Timing Matters: Analyzing Climate Policies and Adaptive Resilience

Elisa D'Amico[1*] and Tofigh Maboudi[2]

[1]University of St Andrews.
[2]Loyola University Chicago.

*Corresponding author(s). E-mail(s): ed248@st-andrews.ac.uk;
Contributing authors: tmaboudi@luc.edu;

Abstract

In the realm of climate policy, policymakers and scholars have traditionally focused on the overarching question of whether policies work. In this paper, we shift the focus to a more nuanced inquiry: when do these policies work? Leveraging available data on adaptation laws and adaptative capacity, we utilize a comprehensive change point analysis and segmented regression methodology to explore the temporal dynamics of climate policies and uncover patterns indicating the critical junctures at which these policies lead to their intended outcomes. We find that adaptation laws had more positive impact on adaptative readiness between 1999 and 2006, while they negatively correlate with climate readiness in post-2016 years. This analysis highlights the importance of exogenous factors, the rule of law, and regional variations in studying climate policy effectiveness. By emphasizing the temporal alignment between policy implementation and climate outcomes, this research underscores the importance of proactive efforts in combating climate change.

Keywords: Climate Adaptation, Climate Policy, Adaptive Readiness, Resilience, Rule of Law

The urgency of climate change necessitates not only the implementation of effective policies but also a nuanced understanding of when these policies yield (or do not yield) the desired outcomes. As global temperatures rise and extreme weather events become more frequent, the need for proactive and timely climate action has never been more apparent [1, 2]. This research delves into the temporal dynamics of climate adaptation policies, emphasizing the critical importance of timing in achieving successful adaptation outcomes. At the heart of our inquiry lies a fundamental question: when do climate adaptation policies effectively mitigate the impacts of climate change? While much attention has been directed towards mitigation strategies and how mitigation policies might reduce greenhouse gas emissions[3], the pressing reality is that climate change is already impacting millions worldwide [4, 5]. Thus, targeted responses to adapt to these changes are imperative. However, the focus on adaptation has often been overshadowed by mitigation efforts [6, 7].

While for long, adaptation had been underemphasized, the increased frequency and severity of climate-related extreme weather events in the last two decades has brought it to the forefront of climate policy agenda. However, as scholars have noted adaptation as a policy response is still much less developed compared to mitigation (see, for example, Burton et al. 2002 [8]). The literature on adaptation has focused on some very important questions, including: Do (or to what extent can) adaptation reduce the impacts of climate change? What type of adaptation policies are needed? What should be the priorities in developing adaptation policy? And how can robust adaptation policies be developed and applied [9–15]?

Some recent studies have more specifically focused on causes and drivers of strong climate (including both adaptation and mitigation) laws and policies. One study, for example, finds that strong and unified governments, where the ruling party has also a clear parliamentary majority, are better able to pass climate legislations [16]. It also finds election cycles, the existence of climate framework legislations, and global frameworks might have an impact on the number of climate laws.

While these studies have made significant contributions to our understanding of adaptation policy and their effectiveness, they have mostly overlooked the temporal aspect of policy and the significant role that exogenous shocks play in impacting the effectiveness of laws and policies. For instance, adopters of policies and laws in the later periods already have a framework to work with, something which early adopters usually lack. Also, past successful and failed experiences give later adopters an insight into policy effectiveness. So, normatively, we should expect that later policy adoptions should be more effective. Yet, the literature on adaptation policy has mostly overlooked these important observations.

The policy literature has long emphasized the importance of timing and the temporal nature of the policy process [17]. From the classic "stages" models of the policy process [18, 19] to the studies of policy diffusion [20]and the more recent agenda setting literature [21], theories of policy processes have always emphasized the temporal aspect of politics. Collectively, these studies suggest that understanding when an event, venue change, or external shock occurs, in a sequence of events, might be just as important as knowing that they occur at all [17].

External shocks, such as a crisis or unexpected disaster [21], or a change in the governing administration [22], can call attention to a problem, provoke new institutional agendas and policy priorities, and mobilize new interests and rules [17]. And these policy innovations can be diffused to other places. Indeed, innovation adoption and policy diffusion has been studied broadly across different disciplines and in different contexts [23–25]. In this endeavor, a plethora of studies, mostly building on literatures in strategic management, institutional analysis, and policy innovations, has elaborated on comparing early and later adapters of policies and policy innovations [26]. However, relatively little research has examined timing and the temporal aspects of climate adaptation policies across the globe.

In this study, we examine when adaptation policies yield their intended outcomes. More specifically, we employ a comprehensive change point analysis and segmented regression methodology to uncover patterns indicating the critical junctures at which adaptation policies lead to their intended outcomes. To this end, we draw on the Climate Change Laws of the World data provided by the Grantham Institute [27], which offers insights into the landscape of adaptation laws and policies worldwide, and the Notre Dame Global Adaptation Initiative (ND-GAIN) data [28], which measures countries' adaptative readiness across economic, governance, and social dimensions. Utilizing these and other datasets, we examine how exogenous conditions, such as socioeconomic factors and environmental pressures, influence the relationship between policy implementation and adaptation success. That is, we hypothesize that an increase in the stock of adaptation laws leads to higher levels of adaptative readiness, but that this relationship is temporally contingent on external global factors.

