Food Policy in a Warming World

Allan Hsiao*
Princeton University

Jacob Moscona†
Harvard University

Karthik A. Sastry‡
Princeton University

December 7, 2023

Abstract

This paper studies the interaction between climate change and agricultural policy. Using a model of tax policy in an open agricultural economy, we show that the effect of climate shocks on policy is theoretically ambiguous and depends on how the government weighs constituent welfare against fiscal revenue. To study these relationships empirically, we construct a new global dataset of agricultural policy, trade, production, and extreme heat exposure by country and crop from 1980 to 2011. We find that extreme heat shocks to domestic production lead to consumer assistance, particularly in election years when politicians may prioritize redistribution over revenue. Extreme heat shocks to import partners lead to producer assistance, implying that foreign policy responses may partially offset, rather than amplify, domestic policy responses. Our estimates, combined with the model, suggest that endogenous trade policy explains 14% of predicted damages from end-of-century climate change, with stark distributional consequences both within and across countries. Our results underscore how climate change affects agricultural policy, which in turn shapes adaptation to global warming.

*Princeton University, Department of Economics. Email: ajhsiao@princeton.edu.
†Harvard University, Department of Economics. Email: moscona@fas.harvard.edu.
‡Princeton University, Department of Economics. Email: ksastry@princeton.edu.
We are grateful to Kym Anderson for extremely helpful discussions. We also thank Daron Acemoglu, Ishan Nath (discussant), Vincent Pons, and seminar participants at Princeton University and the 2023 NBER Fall Conference on Distributional Impacts of Climate Change on the Agricultural Sector for helpful comments. Luong Nguyen provided exceptional research assistance.

1 Introduction

In March 2022 a major heat wave in India reduced India's wheat production by approximately 100 million metric tons, or 11% of expected output (Beillard and Singh, 2022). Citing food security risks, India's government decided on May 13 to ban all wheat exports. While this policy change had potential benefits for Indian consumers, it was met with hostility by farmers. Ashok Gulati, former chairman of India's Commission for Agricultural Costs and Prices, stated in an interview with India Today that the policy was "anti-farmer" and painted "a very sorry picture" of India's role in global commerce (India Today Television, 2022). In 2023 alone, a similar story could be told for palm oil in Indonesia, rice in India and Myanmar, olives in Spain and Turkey, onions in Kenya and Tanzania, and potatoes and tomatoes in Morocco (Ghosal et al., 2023).

This example has ingredients that we might expect to recur in the coming decades as climate change intensifies. First, increased incidence of extreme heat will alter agricultural productivity, affecting both consumers and producers of agricultural commodities. Second, governments will react to climate change by making policy changes that balance different stakeholders' interests. These changes will interact with the extensive policy distortions that already exist in the agricultural sector (see, e.g., Anderson et al., 2013). Third, these policy choices could mitigate or exacerbate the consequences of a changing climate, both domestically and globally.

In this paper, we study the interaction between climate change and agricultural policy. Does agricultural policy systematically respond to increasingly extreme climatic conditions, as the examples above suggest? If so, how and why? And what implications does this policy response have for international adaptation to climate change?

Theory. To illustrate the theoretical ambiguity of our questions, we begin with a model of agricultural policy in an open agricultural economy. A government sets a border tax that distorts the domestic price relative to the international price to maximize a weighted sum of producer surplus, consumer surplus, and government revenue.

We first characterize optimal trade policy. When the government is utilitarian, tariffs are simple Ramsey (1927) "inverse elasticity" rules that equate marginal revenue and marginal deadweight loss. When the government cares about redistribution, it has further incentives to increase or decrease domestic prices to assist producers or consumers, respectively.

We next study how optimal trade policy responds to climate shocks that restrict domestic supply. We characterize the sign of the policy response as a function of the government's relative preference weights and the domestic elasticities of supply and demand. The key condition is whether the government is *constituent-* or *revenue-focused*. A constituent-focused government places higher weight on producer and consumer surplus relative to government revenue. For such a government, the primary consideration is that reduced domestic supply shifts the burden of lowering prices away from domestic producers and toward foreign producers, on whom the government places no weight. Therefore, they respond by adjusting policy to be more pro-consumer. In the opposite case of a revenue-focused government, the dominant concern is that a domestic supply shortage is the most expensive time to subsidize imports (or the least profitable time to tax exports). Therefore, they respond by adjusting policy to be more pro-producer. Critically, this logic differs from what determines the *level* of trade policy. A pro-producer government can subsidize production but still respond to shocks by reducing that assistance; a pro-consumer government could do the opposite.

We also show that foreign climate shocks, which we model as negative import supply shocks, have the opposite effects of domestic shocks. The intuition is the mirror image of the above: during an import supply shortage, a constituent-focused government focuses on the fact that increasing domestic prices does more to help domestic farmers, while a revenue-focused government focuses on the fact that it is more expensive to protect producers.

In further results, we highlight implications for the economic consequences of climate change. "Climate adaptation" through trade policy creates winners and losers. International spillovers can reinforce the initial change in trade policy, consistent with a hypothesis in popular discourse about food policy "contagion." But this is not a foregone conclusion: the model predicts international *dampening* when countries are constituent-focused, as foreign policy responses partially offset domestic responses. Our quantitative exercise below will identify relative winners and losers and account for equilibrium interactions at global scale.

Data and Measurement. We investigate the relationship between climate shocks and agricultural policy by exploiting the differential exposure of country-crop pairs to extreme heat over time. We construct a new global data set that captures exposure to extreme temperature for every crop-by-country pair in each year since 1980. Combining gridded, global data on daily temperature realizations from the ERA-5 dataset (Muñoz-Sabater et al., 2021) with expert-elicited estimates of the maximum growing temperature for individual plant species, we measure the potential exposure of a given crop to extreme heat in a given country over a specific period (Moscona and Sastry, 2023). We use these data to construct crop-specific exposure to extreme heat for each country and each year since 1980. We measure crop-specific agricultural policy across countries with data from the World Bank's "Distortions to Agricultural Incentives" project (Anderson and Valenzuela, 2008; Anderson, 2009). This database reports price distortions for 80 agricultural products and 81 countries, covering about 85% of global agricultural production (Anderson et al., 2013). The project was built from a large set of country-specific policy studies that investigated changes in commodity support over time, which it reports as the "nominal rate of assistance" (NRA) for each country, crop, and year. We take the NRA as our main measure of market intervention. Finally, to measure production and trade, we rely on data from the UN FAOSTAT database.

We validate our measure of extreme heat exposure as a negative shock to agricultural productivity. We document that higher values of extreme heat exposure are associated with substantially lower crop yields. We estimate a regression model that absorbs two-way fixed effects at the country-by-decade level, country-by-crop level, and crop-by-decade level. These fixed effects isolate the differential exposure of different crops *within* a country to temperature trends to identify effects on production and consumption. This approach stands in contrast to existing work, which is based purely on cross-country variation for individual crops (e.g., Lobell and Field, 2007; Lobell et al., 2011). Using this precise variation and comprehensive global data, we estimate that top-quartile extreme heat exposure reduces productivity by over 20% compared to the bottom quartile.

Empirical Results. We then turn to our main results. First, we document that extreme heat exposure substantially reduces NRA. This reduction corresponds to a *pro-consumer* policy change. Through the lens of our model, this finding is consistent with trade policy driven by constituent focus. We find larger effects when focusing on the most economically important crops, and we show that the results are driven by staple crops rather than cash crops. There is no evidence of pre-existing trends in the relationship between extreme heat and policy, but the effect persists for several years after the extreme heat shock itself.

Second, we investigate how *foreign* extreme heat exposure affects agricultural policy. For each country-crop pair, we construct a measure of import-weighted exposure to foreign extreme heat shocks. We find climate shocks lead to more producer-oriented policy, partially offsetting the response to domestic shocks and serving to expand international access to agricultural commodities. International interactions thus serve as a stabilizing, rather than amplifying, force globally. This finding is consistent with our model, but inconsistent with popular narratives of food policy "contagion" (Ghosal et al., 2023) and "multiplier effects" (de Guzman, 2022).

Third, we study long-run, decade-to-decade changes in climate and policy. In principle, short-run responses could differ from long-run responses if there is mean reversion in policy or adaptation via production techniques and trade. However, we estimate decade-level effects of extreme heat on policy that are similar to our baseline estimates and, if anything, slightly larger. This finding is consistent with our dynamic event study estimates, which suggested a persistent effect of weather fluctuations on policy.

Fourth, we test for evidence of our key model mechanism centered around constituent vs. revenue focus. A large body of work documents the existence of "political cycles," in which upcoming elections lead governments to place less emphasis on fiscal responsibility.[1] Consistent with our proposed mechanism, our findings are more pronounced in years during or immediately preceding elections. The effect of an extreme heat shock on policy is almost four times as large in magnitude, and the difference is statistically significant. Political incentives shape policy responses to climate change.

Quantification: Policy and Climate Adaptation. Finally, we combine our model and empirical estimates to quantify how policy responses affect aggregate climate damages. We simulate the effects of global end-of-century climate change (2091-2100), as well as "heat waves" in each continent that match in-sample weather extremes. The former highlights how food policy shapes the global and distributional consequences of climate change. The latter highlights how food policy shapes the international consequences of region-specific environmental shocks that are already happening today.

Endogenizing trade policy exacerbates welfare loss from end-of-century climate change by 14%. However, this aggregate finding masks stark heterogeneity. Consumer-oriented policy reduces losses for consumers in more climate-affected regions, but it increases losses for producers in more climate-affected regions and for consumers in less climate-affected regions. A similar story emerges when we focus on continent-specific heat waves. Endogenous policy reduces losses for consumers in the affected continent, but it increases losses for producers in the affected continent and for consumers in the rest of the world.

These results highlight how endogenous food policy shapes economic losses from climate damage to the agricultural sector. Perhaps even more importantly, they show that policy drastically changes the distribution of those losses across producers and consumers in different regions of the world.

Related Literature. Our main contribution is to show how endogenous agricultural policy affects the aggregate and distributional effects of climate shocks. A large literature in environmental economics quantifies the large negative impacts of climate shocks on agricultural production (Mendelsohn et al., 1994; Deschênes and Greenstone, 2007; Lobell and Field, 2007; Schlenker and Roberts, 2009; Lobell et al., 2011; Ortiz-Bobea et al., 2021; Ortiz-Bobea, 2021). Costinot et al. (2016) shows how global adaptation via trade can reduce these losses, and others study how trade interacts with crop switching (Baldos et al., 2019; Hultgren et al., 2022), land and water use (Gouel and Laborde, 2021; Carleton et al., 2022), labor and sectoral reallocation (Rudik et al., 2022; Nath, 2023), and migration and innovation (Cruz and Rossi-Hansberg, 2023). Each takes trade costs as fixed. We document that trade policy

[1] See Nordhaus (1975), Rogoff (1990), Alesina and Roubini (1992), and Akhmedov and Zhuravskaya (2004), as well as Balboni et al. (2021) for a recent application to forest fires in Indonesia.

responds to climate shocks, and we quantify the implications for global adaptation.[2]

In studying the role of policy, we connect to a long-standing literature in international trade that studies distributional motivations for trade policy. This work examines trade policy motivated by redistribution or political favoritism (Grossman and Helpman, 1994; Goldberg and Maggi, 1999; Fajgelbaum et al., 2020; Adão et al., 2023) and terms-of-trade manipulation (Johnson, 1953; Putnam, 1988; Bagwell and Staiger, 1999; Grossman and Helpman, 1995; Ossa, 2014). Baldwin (1989), Rodrik (1995), and Gawande and Krishna (2003) review the resulting political considerations. We model trade policy as a function of these redistributive and revenue motives, and we study welfare implications for the agricultural sector. This sector is subject to wide-ranging distortions, which an important literature measures across countries and crops (Johnson, 1991; Anderson, 2009; Anderson and Masters, 2009; Anderson et al., 2013; Bates, 2014). We quantify how they shape global resilience to the increasing volatility of a warming world.

Outline. Section 2 presents the model and theoretical results. Section 3 introduces our data and measurement strategies. Section 4 presents our main empirical results. Section 5 quantifies the implications of our findings in several counterfactual exercises. Section 6 concludes.

2 Theory

To understand the origins of trade policy distortions and their possible responses to shocks, we first introduce a model. We show that both a desire for terms-of-trade manipulation and a desire to redistribute between consumers and producers can motivate distortionary trade policy. A condition on the government's preferences and the domestic elasticity of supply and demand, which we refer to as *constituent focus* versus *revenue focus*, determines whether an adverse domestic supply shock induces a pro-consumer or pro-producer policy shift. In further results, we draw out the implications for the response to international productivity shocks, international policy spillovers, and domestic adaptation.

2.1 Set-up

We study an equilibrium model of the market for one crop in a country open to trade. Consumer demand is represented by a decreasing, continuously differentiable demand function $Q : \mathbb{R}_+ \to \mathbb{R}_+$, which depends on the price $p \in \mathbb{R}_+$. Domestic supply is represented by

[2] Bastos et al. (2013) study how rainfall shocks affect agricultural tariffs. Our results are consistent with their finding that country-level rainfall shortages lead to lower agricultural import tariffs.

a strictly increasing, continuously differentiable supply function $Y : \mathbb{R}_+ \times \mathbb{R} \to \mathbb{R}_+$, which depends on both the price and a domestic supply shock $\omega \in \mathbb{R}$. We assume that $Y(p, \cdot)$ is decreasing for all values of $p \in \mathbb{R}_+$, so ω is an adverse event (e.g., extreme temperatures). Similarly, international net supply is represented by an increasing, continuously differentiable function $M : \mathbb{R}_+ \times \mathbb{R} \to \mathbb{R}$, which depends on the price and an international supply shock $\omega' \in \mathbb{R}$. We assume that $M(p, \cdot)$ is decreasing for all $p \in \mathbb{R}_+$, so ω' is also an adverse shock. When net supply is positive, then the studied country is a net importer; when net supply is negative, then the country is a net exporter. To ensure that an equilibrium exists, we assume that $\lim_{p\to 0} Q(p) = \infty$, $\lim_{p\to\infty} Q(p) = 0$, $\lim_{p\to 0} Y(p, \omega) = 0$, and $\lim_{p\to\infty} Y(p, \omega) = \infty$ (where the latter two hold for all ω). Finally, we let q, y, and m respectively denote realized quantities demanded (consumed), produced, and imported.

We study equilibrium under a tax $\tau \in \mathbb{R}$ that creates a wedge between domestic prices and international prices. The market clears at some domestic equilibrium price $p^* \in \mathbb{R}_+$ if

$$Q(p^*) = Y(p^*, \omega) + M(p^* - \tau, \omega') \tag{2.1}$$

If $\tau > 0$, then the domestic equilibrium price is higher than the international price. In this case, imports ($m > 0$) are being taxed or exports ($m < 0$) are being subsidized. If $\tau < 0$, then the domestic equilibrium price is lower than the international price. In this case, imports ($m > 0$) are being subsidized and exports ($m < 0$) are being taxed.

Under our maintained monotonicity, differentiability, and limit-value assumptions on Q, Y, and M, the equilibrium price is unique can be represented by a function $P^* : \mathbb{R}^3 \to \mathbb{R}_+$ that depends on (τ, ω, ω') that is differentiable and increasing in the first argument (i.e., import taxes or export subsidies increase the domestic price).

