α meaning stronger representation of asset holders in the decisions of the government.

A larger κ term meaning smaller influence of the one-off realization of expropriation risk, τ_1, on investor belief–corresponding to the realization of the expropriation risk being "noisy"[4]. Put differently, the κ is larger when the investor perceives a large variability in the realized κ values, corresponding to weak executive constraint.

Lastly, we require a set of assumptions to ensure that the model is well-behaved:

Assumption 1. For $\tau \in \{\tau_0, \tau_1\}$, $\tau r_f < (1-\tau)(A - r_f)$.

Essentially, this assumption requires that the risk of expropriation is enough to justify a holding of non-zero capital stock in the economy–hence guaranteeing interior solution. The next assumption pertains to the α coefficient:

Assumption 2. For the objective function of the government (4), $0 < \alpha < 1$.

The assumption requires that the government prioritizes its expropriation rent over future investment returns.

[4]This is equivalent to the normal-normal conjugate prior, where the weight given to the sample mean of the observed values, with known variance, is smaller when the data (with known variance) are noisy.

5.1.2 Empirical predictions

The above setting provides a set of empirical predictions. We start with the partial equilibrium of the investor's optimal investment, given their belief p:

Proposition 1 (Investment decreases with perceived expropriation risk)**.** Under assumption 1, the optimal future capital given investor belief p is a decreasing function of $\mathbb{E}[p]$:

$$\frac{\partial k^*_{t+1}}{\partial \mathbb{E}[p_t]} < 0$$

The proof can be found in the Appendix. The result is in line with the effect of expropriation risk rating downgrade on macroeconomic outcomes (Figure 1b), and confirms the effect of expropriation, as in line with traditional theoretical studies on the impact of expropriation risk (Eaton and Gersovitz, 1984; Besley and Ghatak, 2010).

Further, the model suggests that the optimal probability of expropriation, τ_1, *increases* under higher productivity A:

Proposition 2 (Positive productivity shocks increase expropriation risk)**.** Under assumptions 1 and 2, the investor-expected probability of expropriation, $\mathbb{E}[p_1]$, satisfies

$$\frac{\partial \mathbb{E}[p_1(\tau^*_1; \tau_0)]}{\partial A} > 0$$

where τ^*_1 is the optimal actual expropriation risk rate that maximizes (4).

The results imply that the expected probability of expropriation following the actual expropriation would also increase with positive productivity shock–potentially explaining the temperature and precipitation effects on perceived risk of expropriation (Figures 2 and 3). We can also derive the following second-order comparative statics for productivity-induced expropriation risk increases:

Proposition 3 (Drivers of heterogeneous effects of productivity shocks)**.** Under assumptions 1 and 2, the parameters have the following second-order comparative statics:

$$\frac{\partial}{\partial \alpha}\left(\frac{\partial \mathbb{E}[p_1(\tau^*_1; \tau_0)]}{\partial A}\right) < 0, \frac{\partial}{\partial N}\left(\frac{\partial \mathbb{E}[p_1(\tau^*_1; \tau_0)]}{\partial A}\right) < 0, \frac{\partial}{\partial \kappa}\left(\frac{\partial \mathbb{E}[p_1(\tau^*_1; \tau_0)]}{\partial A}\right) > 0$$

Put differently, a stronger voice (higher α) and the existence of more investors (larger N) dampen the malicious effects of positive productivity shocks. A weaker executive

constraint (larger κ) amplify the effect of positive productivity shocks. Note that contrary to previous theoretical literature, such productivity shocks–and their second-order comparative statics–are on investor *beliefs* of expropriation risk.

While Propositions 2 and 3 focus on the effect of productivity shocks and their heterogeneity, changes in α, N, and κ themselves can lead to changes in equilibrium:

Proposition 4 (Voice, executive constraint, and investor-perceived risk)**.** Under Assumption 1, the following stands:

$$\frac{\partial \mathbb{E}[p_1(\tau_1^*; \tau_0)]}{\partial \alpha} < 0, \frac{\partial \mathbb{E}[p_1(\tau_1^*; \tau_0)]}{\partial \kappa} > 0, \frac{\partial \mathbb{E}[p_1(\tau_1^*; \tau_0)]}{\partial N} < 0$$

That is, stronger voice and increase in the number of investors (larger α and N) reduce the equilibrium perceived expropriation risk, while weaker executive constraint increases perceived risk. Proposition 4 hence suggests that other than its impact as moderators of productivity shock effect, changes in political institutions themselves could be mediators of climate shocks.

5.1.3 Model extensions

We briefly explore natural extensions of the model discussed above. First, the above set-up treats the prior expected risk $\bar{\tau}$ is a parameter. One can relax this assumption and instead endogenize the $\bar{\tau}$ by assuming $\mathbb{E}[p_0] = \tau_1$ at equilibrium. The assumption, which assumes that the prior beliefs will be accurate in expectation, substantially simplifies the first-order conditions (see Appendix). The comparative statics still remain the same under this assumption.

Further, the main model does not accommodate uncertainty in the productivity A. One can naturally introduce such uncertainty by defining expected productivity $\mathbb{E}[A] = \hat{A}$. Then, k_1 becomes a function of the parameters and $\hat{A}$, while government in time 1 will use the *ex post* revealed productivity, A_1, in the first term of (4). The comparative statics will stand with respect to variations in the expected productivity $\hat{A}$.

The α term above is a reduced-form parameter that captures the weight assigned to the investors' expected one-time returns. Nevertheless, the term can be naturally extended to include *future* returns, with the α transformed into $\frac{\alpha}{1-\beta}$ and β being the government's discount rate.

5.2 Empirical analysis of potential mechanisms

We build on the theoretical analysis above to evaluate several potential mechanisms of climate shock's effect on PRI risk ratings. In doing so, we distinguish "mediators" from "moderators," where the former refers to variables that are directly affected by climate shocks and subsequently affect the PRI ratings, versus the latter being a factor that amplifies or dampens the effect of climate shocks (Burke et al., 2024). Propositions 2 and 4 suggest that productivity shocks and democratic institutions could be potential mediators of the PRI rating-climate shock relationship, while Proposition 3 suggest that democratic institutions could be moderators of the productivity-induced shocks.

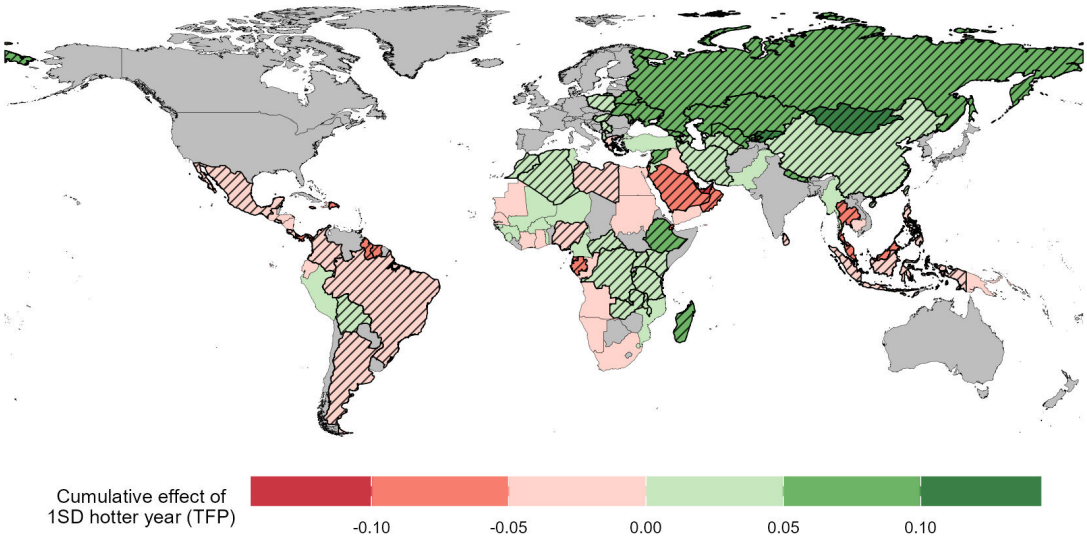
5.2.1 Potential mediators

To assess the role of productivity shocks as the mediator (Proposition 2), we regress total factor productivity (TFP) estimates, from Penn World Table (PWT), against the right-hand side variables in equation (1). The results, shown in Figure 5a, suggest that it is precisely the countries with higher probability of downgrade following warm weather (red fill in Figure 2a) that benefit from the same climate shock (green fill in Figure 5a). We find strong evidence of similar productivity effects for food production (Figure 5b), where we focus on the log of Food Production Index, from FAO (2024), as the outcome variable. The estimates are much noisier for precipitation shocks (Appendix Figure B19).

Further, motivated by Proposition 4, we assess whether temperature shocks are followed by changes in indexes of democratic institutions. Appendix Figures B20 and B21 estimate the model (1) for changes in Polity V index, with increases in the index representing an improvement in democratic institutions. We fail to find significant effects supporting climate-induced changes in democratic institutions. Appendix Figures B22 and B23 find conflicting and economically insignificant effects of temperature and precipitation shocks on Worldwide Governance Indicator's (WGI) "Control of Corruption" index, which measure the extent to which "public power is exercised for private gain (World Bank Group, 2025)." We use the control of corruption as a proxy for the executive constraint (κ in our model).

To summarize, we find strong evidence suggesting that warm temperature shocks are associated with strong increases in productivity in cold-climate countries, while the effects are muted for changes in democratic institutions and executive constraint. Such findings indirectly suggest that it is the *positive* productivity shock channel (Proposition 2), rather

(a) Total factor productivity



(b) log(Food production index)

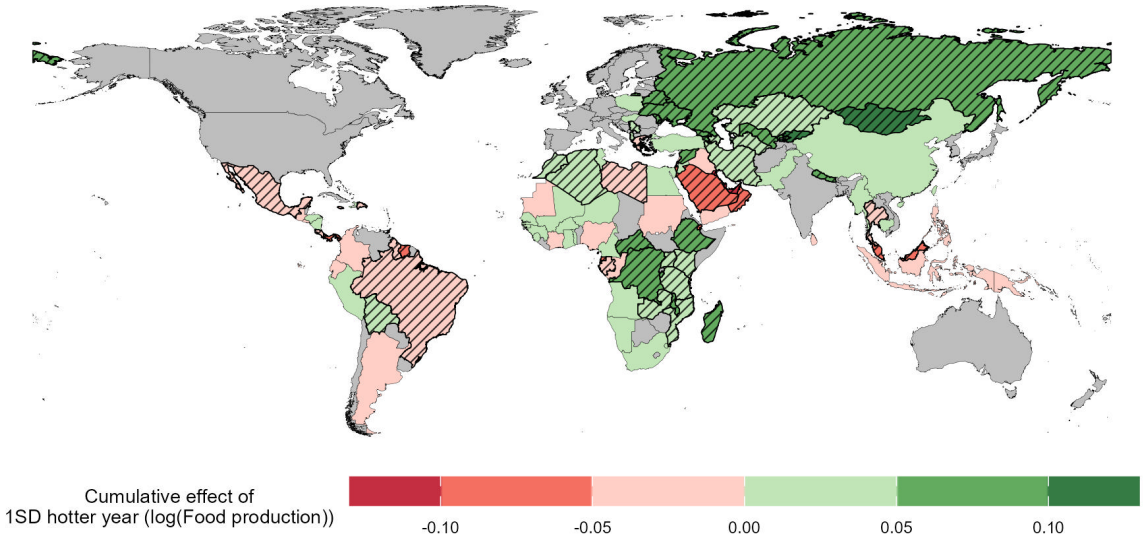
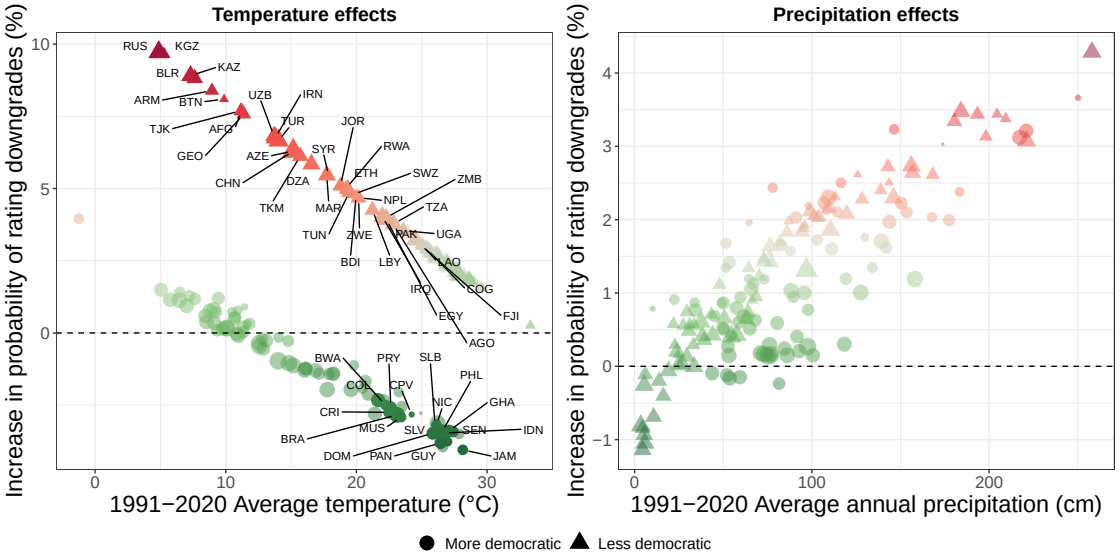