1 Results: Critical Junctures in Adaptation Laws

To empirically investigate the temporal dynamics of adaptation policies, we employ a change point analysis, statistically examining the aggregated percent change in adaptation law features over time. This analysis identifies distinct periods during which significant changes in adaptation policy implementation occurred. As illustrated in Figure 1, this analysis identifies four distinct eras where climate adaptation policies have undergone major transformations.

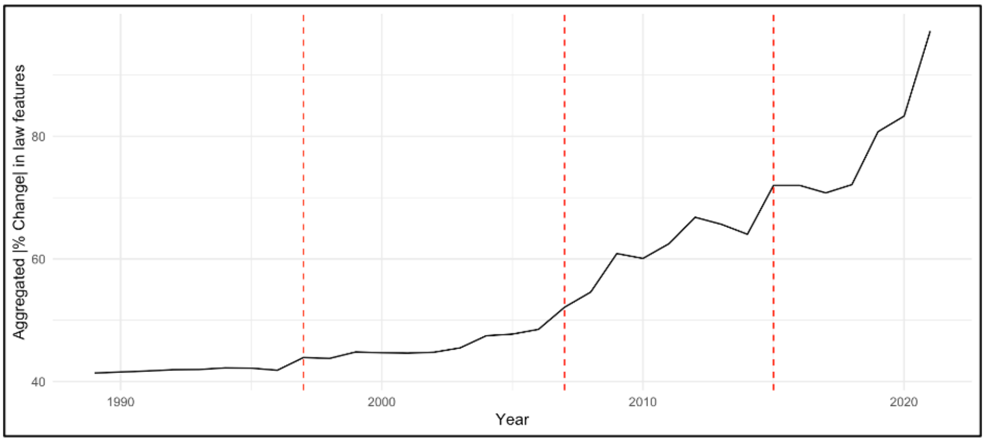

Fig. 1 Empirical Change Points in the Nature of Climate Adaptation Laws

Note: This figure shows changes in climate adaptation laws over time from the Grantham Institute's database, including document types, categories, sectors, and hazards, highlighting key legislative shifts.

Early experience Era (Pre-1998): Before 1998, global recognition of climate change and the need for adaptation policies were still in their nascent stages. During this period, adaptation measures were sporadic and largely reactive, with few comprehensive laws or policies in place (see Table A1 in Online Appendix A). This era constitutes an initial acknowledgment of climate risks and the gradual move towards formal policy responses.

Global Acknowledgment Era (1999-2006): The period following 1998 marked a significant shift in global climate policy, driven by increased awareness and acknowledgment of climate change. This era saw a proliferation of international agreements and national laws aimed at addressing climate issues. The increased scientific consensus on climate change and its impacts galvanized governments to implement adaptation policies, recognizing the need for proactive measures to enhance adaptive resilience. The theoretical underpinning here is that early acknowledgment and policy implementation can set the stage for long-term resilience, as initial investments and strategic planning create a foundation for future adaptations.

Financial Crisis and Recovery Era (2007-2015): The global financial crisis of 2008 had profound implications for climate policy. The economic downturn strained national budgets and diverted attention away from costly adaptation measures [29]. As a result, the implementation of adaptation policies lagged, highlighting the vulnerability of climate initiatives to economic pressures [30]. This period demonstrates how exogenous economic shocks can hinder the progress of adaptation efforts. The recession underscored the need for resilient economic policies that can support sustained investment in climate adaptation, even in times of financial strain.

Political Shifts Era (Post-2016): The rise of populism and significant political shifts post-2016 (From the U.S. and Brazil to, more recently, Italy and Sweden) have introduced new challenges to the implementation of adaptation policies. Populist movements often prioritize short-term economic gains and national sovereignty over global climate commitments, potentially undermining long-term adaptation strategies [31]. This period has seen a retreat from multilateral climate agreements and a rollback of environmental regulations in some countries (most notably, the U.S.), affecting the overall effectiveness of adaptation policies. This era points to the importance of government change as an exogenous shock and how it can undermine (or strengthen) policy effectiveness, suggesting that political stability and international cooperation are critical for sustained adaptation efforts.

Throughout these different eras, the relationship between adaptive resilience and adaptation laws has evolved uniquely. In times of economic prosperity and political stability, adaptation policies tend to be more effective due to the availability of resources and sustained political commitment. Conversely, during periods of economic downturn or political upheaval, the effectiveness of adaptation measures often declines. This dynamic underscores the importance of aligning adaptation policies with broader socio-political and economic contexts to enhance their impact.

This analysis finds other notable trends in climate adaptation laws including across different categories, responses, and document types over distinct time periods. Executive actions, for example, initially dominated, peaking during 2007-2015 before declining, while legislative measures showed a steady decrease over time. UNFCCC-related laws emerged significantly during the same period (Table B2 in online appendix B), while domestic laws exhibited a gradual decline (see also Table C3 in online appendix C on the evolution of global climate commitments in addressing climate change). Indeed, the evolving landscape of climate adaptation policies and the shifting priorities across different legislative and response categories over time can indicate that the timing of adaptation policy implementation plays a critical role in their effectiveness.

1.1 The Impact of Adaptation Laws on Climate Readiness

To examine the impact of adaptation laws on climate readiness, we utilize cross-national time series data, accounting for a standard set of controls. Our empirical design and data are discussed in greater detail in the Methods section. In brief, we employed change point analysis to identify distinct time periods, or "eras," within the data. In what follows, we use segmented panel linear modeling (PLM) regression to assess whether adaptation laws are associated with increased climate readiness across these eras or critical junctures.