The government sets an optimal border tax $\tau^* \in \mathbb{R}$ to maximize a weighted sum of consumer surplus, producer surplus, and government revenue. That is,

$$\begin{aligned} \tau^* \in \underset{\tau\in(-\infty,p^*)}{\arg\max} & \left\{ \lambda^C \int_{p^*}^{\infty} Q(p)\,\mathrm{d}p + \lambda^P \int_0^{p^*} Y(p,\omega)\,\mathrm{d}p + \lambda^G \tau M(p^* - \tau, \omega') \right\} \\ \text{s.t. } & p^* = P^*(\tau, \omega, \omega') \end{aligned} \tag{2.2}$$

where $\lambda^C, \lambda^P, \lambda^G \in \mathbb{R}_+$ are exogenous parameters specifying the relative weights on each payoff component. We make the simplifying assumption that Program 2.2 is globally concave in τ. To ensure an interior solution, we assume that $\frac{\partial M}{\partial p}\frac{p}{m} \notin (-1, 1)$.[3]

In a general equilibrium production economy (e.g., as in Dixit, 1985; Adão et al., 2023),

[3] Intuitively, this rules out cases in which the government's tax revenue function, acting as a monopolist or monopsonist in the international market, is not concave.

consumer and producer surplus can map to the utilities of two separate agents that have quasi-linear preferences. The former obtains income from an endowment of the outside good, and the latter obtains income completely from producing and selling the agricultural commodity. While this structure is extreme, we believe it stylizes the trade-off between consumer and farmer welfare that is front-and-center in the popular discourse and political debate surrounding our motivating examples. An alternative approach would be to focus on Pareto second-best-efficient policies in an economy with heterogeneous consumers, who differ in their consumption and income exposures to the agricultural good, and a fixed transfer rule (Adão et al., 2023). We conjecture that our basic insights about the ambiguity of the sign of distortionary policy and its response to shocks would hold trivially in such an economy (with no more restrictions), but we would not be able to characterize more sharply the economic determinants of these predictions.

2.2 What Determines Trade Policy?

We first study what determines trade policy for a fixed level of productivity. Since Program 2.2 is concave and differentiable, a necessary and sufficient condition for optimality of an interior tariff is that the first-order benefit of changing τ is zero. That is,

$$0 = \frac{\partial P^*(\tau,\omega,\omega')}{\partial \tau}\left(-\lambda^C x + \lambda^P y\right) + \lambda^G m + \lambda^G \tau \frac{\partial M(p^* - \tau, \omega')}{\partial p}\left(\frac{\partial P^*(\tau,\omega,\omega')}{\partial \tau} - 1\right) \quad (2.3)$$

The first term measures marginal redistribution between producers and consumers. Raising τ raises domestic prices, which benefits producers in proportion to their production and hurts consumers in proportion to their consumption. The second and third terms measure the marginal changes in government revenue.

Toward deriving the optimal tariff, we define the equilibrium demand, supply, and import elasticities as

$$\epsilon_d = \left.\frac{\partial X}{\partial p}\right|_{p=p^*} \frac{p^*}{x}, \qquad \epsilon_s = \left.\frac{\partial Y}{\partial p}\right|_{p=p^*} \frac{p^*}{y}, \qquad \epsilon_m = \left.\frac{\partial M}{\partial p}\right|_{p=p^*-\tau} \frac{p^* - \tau}{m} \quad (2.4)$$

Under our conventions, $\epsilon_m > 0$ when $m > 0$, or the country is a net importer, and $\epsilon_m < 0$ when $m < 0$, or the country is a net exporter. To simplify the expressions below, we drop the dependence of each of these elasticities on (p, ω, ω'). We define the import share as

$$s_m = \frac{m}{q} \quad (2.5)$$

and observe that $s_m \in (-\infty, 1]$: negative imports correspond to net exports, but imports cannot exceed domestic consumption. We finally define the following transformation of the policy variable which equals the proportional deviation of domestic prices from border prices, or *ad valorem* border tax:

$$\alpha = \frac{\tau}{p^* - \tau} \tag{2.6}$$

This will correspond to our empirical definition of Nominal Rates of Assistance (NRA).

Optimal Policy. We derive the following equation that characterizes optimal policy:

Proposition 1 (Optimal Trade Policy). *The optimal trade policy satisfies:*

$$\alpha^* = \frac{1}{\epsilon_m}\left(\frac{\lambda^G\left((1-s_m)\epsilon_s - \epsilon_d\right) + \epsilon_m\left(\lambda^P(1-s_m) + \lambda^G s_m - \lambda^C\right)}{\lambda^G\left((1-s_m)\epsilon_s - \epsilon_d\right) - \left(\lambda^P(1-s_m) + \lambda^G s_m - \lambda^C\right)}\right) \tag{2.7}$$

Proof. See Appendix A.1 □

To obtain intuition for this expression, consider first the case in which $\lambda^P = \lambda^C = \lambda^G$. This corresponds to fully transferable utility—that is, "as if" transfers through prices are meaningless in this benchmark. In this case, the optimal rate of assistance reduces to $\alpha^* = 1/\epsilon_m$, which is a familiar "inverse elasticity rule" or "Ramsey rule," obtained from setting marginal revenue equal to marginal deadweight loss (see, e.g., Limão, 2017). For a net importer, the Ramsey rule implies producer support via an import tax; for a net exporter, it implies consumer support via an export tax.

We next consider the general case. A second determinant of optimal policy is the government's desire for redistribution. To the first order, increasing the price transfers surplus away from consumers and toward producers and affects tax revenue indirectly through net imports. The extent of this pecuniary transfer scales with the price impact of marginal trade policy. That price impact is high when domestic supply and demand are relatively inelastic and when the import share is high.

When do Governments Support Producers *vs.* Consumers? Proposition 1 reveals forces that push toward either positive or negative τ. We next give a condition that characterizes the sign of τ as a function of primitive welfare weights, import shares, and elasticities:

Corollary 1 (Producer *vs.* Consumer Support). *The government supports producers ($\alpha > 0$) if and only if*

$$\lambda^C < \lambda^P(1-s_m) + \lambda^G s_m + \frac{\lambda^G}{\epsilon_m}\left((1-s_m)\epsilon_s - \epsilon_d\right) \tag{2.8}$$

The government imposes no taxes or subsidies if the above holds at equality, and the government supports consumers if the opposite inequality holds strictly. Moreover, sign$[\alpha]$ *decreases* *in λ^C and increases in λ^P. For a net importer, sign$[\alpha]$ increases in ϵ_s and $|\epsilon_d|$; for a net exporter, sign$[\alpha]$ decreases in ϵ_s and $|\epsilon_d|$*

Proof. See Appendix A.2. □

A high consumer weight pushes the government to subsidize imports or to tax exports. A high producer weight pushes the government to subsidize exports or to tax imports. These predictions follow intuitively from the pecuniary distribution channel described above.

Relatively inelastic supply and demand increase the relative importance of the redistribution motive, for fixed $(\lambda^C, \lambda^P, \lambda^G)$, relative to the terms-of-trade manipulation motive. Intuitively, inelastic domestic supply and demand increase the government's ability to move domestic prices and, therefore, redistribute via prices for fixed ϵ_m, while not affecting the logic of terms-of-trade manipulation. Whether this pushes toward consumer or producer assistance depends on the sign of ϵ_m or, equivalently, the sign of m. For a net importer, decreasing the importance of redistribution pushes away from the import tax that optimally manipulates terms of trade, and therefore toward consumer assistance; for a net exporter, the opposite is true.

2.3 How Does Trade Policy Respond to Shocks?

We now study the comparative statics of optimal trade policy. That is, in response to a productivity shock at home or abroad, how does trade policy respond?

To study this tractably, we restrict to the case in which the supply, demand, and net import curves have constant elasticity. This isolates equilibrium interactions via the import share s_m, while shutting down the possibility that the optimal extent of terms-of-trade manipulation or the price impact of taxation varies in response to shocks. We furthermore require that $\epsilon_m > \epsilon_s$ or $\epsilon_m < \epsilon_d$: that is, foreign supply (or demand) is more elastic than its domestic counterpart. This guarantees that the import share is increasing in the domestic (adverse) supply shock ω' and decreasing the foreign (adverse) supply shock ω.

Key Condition: Constituent *vs.* Revenue Focus. Toward stating our main results, we define a key condition on government preferences and elasticities of supply and demand that defines whether the government is *constituent-focused* or *revenue-focused*:

Definition 1. *The government is constituent-focused if*

$$\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) > 0 \tag{2.9}$$

The government is revenue-focused if the opposite inequality holds strictly and neutral if the condition holds at equality.

A *constituent-focused* government has relatively high weights λ^C, λ^P on consumers and producers, respectively, and a relatively low weight λ^G on government revenue. Comparing this condition with the comparative statics in Corollary 1, we observe that a constituent-focused government can have pro-consumer or pro-producer policy depending on *which* constituents it values the most. What the condition disciplines, instead, is the relative importance of maximizing domestic welfare versus raising revenue.

Equilibrium Optimal Tariffs. The government's optimal trade policy in Equation 2.7 depends on the endogenous import share. In equilibrium, the import share also depends on the government's policy. The fixed-point of these two relationships in (α, s_m) describes equilibrium. The following Lemma summarizes this, along with several key properties of the equilibrium relationships. We let $\alpha = A^*(s_m)$ denote the optimal producer assistance derived in Proposition 1.

Lemma 1. *A pair* (α^*, s_m^*) *constitutes an equilibrium if*

$$\begin{aligned} \alpha^* &= A(s_m^*) \\ s_m^* &= S(\alpha^*, \omega, \omega') \end{aligned} \tag{2.10}$$

where (i) $\frac{\partial S}{\partial \alpha} < 0$*, (ii)* S *increases in* ω*, and (iii)* S *decreases in* ω'*. Moreover, under an additional assumption of the form*

$$\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) < F(s_m, \epsilon_s, \epsilon_m, \epsilon_d, \lambda^C, \lambda^P, \lambda^G) \tag{2.11}$$

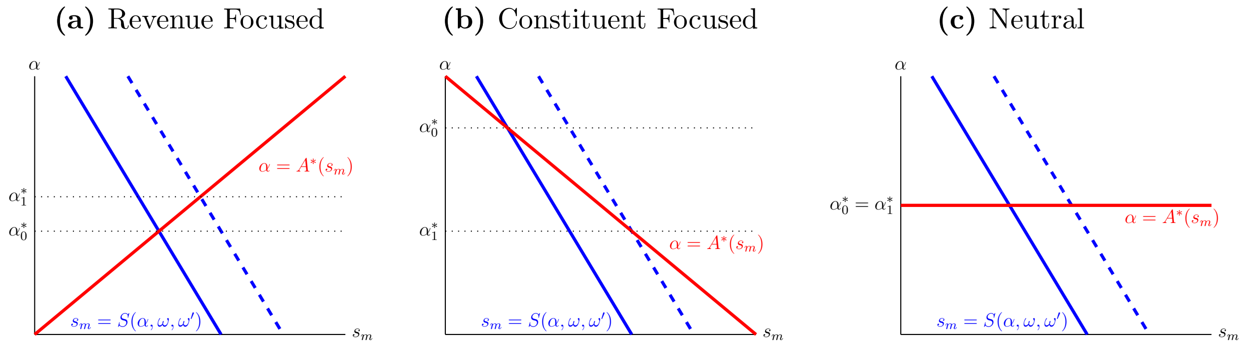
that is given in the proof, then (iv) $\left(\frac{\partial S}{\partial \alpha}\right)^{-1} < \frac{\mathrm{d}A^*}{\mathrm{d}s_m}$.

Proof. See Appendix A.4. □

The first three properties are natural. Holding fixed shocks, the import share decreases in producer assistance (i.e., import taxes or export subsidies); the import share increases when domestic conditions worsen; and the import share decreases when foreign conditions worsen. The fourth property requires an additional technical assumption spelled out in the proof, which guarantees that constituent focus is "not too much." The condition rules out the possibility that the import share falls so quickly in α, that there can be a non-convergent "negative feedback loop" between policy and the import share.[4] We maintain this additional assumption henceforth.

[4]That is, if we defined a *tâtonnement* process in which a shock hit markets, then policy responded, then markets responded, and so forth, we would not converge to a new equilibrium.

Figure 1: Trade Policy and Climate Shocks



Notes: Each panel illustrates a case from Proposition 2, obtained from the equilibrium representation of Lemma 1. The blue lines correspond to the condition $s_m = S(\alpha, \omega, \omega')$. The dashed line corresponds to a higher value of ω or a lower value of ω'. The red line corresponds to the condition $\alpha = A^*(s_m)$. We mark the equilibrium values of α^* on the y-axis.

Policy and Climate Shocks. We can now show our main comparative static result:

Proposition 2 (Policy and Supply Shocks)**.** *The following statements are true:*

1. *If the government is revenue-focused, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) < 0$, *then* α^* *increases in* ω *and decreases in* ω'.
2. *If the government is constituent-focused, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) > 0$, *then* α^* *decreases in* ω *and increases in* ω'.
3. *If the government is neutral, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) = 0$, *then* α^* *is invariant to* ω *and* ω'.

Proof. See Appendix A.5. □

Domestic climate shocks can either induce producer assistance (revenue-focused) or consumer assistance (constituent-focused). In either case, domestic and foreign shocks must always have opposite effects from one another. The proof of this result follows from a graphical argument, visualized in Figure 1.

The revenue-focused government in case 1 of Proposition 2 wants to increase producer assistance when the import share rises. When the import share is higher, the government has a higher marginal incentive to tax imports; when the import share is lower (or export share is higher), the opposite is true. By supporting producers, the government "stabilizes" the original shock to the import share—that is, the import share goes down less than it would have had the government not reacted (Panel (a) of Figure 1). Since domestic prices are increasing in α, this cushions the blow for domestic producers while hurting domestic consumers.

The constituent-focused government in case 2 of Proposition 2 wants to increase consumer assistance when the import share rises. Higher relative imports shift the benefits of increasing prices toward foreigners, while the costs of increased prices are borne by domestic consumers. This gives the government a marginal incentive to pursue a policy that lowers the domestic equilibrium price—that is, consumer assistance. This policy has an indirect effect on the import share that *amplifies* the direct effect, further inducing imports or curbing exports (Panel (b) of Figure 1). For the opposite reason as what is cited above, this cushions the blow for domestic consumers while further harming domestic producers.

Finally, the neutral government keeps policy completely steady in response to the shock. Thus, trade policy does not further tip the scales of winners and losers. A sufficient, but not necessary, condition for case 3 is the utilitarian assumption $\lambda^G = \lambda^P = \lambda^C$.

2.4 Implications for Climate Adaptation

We now describe the model's implications for adaptation to climate change.

Adaptation via Distortions Cannot Help Everyone. So far, we have established that optimal policy can respond to domestic and foreign productivity shocks either by increasing assistance to either consumers or producers. But is this "adaptation?"

To formalize this question, let us consider the case in which there is an adverse domestic climate shock, or a parameter shift from ω_0 to $\omega_1 > \omega_0$. We let $\mathcal{C}(\alpha, \omega)$, $\mathcal{P}(\alpha, \omega)$, and $\mathcal{R}(\alpha, \omega)$ respectively denote consumer surplus, producer surplus, and government revenues as a function of a fixed α and ω, and define the government's payoff as $\mathcal{G}(\alpha, \omega) = \lambda^C \mathcal{C}(\alpha, \omega) + \lambda^P \mathcal{P}(\alpha, \omega) + \lambda^G \mathcal{G}(\alpha, \omega)$. We say that policy "helps an agent's adaptation" if the corresponding surplus is larger under $(\alpha^*(\omega_1), \omega_1)$ than under $(\alpha^*(\omega_0), \omega_1)$. In this language, we can express the following very simple corollary of Proposition 2:

Corollary 2 (Adaptation Through Distortions)**.** *Optimal policy always helps the government's adaptation. The following statements are also true:*

1. *If the government is revenue-focused, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) < 0$*, then optimal policy helps producers' adaptation and hurts consumers' adaptation.*
2. *If the government is constituent-focused, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) > 0$*, then optimal policy helps consumers' adaptation and hurts producers' adaptation.*
3. *If the government is neutral, or* $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) = 0$*, then optimal policy neither helps nor hurts consumers' and producers' adaptation.*

The first part of the result follows directly from the definition of the government's maximization—obviously, optimal policy achieves a higher objective than the old policy.

The next three statements follow from observing that consumer and producer surplus are monotone in domestic prices.

The upshot of this result is that policy responses to climate change are not straightforward to interpret as "adaptation" for an entire country via a simple Pareto criterion. That is, there are winners and losers. Moreover, there are cases in which governments amplify or dampen the direct effects of climate-induced shocks.