Figure 5. Productivity shock as potential mediator of temperature shock effects

Notes: Figure explores the potential role of productivity shocks as *mediators* of the relationship between PRI rating downgrades and temperature shocks. Figure 5a estimates the model (1) with TFP estimates from the Penn World Table as the outcome, while Figure 5b uses log of per capita Food Production Index (FAO, 2024), with the index set to 100 for the 2014–2016 average food production quantity.

than changes in other aspects of the institution (Proposition 4), that potentially explain the climate shock effects.

(a) Democratic institutions



(b) Corruption

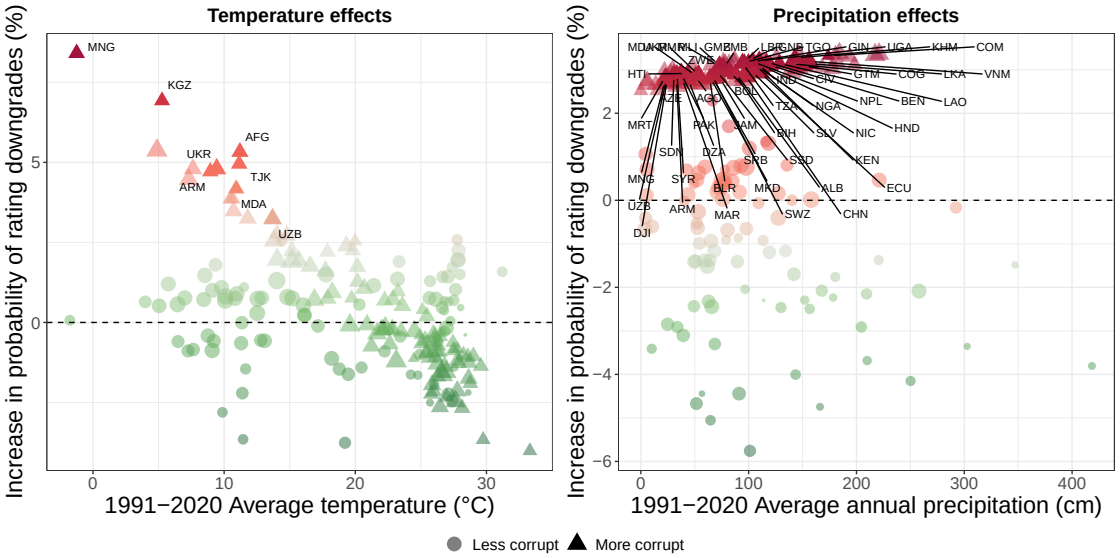


Figure 6. Heterogeneous responses to climate shocks from subsample analyses

Notes: Figure explores potential mechanisms driving the results by dividing the countries in the sample into two groups, using the averages of indexes representing the quality of their democratic institutions and anti-corruption institutions. We use Polity V index for the former, and World Bank's Worldwide Governance Index for the latter. Figures on the panel show the temperature marginals (1SD hotter year), versus precipitation marginals (1SD drier year) for the right panel. ISO codes are shown for countries with statistically significant marginals. Points' shape represent the subsample that they belong to.

5.2.2 Potential moderators

While the previous analysis fail to find evidence that democratic institutions and executive constraint likely *mediate* changes in PRI ratings, such aspects of the political institution can still function as *moderators* of productivity shock's effects (Proposition 3). We hence divide the *countries* into two subsamples based on the within-sample average of the Polity V and WGI Control of Corruption indexes, and assign the observations belonging to each country to the two subsamples. We then estimate the regression (1) for the two subsamples and plot the marginal effect of climate shocks.

Figure 6a presents the results for the subsample regressions using country-average Polity V index. The temperature marginals (left panel) strongly suggest that the less democratic countries, in triangesl, have a significantly larger marginal effect (i.e., more likely to experience downgrades) than their more democratic counterparts with similar climate conditions, in circle. In fact, none of the more democratic countries have a statistically significant positive marginal. The general pattern of colder-climate countries being more prone for downgrades faced with warm weather remains for both subgroups.

In contrast, the right panel of Figure 6a, which shows the precipitation marginals, suggests that the two groups do not differ in their responses to droughts. The marginals are largely just a function of average precipitation levels, with the triangle and circle points largely overlapping.

The two panels of Figure 6b repeat the exercise, but using the WGI "control of corruption" index. The results suggest that while temperature effects' heterogeneity are not strongly driven by temperature, the drought effects are substantially larger and almost exclusively focused on more corrupt countries–to the extent that there is no overlap in the distribution of less- and more-corrupt countries.

Taken together, the results highlight the interaction between democratic institutions, anti-corruption institutions, and property-right institutions as captured by PRI expropriation risk rating. We leave the establishment of causal link between democratic institutions and resilience to climate shocks for future studies.

6 Conclusion

Combining novel global panel data set of PRI risk ratings, gridded weather data set, and other macroeconomic outcomes, we find that countries in colder and wetter climates are

particularly likely to have their risk rating downgraded following hotter- and drier-than-average climate conditions. Such results also follow through for actual expropriation cases and in the sudden accumulation of government capital. We identify democratic institutions as a potential driver of the effects that we observe throughout the analysis.

Future studies could potentially aim to link the firm-level expropriation records, as presented in Arel-Bundock et al. (2020), with firm-level balance sheet results. Additional studies that highlight the flow of exogenous gains from weather shocks to actual government capital would also be very useful.

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Appendix

A Theoretical model and proofs

This section lays out the model of government expropriation, introduced in Section 5. We briefly recall the model set-up:

Definition A.1 (Investor beliefs and objective function)**.** There are N symmetric investors that share the prior belief on the probability of expropriation $p_0 \sim \text{Beta}(\kappa\tau_0, \kappa(1-\tau_0))$. The investors, subject to the law of motion $k_{t+1} = (1-\delta)k_t + i_{t+1}$, set their future investment i_{t+1} to maximize the expected returns subject to a linear production technology:

$$(1-\tau_0)u\left(Ak_1 + (CF_0 - (k_1 - (1-\delta)k_0))r_f\right) + \tau_0 u\left((CF_0 - (k_1 - (1-\delta)k_0))r_f\right)$$

Following the government's realization of expropriation probability in time 1, τ_1, the investors update their beliefs to form a posterior $p_1 \overset{\text{iid}}{\sim} \text{Beta}\left(\kappa\tau_0 + N\tau_1, \kappa(1-\tau_0) + N(1-\tau_1)\right)$. The felicity function $u(x)$ is

$$u(x) = 1 - \exp(-\lambda x)$$

Definition A.2 (Government objective function)**.** There is a unitary expropriating agent ("government") that chooses τ_1 to maximize the following:

$$N\tau_1 A k_1^*(p_0) + \alpha N\left[(1 - \mathbb{E}[p_1(\tau_1; p_0)])Ak_2^*(p_1(\tau_1; p_0))\right]$$

A.1 Proof of main results

We start with a partial equilibrium for the investor:

Theorem A.1 (Optimal investment given belief)**.** Consider an arbitrary investor with belief p for future expropriation probability. Under Assumption 1, the investors' optimal future capital is

$$k_{t+1}^*(p_t) = \frac{1}{\lambda A}\log\left(\frac{1-\mathbb{E}[p_t]}{\mathbb{E}[p]}\frac{A - r_f}{r_f}\right)$$

When Assumption 1 is violated $k_{t+1}^* = 0$.

Proof. This is a simple result of solving the unconstrained optimization, defined in Definition A.1. □

Note that the above statement applies for all p, for beliefs at any time. This directly proves Proposition 1:

Corollary A.1.1 (Proof of Proposition 1)**.** See that

$$\frac{\partial k^*_{t+1}}{\partial \mathbb{E}[p]} = -\left(\frac{1}{1-\mathbb{E}[p]} + \frac{1}{\mathbb{E}[p]}\right) < 0$$

We now move onto the Propositions regarding the optimal expropriation probability, τ_1^*. We first present a Lemma:

Lemma A.2 (FOC with respect to τ_1)**.** Given Bayesian investors in Definition A.1 with $\mathbb{E}[p_0] = \tau_0$ and the objective function in Definition A.2, the optimal τ_1^* satisfies

$$\log\left(\frac{1-\tau_0}{\tau_0}\frac{A-r_f}{r_f}\right) - \alpha\frac{N}{\kappa+N}\left[\log\left(\frac{A-r_f}{r_f}\frac{1-\mathbb{E}[p_1(\tau_1^*;p_0)]}{\mathbb{E}[p_1(\tau_1^*;p_0)]}\right) + \frac{1}{\mathbb{E}[p_1(\tau_1^*;p_0)]}\right] = 0 \quad \text{(A1)}$$

where $\mathbb{E}[p_1(\tau_1;p_0))] = \frac{\kappa}{\kappa+N}\mathbb{E}[p_0] + \frac{N}{\kappa+N}\tau_1 = \frac{\kappa}{\kappa+N}\tau_0 + \frac{N}{\kappa+N}\tau_1$.