Table 1 presents the outcomes across the full sample period from 1960 to 2023. It indicates a positive sign between the stock of adaptation laws and adaptative readiness in both the 1-year and 7-year lag model, with the latter being statistically significant. This suggests that there may be more temporal nuance in identifying when adaptation policies effectively contribute to resilience, but that long-term effects of climate adaptation policies remain stable.

Table 1 Climate Readiness (All Years)

	Short-term Effects (t-1)	**Long-term Effects** (t-7)
Adaptation Law Stock	0.0001	0.0008
	(0.0002)	(0.0002)***
Rule of Law	0.0012	0.0005
	(0.0001)***	(0.0001)***
GDP (logged)	-0.0315	-0.0219
	(0.0032)***	(0.0027)***
GDP (logged)^2	0.0002	-0.0001
	(0.0001)**	(0.0001)
Services (percent of GDP)	0.0003	0.0004
	(0.0001)**	(0.0001)***
Imports (percent of GDP)	0.0003	0.0001
	(0.0001)***	(0.0001)
Federalism	0.0136	0.0257
	(0.0032)***	(0.0035)***
Climate Exposure	-0.2797	-0.1555
	(0.0727)***	(0.0787)*
Country FEs	YES	YES
Year FEs	YES	YES
Observations	11970	10830
R-Squared	0.0558	0.026024

*Note: Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05*

In Table 2, we analyze the periods preceding 1998 and between 1999 and 2006. For the period proceeding 1998, the coefficient for the adaptation law stock remains statistically insignificant. This lack of statistical significance aligns with our expectations, considering that climate policies and awareness saw a more pronounced increase around the turn of the century. This, however, changes for the years 1999-2006, where we see a positive and statistically significant association emerges between the adaptation law stock and adaptative readiness in both the 1- and 7-year lag models. This pattern aligns with the notion that these policies were in their nascent stages and required further development. The Global Acknowledgment Era was perhaps the golden age of adaptation laws as these laws potentially influenced adaptative readiness in both short term and long term. Our results show, however, that this impact declined significantly over the next few years.

Table 2 Climate Readiness (Pre-1998 & 1999-2006)

	Pre-1998		**1999-2006**	
	(t-1)	(t-7)	(t-1)	(t-7)
Adaptation Law Stock	-0.0022	0.0019	0.0023	0.0116
	(0.0032)	(0.0031)	(0.0009)**	(0.0027)***
Rule of Law	0.0000	0.0000	0.0001	-0.0015
	(0.0001)	(0.0001)	(0.0001)*	(0.0001)***
GDP (logged)	0.0014	-0.0005	0.0114	-0.0100
	(0.0035)	(0.0029)	(0.0048)*	(0.0112)
GDP (logged)^2	0.0000	-0.0001	0.0002	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0003)
Services (percent of GDP)	-0.0001	-0.0002	-0.0001	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0003)
Imports (percent of GDP)	0.0001	-0.0001	0.0001	-0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0002)
Federalism	0.0025	-0.0051	-0.0086	0.0053
	(0.004)	(0.0045)	(0.0045)	(0.0145)
Climate Exposure	-0.0189	-0.0265	-0.2263	-0.0757
	(0.0891)	(0.0949)	(0.0685)***	(0.2192)
Country FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	6840	5700	1900	1900
R-Squared	0.0006	0.0017	0.0378	0.0915

*Note: Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05*

As Table 3 shows, our results from 2007 to 2015 indicate that the relationship between adaptation laws and adaptive readiness for both the 1-year and 7-year lag models lacks statistical significance. This observation aligns with our expectation that the economic shock experienced in 2008 significantly undermined efforts to increase adaptive resilience, as adaptation initiatives involve substantial costs. The asset bubble collapse and ensuing global recession redirected substantial resources towards economic recovery, leaving only a small share of stimulus funds for addressing climate change vulnerability [32]. This emphasis on immediate economic stabilization rather than sustainable development represents a lost chance to invest in green technologies and essential changes needed for enduring resilience and sustainability.

Table 3 Climate Readiness (2007-2015 & post-2016)

	2007-2015		Post-2016	
	(t-1)	(t-7)	(t-1)	(t-7)
Adaptation Law Stock	-0.0004	0.0003	-0.0017	-0.0010
	(-0.0004)	(-0.0005)	(0.0004)***	(0.0003)***
Rule of Law	0.0009	0.0005	0.0017	0.0000
	(0.0001)***	(0.0001)***	(0.0002)***	(-0.0001)
GDP (logged)	-0.0151	-0.0424	-0.0409	-0.0034
	(-0.0085)	(0.0091)***	(0.0098)***	(-0.0053)
GDP (logged)^2	0.0000	0.0002	-0.0002	0.0002
	(-0.0002)	(-0.0002)	(-0.0002)	(-0.0001)
Services (percent of GDP)	-0.0007	-0.0007	0.0006	0.0001
	(0.0002)***	(0.0002)**	(0.0003)*	(-0.0002)
Imports (percent of GDP)	-0.0002	0.0001	0.0004	0.0001
	(0.0001)*	(-0.0001)	(0.0001)**	(-0.0001)
Federalism	0.0044	-0.0126	0.0112	-0.0034
	(-0.012)	(-0.0115)	(-0.0061)	(-0.0042)
Climate Exposure	-0.2824	0.3262	-0.1982	-0.0004
	(0.1248)*	(0.1403)*	(-0.1617)	(-0.1108)
Country FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	1710.0000	1710.0000	1520.0000	1520.0000
R-Squared	0.0447	0.0357	0.1099	0.0133