Multi-Country Interactions. So far, we have studied the problem of a single country setting trade policy in isolation. We now consider a simple multi-country extension of our baseline framework. Imagine that there are additional countries $\ell \in \{1, \ldots, L\}$, each with demand function Q_ℓ and supply function Y_ℓ. Each country levies its own distortionary producer assistance τ_ℓ. Markets clear internationally. Thus, equilibrium prices in each "foreign" country, p_ℓ^*, can be written as $p_\ell^* = p^w - \tau_\ell = p^* - \tau - \tau_\ell$, where the second equality defines the world price as $p^* - \tau$. Global trade balance requires

$$Q(p^*) - Y(p^*, \omega) = \sum_{\ell=1}^{L} \left(Q_\ell(p^* - \tau - \tau_\ell) - Y_\ell(p^* - \tau - \tau_\ell, \omega_\ell)\right) \tag{2.12}$$

This fits into our main model with the new net import function

$$M(p^* - \tau, (\omega_\ell, \tau_\ell)_{\ell=1}^L) = \sum_{\ell=1}^{L} \left(Q_\ell(p^* - \tau - \tau_\ell) - Y_\ell(p^* - \tau - \tau_\ell, \omega_\ell)\right) \tag{2.13}$$

Moreover, an increase in any τ_ℓ, or producer assistance in the foreign country, is tantamount to a positive net imports shock.

A Nash equilibrium in government policy can be defined as a fixed-point between optimal choices of $(\tau, (\tau_\ell)_{\ell=1}^L)$, solving the respective versions of Program 2.2, with each country taking the other's policy as given. But even without a full analysis of this case, we can make the following observations about the "best-response" functions of each country. Using the observation above that a positive shock to τ_ℓ is tantamount to a positive shock to import supply, it is clear that the cases of Proposition 2 already describe this best-response function.

This can be illustrated via a two-country example. Imagine that the "foreign" country is a net exporter and it limits exports during a climate emergency. Under case 1 (a revenue-focused government), this as-if negative overseas productivity shock leads to an increase in consumer support in the "home" country, or an import subsidy. Under case 2 (a constituent-focused government), the home country increases producer support, or taxes imports.

Consider now what happens if both countries are revenue focused or both countries are constituent focused. Under the former case, the home country's consumer support registers as a negative overseas productivity shock, which pushes toward further consumer support or deepening the export tax. Thus, equilibrium interactions in this round (and all subsequent rounds) *amplify* the initial change to trade policy. Under the latter case, the home country's producer support registers as a positive overseas productivity shock. This pushes the scales in the foreign country toward producer support. Thus, equilibrium interactions in this round (and all subsequent rounds) *dampen* the initial change to trade policy. This highlights a further, potentially dramatic difference between the two cases: the former implies that trade distortions form a positive feedback loop in equilibrium, while the latter implies that they form a negative feedback loop. We will return to this idea in our quantification of global climate shocks in Section 5.

2.5 Key Predictions

We now distill our model findings into three predictions that we can test using data on agricultural productivity shocks and distortions in agricultural markets.

Our first prediction is that negative domestic productivity shocks can push policy toward producer assistance or consumer assistance:

Prediction 1. *An adverse domestic climate shock can either increase or decrease producer assistance, depending on the government's priorities.*

As shown in Proposition 2, adverse shocks lead to consumer assistance when the government is relatively more focused on constituents than government revenues and toward producer assistance in the opposite case. A utilitarian government implementing a Ramsey rule would not respond at all, provided that the elasticity of foreign supply or demand remains constant. Finally, these predictions are potentially decoupled from the initial *level* of pro-producer or pro-consumer support, which hinges on the relative welfare weights on consumers and producers. We will test this prediction directly using country-by-crop panel data on crop-specific extreme heat exposure and nominal rates of assistance.

Our second prediction is that negative supply shocks to import sources should have the *opposite* effect as an adverse local supply shock:

Prediction 2. *An adverse foreign climate shock has the opposite effect on producer assistance as an adverse domestic climate shock.*

This followed from the logic of Proposition 2. Moreover, as discussed in Section 2.4, this was at the core of the model's further predictions for international equilibrium interactions between policy setters and "trade wars." We test this prediction by constructing panel data on trade-weighted foreign productivity shocks and measuring its relationship with domestic nominal rates of assistance.

Our final prediction relates to the conditions under which we expect each signed response in Prediction 1. In particular, pro-consumer bias in response to shocks should emerge when the government is constituent- rather than revenue-focused:

Prediction 3. *An adverse domestic climate shock should increase consumer assistance more when concerns about redistribution are high relative to concerns about fiscal responsibility.*

To test this mechanism in the data, we will proxy for time-varying preference weights for governments using the timing of elections. In particular, we will test whether climate shocks near elections induce relatively more consumer support than climate shocks at other times.

3 Data and Measurement

3.1 Agricultural Policy

To measure price distortions in agricultural markets, we use data from the World Bank's "Distortions to Agricultural Incentives" project (Anderson and Valenzuela, 2008; Anderson, 2009; Anderson et al., 2013). This data set is an unbalanced panel of information about price distortions for 80 agricultural products and 82 countries from 1955 to 2011. While the data do not cover all countries and crops, the sample accounts for more than 85% of agricultural production and employment both globally and within each of Africa, Asia, Latin America, and the OECD (Anderson et al., 2013).

The key statistic of interest is the *nominal rate of assistance*. Conceptually, this measures how much higher domestic producer prices are versus prevailing "free market" prices. That is, for crop k in country ℓ at time t,

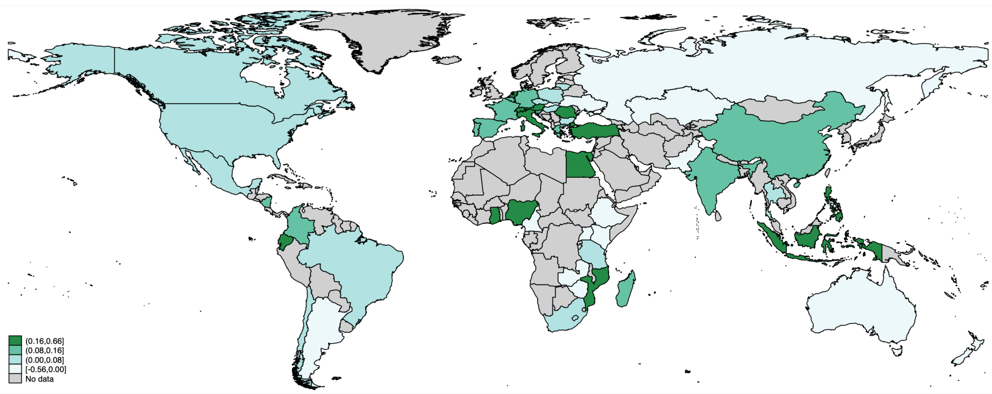
$$\text{NRA}_{\ell kt} = \frac{P^d_{\ell kt} - P^m_{\ell kt}}{P^m_{\ell kt}} \tag{3.1}$$

where $P^d_{\ell kt}$ is the unit value of production at a distorted price and $P^m_{\ell kt}$ is the unit value of production at an undistorted market price. In the model, this corresponds to our definition of α if we interpret $P^d_{\ell kt}$ as p^*, the domestic equilibrium price, and we interpret $P^m_{\ell kt}$ as $p^* - \tau$, the equilibrium price at the border.

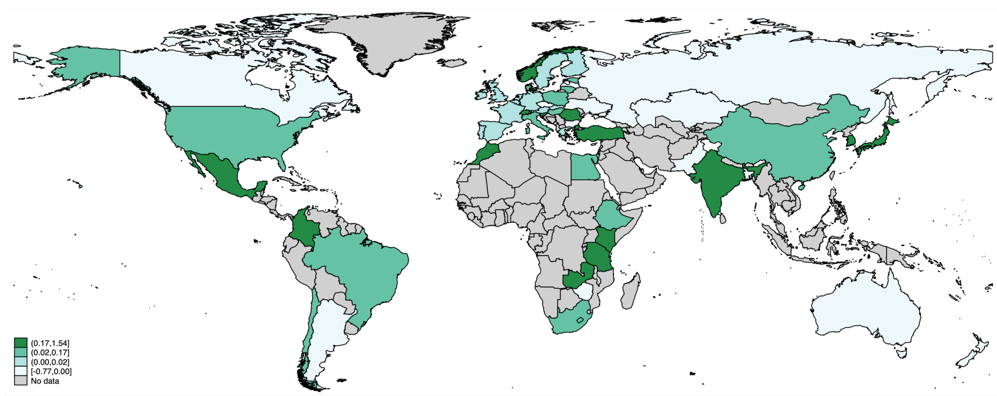
In practice, the NRA is computed by measuring the ratio of total assistance paid to producers (in dollars) relative to the total value of production. These sources of assistance include market price support, payments to producers based on output, payments to producers

Figure 2: Global Policy Variation for Select Crops

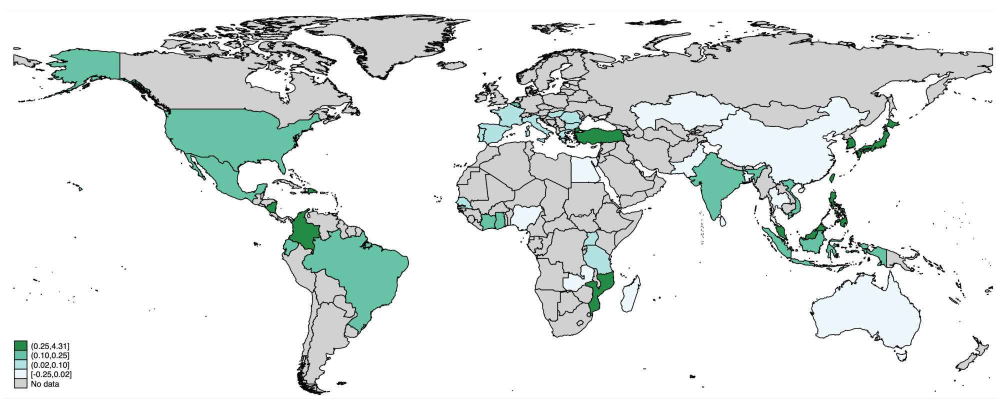
(a) Maize



(b) Wheat



(c) Rice



Notes: This figure displays the value of NRA for maize (Figure 2a), wheat (Figure 2b), and rice (Figure 2c) averaged from 2001-2010. Countries are color-coded by quartile where darker colors correspond to larger values of NRA.

based on inputs, and payments to producers based on other indicators (e.g., area cultivated). The first category by itself captures purely the gap between international and domestic prices, which maps to the import tax in the model. Because it is measured in price terms, this component of NRA also measures in price units the effects of non-price trade policies (e.g., quotas). In our empirical analysis, we will use both the summary NRA measure, which captures all forms of policy intervention, as well as the individual components of this summary measure. In principle, the different components need not go in the same direction and could be substitutes for one another.

Figure 2 presents global maps of average NRA around the world from 2001-2010 for three major crops: maize, wheat, and rice. Countries are color-coded by NRA quartile with darker colors corresponding to higher (i.e. more producer-oriented) NRA values. There is substantial variation in agricultural policy, both across countries for each crop and within countries across crops. For each crop, there is a large set of countries with policies on either sides of zero. And even with this coarse categorization of policy by quartile, it is possible to see that several countries have very different policies across crops. Not only are there differences in the level of policy across crops and countries, there are also large differences in how policies have changed over the last several decades. Figure A.1 reports an analogous set of maps but instead displays the *change* in NRA for each country and crop from the 1980s to the 2010s. Again, there are clear differences across crops and countries.

3.2 Extreme Heat Exposure

To measure climatic shocks to agricultural products, we construct a global dataset of crop-level exposure to extreme heat in each country. This extends existing work constructing global panel data for the exposure of staple crops to average temperature trends (Lobell and Field, 2007; Lobell et al., 2011) and panel data within the United States (Schlenker and Roberts, 2009; Moscona and Sastry, 2023). These data may be of independent interest to researchers interested in studying global trends in climate change and agricultural productivity.

Data Inputs. Our strategy requires three main data inputs. The first are global historical estimates of temperature from Muñoz-Sabater et al. (2021). This is the fifth-generation data set produced by the European Centre for Medium-Range Weather Forecasts, in collaboration with the European Commission and Copernicus Climate Change Service. It is a reanalysis data set that combines weather observations from around the world from 1979-present with model data to generate a complete global gridded temperature data set at the hourly level with a grid size of 0.25 degrees.

The second are estimates for the global geography of agricultural production in the year 2000 from the *Earthstat* database of Monfreda et al. (2008). These data were created by combining national, state, and county level census data with crop-specific maximum potential yield data, to construct a 5-by-5 minute grid of the area devoted to each crop circa 2000.

The third are estimates of crop-specific temperature sensitivity from the United Nations Food and Agriculture Organization's (FAO) *EcoCrop* database. The EcoCrop data provide information about crop-specific growing conditions, including numerical tolerance ranges for temperature, rainfall, and pH for over 2,500 plants. The data are compiled from expert surveys and textbooks. The key piece of information for our analysis is EcoCrop's reported upper temperature threshold for optimal growing. This information is frequently used in agronomics and climate science to estimate crop-specific tolerance to climate change (e.g., Hijmans et al., 2001; Ramirez-Villegas et al., 2013; Kim et al., 2018; Hummel et al., 2018), and in our own past work to define crop-specific exposure to extreme temperatures (Moscona and Sastry, 2023; Hsiao, 2023).

Measuring Extreme Heat Exposure. We follow the method of Moscona and Sastry (2023) to measure crop-specific extreme heat exposure as *the average exposure to extreme temperatures, in degree-days, for land cultivating a given crop.* In particular, to define this formally, we partition each country ℓ into grid cells $c \in \ell$ and calculate, for each country, crop, and year:

$$\text{ExtremeExposure}_{\ell kt} = \sum_{c \in \ell} \frac{\text{Area}_{ck}}{\sum_{c' \in \ell} \text{Area}_{c'k}} \cdot \text{DegreeDays}_{ct}(T_k^{max}) \tag{3.2}$$

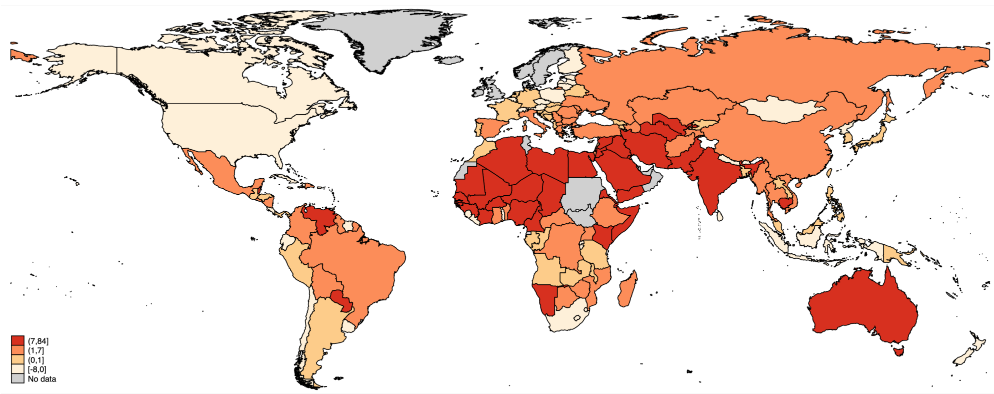
where $\text{DegreeDays}(x)$ returns total degree days in excess of threshold x, T_k^{max} is the maximum optimal growing temperature for crop k from EcoCrop, and Area_{ck} is the area growing crop k in cell c from the EarthStat data.

Figure 3 maps changes in $\text{ExtremeExposure}_{\ell k}$ between the 1980s and the 2000s for maize, wheat, and rice. Countries are color-coded by quartile where darker colors correspond to larger increases in extreme heat exposure. Extreme heat exposure is increasing in most countries for all three crops. However, for each crop there is substantial variation in the extent of extreme heat exposure growth across countries. Moreover, for many countries, there are large differences in changes in extreme heat exposure *across crops.* For example, Brazil is in the third quartile for maize, second quartile for wheat, and fourth quartile for rice. This within-country, cross-crop variation is what we will exploit in the empirical analysis.