Proof. Note first that the objective function of the government is, dropping the N terms and using the optimal investment in Theorem A.1,

$$\begin{aligned}
&\tau_1 A k^*_{t+1}(p_0) + \alpha\left(1 - \frac{\kappa}{\kappa+N}\tau_0 - \frac{N}{\kappa+N}\tau_1\right) \times A k_2^*(p_1(\tau_1;p_0)) \\
&= \tau_1 \frac{1}{\lambda}\log\left(\frac{1-\tau_0}{\tau_0}\frac{A-r_f}{r_f}\right) + \alpha\left(1 - \frac{\kappa}{\kappa+N}\tau_0 - \frac{N}{\kappa+N}\tau_1\right) \times \left(A\frac{1}{\lambda A}\log\left(\frac{A-r_f}{r_f}\frac{1-\frac{\kappa}{\kappa+N}\tau_0 - \frac{N}{\kappa+N}\tau_1}{\frac{\kappa}{\kappa+N}\tau_0 + \frac{N}{\kappa+N}\tau_1}\right)\right)
\end{aligned}$$

Taking the derivative of this equation with respect to τ_1 and dropping λ yields the FOC:

$$\log\left(\frac{1-\tau_0}{\tau_0}\frac{A-r_f}{r_f}\right) - \alpha\frac{N}{\kappa+N}\log\left(\frac{A-r_f}{r_f}\frac{1-\frac{\kappa}{\kappa+N}\tau_0 - \frac{N}{\kappa+N}\tau_1^*}{\frac{\kappa}{\kappa+N}\tau_0 + \frac{N}{\kappa+N}\tau_1^*}\right) - \alpha\frac{\frac{N}{\kappa+N}}{\frac{\kappa}{\kappa+N}\tau_0 + \frac{N}{\kappa+N}\tau_1^*} = 0$$

Using the definition of $\mathbb{E}[p_1(\tau_1;p_0)]$, we get

$$\log\left(\frac{1-\tau_0}{\tau_0}\frac{A-r_f}{r_f}\right) = \alpha\frac{N}{\kappa+N}\log\left(\frac{A-r_f}{r_f}\frac{1-\mathbb{E}[p_1(\tau_1^*;p_0)]}{\mathbb{E}[p_1(\tau_1^*;p_0)]}\right) + \alpha\frac{\frac{N}{\kappa+N}}{\mathbb{E}[p_1(\tau_1^*;p_0)]}$$

Cleaning up terms lead to the result above. □

The proof of Proposition 2 is the result of Implicit Function Theorem:

Theorem A.3 (Proof of Proposition 2)**.** Let us define the first-order condition in Lemma A.2 as $F(\tau_1, A, \cdots) = 0$. Then, the following stands under Assumptions 1 and 2:

$$\frac{\partial F}{\partial A} > 0, \frac{\partial F}{\partial \mathbb{E}[p_1(\tau_1^*; p_0)]} > 0$$

Under implicit function theorem

$$\frac{\partial \mathbb{E}[p_1(\tau_1^*; p_0)]}{\partial A} < 0$$

Proof. See first that

$$\frac{\partial F}{\partial A} = \frac{r_f}{(A - r_f)r_f} - \alpha \frac{N}{\kappa + N} \frac{r_f}{(A - r_f)r_f} = \frac{1 - \alpha \frac{N}{\kappa + N}}{A - r_f}$$

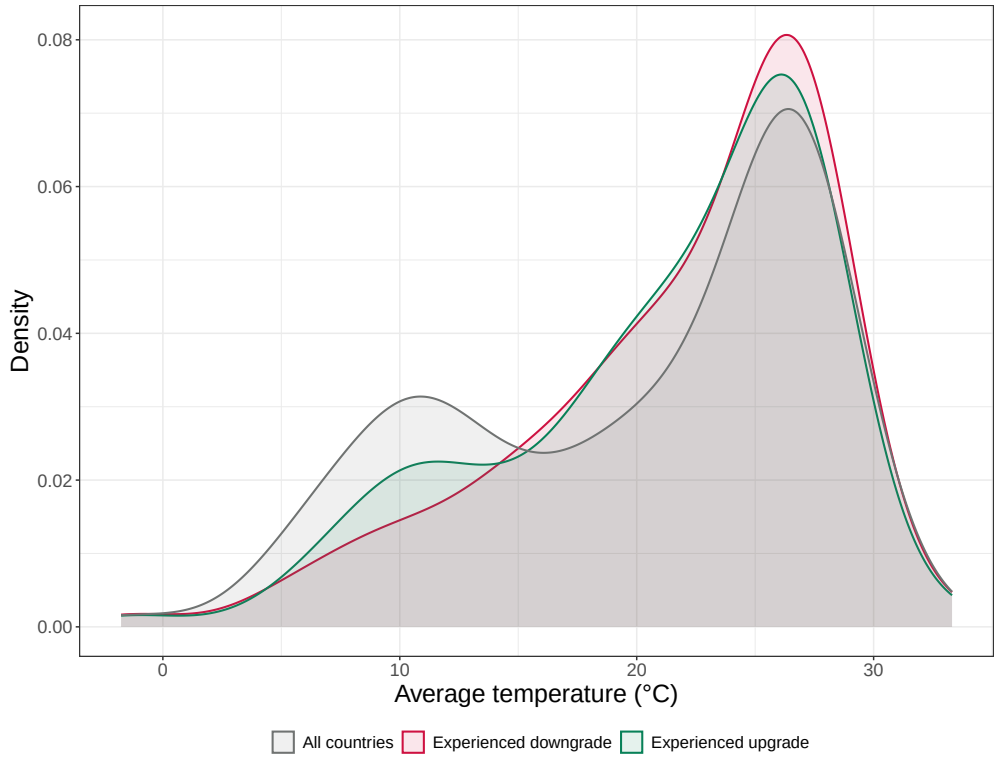
as $\alpha < 1$ by assumption and $\frac{N}{\kappa+N} < 1$, we have $\frac{\partial F}{\partial A} > 0$. Further,

$$\begin{aligned}\frac{\partial F}{\partial \mathbb{E}[p_1(\tau_1^*; p_0)]} &= -\alpha \frac{N}{\kappa + N} \left(- \frac{1}{(1 - \mathbb{E}[p_1(\tau_1^*; p_0)])\, \mathbb{E}[p_1(\tau_1^*; p_0)]} \right) + \alpha \frac{N}{\kappa + N} \frac{1}{\mathbb{E}[p_1(\tau_1^*; p_0)]^2} \\ &= \alpha \frac{N}{\kappa + N} \frac{1}{\mathbb{E}[p_1(\tau_1^*; p_0)]^2 (1 - \mathbb{E}[p_1(\tau_1^*; p_0)])}\end{aligned}$$

Again, $\alpha < 1$ assumption, combined with $\mathbb{E}[p_1(\tau_1^*; p_0)] < 1$ and $\frac{N}{\kappa+N} < 1$, yields $\frac{\partial F}{\partial \mathbb{E}[p_1(\tau_1^*; p_0)]} > 0$. □

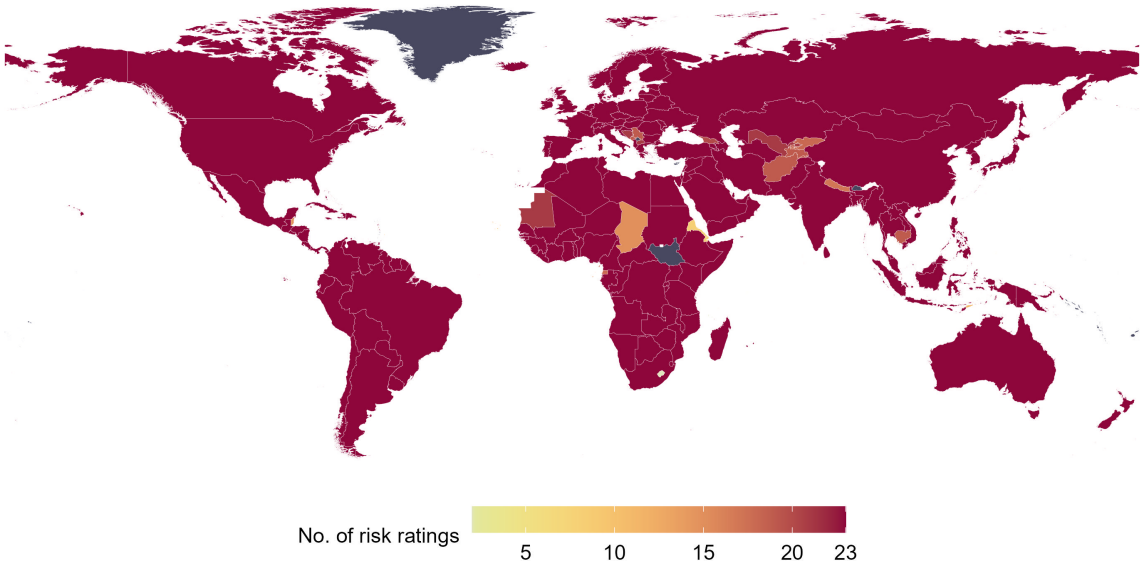
A.2 Model extensions

B Additional Tables and Figures



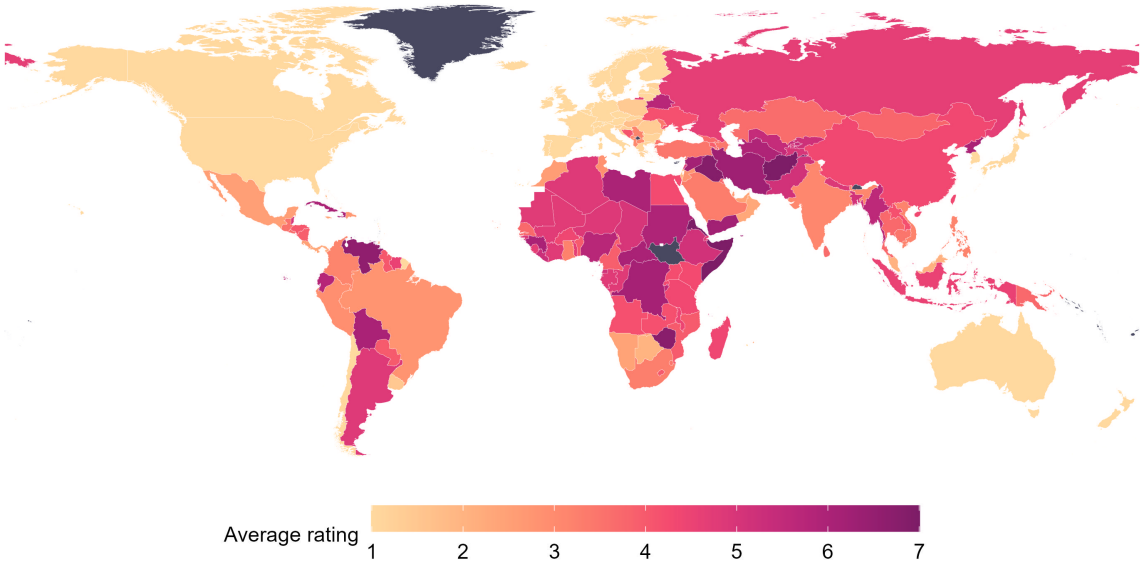
Appendix Figure B1. Distribution of average temperature and experience of rating shifts

Notes: Figure shows the distribution of average temperature for all countries in this study' data set (black), versus those of countries that have experienced upgrades at least once (green) and downgrades at least once (red).



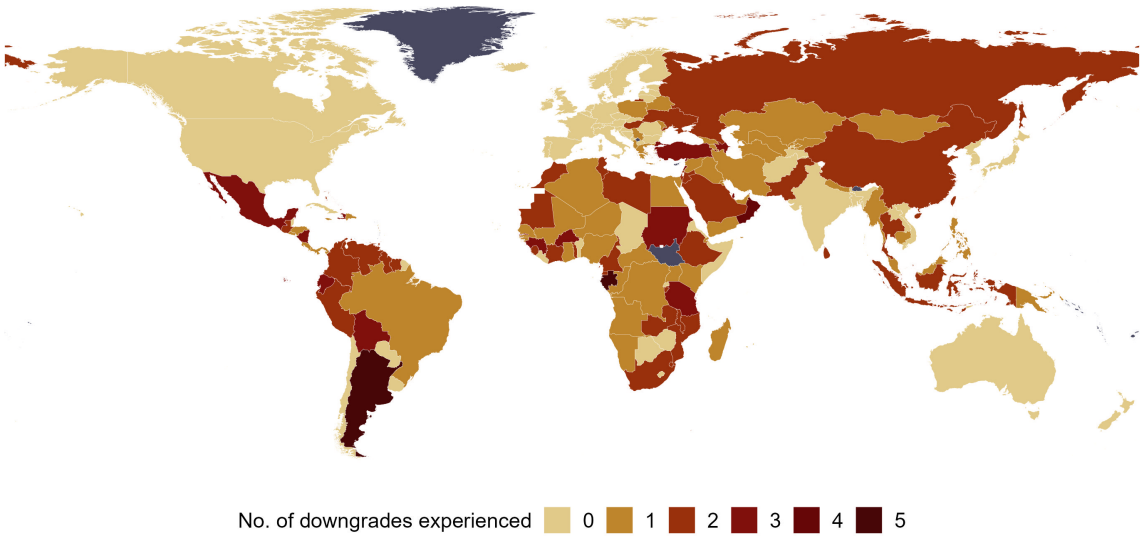
Appendix Figure B2. Number of Credendo expropriation risk ratings for each country

Notes: Figure shows the number of expropriation risk ratings recorded for each country. Countries with missing expropriation risk ratings shown in grey.