*Note: Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05*

A notable finding emerges for the post-2016 era: a negative and statistically significant correlation between the adaptation law stock and adaptative readiness for both lag models. That is, in more recent years, a greater accumulation of adaptation laws may coincide with decreased levels of adaptative readiness. Such a trend prompts reflection on the rise of populism and its objectives during this period, possibly influencing the efficacy of policy measures. Increased political polarization, alongside a prioritization of economic interests over environmental concerns, could be contributing factors to this phenomenon. In this polarized landscape, the ability to enact effective and comprehensive adaptation policies might have been hindered, leading to unintended consequences for adaptative readiness. It is also important to note that countries adopted a substantial number of new laws during this period, totaling 4,259. However, there was a significant decrease from the previous period, with adaptation-related laws dropping from 45% to 25% post-2016. This trend might suggest a shift away from inclusive climate policy during this period.

In these models, several control variables consistently show robust relationships with adaptive readiness. The *Rule of Law*, for example, consistently demonstrates a positive association with adaptive readiness across the models, highlighting the indispensable role of robust legal frameworks in bolstering resilience against climate impacts. By contrast, *GDP* (logged) consistently exhibits a negative association with adaptative readiness, indicating that higher GDP levels are associated with lower adaptive readiness levels. Moreover, *Services* (percent of GDP) consistently demonstrates a positive association with adaptive readiness across different lag models.

The negative association between *GDP* (logged) and adaptive readiness suggests that wealthier nations may prioritize economic growth or development over investing in climate adaptation. Additionally, more developed countries are large emitters which have traditionally prioritized mitigation over adaptation. They also tend to have lower levels of climate exposure, leading to less emphasis on adaptation and a greater focus on mitigation strategies instead. Conversely, the positive association between *Services* (percent of GDP) and adaptive readiness indicates that economies with a larger services sector are more adaptable to climate change. Service-based economies demonstrate greater flexibility to innovate and adapt to changing environmental conditions compared to those reliant on heavy industry or agriculture. Moreover, the service sector's adaptability facilitates the adoption of new technologies and practices that enhance adaptive readiness.

2 Discussion

Climate adaptation laws have been on the rise since mid-1990s, but as Figure 2 shows, this increase in adaptation laws and policies has not necessarily translated into improved climate preparedness which seems to fluctuate independent of the sheer number of climate laws. When we compare the two graphs, we might conclude that adaptation laws do not correlate with climate preparedness. However, when we use change point analysis and segmented regression methodology, we uncover new patterns that indicate some critical junctures at which adaptation policies lead to their intended outcomes. More specifically, we found the years between 1999 and 2006 to be the golden age of adaptation laws, a time when these laws had more positive impact on adaptative readiness across the world. By contrast, adaptation laws seem to negatively correlate with climate readiness in post-2016 years.

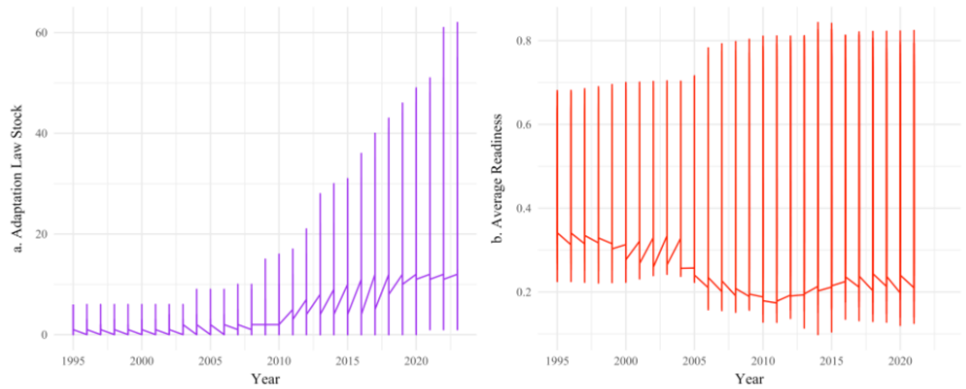

Fig. 2 Trends in Adaptation Law Stock and Average Readiness

Note: This figure shows trends in climate adaptation laws and readiness scores over time based on the Grantham Institute's database and ND-GAIN respectively.

To understand these results, we need to highlight a few key issues which require further research. First, we a need to more systematically consider the role of exogenous factors and their impact of climate policy effectiveness. Our results in this paper pointed to two important exogenous factors (i.e., global financial crisis and increased polarization and populist outlooks). Indeed, the global financial crisis undermined climate adaptation policies by diverting financial resources towards the more pressing issue of economic recovery. By contrast, increased political polarization across the world and the rise of populist and far-right political parties in many Western countries not only rendered these policies ineffective but might have also led to a decline in adaptation readiness. Circling back to our question of *when* adaptation policies yield (or do not yield) the desired outcomes, this analysis identifies the years between 1999 and 2006 to be the most effective time for climate policies, but the impact of adaptation policies on climate readiness lost its significance between 2007 and 2015. Most surprisingly, policies after 2016 seem to correlate negatively with climate readiness. While further research is needed to identify and isolate the causes behind this trend, we speculate that when major economic crises divert financial resources away from climate actions and when populist far-right parties rise to power (in a polarized environment) adaptation policies fail to yield their desired outcome.