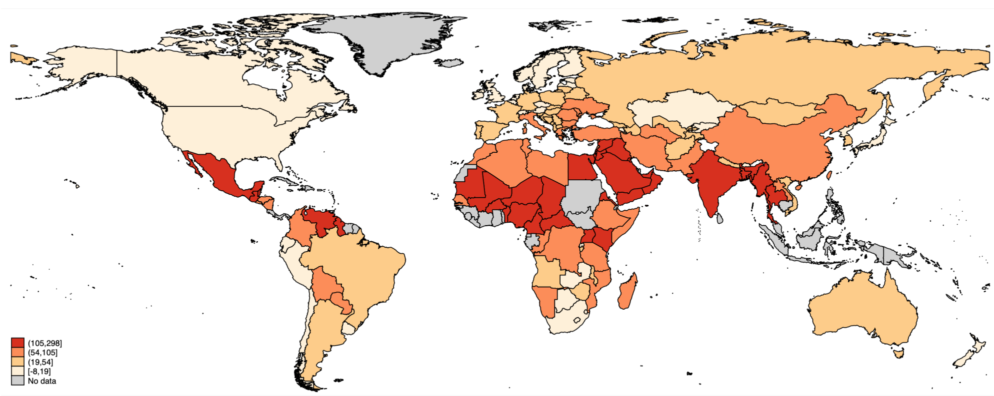
When merged with our data on production and trade, our dataset covers 166 countries and 126 crops. When merged with our data on agricultural policy, our dataset covers 79

Figure 3: Global Changes in Extreme Heat Exposure for Select Crops

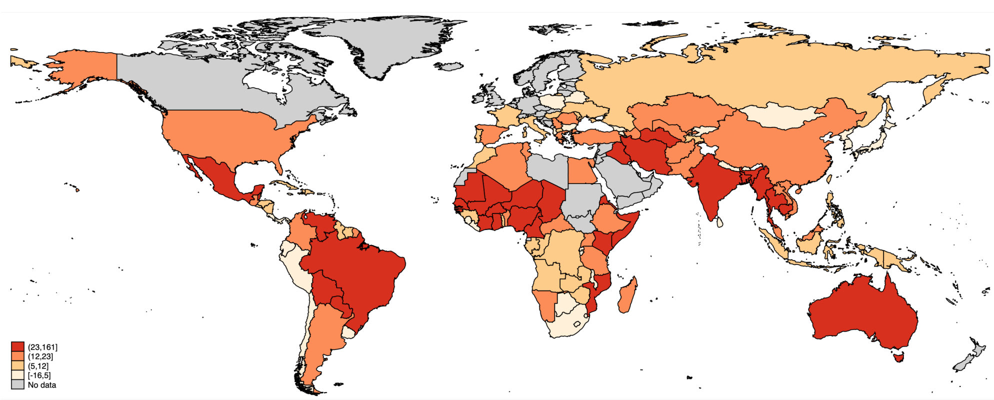
(a) Maize



(b) Wheat



(c) Rice



Notes: This figure displays the change in extreme heat exposure for maize (Figure 3a), wheat (Figure 3b), and rice (Figure 3c) between the 1980s and the 2010s. Countries are color-coded by quartile where darker colors correspond to larger increases in extreme heat exposure.

countries and 61 crops.

3.3 Production, Trade, and Elections

We compile data on production, exports, and imports at the crop by country by year level from the United Nations (UN) Food and Agriculture Organization (FAO) FAOStat database. The production data allow us to validate that our constructed climate shocks reduce agricultural yields. The trade data make it possible to identify which countries are net exporters (or importers) of each crop, and to construct import shares for each country pair to measure exposure to foreign temperature change.

We also compile data on all election years during our sample period from the latest edition of the Database of Political Institutions (DPI), first introduced by Beck et al. (2001). The database covers elections in 180 countries from 1975-2020 and presents information about election and regime characteristics at the country-year level. Using these data, we code an indicator that equals one during the year of or immediately preceding any national election.

3.4 Validation: Extreme Heat Exposure Lowers Productivity

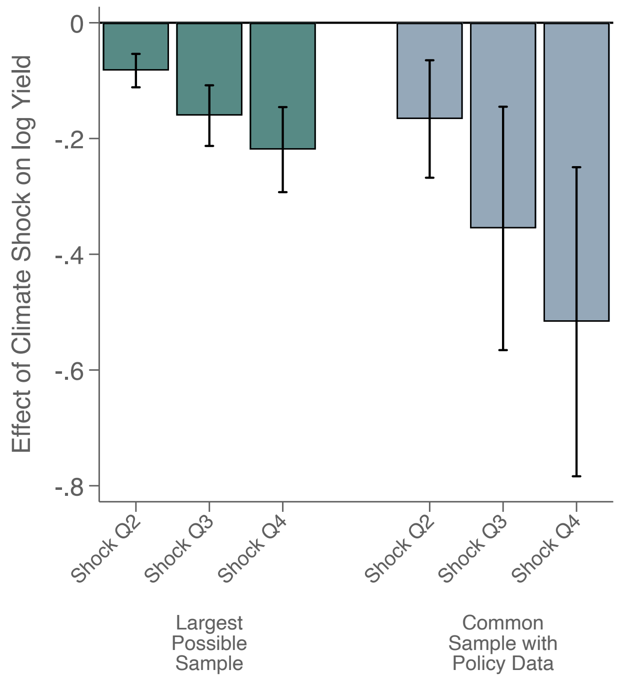
We investigate whether this measure of extreme heat exposure affects crop-specific productivity around the world. Moscona and Sastry (2023) validate, in historical panel data from the United States, that this measure predicts adverse agricultural outcomes and, moreover, outperforms comparable measures that do not account for crop-specific tolerance. We extend this analysis to our global sample by estimating the specification

$$\log(\text{yield}_{\ell kt}) = f(\text{ExtremeExposure}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt} \tag{3.3}$$

where $\text{yield}_{\ell kt}$ is output-per-area of crop k in country c and year t, and all possible two-way fixed effects are included. $\text{ExtremeExposure}_{\ell kt}$ is defined in Equation 3.2, and we estimate function f that encodes effects by quartile of $\text{ExtremeExposure}_{\ell kt}$. The two-way fixed effects mean that our estimates only exploit variation across crop *within* country-years. As a result, they are not driven by any country-specific or crop-specific trends, or differences in crop specialization across countries.

Estimates of Equation 3.3 are displayed in Figure 4. The left three bars report the effects of the second through fourth quartiles of the extreme heat distribution on yields, using the full sample of crops and countries for which we were able to collect production data. The estimates suggest that there is a large, negative effect of extreme heat exposure, as we measure it, on crop yields. Compared to the yields in the bottom extreme heat quartile,

Figure 4: Extreme Heat and Crop Yields



Notes: This figure displays the relationship between quartiles of extreme heat exposure and (log of) crop yields. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to the estimates from a single regression. The left set of bars is from a regression that includes the full sample for which we can measure the temperature shock and production and the right set of bars is from a regression in which the sample is restricted to the crop-country-year triplets for which we have NRA data. We report 90% confidence intervals.

yields in the top extreme heat quartile are over 20% lower. The right three bars report the same estimates but restrict attention to the crop-country pairs for which we have policy data. If anything, the marginal effect of extreme heat on yields is larger in this sample.

Together, these estimates indicate that our measure of extreme heat exposure captures the negative effects of temperature on agricultural productivity. More generally, they document the negative effect of extreme heat on agricultural production using a consistent method for all country-crop pairs.

4 Results

We investigate the relationship between climate change and agricultural policy, focusing on the predictions of the model presented in Section 2. Our main estimating equation for the analysis is

$$\text{NRA}_{\ell kt} = g(\text{ExtremeExposure}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt} \tag{4.1}$$

where $\text{NRA}_{\ell kt}$ is a measure of crop-specific policy for crop k in country ℓ and year t. We estimate non-parametric function g with indicator functions for each of the four quartiles of $\text{ExtremeExposure}_{\ell kt}$. All specifications include the full set of two-way fixed effects, fully absorbing any differences in baseline specialization across countries, as well as country-specific and crop-specific trends. We ask (1) how extreme heat exposure affects crop-specific policy and (2) what mechanisms underpin this relationship.

4.1 Local Temperature Extremes Lead to Pro-Consumer Policy

We first investigate the relationship between local extreme heat exposure and crop-specific policy (Prediction 1). We do this by estimating Equation 4.1 with $\text{NRA}_{\ell kt}$ as the outcome variable. Figure 5 reports our estimated coefficients, in which each set of three bars corresponds to a separate regression. In each case, we report the effect of the second through fourth quartiles of heat exposure on the nominal rate of assistance ($\text{NRA}_{\ell kt}$).

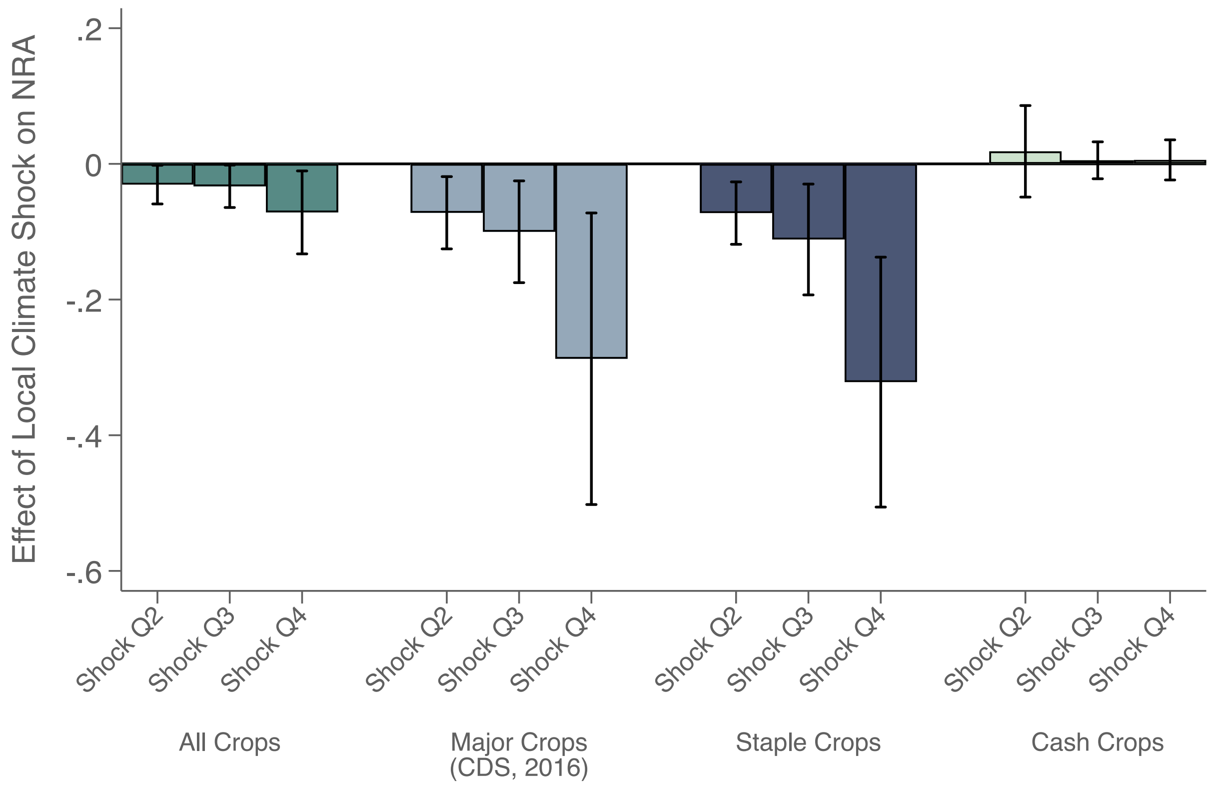
In the first specification (dark-green bars), we use the full sample of crops for which policy data were collected. High exposure to extreme temperatures leads to lower nominal rates of assistance, or more *consumer-friendly policy.* Experiencing high (compared to low) extreme heat exposure reduces NRA by 0.072, or approximately 0.092 standard deviations.

Through the lens of the model, this finding is consistent with a *constituent friendly* government (i.e., case 2 of Proposition 2). The finding is moreover consistent with the motivating stories of the Introduction, including India's 2022 ban on wheat exports following a national drought. Viewed through this lens, our results confirm that such policy reactions are systematic and quantitatively large relative to the baseline cross-country and cross-crop variation in agricultural policy.

Next, we focus on the most economically important crops by restricting the sample to the ten crops that are the subject of analysis in Costinot et al. (2016).[5] Our estimates using this sub-sample (blue-grey bars) are substantially larger in magnitude: experiencing high (compared to low) extreme heat exposure reduces NRA by 0.37 standard deviations. While the second and third quartiles are both statistically significant, the highest level of extreme heat exposure has a substantially larger effect. The fourth-quartile effect is substantially larger than, and statistically distinguishable from ($p = 0.06$), the third-quartile effect. This finding suggests that most extreme climate shocks may have a disproportionate effect on policy.

[5] These crops are bananas, cotton, maize, rice, soybeans, sugar, tomatoes, wheat, potatoes, and palm oil.

Figure 5: Extreme Heat and Agricultural Policy

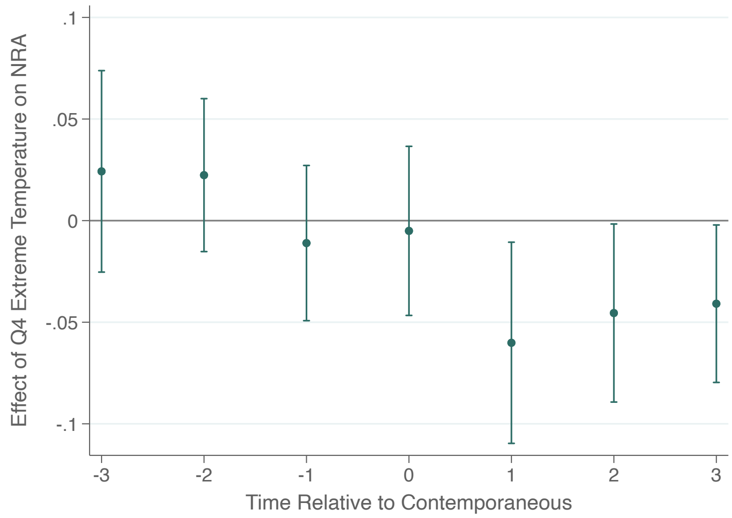


Notes: This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. We report 90% confidence intervals.

Finally, we compare the effect for major staple crops and major cash crops.[6] The third set of bars (dark-blue bars) reports our estimates for staple crops, and the results closely mirror the preceding specification. We find large, negative effects of higher extreme heat exposure on policy and the effect is particularly large for the highest values of extreme heat exposure. Experiencing high (compared to low) extreme heat exposure for staple crops reduces NRA by 0.41 standard deviations and again, the fourth-quartile effect is statistically distinguishable from the third-quartile effect ($p < 0.01$). In contrast, we find very different effects on cash crops (light green bars). We find no evidence that extreme heat exposure affects agricultural policy for cash crops. The effect for all quartiles is statistically indistinguishable from zero.

[6]The staple crops we include are maize, soybeans, rice, wheat, tomatoes, potatoes, and onions. The cash crops are cocoa, coffee, cotton, palm oil, sugar, and tobacco.

Figure 6: Extreme Heat and Agricultural Policy, Dynamics



Notes: This figure displays the relationship between leads and lags of top-quartile extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. All displayed coefficients are estimated from a single regression that includes three leads and three lags of top-quartile exposure, along with the contemporaneous value. Each bar corresponds to an estimate from a separate regression. We report 90% confidence intervals.

This suggests that the economic mechanisms underlying the determination of staple-crop and cash-crop policy may be very different.