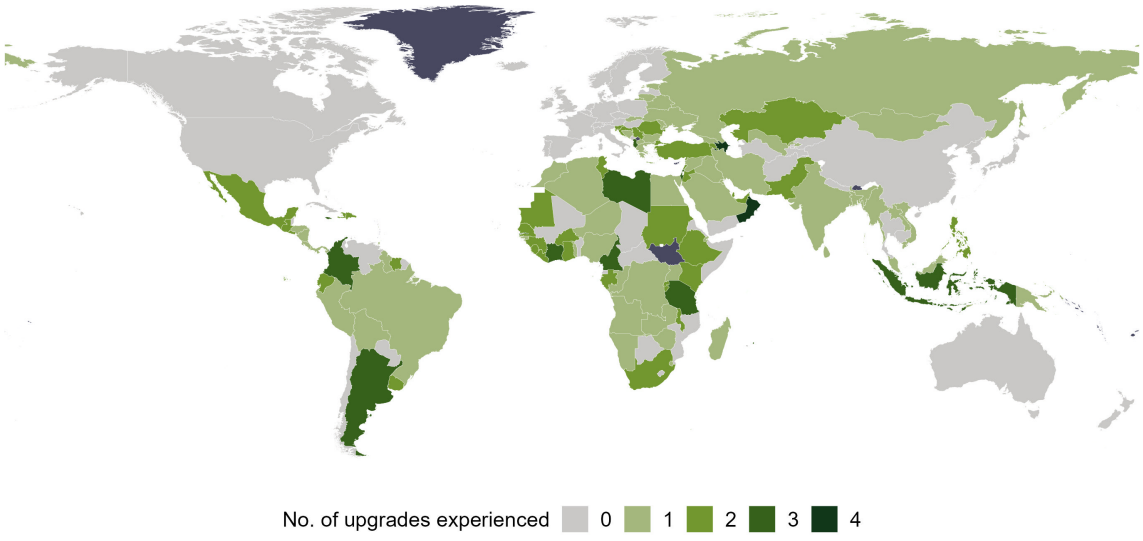
Appendix Figure B3. Average Credendo expropriation risk ratings for each country

Notes: Figure shows the average rating of Credendo expropriation risk in each country, where higher value (on a scale of 1 to 7) represents higher expropriation risk (lower institutional quality).



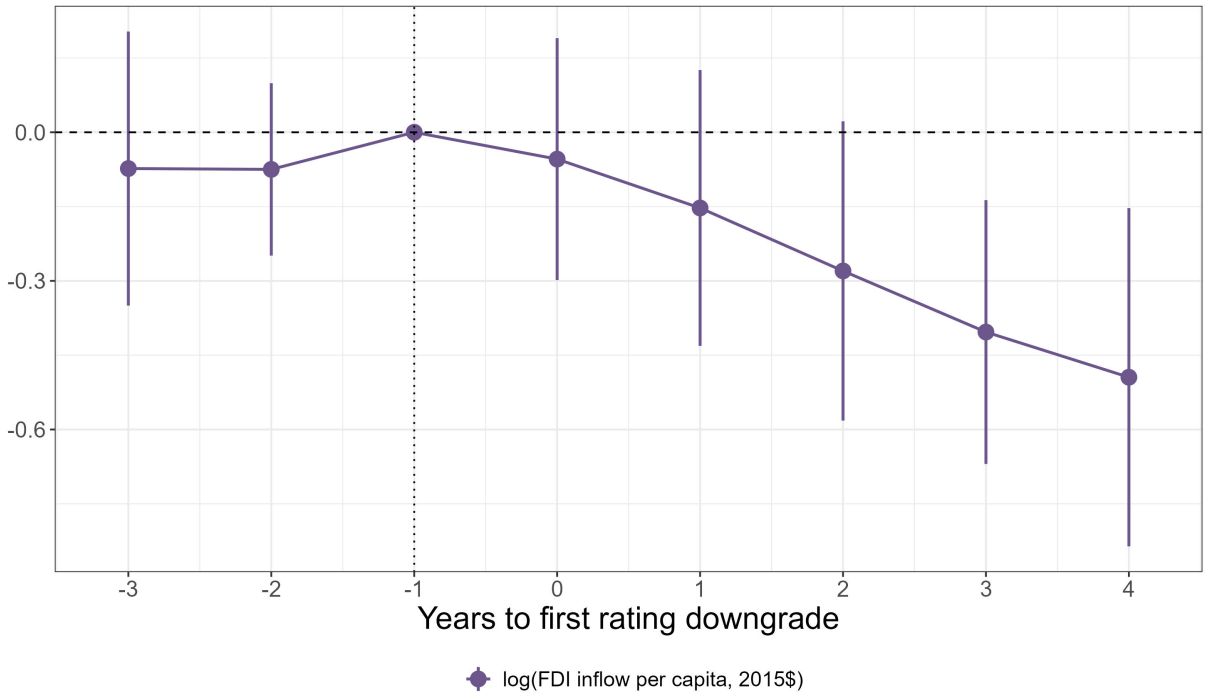
Appendix Figure B4. Frequencies of expropriation risk rating downgrades

Notes: Figure shows the frequency of Credendo expropriation risk rating downgrade experienced by each country. Countries without ratings shown in dark grey.

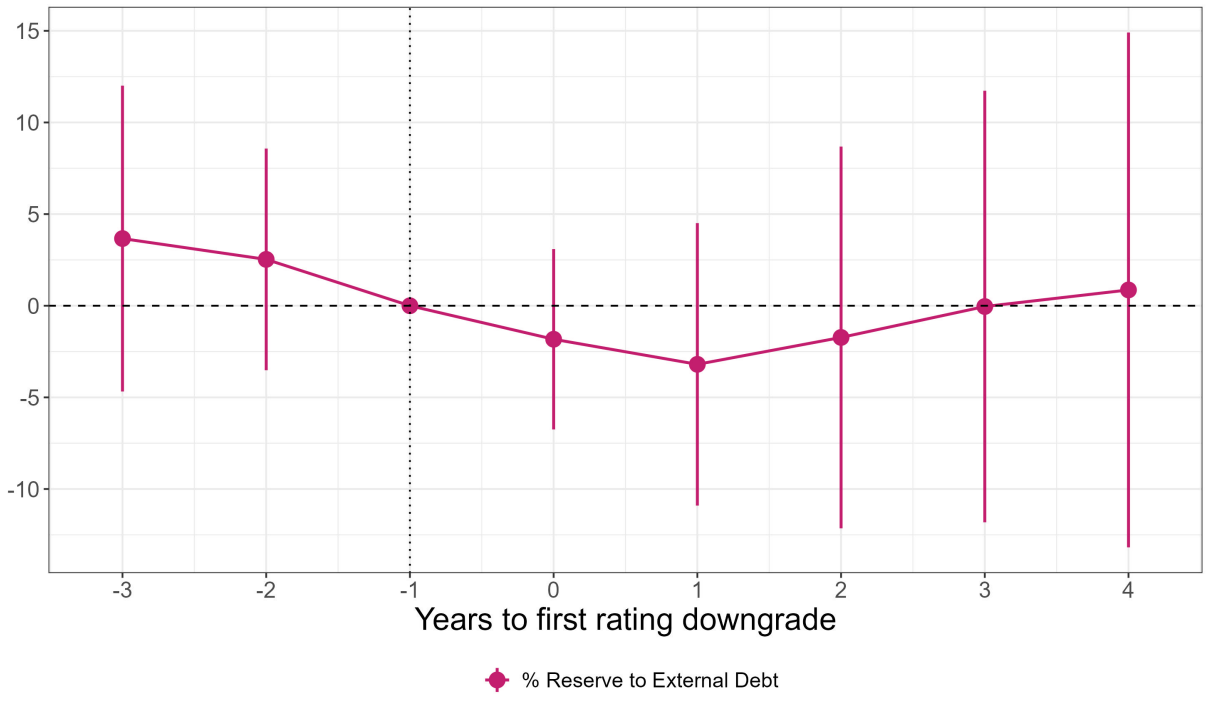


Appendix Figure B5. Frequencies of expropriation risk rating upgrades

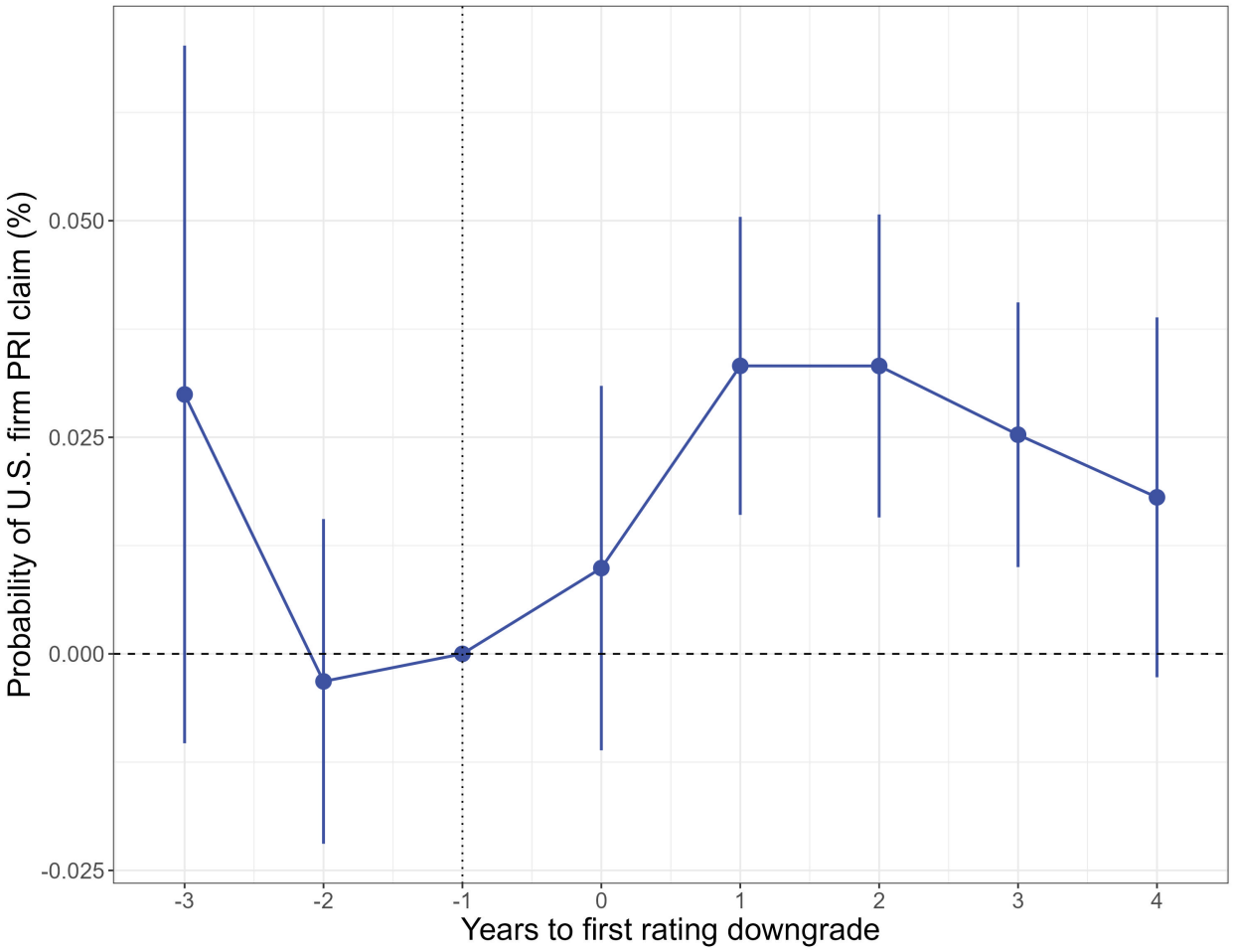
Notes: Figure shows the frequency of Credendo expropriation risk rating upgrade experienced by each country. Countries without ratings shown in dark grey.