Second, rule of law seems to matter more than the sheer number of laws. Across most of our models, the Rule of Law variable shows a positive and statistically significant correlation with adaptive readiness. The consistent positive association between the Rule of Law and adaptive readiness suggests that strong legal frameworks might matter more than just sheer number of laws for a country's ability to adapt to climate change. Clear regulations, effective governance, and enforcement mechanisms enable efficient implementation of adaptive policies, underscoring the importance of good governance in building resilience to climate impacts. Indeed, our findings emphasize the need for coherent and enforceable legal structures to support comprehensive climate adaptation strategies at local, national, and global levels.

Lastly, there seems to be some regional or country-level variations which can matter for the effectiveness of adaptation laws. The contrast between the two maps in Figure 3 highlights the uneven relationship between adaptation laws and climate readiness across different countries and regions. For example, most European and some Asian nations exhibit a positive correlation between adaptation laws and readiness. By contrast, many Latin American countries show that increased legislation does not always reflect higher readiness, with Brazil standing out as a case where a very high score of adaptation law stock correlates with a low readiness score. Meanwhile, African countries generally display lower levels of both adaptation laws and readiness, which aligns with the expectation of less developed regulatory frameworks and preparedness.

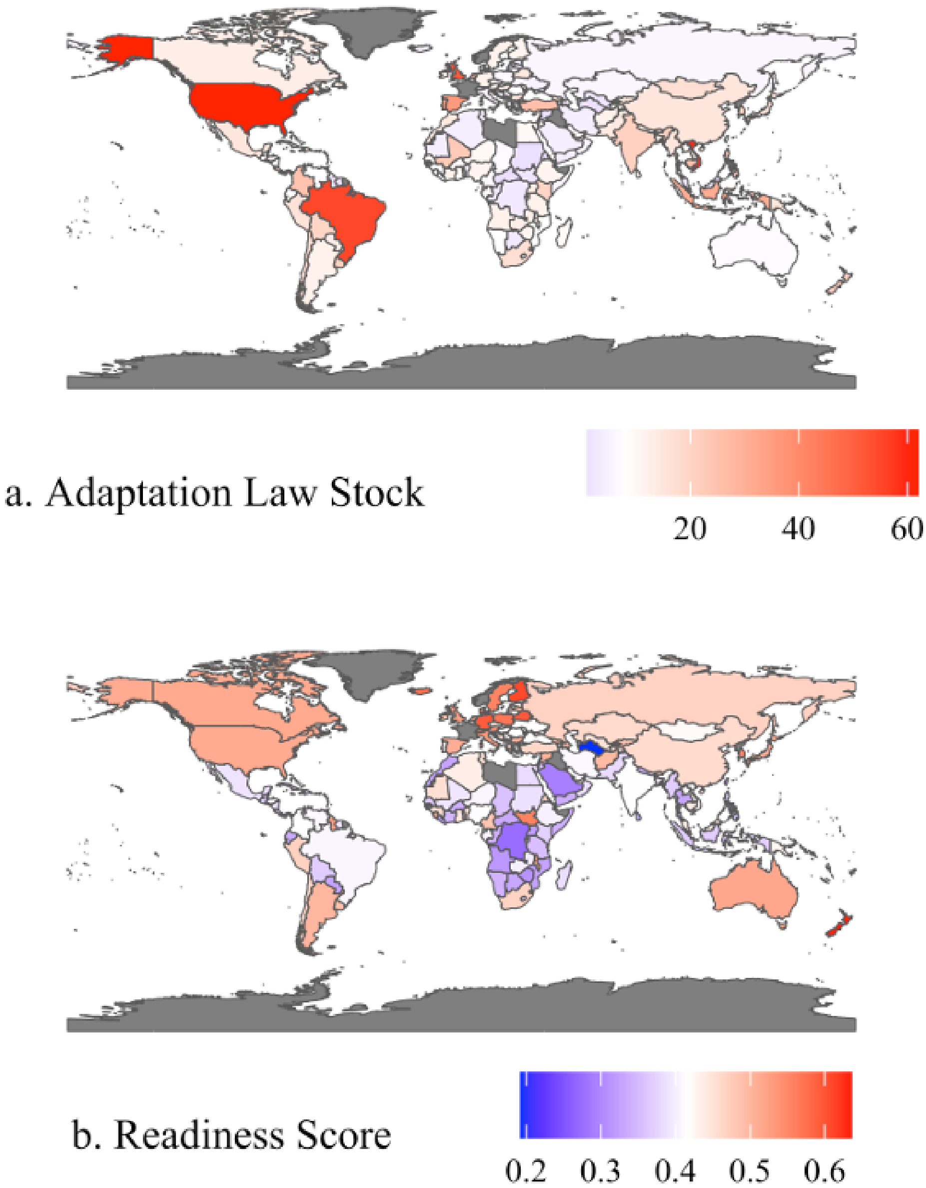

Fig. 3 Adaptation Law Stock and Average Readiness by Country

Note: This figure shows a global map of climate adaptation laws and readiness scores based on the Grantham Institute's database and ND-GAIN respectively.