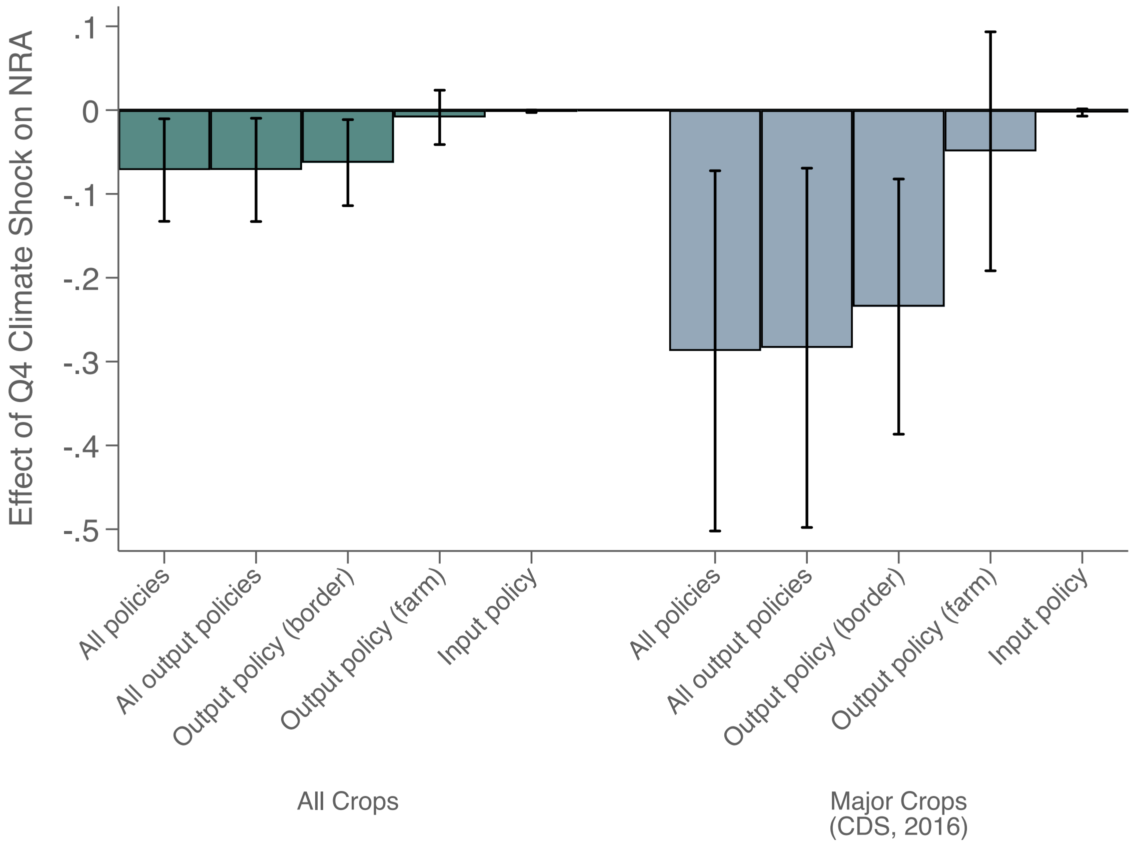
Together, these estimates suggest that exposure to extreme heat reduces NRA, leading to more consumer-oriented agricultural policy. The effects are particularly pronounced for staple crops and for the highest levels of exposure to extreme temperatures.

Before proceeding to study the model's additional predictions, we comment on several other findings which refine and clarify our main result in this subsection.

Dynamics. So far, we have estimated the contemporaneous effect of extreme heat exposure on policy. We next investigate the effect of leading and lagged values of extreme heat exposure. This makes it possible to check if our main estimates are driven by pre-existing trends and to investigate persistence in the effect.

Figure 6 reports estimates of Equation 4.1 focusing only on the top-quartile effect and including three leads and three lags in the regression. Each coefficient can be interpreted as the effect of an extreme temperature shock in that period holding fixed temperature realizations in the contemporaneous period and all other included lags and leads. The first conclusion from the figure is that there is no evidence of pre-existing trends: the coefficient estimates on all the leading values are small in magnitude and statistically indistinguishable from zero. The second conclusion is that the effect of an extreme temperature shock on trade

Figure 7: Extreme Heat and Agricultural Policy by Policy Type



Notes: This figure displays the relationship between top-quartile extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each bar corresponds to an estimate from a separate regression. The outcome in each case is a different component of policy, labelled below the bar. The sample of crops included in each regression is also noted below the left and right set of bars. We report 90% confidence intervals.

policy seems to persist. The three lagged values suggest that a temperature shock reduces NRA for the subsequent three years, with the largest effect taking place in the year following the shock year. We will explore these long-run effects in more detail in Section 4.3, where we investigate decade-level effects of extreme temperature on crop-specific policy.

Types of Policy. The results in Figure 5 focus on the summary NRA measure which combines all types of farm output and input policy. To investigate which types of policy drive the overall effect, we estimate Equation 4.1 using each component of overall NRA as a separate dependent variable. The estimates are presented in Figure 7. We report the effect of the top quartile of extreme heat exposure; the left set of bars uses the full sample while the right set of bars focuses on only the major crops.

The main conclusion is that the results seem to be driven by output-related policies and, in particular, policies that affect prices at the border. All forms of policy move in the same direction, which need not have been the case. However, the effect is weaker for policies that affect output prices at the farm gate (e.g., output price support) and absent for policies that affect agricultural inputs (e.g., fertilizer subsidies). The pattern is similar for the full sample and for the most economically important crops, although again all effects are larger in magnitude for the important crops. This is consistent with our modeling approach in Sections 2 and 5, which focuses on border price distortions.

Country-Level Estimates and Cross-Crop Interactions. To this point, our estimates have exploited variation in temperature and policy not only across countries and over time, but also across *crops* within the same country. There are several reasons to focus on the country-crop-year level analysis. First, the country-crop-year level is the unit of analysis at which policy is set and measured and the relevant unit for measuring exposure to damaging climate trends. Second, as illustrated by Figures 2 and 3, there is substantial variation in both policy and extreme heat exposure across crops and within countries. Finally, the ability to include country-by-year fixed effects in our baseline specification makes it possible to fully absorb any country-level trends or shocks that might spuriously co-vary with either policy or temperature (e.g., political turnover or changing economic conditions).

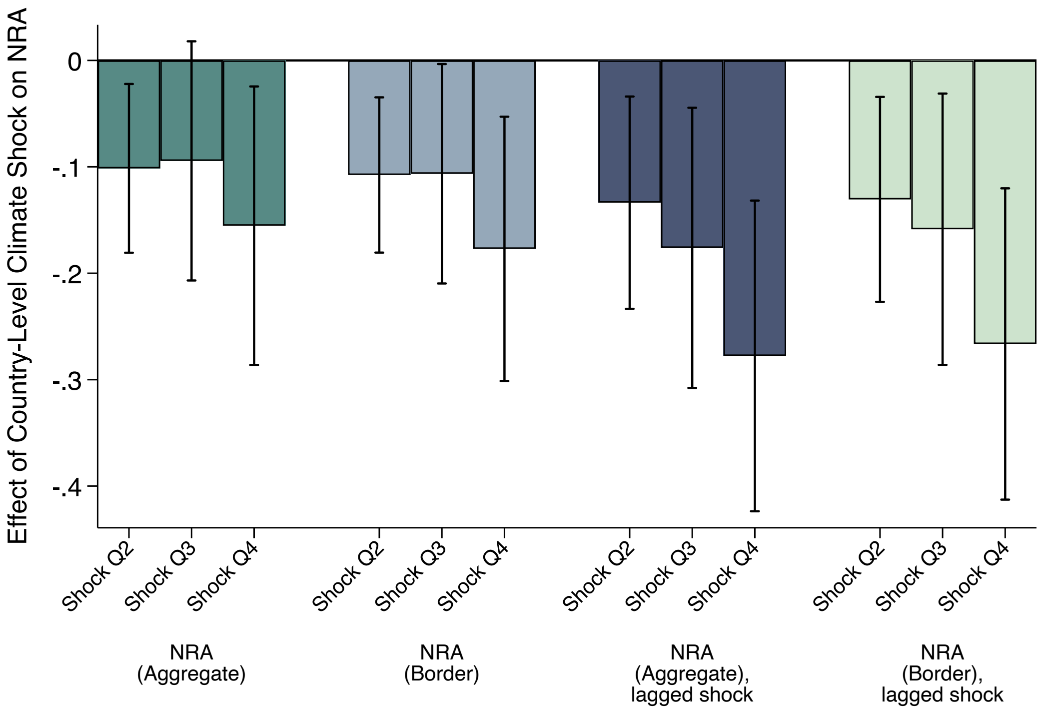
Nonetheless, it is also useful to study trends at the country level to investigate how our crop-country-year estimates "add up." These estimates could be larger in absolute value than our baseline estimates if governments are more responsive to high overall exposure to extreme heat, rather than high exposure for a single crop, since this amplifies hardship for consumers. They could be smaller in absolute value if politicians face a political budget that makes it harder to change policy across multiple crops at the same time.

We collapse our baseline data to the country-year level, focusing on the ten major crops and weighting each crop-country-year observation by average calorie-weighted production during the first decade of our sample period (1980-1989). We then estimate the following specification, which is the country-year analog of our baseline specification:

$$\text{NRA}_{\ell t} = g(\text{ExtremeExposure}_{\ell t}) + \gamma_\ell + \delta_t + \varepsilon_{\ell t} \tag{4.2}$$

The estimates are reported in Figure 8. While the estimates are less precise than our baseline results, they point to a negative relationship between country-level extreme heat exposure and weighted country-level NRA. Consistent with the findings from Figure 7, these estimates are driven by border market policies (second set of bars) and country-level extreme heat

Figure 8: Extreme Heat and Agricultural Policy: Country-Year Estimates



Notes: This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-year and both country and year fixed effects are included. Each set of three bars corresponds to estimates from a single regression. We report 90% confidence intervals.

shocks have no effect on input market policy (not reported). Moreover, consistent with Figure 6, we estimate slightly larger and more precise effects focusing on the first lag of the extreme heat shocks (third and fourth set of bars). Finally, these estimates are comparable in magnitude to the estimates from the country-crop-year specification (see Figure 5), indicating that cross-crop interactions do not seem to have a quantitatively important effect.

Sensitivity Analysis. We conduct a series of sensitivity checks to probe the robustness of our baseline estimates. First, we reproduce our baseline findings using all NRA data from 1955-2011 (Figure A.3). In our baseline estimates, we focus on the period 1980-2011 because this is the period during which there is higher-quality global temperature data; however, the results are very similar if we use the back-filled version of the ERA temperature data and NRA data starting in 1955. Second, we show that the results are also similar if we extend the sample to more recent years (and to a handful of additional crop-country pairs) using alternative data on nominal rates of assistance. We combine our baseline NRA data (Anderson and Valenzuela, 2008; Anderson, 2009; Anderson et al., 2013) with recently collected data from Ag-Incentives[7] and re-estimate our baseline specification on this combined sample, which increases the sample size by about 25%.[8] Reassuringly, the results are very similar (Figure A.4). Finally, we show that our baseline results are not driven by temperature extremes or policy regimes during any particular decade in our sample period: the results are very similar if we drop each decade from the analysis (although the standard errors are somewhat larger due to the smaller sample size). These findings are displayed in Figures A.5 to A.7.

4.2 Importer Temperature Extremes Lead to Pro-Producer Policy

The previous section documented that local extreme heat shocks significantly reduce NRA, leading to more consumer-oriented policy. Anecdotal evidence suggests that this could lead to international cascades: if one country limits exports following an period of extreme heat, so too might other countries, compounding the effect of the initial shock on international trade. Ghosal et al. (2023) refer to this process as the "contagion of food restrictions" and point to several examples in which countries restricted exports following export restrictions enacted by their trading partners.[9] In our model, both this contagion mechanism and the opposite, whereby international interactions *dampen* initial policy responses, were possible. But only the latter would be consistent with our earlier finding that climate shocks induce pro-consumer policy (see Proposition 2 and the discussion in Section 2.4).

To systematically investigate how policy reacts to foreign climate shocks (Prediction 2), we measure the extreme heat exposure experienced by import partners as

$$\text{ForeignExtremeExposure}_{\ell kt} = \sum_{\ell' \neq \ell} \text{ImportShare}_{\ell' \to \ell k} \cdot \text{ExtremeExposure}_{\ell' kt} \tag{4.3}$$

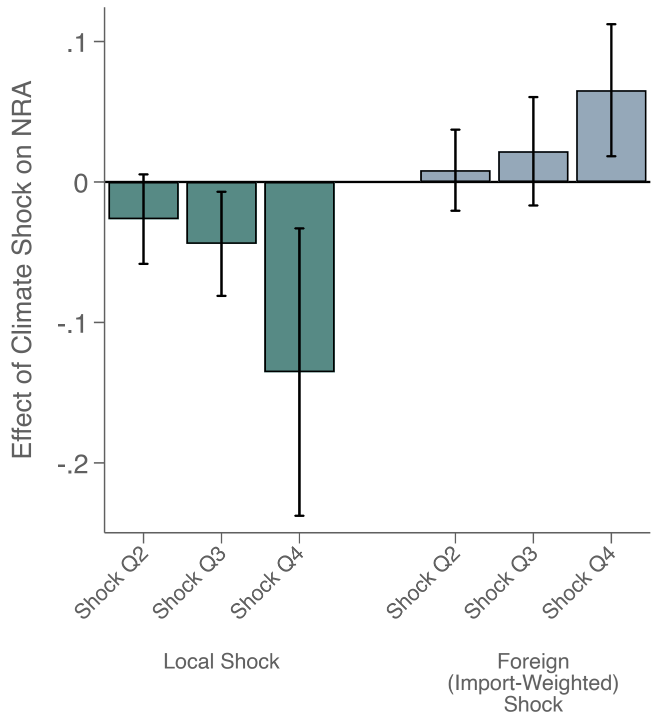
where $\text{ImportShare}_{\ell' \to \ell k}$ is the share of imports of crop k in ℓ coming from ℓ'. In words, this measure captures the exposure of each country-crop to foreign climate shocks, weighted by import shares. Figure A.2 maps the change in $\text{ForeignExtremeExposure}_{\ell kt}$ from the 1980s to the 2010s for maize, wheat, and rice, revealing substantial variation both across countries and within countries across crops. We then estimate an augmented version of Equation 4.1

[7] See here: https://www.agincentives.org/

[8] We do not treat this as the baseline specification because there are differences in methodology between the two data sets and we do not have access to the raw data to construct one from the other. While the two measures are positively correlated on the sample in which they overlap, they do not line up completely. As a result of this, when we estimate a regression that includes data from both, we include an indicator that equals one if the outcome data came from Ag-Incentives with all the two-way fixed effects.

[9] For example, they write, "India banned shipments of some rice earlier this year, resulting in a shortfall of roughly a fifth of global exports. Neighboring Myanmar, the world's fifth-biggest rice supplier, responded by stopping some exports of the grain." (Ghosal et al., 2023).

Figure 9: Local vs. Foreign Extreme Heat Shocks



Notes: This figure displays the relationship between quartiles of local and foreign (import-weighted) extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. All bars are estimated from a single regression. The left of bars presents the effect of quartiles of local extreme heat exposure and the right set of bars presents the effect of quartiles of foreign extreme heat exposure. We report 90% confidence intervals.

that includes both the local and the foreign temperature shocks.

$$\text{NRA}_{\ell kt} = g(\text{ExtremeExposure}_{\ell kt}) + h(\text{ForeignExtremeExposure}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt} \quad (4.4)$$

Functions g and h capture effects by quartile, and we include all two-way fixed effects.

Estimates of Equation 4.4 are displayed in Figure 9. The left three bars show the effect of each quartile in local extreme exposure. Consistent with the baseline results, we continue to find negative effects of local extreme heat exposure on NRA after also conditioning on foreign extreme heat exposure. The right three bars show the effect of foreign extreme heat exposure. Higher foreign extreme heat exposure is associated with an *increase* in NRA (i.e., more producer-friendly policy). These effects are smaller in absolute value than the effect of local extreme heat exposure, suggesting a stronger response to local climate distress. Nevertheless, our estimates are precise enough to rule out negative effects of foreign temperature effects and are inconsistent with the "contagion of food restrictions" view of global food policy.

Instead, foreign temperature shocks have the opposite effect of local temperature shocks, each one moderating the effect of the other. As discussed above, this is consistent with the model's predictions.