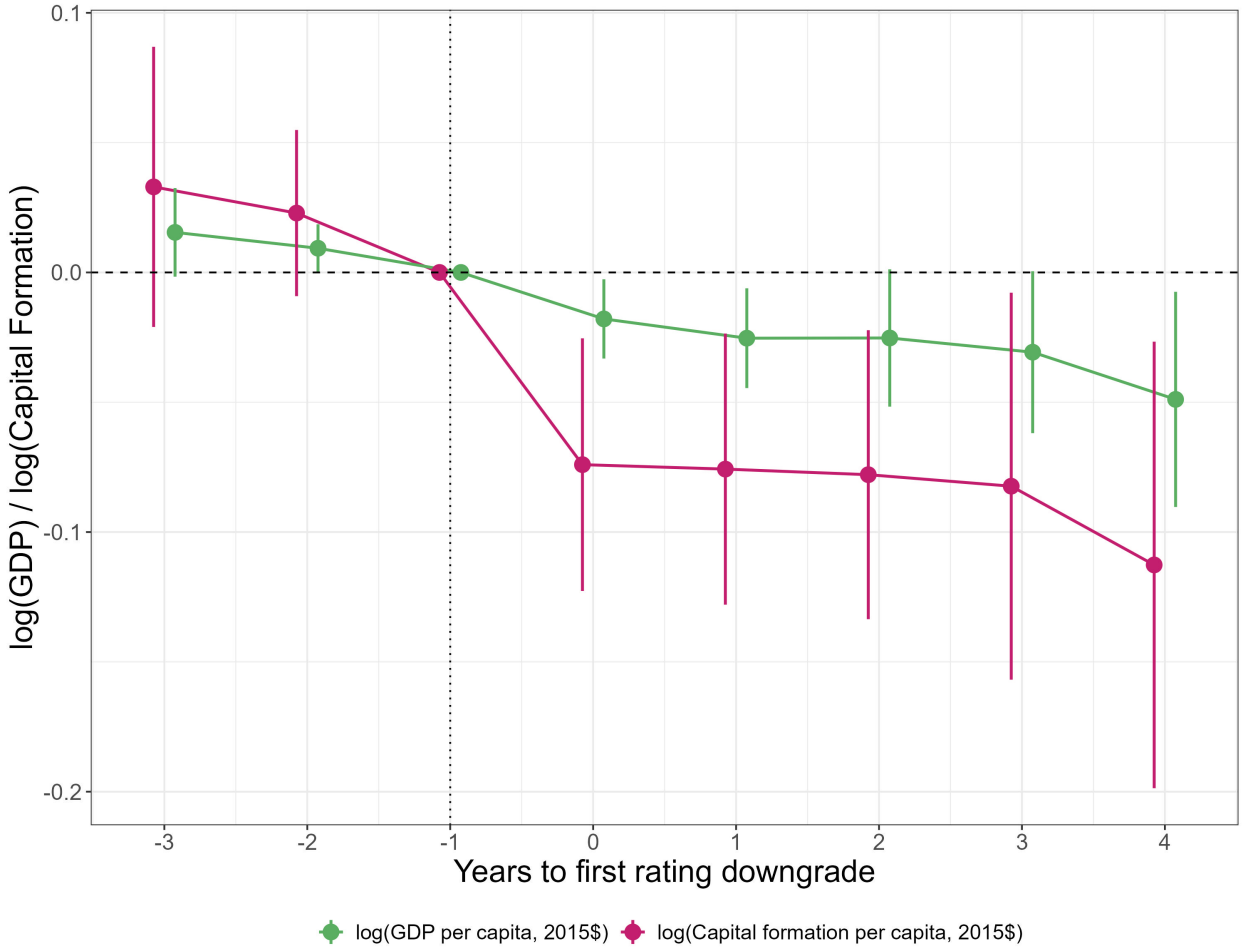
Appendix Figure B6. Credendo expropriation ratings and log of FDI per capita



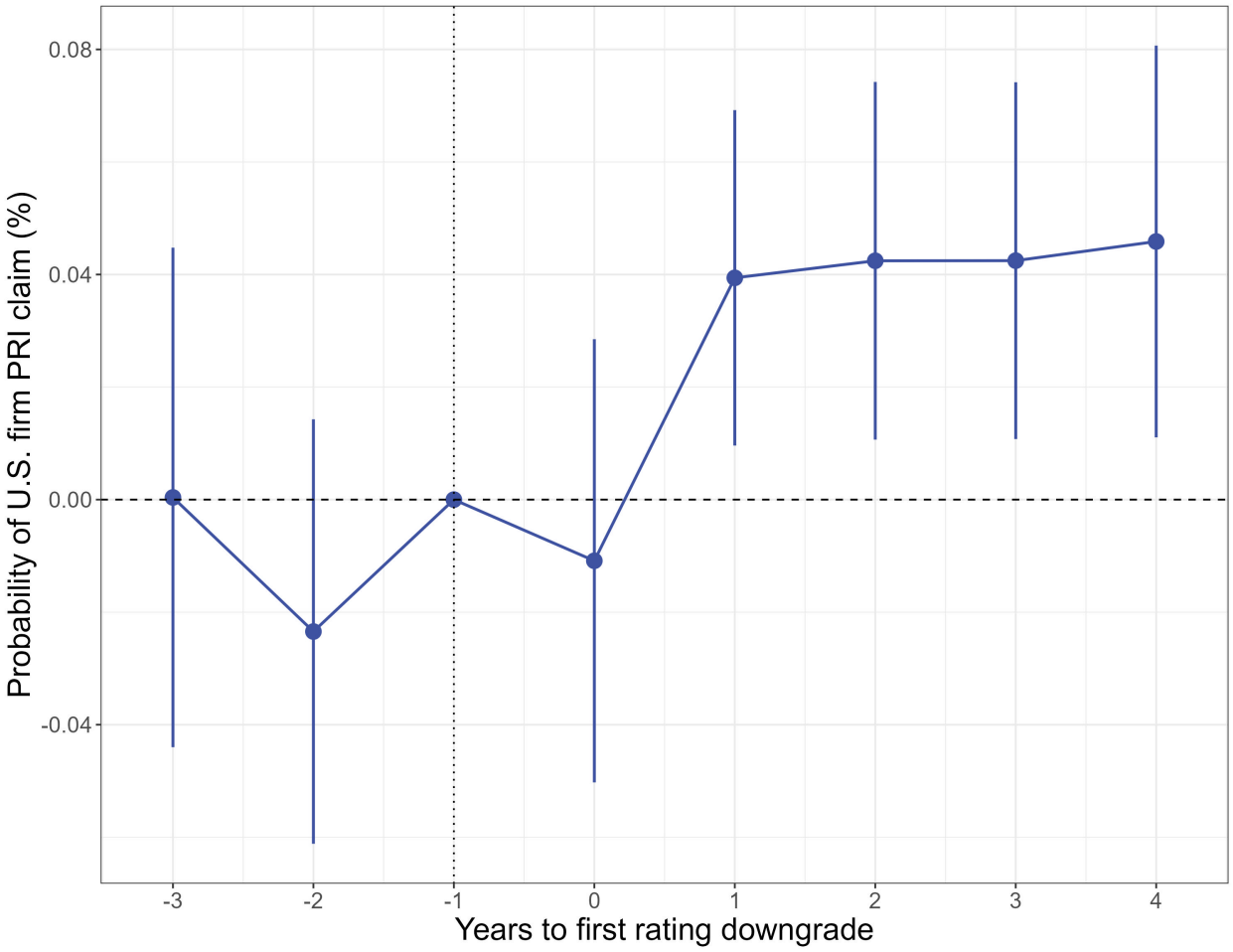
Appendix Figure B7. Credendo expropriation ratings and % of Reserve to External Debt



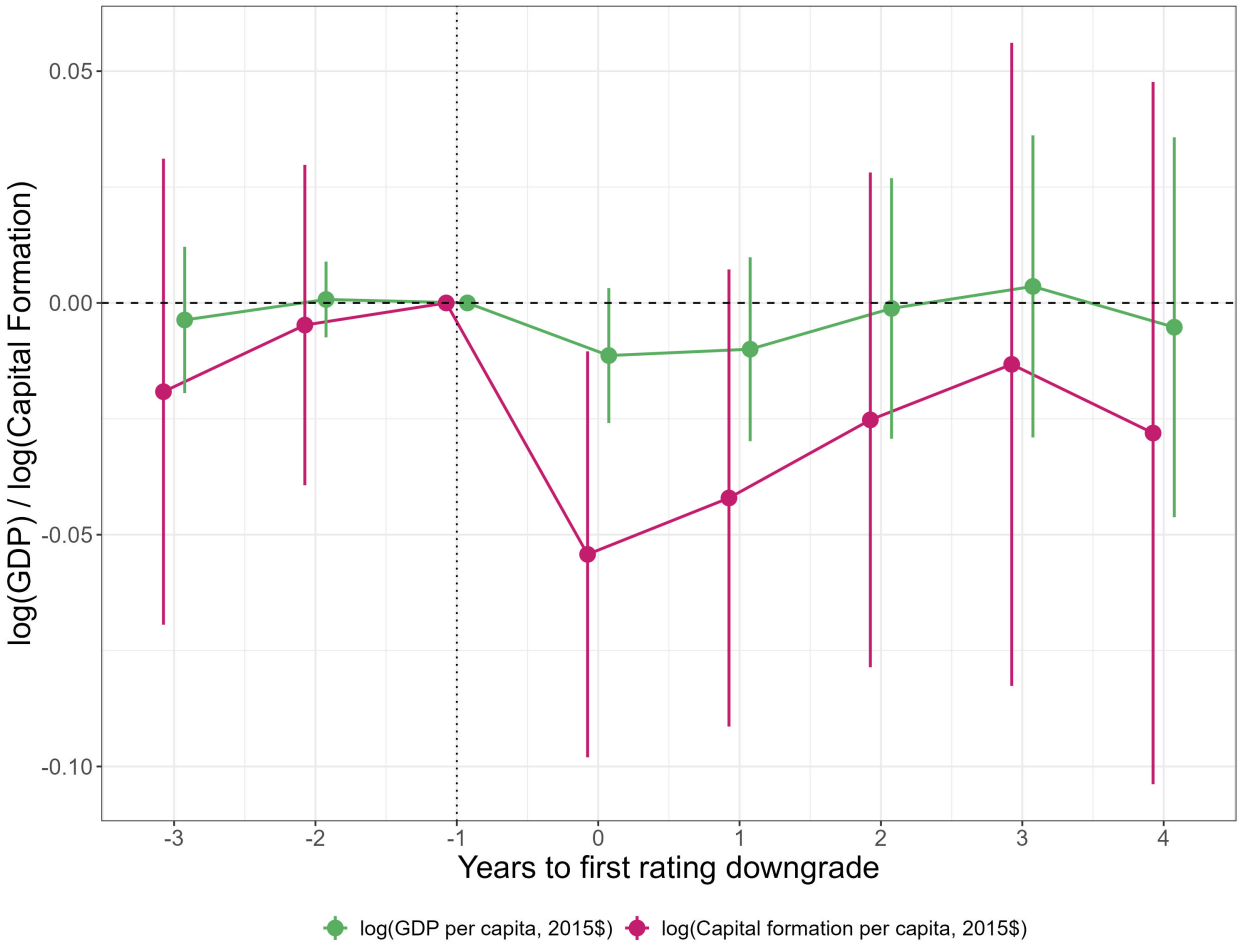
Appendix Figure B8. Downgrades and PRI claims, alternative control group