Our research underscores the critical importance of temporal dynamics in our understanding of climate adaptation policies. As global temperatures rise and extreme weather events become more frequent, the need for proactive and timely action has never been more urgent. By shifting the focus from the mere implementation of policies to a nuanced understanding of *when* these policies yield desired outcomes, we reveal important insights for policymakers and scholars alike.

While an aggregate regression analysis shows no meaningful relationship between adaptation laws and climate readiness, when we use segmented regression analysis, we uncover new patterns indicating a significant correlation between adaptation laws and readiness at some important critical junctures. Our results identified distinct periods of transformation in adaptation policies, shaped by socio-economic and political factors. Particularly noteworthy is the importance of exogenous factors, the Rule of Law, and regional variations for adaptive readiness.

Overall, our research calls for proactive efforts in combating the impacts of climate change. By recognizing and addressing the unique challenges presented by different eras and exogenous global dynamics, policymakers can develop more effective and resilient adaptation strategies, capable of withstanding the test of time and varying external pressures. Future research should delve deeper into understanding why legal frameworks on climate adaptation are fragmenting, particularly in light of the observed trends.

3 Online Methods

This section details the data and methods employed in this analysis. All analyses and visualizations were conducted in R. It begins with an overview of the data sources and the variables utilized in the study. Next, the discussion shifts to the Change Point Analysis, highlighting the various statistically meaningful eras, identifying our segments. Following this, the Segmented Panel Linear Regression Models are specified. Finally, robustness is ensured through a discussion of the Hausman, Granger Causality, and Random Forest Variable Importance test results.

3.1 Data

Data for the dependent variable, *Climate Readiness*, was obtained from the Notre Dame Global Adaptation Initiative (ND-GAIN) [28]. We lag our dependent variable to account for short-term (t-1) and long-term (t-7) effects. Data for the main independent variable, *Adaptation Law Stock*, was collected from the Grantham Institute Climate Change Laws of the World database [27]. Additionally, we control for economic indicators such as *GDP (PPP) (logged)*, *GDP^2 (PPP)* (to account for Kuznets curve dynamics, see Equation 1 below), *Imports of Goods and Services* as a percent of GDP, and *Services Value Added* as annual percent growth, all of which come from the World Bank.

$$I = \alpha + \beta_1 \mathrm{GDP} + \beta_2 \mathrm{GDP}^2 + \epsilon \tag{1}$$

where the positive impact of GDP on inequality is offset by the negative impact of GDP squared. This indicates that while initial economic growth can exacerbate inequality, sustained development may ultimately promote greater equity, reflecting the complexities of economic advancement and social welfare. The variable I represents the level of income inequality in an economy, measured by indices such as the Gini coefficient. The constant α denotes the baseline level of inequality when GDP is zero. The coefficient β_1 indicates the positive effect of GDP on income inequality during early economic development, while GDP represents the gross domestic product, a measure of economic activity. The coefficient β_2 reflects the negative effect of GDP^2 on inequality, capturing the decline in inequality as development continues. Lastly, ϵ represents the error term, accounting for other factors influencing inequality not included in the model.

The World Bank Governance Indicators provided data on the *Rule of Law*, reflecting the legal and institutional framework within which adaptation measures are implemented. Furthermore, as federalism increases the number of veto players, making it more difficult to implement policy, we control for *Federalism* using the Database of Political Institutions 2017 (DPI2017) [33].

3.1.1 Change Point Analysis

To identify significant shifts in the nature of climate laws over time, we execute a change point analysis using the Grantham Institute's Climate Change Laws of the World Data, which is presented in Figure 2 in the main text. This analysis focuses on the post-1988 period, as climate laws were relatively infrequent, and trends were stable prior to this year. The change point analysis fitted a piecewise constant model to the climate laws data, identifying statistically meaningful points in time where the mean of aggregated percent change in climate law features changed significantly. These features included the category of laws (e.g., legislative, executive, UNFCCC, domestic), document type (e.g., constitutional, framework, decree, policy, etc.), and response type (e.g., mitigation, adaptation, loss and damage, disaster risk management). The three statistically meaningful change points identified in the analysis are 1998, 2008, and 2016, providing us with four distinct eras for analysis. By examining these features over time, the analysis provides insights into the changing nature of climate legislation and potential shifts in policy priorities. With these eras distinguished, we can then test the effectiveness of such shifts.

Equation 2 captures the mean squared error change points and is specified as:

$$\text{MSE}(k) = \sum (y_i - \mu_i)^2 \tag{2}$$

where $\text{MSE}(k)$ represents the mean squared error for a model with k change points, y_i is the observed value at time i, and μ_i is the estimated mean for time i based on the piecewise constant model.

3.2 Panel Linear Segmented Regression Models

To identify significant shifts in the nature of climate laws over time, we employ a panel linear regression analysis with robust standard errors and high-dimensional fixed effects. This analysis covers observations from 1960 to 2023 across 190 countries. First, we construct a comprehensive model, encompassing all time periods (non-segmented) to assess the collective impact of *adaptation laws* on *adaptive readiness* across the full temporal span of the data. Next, we segment the data into four distinct time periods to explore how this relationship evolved over time, using segmented panel linear regression models for each period.