4.3 Long-Run Effects

So far, we have investigated the relationship between yearly fluctuations in extreme heat exposure and yearly changes in policy. This year-to-year variation is useful because it makes it possible to identify the causal effect of quasi-random variation in extreme heat exposure on policy. But the changes in policy due to climate change might be better approximated by estimates of the effect of long-run changes in the climate on policy (see e.g. Burke and Emerick, 2016). For example, while policy might respond to short-run fluctuations in temperature, in the long run patterns of trade or production might adapt to the change in climate and limit the effect of warming on policy.

To investigate this, we collapse our data to the decade-level and estimate versions of Equation 4.1 in which the unit of observation is a country-crop-decade triplet. The independent variables of interest are the number of years during the decade with high (fourth-quartile) *local* exposure to extreme heat and the number of years during the decade with high *foreign* exposure to extreme heat. These estimates are reported in Table 1. In the first column, we focus on the full sample of crops and only include local extreme heat exposure. Consistent with the yearly analysis, we estimate a negative and significant effect. Each additional year of extreme heat exposure reduces the decade's average NRA by about 0.04 standard deviations and ten years of extreme heat exposure (which occurs in about 5% of the sample) reduces the decade's average NRA by about 0.4 standard deviations.

In column 2, we also include foreign extreme heat exposure. We again find that the effect of foreign extreme heat exposure goes in the opposite direction and is (weakly) statistically significant. In the next two columns, we restrict attention to the major crops in Costinot et al. (2016) and to staple crops. Consistent with the yearly analysis, we estimate substantially larger effects of local extreme heat exposure on this sample. In the case of the staple crop sample, an additional year of extreme heat exposure reduces NRA by 0.11 standard deviations. Finally, in column 5 we restrict attention to cash crops. As in the yearly analysis, we find no evidence of a relationship between extreme heat exposure and crop-specific policy.

4.4 Mechanisms: Testing for Constituent Focus Using Elections

All of our results to this point suggest that the "constituent-focused" case from Proposition 2 dominates on average. To investigate this mechanism directly, and to test Prediction 3

Table 1: Decade-Level Estimates

	(1)	(2)	(3)	(4)	(5)
	Dependent Variable is NRA				
Sample:	Full Sample		Major Crops	Staple Crops	Cash Crops
Years of Extreme Heat (Local)	-0.0242**	-0.0252**	-0.0620**	-0.0758**	-0.0311
	(0.0111)	(0.0110)	(0.0259)	(0.0266)	(0.0400)
Years of Extreme Heat (Foreign Import-Weighted)		0.0179*	0.0254*	0.0237	0.0272
		(0.00969)	(0.0123)	(0.0127)	(0.0185)
Country x Decade Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country x Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes
Crop x Decade Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	1,951	1,951	905	771	215
R-squared	0.905	0.905	0.917	0.919	0.902

Notes: The unit of observation is a country-crop-decade triplet. The dependent variable is the NRA and the sample is listed at the top of each column. Standard errors are double-clustered by country and crop and *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

of the model, we use elections as a positive shock to concerns about constituents relative to fiscal responsibility. A large literature on political cycles has documented that upcoming elections tend to reduce fiscal responsibility and to lead to policies designed to win the support of constituents (e.g. Alesina and Roubini, 1992; Akhmedov and Zhuravskaya, 2004). Therefore, if our proposed mechanism is true, we would expect all of our baseline results to be exacerbated when there is an election and when politicians are more likely to sacrifice fiscal responsibility in order to keep voters content.

To investigate this, we estimate an augmented version of Equation 4.1 that includes interaction terms between extreme heat exposure and (i) indicators for election years and (ii) indicators for non-election years.[10] The findings are presented in Table 2. Across the board, we find evidence of much more extreme effects during elections. As in the main results, this is especially true when we restrict attention to major crops or staple crops (columns 2-3), and we find no effect in either election or non-election years when we focus on cash crops (column 4). In column 2, for example, the effect of a high extreme heat shock is four times as large during an election year, and the difference is significant ($p = 0.03$).

[10]We define election years as the year during or immediately prior to any election. The results are qualitatively similar if we only include the election year itself.

Table 2: Extreme Heat and Agricultural Policy Heterogeneity by Election Year

	(1)	(2)	(3)	(4)
	Dependent Variable is NRA			
	Full Sample	Major Crops	Staple Crops	Cash Crops
Q2 Extreme Heat Exposure x No Election	-0.0429*	-0.0724	-0.0509	-0.0259
	(0.0222)	(0.0445)	(0.0390)	(0.0486)
Q3 Extreme Heat Exposure x No Election	-0.0138	-0.0788	-0.0561	-0.0182
	(0.0236)	(0.0654)	(0.0719)	(0.0163)
Q4 Extreme Heat Exposure x No Election	-0.0172	-0.0948	-0.104	-0.0126
	(0.0374)	(0.101)	(0.0946)	(0.0216)
Q2 Extreme Heat Exposure x Election	-0.0120	-0.0689**	-0.0820**	0.0680
	(0.0172)	(0.0315)	(0.0316)	(0.0600)
Q3 Extreme Heat Exposure x Election	-0.0363	-0.110**	-0.145**	0.0217
	(0.0230)	(0.0543)	(0.0627)	(0.0223)
Q4 Extreme Heat Exposure x Election	-0.108**	-0.382**	-0.436***	0.0203
	(0.0490)	(0.149)	(0.142)	(0.0246)
p-value, Q4 x Election - Q4 x No Election	*0.08*	*0.03*	*0.04*	*0.34*
Country x Year Fixed Effects	Yes	Yes	Yes	Yes
Crop x Year Fixed Effects	Yes	Yes	Yes	Yes
Country x Crop x Election Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	15,860	7,432	5,671	2,343
R-squared	0.855	0.851	0.874	0.923

Notes: The unit of observation is a country-crop-year. Election is an indicator that equals one in the year before or year during an election. The sample used in each specification is noted at the top of each column. Standard errors are double clustered by country and crop-year and *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

These estimates suggest that the constituent focus of politicians is an important mechanism driving our results. They also indicate that the timing of climate shocks *vis-à -vis* political cycles may shape the economic impacts of climate change.

5 Counterfactuals: Policy and Climate Adaptation

We now combine our empirical estimates with our model to quantify the effects of endogenous agricultural policy on global adaptation to climate change.

5.1 Methods

Supply, Demand, and Policy. We consider a multi-crop and multi-country extension of our model. For countries ℓ and crops k, we specify log-linear demand and supply curves

$$\log q_{\ell k} = \log q^0_{\ell k} - \epsilon_d \log p_{\ell k} \tag{5.1}$$

$$\log y_{\ell k} = \log y^0_{\ell k} + \epsilon_s \log p_{\ell k} + f(\text{ExtremeExposure}_{\ell k}) \tag{5.2}$$

where (ϵ_d, ϵ_s) correspond respectively to the elasticities of demand and supply and f corresponds to the non-parametric damage function we estimated in Section 3.4. Crop markets clear at the international level,

$$\sum_{\ell} q_{\ell k}(p_k) = \sum_{\ell} y_{\ell k}(p_k) \quad \forall\ k \tag{5.3}$$

We specify the government's policy function as a non-parametric function of extreme heat exposure, both locally and for import partners.

$$\alpha_{\ell k} = \alpha^0_{\ell k} + g(\text{ExtremeExposure}_{\ell k}) + h(\text{ForeignExtremeExposure}_{\ell k}) \tag{5.4}$$

This corresponds exactly to our estimates of Equation 4.4 visualized in Figure 9. This allows us to capture the systematic relationship between both local and foreign climate shocks and policy. This policy function is consistent with our specific model of Section 2 insofar as the climate variables non-parametrically span the endogenous variables that enter the government's optimal policy (e.g., the import share in Proposition 1). Directly using our regression estimate allows us to proceed without needing to estimate the government's preferences in our model and, more generally, to be robust to alternative possible models that may generate the empirical patterns in nominal rates of assistance. We will also study an "exogenous policy" scenario in which we counterfactually assume that $\alpha_{\ell k}$ is fixed as the climate (i.e., Extreme Exposure and Foreign Extreme Exposure) changes.

Measuring Welfare. We evaluate welfare in terms of consumer surplus, producer surplus, and government revenue, defined below:

$$\mathcal{C}_{\ell k} = \frac{q^0_{\ell k}}{1-\epsilon_d} p^{1-\epsilon_d}_{\ell k}, \quad \mathcal{P}_{\ell k} = \frac{y^0_{\ell k}}{1+\epsilon_s} p^{1+\epsilon_s}_{\ell k} e^{f(\text{ExtremeExposure})}_{\ell k}, \quad \mathcal{R}_{\ell k} = \frac{\alpha_{\ell k}}{1+\alpha_{\ell k}} p_k (q_{\ell k} - y_{\ell k}) \tag{5.5}$$

We note that the per-unit tariff is $\tau_{\ell k} = \frac{\alpha_{\ell k}}{1+\alpha_{\ell k}} p_k$ by Equation 3.1. We moreover define total surplus as the equal-weighted sum of these components

$$\mathcal{S}_{\ell k} = \mathcal{C}_{\ell k} + \mathcal{P}_{\ell k} + \mathcal{R}_{\ell k} \tag{5.6}$$

This is just one welfare criterion that respects the Pareto ordering over consumer surplus, producer surplus, and revenue, and it may differ from the objective function that we expect governments to use (see Equation 2.2). Nonetheless, we argue that it is a sensible baseline. When we report international results, we sum total surplus with equal weights across countries. Of course, we measure all of these objects as a function of temperature realizations. This allows us to compare the observed equilibrium with different climate scenarios.

Calibration. We measure $\text{ExtremeExposure}_{\ell k}$ and $\text{ForeignExtremeExposure}_{\ell k}$, and we observe consumption $q_{\ell k}$, production $y_{\ell k}$, domestic prices $p_{\ell k} = p_k(1 + \alpha_{\ell k})$, world prices p_k, and domestic NRA $\alpha_{\ell k}$ under the realized equilibrium. We use average data from 2000-2010 to capture a modern steady state.[11] As mentioned above, we directly calibrate the damage function f and the policy response functions g and h using our regression estimates from Section 4. Using these data, we can estimate $(q^0_{\ell k}, y^0_{\ell k}, \alpha^0_{\ell k})$ from the data, and we treat these values as constants. We calibrate $\epsilon_d = 2.82$ and $\epsilon_s = 2.46$ based on estimates from Costinot et al. (2016).[12] Our sample consists of the ten "major crops" from our main analysis and, for each crop, all countries for which we have data on policy.

Climate Scenarios. We model two different climate scenarios. The first scenario is realistic projected warming by the end of the century. Specifically, we predict Extreme Exposure at the crop-by-country level in the decade 2091-2100 under the GFDL-ESM4 model, produced by the US National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory and included in the CMIP 6 model ensemble. To construct the estimates, we take central model forecasts from NASA's Global Daily Downscaled Projections at the 0.25 degree grid cell level, corresponding to the SSP 4.5 pathway for global greenhouse gas concentrations.[13] From this dataset, which projects daily maximum and minimum temperatures. As in Schlenker and Roberts (2009), we estimate the within-day exposure to temperatures above any given cut-off level and translate this into estimates for the average per-year exposure to degree days above each of our crop-specific thresholds in each of our

[11] We compute unmodeled net production as total production less total consumption for the studied subsample of country-crop pairs, which must have NRA data. We hold this net supply fixed in counterfactuals when we calculate global market clearing.

[12] We take estimates $\theta = 2.46$ and $\kappa = 2.82$ from Table 2 in that paper.

[13] The data are available at https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp-cmip6.

Table 3: Endogenous Trade Policy and the Welfare Effects of Climate Change

	(1)	(2)	(3)
	Percent change with:		Percent difference
	Endogenous policy	Exogenous policy	
Full sample			
Total surplus	-2.96	-2.55	-14
Consumer surplus	-1.48	-1.72	16
Producer surplus	-0.37	-0.81	119
Government revenue	-1.11	-0.02	-98
More impacted country-crop pairs			
Total surplus	-2.41	-1.73	-28
Consumer surplus	0.63	-0.64	202
Producer surplus	-2.13	-1.15	-46
Government revenue	-0.92	0.06	-107
Less impacted country-crop pairs			
Total surplus	-0.55	-0.82	49
Consumer surplus	-2.11	-1.08	-49
Producer surplus	1.76	0.34	81
Government revenue	-0.19	-0.08	-58

Notes: This table reports changes in total surplus, consumer surplus, producer surplus, and government revenue (defined in Equations 5.5 and 5.6) under the projected end-of-century warming scenario (see Section 5.1 for methodological details). We define "more impacted" country-crop pairs as those which, for each crop, are in the 10% right tail of production losses (evaluated at fixed prices). We define "less impacted" country-crop pairs as the complement. The third column reports the percent difference in the percent changes attributable to endogenous policy. That is, letting x_n denote the value in column n, $x_3 = (x_1 - x_2)/|x_1|$.

studied countries.

Our second climate scenario captures in-sample extremes. Specifically, we measure the 95% percentile extreme event for each country-crop pair (e.g., the 5% tail of extreme weather realizations for wheat in India), and consider the scenario of moving all or part of the world to this new climate.

5.2 Global Adaptation to Climate Change

We first study the effect of global climate change, or moving from the observed climate of the 2000s to the predicted end-of-century climate. Table 3 reports welfare losses from climate change under each policy regime. The top panel focuses on the full sample of country-crop pairs. Our estimates suggest that rising temperatures will reduce global welfare by 2.96% by 2100 (column (1)). This is driven by losses in consumer surplus, producer surplus, and government revenue.

We next isolate the role of endogenous trade policy by comparing to a second counterfactual in which we hold policy fixed—that is, we keep agricultural tariffs at their modern-day levels. In this counterfactual, global welfare declines by 2.55%. Thus, endogenous policy explains 14% of the predicted total damage. Put differently, assuming exogenous trade policy would understate total welfare losses by 14%. The endogenous policy results in dampened welfare losses for both consumers and producers, while reducing government revenue. The former effect is intuitive given our finding that, in response to warming, governments respond with pro-consumer policy. The latter is possible only through equilibrium effects. Even though almost all countries shift policies toward consumer assistance (i.e., import subsidies or export taxes), equilibrium food prices rise enough to compensate producers on net.

A different interpretation of the comparison between columns (1) and (2) is that, in the empirically relevant case, the global shift toward pro-consumer policy increases global deadweight loss. In particular, we can define global deadweight loss as the difference between total surplus under free trade with total surplus under a fixed set of trade distortions, holding fixed production possibilities and demand. Since production possibilities and demand are identical in columns (1) and (2), it must be that deadweight loss has increased. This allows us to return quantitatively to a central point of ambiguity in the previous analysis: whether or not a global tilt toward pro-consumer policy increases or decreases *trade distortions* depends on the initial levels of policy, production, and demand.

We next investigate the distributional effects of the shock, and the distributional consequences of trade policy, across the world. To do this, we define the 10% tail of "most impacted" countries for each crop in terms of lost production. In more impacted countries, governments use policy to more than completely offset the loss of consumer surplus (a 202% abatement, which leads to a net consumer gain). The cost is a further reduction in producer surplus (a 46% amplification), which for the most impacted markets overpowers the aforementioned equilibrium price-hedging effect. This finding is consistent with our "winners and losers" analysis in Corollary 2. In less impacted countries, governments use policy to prop up producers at the cost of further reducing consumer surplus. This is consistent with our empirical finding that *indirectly* affected countries move toward pro-producer policy. Thus, when we disaggregate the analysis across countries, we observe that endogenous food policy leads to vastly different outcomes for consumers and producers depending on the heterogeneous incidence of climate change in different parts of the world.

Table 4: Endogenous Trade Policy and the Impact of Heat Waves

	(1)	(2)	(3)	(4)	(5)
	Percent change in surplus due to endogenous policy				
Heat wave (95th percentile in-sample temperature shock) in:	Africa	Americas	Asia	Europe	Global
Full sample					
Consumer surplus	6	1	890	-5	26
Producer surplus	11	3	-48	147	-8
Affected continent (or more impacted country-crop pairs in column 5)					
Consumer surplus	116	16	438	366	215
Producer surplus	-18	-1	-31	-3	-35
Unaffected continents (or less impacted country-crop pairs in column 5)					
Consumer surplus	-26	-11	237	-32	-36
Producer surplus	27	6	-53	31	49

Notes: This table reports the percentage effect of endogenous policy on total surplus, consumer surplus, producer surplus, and government revenue (defined in Equations 5.5 and 5.6) under the in-sample heat wave scenario (see Section 5.1 for methodological details). That is, letting x_n, x_e respectively denote the corresponding surplus term under endogenous and exogenous policy, we report $y = (x_n - x_e)/|x_n|$ (i.e., as in column 3 of Table 4. In column 5, we define "more affected" country-crop pairs as those which, for each crop, are in the 10% right tail of production losses (evaluated at fixed prices). We define "less affected" country-crop pairs as the complement.