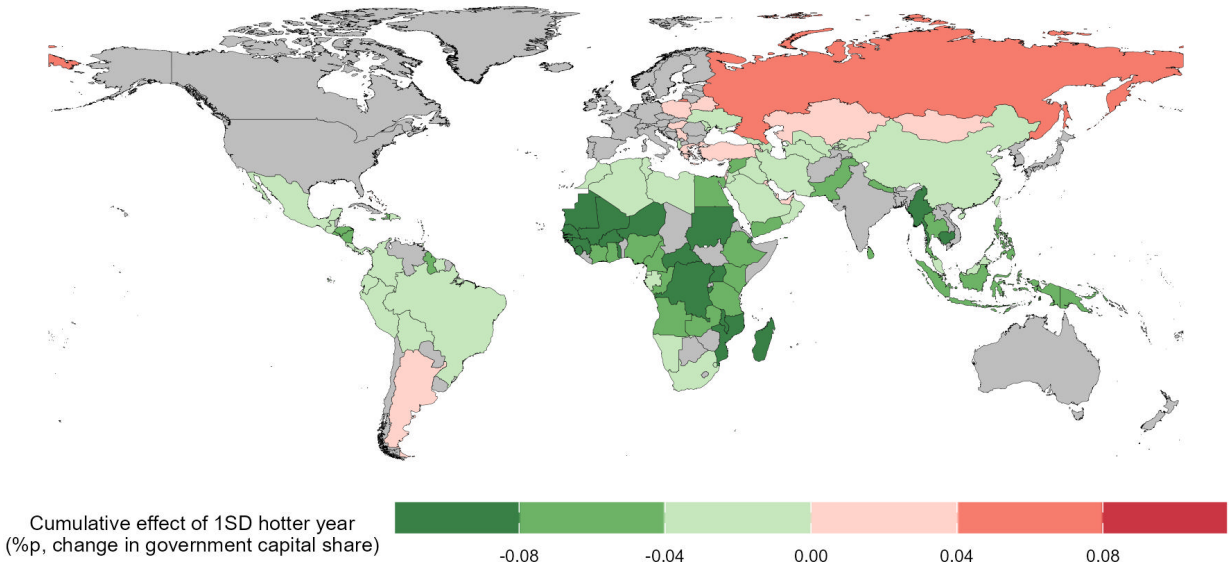
Appendix Figure B9. Downgrades and macroeconomic outcomes, alternative control group



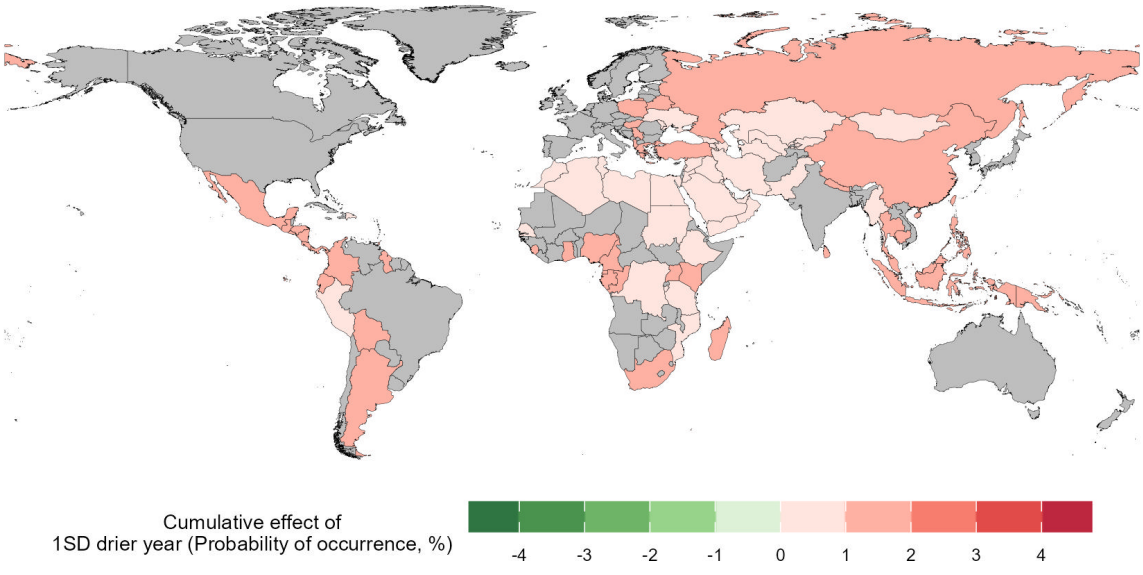
Appendix Figure B10. Downgrades and expropriation-related PRI claims



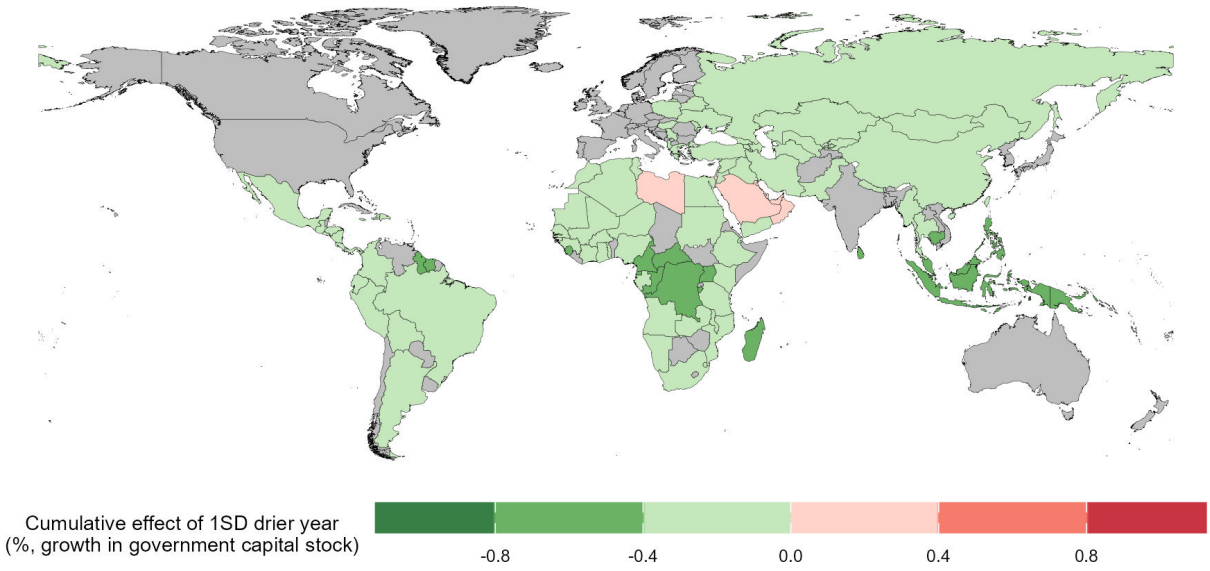
Appendix Figure B11. Downgrades and macroeconomic outcomes, unconditional



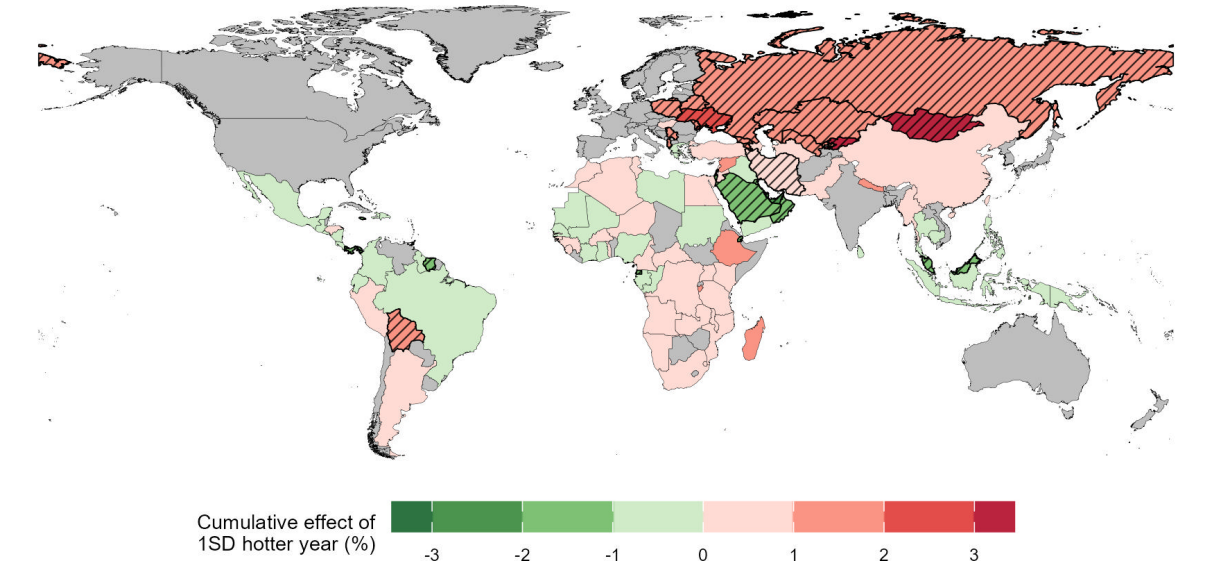
Appendix Figure B12. Temperature shocks and government capital stock share



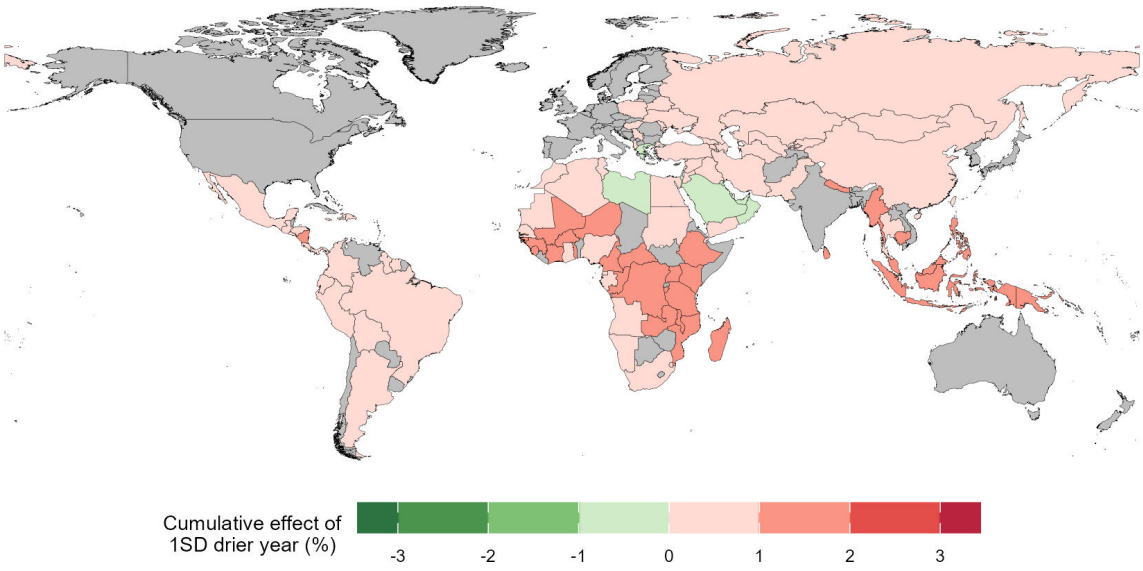
Appendix Figure B13. Precipitation shocks and expropriation cases