The standard relationship of our dependent and main independent variable across eras is specified in Equation 3:

$$\text{Adaptive Readiness}_{it} = \beta_0 + \beta_1 \times \text{Adaptation Law Stock}_{it} + \cdots + u_{it} \tag{3}$$

where Adaptive Readiness$_{it}$ represents the lagged adaptive readiness in country i at time t, Adaptation Law Stock$_{it}$ represents the stock of adaptation laws in country i at time t, β_0 represents the intercept term, β_1 is the coefficient indicating the effect of the stock of adaptation laws on lagged adaptive readiness, and u_{it} represents the error term. Two models are calculated to measure both the short-term $(t-1)$ and long-term $(t-7)$ associations between climate adaptation policies and climate-related resilience.

3.3 Robustness

This section assesses the robustness of the analytical models employed in this study. It begins with the Hausman test results, which compare the Fixed Effects Model (FEM) and Random Effects Model (REM) to ensure the appropriateness of the selected model. Following this, the Looped Granger Causality Test evaluates the causal direction between adaptation laws and climate readiness scores. Finally, the Random Forest Variable Importance analysis identifies key predictors influencing climate readiness, demonstrating a strong variable selection process that enhances the model's predictive accuracy. Collectively, these analyses substantiate the robustness and validity of the research findings.

3.3.1 Hausman Test Results

The Hausman test was conducted to compare the Fixed Effects Model (FEM) and the Random Effects Model (REM). The null hypothesis states that both models are consistent, which implies that the Random Effects estimator is appropriate. The test statistic can be expressed in Equation 4 as:

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'[\mathrm{Var}(\hat{\beta}_{FE}) - \mathrm{Var}(\hat{\beta}_{RE})]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE}) \tag{4}$$

where $\hat{\beta}_{FE}$ represents the coefficients estimated by the Fixed Effects Model, while $\hat{\beta}_{RE}$ denotes the coefficients estimated by the Random Effects Model. The term $\mathrm{Var}(\hat{\beta}_{FE})$ indicates the variance of the coefficients from the Fixed Effects Model, and $\mathrm{Var}(\hat{\beta}_{RE})$ refers to the variance of the coefficients from the Random Effects Model. The results of the Hausman test are as in Table 4:

Table 4 Hausman Test

Statistic	Value
Chi-squared statistic	30.057
Degrees of freedom	8
P-value	0.0002

Given the results, we reject the null hypothesis, indicating that the Random Effects model is inconsistent. This suggests that the Fixed Effects Model should be preferred for this analysis, as the unique errors (individual-specific effects) are likely correlated with the regressors in the model. Therefore, the fixed effects model is what is used in the main analyses.

3.3.2 Looped Granger Causality Test

The Granger causality test is a statistical hypothesis test used to determine whether one time series can predict another. In the context of this analysis, we are testing the equation shown in Table 1 above, where X represents *adaptation laws* and Y denotes the *climate readiness score* in the full sample. This test assesses whether past values of adaptation laws (X) provide any information about future values of the climate readiness score (Y). The underlying premise is that if adaptation laws Granger-cause the climate readiness score, it suggests a predictive relationship between the two, providing evidence on the direction of their relationship. The Granger causality test can be formulated by Equation 5:

$$Y_t = \alpha + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=1}^{q} \theta_j X_{t-j} + \epsilon_t \tag{5}$$

where Y_t represents the *climate readiness score*, the dependent variable being predicted, while X_t denotes the *adaptation laws*, the independent variable tested for Granger causality. The parameters p and q indicate the number of lags for Y and X, respectively. The constant term is represented by α, and the coefficients for the respective lagged variables are denoted by β_i and θ_j. Finally, ϵ_t represents the error term in the model. The median results from the looped Granger causality test are in Table 5:

Table 5 Granger Causality

Statistic	Value
Median F-value	4.826856
Median P-value	0.03241531

The Granger causality tests across the panels indicate that there are 104 countries with significant relationships at the 0.05 level. The median F-value across panels was 4.827 with a standard deviation of 6.131 . The median p-value across panels was 0.032 with a standard deviation of 0.283. These results suggest that adaptation law stock significantly influences lagged readiness in most countries.

3.3.3 Random Forest Variable Importance

To investigate the factors influencing climate readiness, we employed a Random Forest (RF) model. This ensemble learning method is particularly effective for regression tasks, as it builds multiple decision trees and aggregates their predictions, thereby enhancing accuracy and controlling overfitting. The RF model is beneficial in handling complex interactions and non-linear relationships among variables without the need for explicit model specification. Equation 6 for the RF model can be expressed as follows:

$$\text{Readiness} = f\begin{pmatrix} \text{Adaptation Laws,} \\ \text{Rule of Law,} \\ \text{GDP,} \\ \text{GDP}^2\text{,} \\ \text{Services,} \\ \text{Imports,} \\ \text{Federalism,} \\ \text{Climate Exposure} \end{pmatrix} \tag{6}$$

where *Readiness* represents the climate readiness score lagged by one period, while the other variables denote the predictors included in the analysis. This formulation allows us to assess how each factor contributes to the overall readiness in the context of climate adaptation. The results of the variable importance analysis are illustrated in Figure 4, which shows the significance of each variable in predicting Climate Readiness.