5.3 Heat Waves

We next study the scenario of "heat waves," on specific continents and across the world. As mentioned above, we define a heat wave event as moving Extreme Exposure to the observed 95% percentile value (from 1980 to 2021) at the country-crop level. In Table 4, we report our findings for the percentage change in consumer and producer surplus that can be attributed to endogenous policy. In contrast to our findings with global climate change, we find ambiguous effects (depending on the scenario) for whether endogenous policy betters or worsens the effects of the shock. This is sensible in light of the earlier discussion that the ultimate effect of policy shifts on deadweight loss depends on initial conditions and the precise incidence of the shock.

Separating the effects by affected and unaffected continents, we see a pattern of endogenous policy assisting consumers at the expense of producers in places hit by the heat wave, while doing the opposite in the rest of the world. Across all specifications, endogenous policy increases consumer surplus and reduces producer surplus in the continent affected by the heat wave (second panel). And in all but one specification, endogenous policy reduces consumer surplus and increases producer surplus in the unaffected continents.[14]

These findings echo the anecdotal evidence that motivated our analysis: governments systematically respond to heat waves by shielding their consumers and amplifying losses for their producers. Meanwhile, the *opposite* pattern of gains and losses emerges for consumers and producers in the rest of the world. Together, these findings highlight how food policy shapes the global distributional consequences of climate shocks in a quantitatively meaningful way.

6 Conclusion

We study the relationship between trade policy and temperature stress on the agricultural economy. We use a simple model to show how distributional concerns can motivate distortionary agricultural policy. The response of this policy to climatic productivity shocks is ambiguous *ex ante* and hinges on the government's relative preferences for constituent well-being and government revenue. Therefore, to understand the interaction between climate change and agricultural policy, it is essential to turn to data. We construct a new global panel dataset of crop-specific extreme heat exposure, production, trade, and policy distortions since 1980.

We find that extreme heat exposure significantly shifts policy in a pro-consumer direction, in both the short-run and long-run. Consistent with our model, extreme heat exposure to import partners has the opposite effect, stabilizing the global impact of temperature on policy. Finally, the results are most pronounced during elections, when politicians are perhaps especially attuned to the demands of their constituents.

We finally combine theory and data to under how endogenous trade policy shapes global adaptation in a warming world. We find that endogenous trade policy amplifies the losses from climate change by 14%. This overall effect masks substantial heterogeneity: policy is effective at shielding consumers in the most affected areas, at the cost of amplifying damages for producers in the most affected parts of the world and consumers in the rest of the world. Together, these results highlight how climate change affects economic policy, and how economic policy in turn mediates the consequences of climate change.

[14] The one exception is our finding for the effects of a heat wave in Asia (third panel, column (3)).

References

Adão, R., Costinot, A., Donaldson, D., and Sturm, J. (2023). Why is trade not free? A revealed preference approach.

Akhmedov, A. and Zhuravskaya, E. (2004). Opportunistic political cycles: Test in a young democracy setting. *Quarterly Journal of Economics*, 119(4):1301–1338.

Alesina, A. and Roubini, N. (1992). Political cycles in OECD economies. *Review of Economic Studies*, 59(4):663–688.

Anderson, K., editor (2009). *Distortions to Agricultural Incentives: A Global Perspective.* Palgrave Macmillan.

Anderson, K. and Masters, W. (2009). *Distortions to Agricultural Incentives in Africa*. World Bank Publications.

Anderson, K., Rausser, G., and Swinnen, J. (2013). Political economy of public policies: insights from distortions to agricultural and food markets. *Journal of Economic Literature*, 51(2):423–477.

Anderson, K. and Valenzuela, E. (2008). Estimates of global distortions to agricultural incentives, 1955 to 2007. *World Bank, Washington, DC*.

Bagwell, K. and Staiger, R. (1999). An economic theory of GATT. *American Economic Review*, 89(1):215–248.

Balboni, C., Burgess, R., Heil, A., Old, J., and Olken, B. (2021). Cycles of fire? Politics and forest burning in Indonesia. *AEA Papers and Proceedings*, 111:415–419.

Baldos, U., Hertel, T., and Moore, F. (2019). Understanding the spatial distribution of welfare impacts of global warming on agriculture and its drivers. *American Journal of Agricultural Economics*, 101(5):1455–1472.

Baldwin, R. (1989). The political economy of trade policy. *Journal of Economic Perspectives*, 3(4):119–135.

Bastos, P., Straume, O. R., and Urrego, J. (2013). Rain, agriculture, and tariffs. *Journal of International Economics*, 90(2):364–377.

Bates, R. (2014). *Markets and States in Tropical Africa: The Political Basis of Agricultural Policies*. Univ of California Press.

Beck, T., Clarke, G., Groff, A., Keefer, P., and Walsh, P. (2001). New tools in comparative political economy: The database of political institutions. *World Bank Economic Review*, 15(1):165–176.

Beillard, M. and Singh, S. (2022). Extreme temperatures scorch indian wheat production. Attaché Report (GAIN) IN2022-0045, USDA Foreign Agricultural Service.

Burke, M. and Emerick, K. (2016). Adaptation to climate change: Evidence from US agriculture. *American Economic Journal: Economic Policy*, 8(3):106–40.

Carleton, T., Crews, L., and Nath, I. (2022). Agriculture, trade, and the spatial efficiency of global water use.

Costinot, A., Donaldson, D., and Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. *Journal of Political Economy*, 124(1):205–248.

Cruz, J.-L. and Rossi-Hansberg, E. (2023). The economic geography of global warming. *Review of Economic Studies*.

de Guzman, C. (2022). Climate crisis is driving food nationalism and changing global trade. *Time Magazine*.

Deschênes, O. and Greenstone, M. (2007). The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *American Economic Review*, 97(1):354–385.

Dixit, A. (1985). Tax policy in open economies. In *Handbook of Public Economics*, volume 1, pages 313–374. Elsevier.

Fajgelbaum, P., Goldberg, P., Kennedy, P., and Khandelwal, A. (2020). The return to protectionism. *Quarterly Journal of Economics*, 135(1):1–55.

Gawande, K. and Krishna, P. (2003). The political economy of trade policy: Empirical approaches. Handbook of International Economics, chapter 8, pages 212–250. Blackwell Publishing.

Ghosal, A., Musambi, E., and Calupitan, J. (2023). Food prices are rising as countries limit exports. Blame climate change, El Nino and Russia's war. *AP News*.

Goldberg, P. and Maggi, G. (1999). Protection for sale: An empirical investigation. *American Economic Review*, 89(5):1135–1155.

Gouel, C. and Laborde, D. (2021). The crucial role of domestic and international market-mediated adaptation to climate change. *Journal of Environmental Economics and Management*, 106:102408.

Grossman, G. and Helpman, E. (1994). Protection for sale. *American Economic Review*, 84(4):833–850.

Grossman, G. and Helpman, E. (1995). Trade wars and trade talks. *Journal of Political Economy*, 103(4):675–708.

Hijmans, R., Guarino, L., Cruz, M., and Rojas, E. (2001). Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genetic Resources Newsletter*, pages 15–19.

Hsiao, A. (2023). Coordination and commitment in international climate action: Evidence from palm oil.

Hultgren, A., Carleton, T., Delgado, M., Gergel, D., Greenstone, M., Houser, T., Hsiang, S., Jina, A., Kopp, R., Malevich, S., McCusker, K., Mayer, T., Nath, I., Rising, J., Rode, A., and Yuan, J. (2022). Estimating global impacts to agriculture from climate change accounting for adaptation.

Hummel, M., Hallahan, B., Brychkova, G., Ramirez-Villegas, J., Guwela, V., Chataika, B., Curley, E., McKeown, P., Morrison, L., Talsma, E., et al. (2018). Reduction in nutritional quality and growing area suitability of common bean under climate change induced drought stress in africa. *Scientific Reports*, 8(1):16187.

India Today Television (2022). Dr. Ashok Gulati calls govt's decision to ban export of wheat as anti-farmer. *India Today*.

Johnson, D. G., editor (1991). *World Agriculture in Disarray*. St. Martin's Press, 2 edition.

Johnson, H. (1953). Optimum tariffs and retaliation. *Review of Economic Studies*, 21(2):142–153.

Kim, H., Hyun, S. W., Hoogenboom, G., Porter, C., and Kim, K. S. (2018). Fuzzy union to assess climate suitability of annual ryegrass (lolium multiflorum), alfalfa (medicago sativa) and sorghum (sorghum bicolor). *Scientific Reports*, 8(1):10220.

Limão, N. (2017). *Optimal Tariffs*, pages 1–5. Palgrave Macmillan UK, London.

Lobell, D. and Field, C. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters*, 2(1):014002.

Lobell, D., Schlenker, W., and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, 333(6042):616–620.

Mendelsohn, R., Nordhaus, W., and Shaw, D. (1994). The impact of global warming on agriculture: A Ricardian analysis. *American Economic Review*, pages 753–771.

Monfreda, C., Ramankutty, N., and Foley, J. (2008). Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, 22(1).

Moscona, J. and Sastry, K. (2023). Does directed innovation mitigate climate damage? Evidence from US agriculture. *Quarterly Journal of Economics*, 138(2):637–701.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., et al. (2021). Era5-land: A state-of-the-art global reanalysis dataset for land applications. *Earth System Science Data*, 13(9):4349–4383.

Nath, I. (2023). Climate change, the food problem, and the challenge of adaptation through sectoral reallocation.

Nordhaus, W. (1975). The political business cycle. *Review of Economic Studies*, 42(2):169–190.

Ortiz-Bobea, A. (2021). The empirical analysis of climate change impacts and adaptation in agriculture. In *Handbook of Agricultural Economics*, volume 5, chapter 76, pages 3981–4073. Elsevier.

Ortiz-Bobea, A., Ault, T., Carrillo, C., Chambers, R., and Lobell, D. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11(4):306–312.

Ossa, R. (2014). Trade wars and trade talks with data. *American Economic Review*, 104(12):4104–4146.

Putnam, R. (1988). Diplomacy and domestic politics: The logic of two-level games. *International Organization*, 42(3):427–460.

Ramirez-Villegas, J., Jarvis, A., and Läderach, P. (2013). Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology*, 170:67–78.

Ramsey, F. (1927). A contribution to the theory of taxation. *Economic Journal*, 37(145):47–61.

Rodrik, D. (1995). Political economy of trade policy. volume 3 of *Handbook of International Economics*, chapter 28, pages 1457–1494. Elsevier.

Rogoff, K. (1990). Equilibrium political budget cycles. *American Economic Review*, 80:21–36.

Rudik, I., Lyn, G., Tan, W., and Ortiz-Bobea, A. (2022). The economic effects of climate change in dynamic spatial equilibrium.

Schlenker, W. and Roberts, M. (2009). Nonlinear temperature effects indicate severe damages to us crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37):15594–15598.

Online Appendix for: Food Policy in a Warming World

A Omitted Proofs

A.1 Proof of Proposition 1

We proceed by deriving the optimal tariff under the assumption that it is interior; at the end, we show that the assumption $\epsilon_m \notin (0, -1)$ is sufficient to guarantee interiority.

We first derive $\partial p/\partial \tau$ by implicitly differentiating market clearing, Equation 2.1:

$$\frac{\partial Q(p)}{\partial p}|_{p=p^*}\frac{\partial p^*}{\partial \tau} = \frac{\partial Y(p)}{\partial p}|_{p=p^*}\frac{\partial p^*}{\partial \tau} + \frac{\partial M(p)}{\partial p}|_{p=p^*-\tau}\left(\frac{\partial p^*}{\partial \tau} - 1\right) \tag{A.1}$$

Re-arranging, and suppressing the evaluations, we obtain

$$\frac{\partial p^*}{\partial \tau} = -\frac{\frac{\partial M(p)}{\partial p}}{\frac{\partial Q(p)}{\partial p} - \frac{\partial Y(p)}{\partial p} - \frac{\partial M(p)}{\partial p}} = -\frac{\epsilon_m s_m}{\epsilon_d\left(1 - \frac{\tau}{p^*}\right) - \left((1-s_m)\epsilon_s\left(1 - \frac{\tau}{p^*}\right) + s_m\epsilon_m\right)} \tag{A.2}$$

where we define the elasticities $\epsilon_z = \frac{\partial z}{\partial p}\frac{p}{z}$, for $z \in \{x, y, m\}$ and with all prices evaluated in equilibrium.

We next re-arrange Equation 2.3 in the following way:

$$\tau = \frac{\frac{\partial p^*(\tau)}{\partial \tau}\left(\lambda^P Y(p^*(\tau)) - \lambda^C Q(p^*(\tau))\right) + \lambda^G M(p^*(\tau) - \tau)}{\lambda^G \frac{\partial M(p^*(\tau)-\tau)}{\partial p}\left(1 - \frac{\partial p^*(\tau)}{\partial \tau}\right)} \tag{A.3}$$

Using our expression for $\frac{\partial p^*}{\partial \tau}$ and expressing $\frac{\partial M}{\partial p}$ as an elasticity, we obtain

$$\tau = \frac{-\frac{\epsilon_m s_m}{\epsilon_d\left(1-\frac{\tau}{p^*}\right) - \left((1-s_m)\epsilon_s\left(1-\frac{\tau}{p^*}\right)+s_m\epsilon_m\right)}\left(\lambda^P Y(p^*(\tau)) - \lambda^C Q(p^*(\tau))\right) + \lambda^G M(p^*(\tau) - \tau)}{\left(1 - \frac{\tau}{p^*}\right)\lambda^G\left(\epsilon_m \frac{M(p^*-\tau)}{p^*-\tau}\right)\frac{\epsilon_d - (1-s_m)\epsilon_s}{\epsilon_d\left(1-\frac{\tau}{p^*}\right) - \left((1-s_m)\epsilon_s\left(1-\frac{\tau}{p^*}\right)+s_m\epsilon_m\right)}} \tag{A.4}$$

Cancelling alike terms in the numerator and denominator, we simplify this to

$$\frac{\tau}{p^*} = \frac{s_m\left(\lambda^P Y(p^*(\tau)) - \lambda^C Q(p^*(\tau))\right)}{\lambda^G M(p^*(\tau) - \tau)((1-s_m)\epsilon_s - \epsilon_d)} - \frac{\epsilon_d\left(1 - \frac{\tau}{p^*}\right) - \left((1-s_m)\epsilon_s\left(1 - \frac{\tau}{p^*}\right) + s_m\epsilon_m\right)}{\epsilon_m((1-s_m)\epsilon_s - \epsilon_d)} \tag{A.5}$$

For the first term, we divide through by domestic consumption x to put everything in terms of import fractions:

$$\frac{\tau}{p^*} = \frac{\lambda^P(1-s_m)-\lambda^C}{\lambda^G((1-s_m)\epsilon_s-\epsilon_d)} - \frac{\epsilon_d\left(1-\frac{\tau}{p^*}\right)-\left((1-s_m)\epsilon_s\left(1-\frac{\tau}{p^*}\right)+s_m\epsilon_m\right)}{\epsilon_m((1-s_m)\epsilon_s-\epsilon_d)} \tag{A.6}$$

For the second term, we split the numerator and cancel to obtain:

$$\frac{\tau}{p^*} = \frac{\lambda^P(1-s_m)-\lambda^C}{\lambda^G((1-s_m)\epsilon_s-\epsilon_d)} + \frac{1}{\epsilon_m}\left(1-\frac{\tau}{p^*}\right)+\frac{s_m}{(1-s_m)\epsilon_s-\epsilon_d} \tag{A.7}$$

Finally, we take τ/p^* to the right-hand side and combine fractions to obtain, as desired,

$$\frac{\tau}{p^*} = \frac{\epsilon_m}{\epsilon_m+1}\left(\frac{\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C}{\lambda^G((1-s_m)\epsilon_s-\epsilon_d)}\right)+\frac{1}{\epsilon_m+1} \tag{A.8}$$

Equation 2.7 follows by defining

$$\alpha = \frac{\tau}{p^*-\tau} \tag{A.9}$$

We next check that the conjectured solution lies in the correct domain, or $\alpha > -1$ (i.e., the true solution is not a corner solution). To do this, we write the condition

$$\frac{1}{\epsilon_m}\left(\frac{\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right)+\epsilon_m\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right)}{\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right)-\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right)}\right) > -1 \tag{A.10}$$

Multiplying both sides by $\epsilon_m s_m > 0$, we obtain

$$\frac{s_m\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right)+s_m\epsilon_m\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right)}{\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right)-\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right)} > -\epsilon_m s_m \tag{A.11}$$

We now split cases. If the denominator is positive, we obtain

$$\begin{aligned} s_m\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right) &+ s_m\epsilon_m\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right) > \\ &- \epsilon_m s_m\left(\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right)-\left(\lambda^P(1-s_m)+\lambda^G s_m-\lambda^C\right)\right) \end{aligned} \tag{A.12}$$

Or

$$s_m\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right) > -\epsilon_m s_m\lambda^G\left((1-s_m)\epsilon_s-\epsilon_d\right) \tag{A.13}$$

or $s_m > -s_m\epsilon_m$. If $\epsilon_m, s_m > 0$, this is immediate. If $\epsilon_m, s_m < 0$, then the condition is $\epsilon_m < -1$. This is consistent with our assumption.