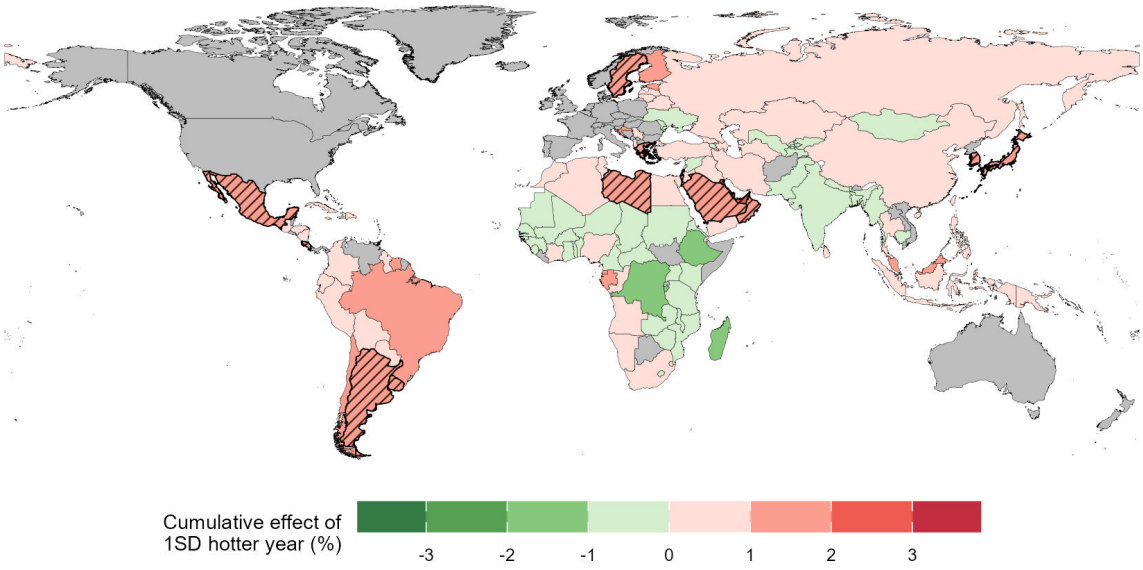
Appendix Figure B14. Precipitation shocks and government capital growth



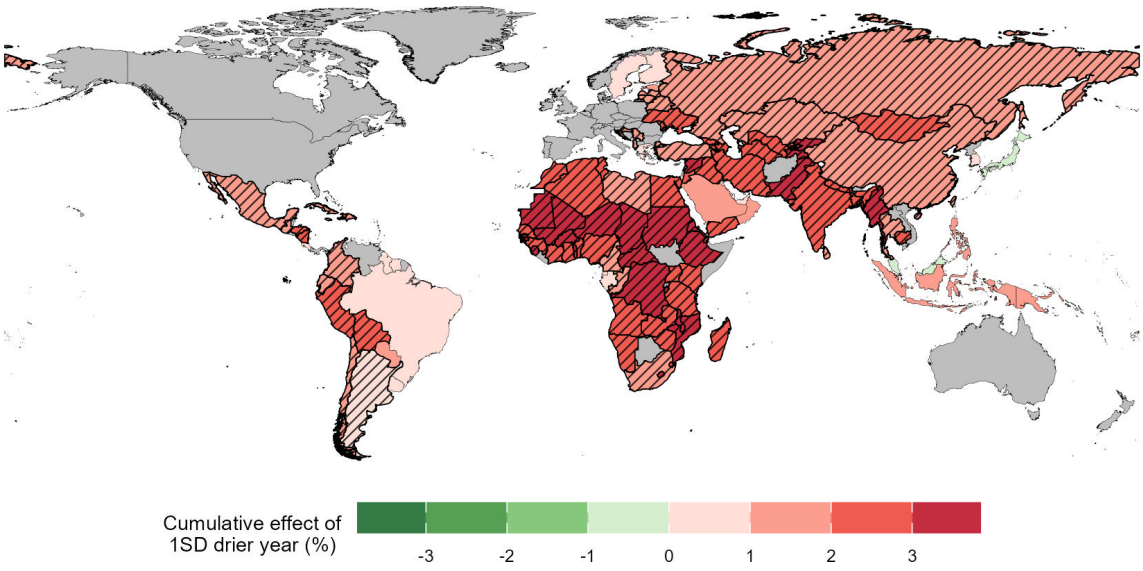
Appendix Figure B15. Temperature and political risk, no lags



Appendix Figure B16. Precipitation and political risk, no lags

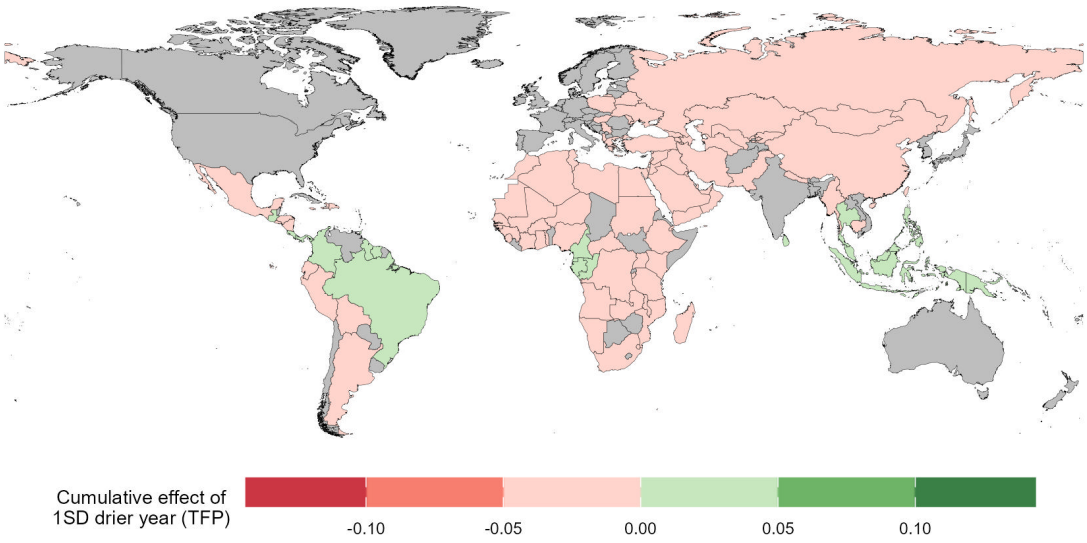


Appendix Figure B17. Temperature and political violence rating downgrade

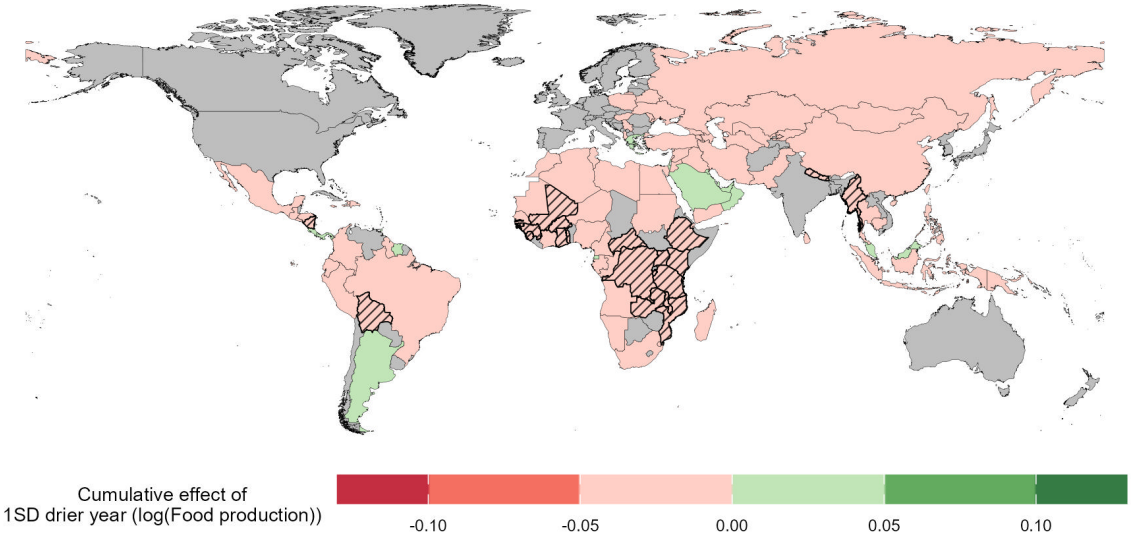


Appendix Figure B18. Precipitation and political violence rating downgrade

(a) Total factor productivity

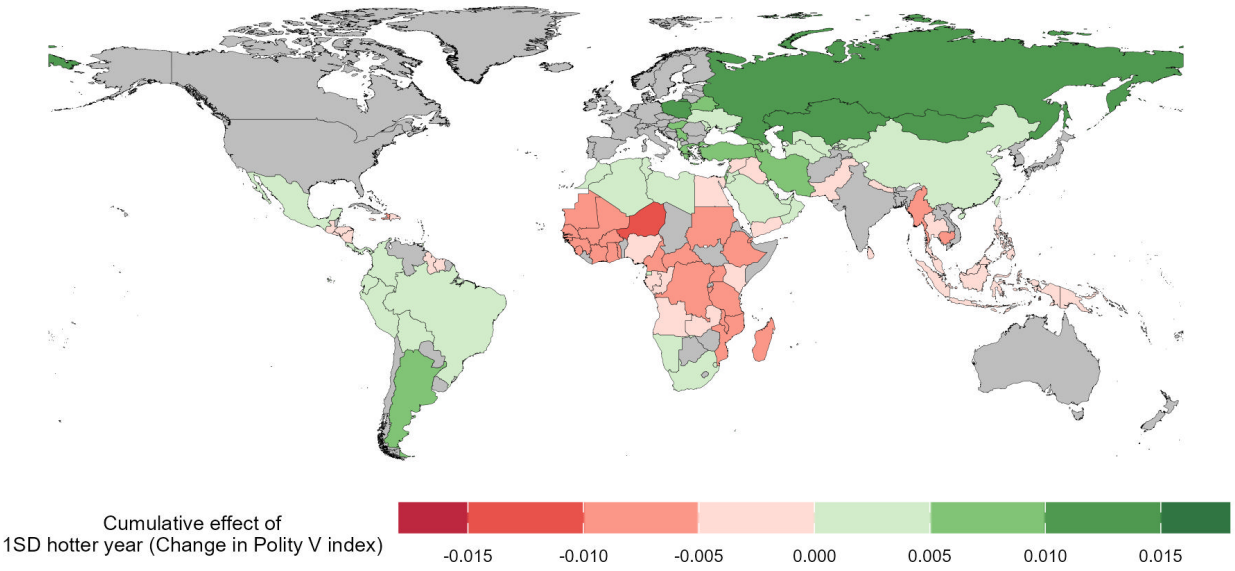


(b) log(Food production index)

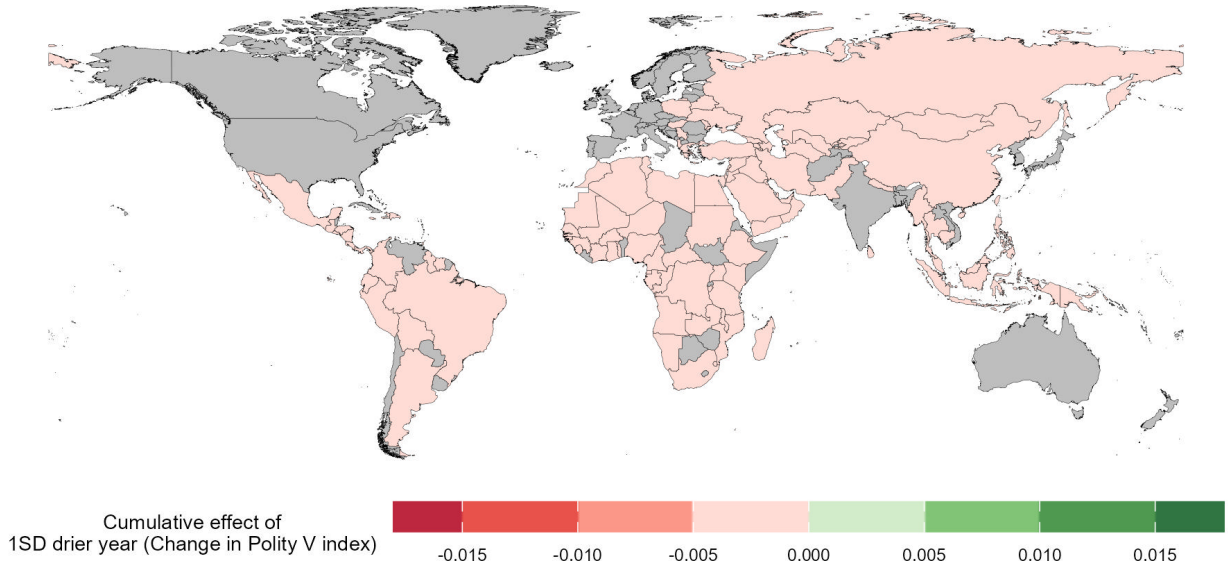


Appendix Figure B19. Productivity shock as potential mediator of precipitation effects