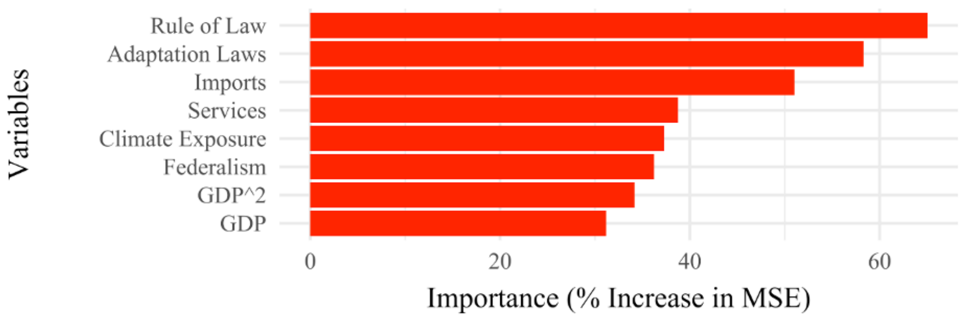

Fig. 4 Random Forest Variable Importance

Note: The variable importance plot displays the significance of various factors influencing climate readiness. Each bar represents the percentage increase in mean squared error (%IncMSE) when the respective variable is permuted, highlighting how each contributes to the model's predictive accuracy.

The variable importance analysis depicted in Figure 4 underscores the robustness of our variable selection for the climate readiness model. Notably, the *Rule of Law* emerges as the most significant predictor, with a mean increase of approximately 65% in mean squared error upon permutation, highlighting its critical influence on climate adaptation outcomes. Similarly, *Adaptation Laws* exhibit a substantial importance score of around 58%, further validating the necessity of effective regulatory frameworks in enhancing climate readiness. The inclusion of these variables, alongside others such as *Imports as a Percentage of GDP*, *Percentage of GDP from Services*, *Climate Vulnerability*, and *Autocracy*, demonstrates a well-informed selection process that captures the multifaceted nature of climate readiness, thus reinforcing the model's predictive accuracy and theoretical underpinnings.

Data Availability Statement. Data come from the following publicly available sources, and the final dataset used in the analysis and visuals will be posted via the authors' GitHub [redacted for DBPR] and via Code Ocean.

- Grantham Institute Climate Change Laws of the World
- Notre Dame Global Adaptation Initiative
- World Bank World Development Indicators
- World Bank Worldwide Governance Indicators
- The Database of Political Institutions 2020 (DPI2020)

Code Availability Statement. All code was developed in RStudio and will be publicly available on the authors' GitHub [redacted for DBPR] and via Code Ocean.

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Appendix A Development, Laws, and Countries

Below, Table A1 summarizes the number of laws, unique countries involved, and the percentage of countries in the Global North over various time periods that are meaningful to this analysis.

Table A1 Number of Laws, Unique Countries, and Percentage of Countries in the Global North by Time Window

Time Window	**Number of Laws**	**Unique Countries**	**Percentage of OECD Countries**
Up to 1996	122 laws	58 countries	29.31%
1997-2006	454 laws	130 countries	26.15%
2007-2015	1872 laws	198 countries	18.69%
2016 onwards	4259 laws	201 countries	18.41%

Appendix B Trends in Category, Response, and Document Types Across Eras

Below, Table B2 details the categories, responses, and types of documents associated with climate policies from 1996 to the present across our eras of interest.

Table B2 Category, Response, and Document Types

	Executive	**Legislative**	**UNFCCC**	**Domestic**
Category (%)				
Up to 1996	13.93	86.07	0.00	100.00
1997-2006	37.22	62.56	0.22	99.78
2007-2015	58.44	36.49	5.07	94.93
2016 onwards	42.78	12.63	44.59	55.41
	Adaptation	**Mitigation**	**Loss & Damage**	**Disaster Risk Management**
Response (%)				
Up to 1996	50.00	59.02	2.46	31.97
1997-2006	25.99	84.58	0.66	10.57
2007-2015	41.68	70.57	1.76	11.86
2016 onwards	25.91	45.62	1.27	6.25
	Act	**Policy**	**Law**	**Plan**
Document Types (%)				
Up to 1996	24.59	5.74	57.38	1.64
1997-2006	12.33	10.35	43.17	5.51
2007-2015	5.72	10.37	24.97	10.05
2016 onwards	4.04	3.90	4.98	12.36

Appendix C Trends in Global Climate Commitments

Below, Table C3 outlines significant global climate commitments made through international agreements, highlighting key legal milestones over the years.

Table C3 Global Climate Commitments

Year	Name of Commitment/Agreement
Up to 1996	1992: United Nations Framework Convention on Climate Change
1997-2006	1997: Kyoto Protocol (COP3)
	2001: Bonn Agreement
	2005: Montreal Action Plan
2007-2015	2007: Bali Road Map (COP13)
	2009: Copenhagen Accord (COP15)
	2010: Cancun Agreements (COP16)
	2011: Durban Platform (COP17)
	2012: Doha Amendment (COP18)
	2013: International Warsaw Mechanism (COP19)
	2015: Paris Agreement
2016 onwards	2016: Kigali Amendment to the Montreal Protocol
	2018: Katowice Rulebook
	2021: Glasgow Climate Pact