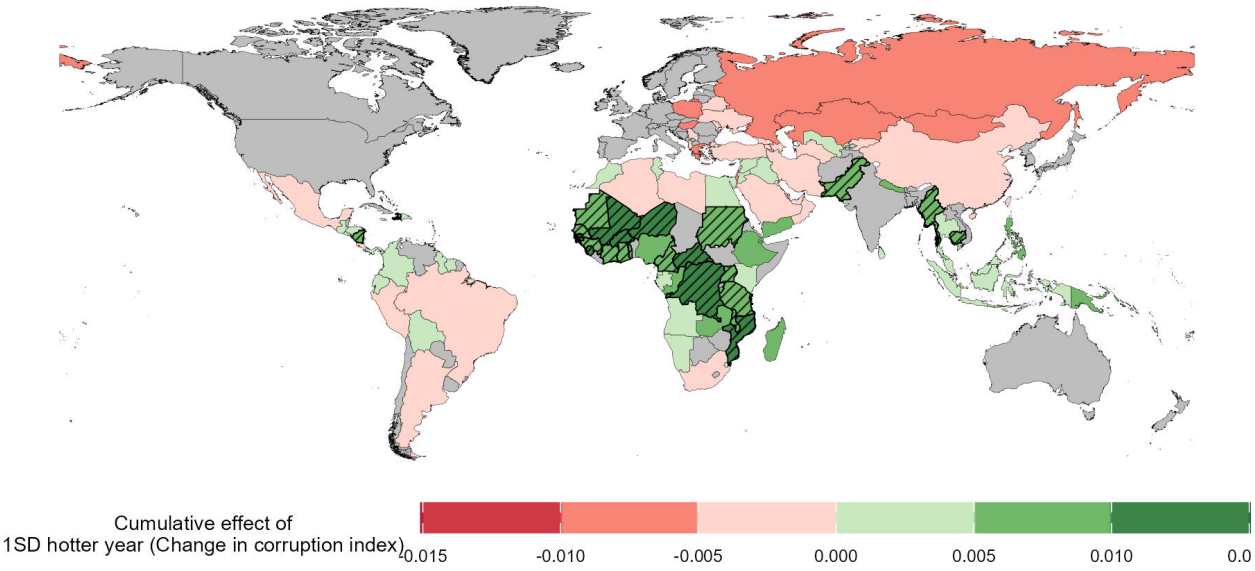
Notes: Figure follows the analysis shown in Figure 5, but for precipitation shocks.



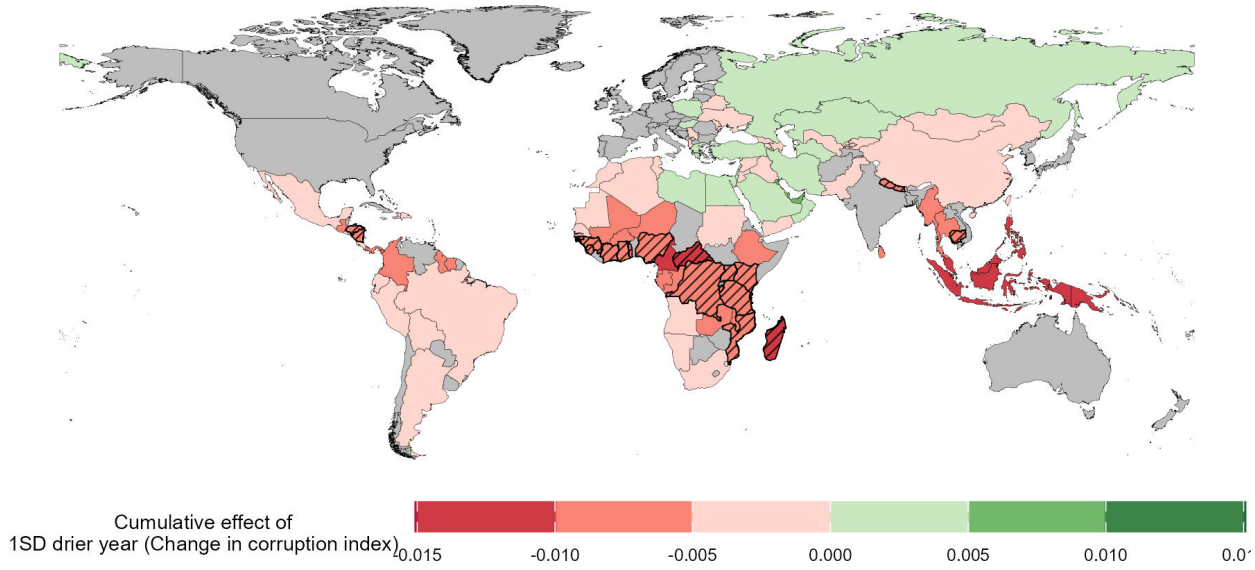
Appendix Figure B20. Temperature shocks and changes in Polity V index



Appendix Figure B21. Precipitation shocks and changes in Polity V index



Appendix Figure B22. Temperature shocks and changes in WGI corruption index



Appendix Figure B23. Precipitation shocks and changes in WGI corruption index

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Education

Columbia University, New York, USA — Sep 2023 -

Ph.D., Sustainable development
- Fields: Environmental economics, public economics, sustainable finance

Yale University, New Haven, USA — Sep 2021 - May 2023

MESc., Environmental economics
- Research Advisor: Robert Mendelsohn

Seoul National University, Seoul, South Korea — Mar 2015 - Aug 2021

B.A., *summa cum laude*, Economics (Minor in Earth Sciences)

Publications

* Lead-authored/Co-lead authored. † Lightly refereed publications.

7. *"Estimating Spring Frost Risk in Apple Farms from Crop Insurance Data" (with Kwansoo Kim and Jeongha Hwang). Forthcoming. *Weather and Climate Extremes*.
6. "Well-water Arsenic Mitigation in Bangladesh: Benefits outweighing risks of sharing private data" (with Lex van Geen, Prabhat Barnwal, Kazi Matin Ahmed, Mahfuz Khan et al.). Forthcoming. *Environmental Science & Technology*.
5. *"Climate Change and Fractional Outcomes: A Long-Run Panel Study of Crop Failure and Pasture Rates" (with Robert Mendelsohn). 2025. *Journal of Environmental Economics and Management* 130:103116.
4. *"Air Pollution and Solar Energy: Evidence from Wildfires" (with Kenneth Gillingham). 2025. *Journal of the Association of Environmental and Resource Economists* 12(2):493-526.
3. †"Measuring the impacts of air pollution" (with Robert Mendelsohn). 2023. *Science* 382: 878-879.
2. *"Climate change to increase crop failure in US" (with Robert Mendelsohn). 2023. *Environmental Research Letters* 18 (1): 014014.
1. *"A Panel Analysis on the Locality of Paddy Rice Yield's Response to Temperature Conditions: The case of South Korean municipalities" (with Jeongha Hwang, Jiwan Han, and Kwansoo Kim). 2020. In Korean. *Journal of Climate Change Research* 11:597-607.

Working Papers

*"Bureaucracy and Political Bias: Evidence from Floods" (with Hannah Farkas). CEEP Working Paper.

*"Evaluating carbon offset projects using machine learning" (with Luke Sanford) Draft Link.

*"Climate change and property-right institutions"

Works in Progress

"Improving state effectiveness in environmental risk mitigation: Large-scale experimental evidence from Bangladesh" (with Prabhat Barnwal, Michael Best, Lex van Geen, and Jack Willis)

"System-level investment" (with Caroline Flammer and Steve Lydenberg)

Awards & Fellowships

* Known number of awardees in parentheses ( ). All awards competitive.

2024-2028	*Ilju Fellowship	(<10, nation-wide)
	– $120,000 in stipend support & research funding (no strings attached).	
2021-2023	*Kwanjeong Fellowship	(<20, nation-wide)
2023	Dean's Scholarship, Yale School of the Environment	
2021	*Best Undergraduate Thesis Award, SNU	(1, departmental)
2015-2019	*Merit scholarships (5 times), SNU	(<5%, university-wide)
2015	*Top Freshman Award, SNU	(<0.5%, university-wide)
	– For top 10 incoming undergraduates at SNU.	

Research Grants

2025	Weiss Special Window for USAID Research (Student Co-PI, PI: Jack Willis)	$77,000
	– Title: "Nolkup: an app to access low arsenic water in Bangladesh"	
2022	Jubitz Family Research Grant (*via* Yale School of the Environment)	$4,300
2020	SNU Undergraduate Research Grant	$7,300
2020	SNU Creative Research Fellowship	$3,000
2016, 2020	SNU ARE Overseas Undergraduate Research Support Program	$13,700

Academic Presentations

* Full presentations ($\geq$ 30 mins).

2025 *Columbia IPWSD; NBER Climate Finance PhD Workshop; Northeast Workshop on Energy Policy and Environmental Economics (Yale); *Virtual SusDev Seminar

2024 *Columbia IPWSD; *Columbia Lamont-Doherty; *Seoul National University

2023 *AAEA Annual Meeting; Northeast Workshop on Energy Policy and Environmental Economics (Cornell); *Yale Carbon Offset Workshop; *Yale Environmental Economics Seminar

-2022 AAEA Annual Meeting; Seoul National University (Faculty of Liberal Education); *Yale School of the Environment (Confluence)

Research Assistantships

Columbia	RA for Prof. Caroline Flammer (System-level investment)	2024-
	RA for Profs. Michael Best, Lex van Geen, Jack Willis, and Prabhat Barnwal (Information and environmental risk: Experimental evidence from Bangladesh)	2023-
Yale	RA for Prof. Kenneth Gillingham (Solar manufacturing employment)	2022
	RA for Prof. Robert Mendelsohn (Temperature and mortality)	2023
	RA for Prof. Luke Sanford (Forest carbon offset projects)	2023
SNU	RA for Profs. Kwansoo Kim & Donghwan An (Climate change policy)	2019-2020
	RA for Prof. Kwansoo Kim (Crop insurance policy)	2021

Teaching Experience

2025F Data Analysis for Policy Research (Columbia, graduate 20+, TA)

2025S Financial Economics of Climate and Sustainability (Columbia+, PhD 100+, TA)

2022F Economics of Natural Resources (Yale, undergrad 130+, Head TA)

2021F Economics of Natural Resources (Yale, undergrad 120+, TA)

Core Coursework

*Received highest grade. All PhD-level courses.

Economics	(Columbia) Micro I/II, Macro I, *Econometrics III, *Political Economy I, *Public Economics and Development, *Topics in Micro Development Economics, *Topics in Organizational Economics (Yale) Econometrics *I/*II, *Environmental and energy economics, *Machine Learning and Causal Inference
Finance	(Columbia) Asset Pricing I, Climate Finance, Empirical Corporate Finance, Financial Economics of Climate and Sustainability
Earth Sciences	(Columbia) *Aquatic Chemistry, Atmospheric Radiation, Biodiversity Data Analysis I (Yale) Climate Dynamics (SNU) *Ecosystem Remote Sensing, Atmospheric Chemistry, Pollutant Dynamics

Skills

Statistical analysis	*R*, MATLAB, Python, Stata
Geospatial analysis	Google Earth Engine, QGIS
Other softwares	LaTeX, WRF numerical weather prediction model
Language	Korean (Native), English, French (Fluent)