If the denominator is negative, we obtain $s_m < s_m\epsilon_m$. If $\epsilon_m, s_m < 0$, this is immediate. If $\epsilon_m, s_m > 0$, then this condition requires $\epsilon_m > 1$. This is also consistent with our assumption.

A.2 Proof of Corollary 1

Since $p^* - \tau > 0$ and $\epsilon_m > 0$, we have that

$$\text{sign}[\alpha^*] = \text{sign}\left[\lambda^G\left((1-s_m)\epsilon_s - \epsilon_d\right) + \epsilon_m\left(\lambda^P(1-s_m) + \lambda^G s_m - \lambda^C\right)\right] \tag{A.14}$$

The claimed expression follows immediately.

A.3 Proof of Lemma 2

A.4 Proof of Lemma 1

First, we observe that

$$S(\alpha, \omega, \omega') = 1 - \frac{Y(P^*(\alpha, \omega, \omega'), \omega)}{Q(P^*(\alpha, \omega, \omega'))} \tag{A.15}$$

We now derive the properties in turn.

Property (i). From market clearing,

$$Q(p^*) = Y(p^*, \omega) + M\left(\frac{p^*}{1+\alpha}, \omega'\right) \tag{A.16}$$

and the fact that M is increasing, Y is increasing, and Q is decreasing, it is immediate that p^* increases in α. Moreover, since Y increases in p and Q decreases in p, we have that $1 - Y/Q$ decreases in α. Differentiability follows from the differentiability of Y, Q and P^*.

Property (ii). We observe that, using market clearing, an equivalent expression for S is

$$S(\alpha, \omega, \omega') = \frac{M\left(\frac{P^*(\alpha,\omega,\omega')}{1+\alpha}, \omega'\right)}{Q(P^*(\alpha, \omega, \omega'))} \tag{A.17}$$

Consider some $\omega_1 > \omega_0$. Under iso-elastic demand, and if $m > 0$,

$$\frac{S(\alpha, \omega_1, \omega')}{S(\alpha, \omega_0, \omega')} = \frac{\left(\frac{P^*(\alpha,\omega_1,\omega')}{P^*(\alpha,\omega_0,\omega')}\right)^{\epsilon_m}}{\left(\frac{P^*(\alpha,\omega_1,\omega')}{P^*(\alpha,\omega_0,\omega')}\right)^{\epsilon_d}} = \left(\frac{P^*(\alpha, \omega_1, \omega')}{P^*(\alpha, \omega_0, \omega')}\right)^{\epsilon_m - \epsilon_d} \tag{A.18}$$

which is > 1 given the observation that P^* increases in ω. If $m < 0$,

$$\frac{S(\alpha, \omega_1, \omega')}{S(\alpha, \omega_0, \omega')} = \left(\frac{P^*(\alpha, \omega_1, \omega')}{P^*(\alpha, \omega_0, \omega')}\right)^{-\epsilon_m - \epsilon_d} \tag{A.19}$$

which is > 1 under the additional assumption that $\epsilon_m > -\epsilon_d$, or foreign demand is more elastic than domestic demand.

Property (iii). This follows from the same logic as the comparative static in α, as the variables enter M with the same sign.

Property (iv). By direct calculation,

$$\frac{\partial S}{\partial \alpha} = -\frac{(1-s_m)\epsilon_s + s_m\epsilon_m - \epsilon_d}{(1+\alpha)(1-s_m)s_m\epsilon_m(\epsilon_s - \epsilon_d)} < 0 \tag{A.20}$$

where the inequality uses $s_m\epsilon_m > 0$ and $\alpha > -1$ (interiority). If $\frac{\mathrm{d}A^*}{\mathrm{d}s_m} \geq 0$, then the claim follows. If not, then we calculate directly:

$$\left(\frac{\partial S}{\partial \alpha}\right)^{-1} - \frac{\mathrm{d}A^*}{\mathrm{d}s_m} = K\Big(\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) - \\ \frac{((1-s)\epsilon_s - \epsilon_d)((1-s)\epsilon_s + s\epsilon_m - \epsilon_d)(\lambda^C + (1-s)\epsilon_s - \epsilon_d)\lambda^G - (s\lambda^G + (1-s)\lambda^P)}{s_m\epsilon_m(1-s_m)(\epsilon_s - \epsilon_d)}\Big) \tag{A.21}$$

for some $K > 0$. Thus, under the additional condition

$$\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) < \\ \frac{((1-s_m)\epsilon_s - \epsilon_d)((1-s_m)\epsilon_s + s_m\epsilon_m - \epsilon_d)(\lambda^C + (1-s_m)\epsilon_s - \epsilon_d)\lambda^G - (s_m\lambda^G + (1-s_m)\lambda^P)}{s_m\epsilon_m(1-s_m)(\epsilon_s - \epsilon_d)} \tag{A.22}$$

the claim follows.

A.5 Proof of Proposition 2

We first and state and prove an auxiliary Lemma:

Lemma 2 (Relative Assistance and Import Shares)**.** *The following statements are true:*

1. *If the government is revenue-focused, or $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) < 0$, then $A^{*\prime} > 0$, or higher import shares are associated with higher producer assistance.*
2. *If the government is constituent-focused, or $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) > 0$, then $A^{*\prime} < 0$, or higher import shares are associated with higher consumer assistance.*
3. *If the government is neutral, or $\epsilon_s(\lambda^C - \lambda^G) - \epsilon_d(\lambda^P - \lambda^G) = 0$, then $A^{*\prime} = 0$, or assistance is invariant to the import share.*

Proof. By direct calculation, we have that

$$\frac{\mathrm{d}A^*(s_m)}{\mathrm{d}s_m} = \frac{\left(\lambda^G(\epsilon_s - \epsilon_d) - \lambda^C\epsilon_s + \lambda^P\epsilon_d\right)(1+\epsilon_m)\lambda_G}{\epsilon_m\left(\lambda^G\left((1-s_m)\epsilon_s - \epsilon_d\right) - \left(\lambda^P(1-s_m) + \lambda^G s_m - \lambda^C\right)\right)^2} \tag{A.23}$$

Thus, if the claimed condition holds, then $\partial A^*(s_m)/\partial s_m < 0$. The additional claims follow from observing that $\alpha = A^*(s_m)$ must hold in any equilibrium. Thus if α^* increases comparing the unique equilibrium associated with two different parameter values, then s_m decreases; and if α^* increases, then s_m decreases. □

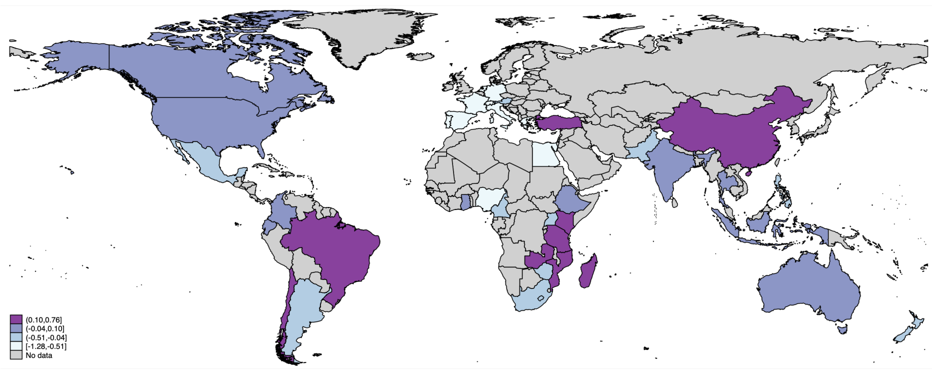
We prove the cases in turn. For all cases, we observe that for $\omega_1 \geq \omega_0$ and $\omega_1' \geq \omega_0'$, then $S(\alpha, \omega_1, \omega_1') \geq S(\alpha, \omega_0, \omega_0')$ for all α. We let α_1^*, α_0^* denote the equilibrium policy in each case. We observe that $\alpha \mapsto S^{-1}(s_m, \omega, \omega')$ is decreasing for any ω, ω'.

1. Since $A(s_m)$ is strictly increasing (Lemma 2), then $f(s_m) = S^{-1}(s_m, \omega_1, \omega_1') - A^*(s_m)$ is a decreasing function and $f(s_{m,0}^*) \geq 0$. Moreover, for any equilibrium $s_{m,1}^*$, $f(s_{m,1}^*) = 0$. Therefore, $s_{m,1}^* \geq s_{m,0}^*$, provided that an equilibrium exists (which has been established earlier). Since A^* is increasing, then $\alpha_1^* = A(s_{m,1}^*) \geq \alpha_0^*$.
2. Since $A(s_m)$ is strictly decreasing (Lemma 2), but $\left(\frac{\partial S}{\partial \alpha}\right)^{-1} < \frac{\mathrm{d}A^*}{\mathrm{d}s_m}$, then $f(s_m) = S^{-1}(s_m, \omega_1, \omega_1') - A^*(s_m)$ is a decreasing function and $f(s_{m,0}^*) \geq 0$. Moreover, for any equilibrium $s_{m,1}^*$, $f(s_{m,1}^*) = 0$. Therefore, $s_{m,1}^* \geq s_{m,0}^*$, provided that an equilibrium exists (which has been established earlier). Since A^* is decreasing, then $\alpha_1^* = A(s_{m,1}^*) \leq \alpha_0^*$.
3. In this case, $A(s_m)$ is constant (Lemma 2). Thus, $\alpha_1^* = \alpha_0^*$.

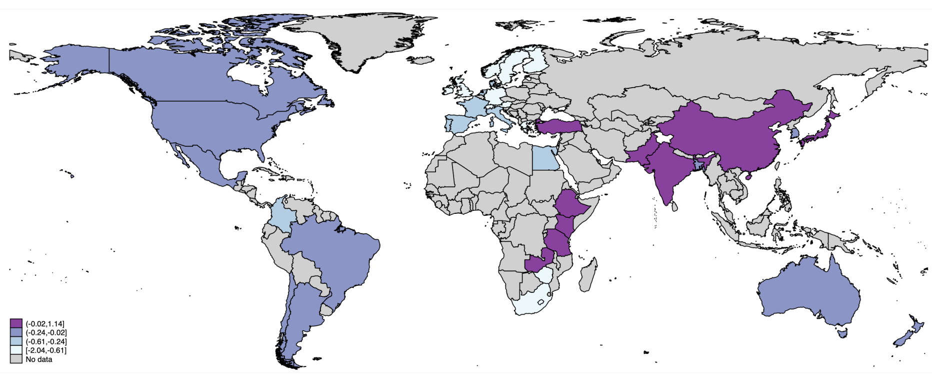
B Additional Figures and Tables

Figure A.1: Global Changes in Policy for Select Crops

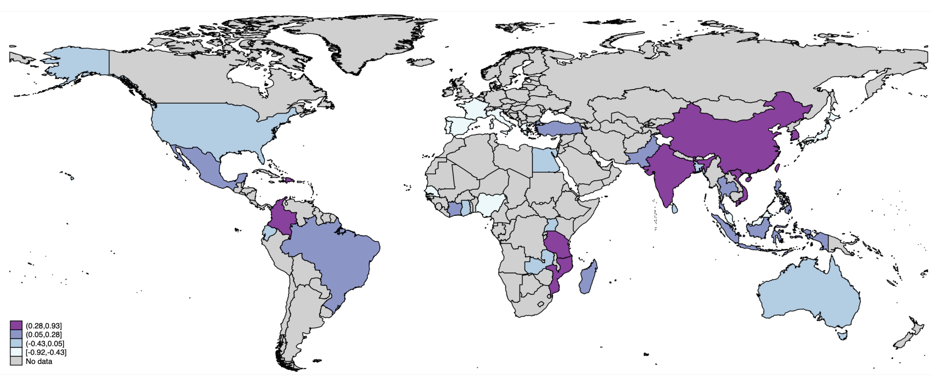
(a) Maize



(b) Wheat



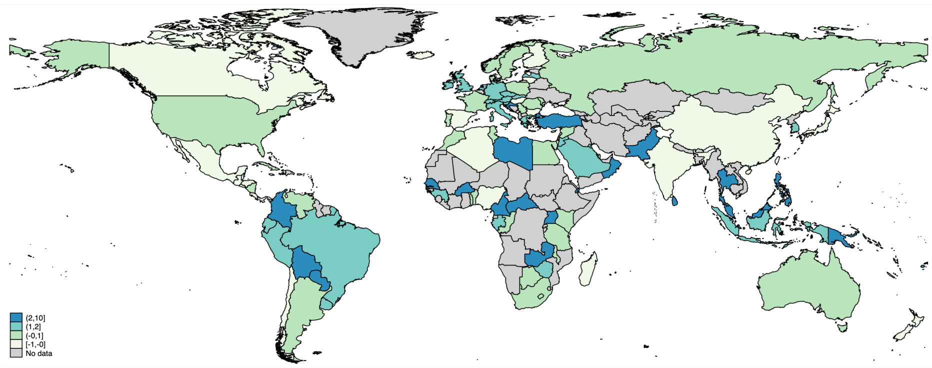
(c) Rice



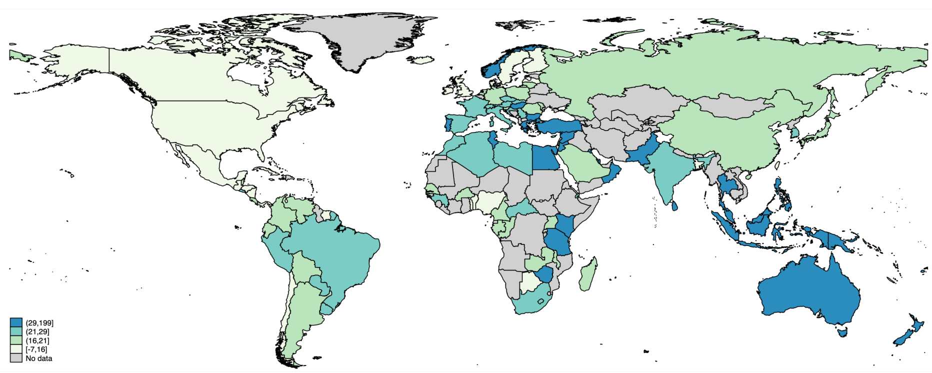
This figure displays the change in NRA (1980s-2000s) for maize (Figure A.1a), wheat (Figure A.1b), and rice (Figure A.1c). Countries are color-coded by quartile where darker colors correspond to larger values of NRA change.

Figure A.2: Global Changes Exposure to Foreign Extreme Temperatures

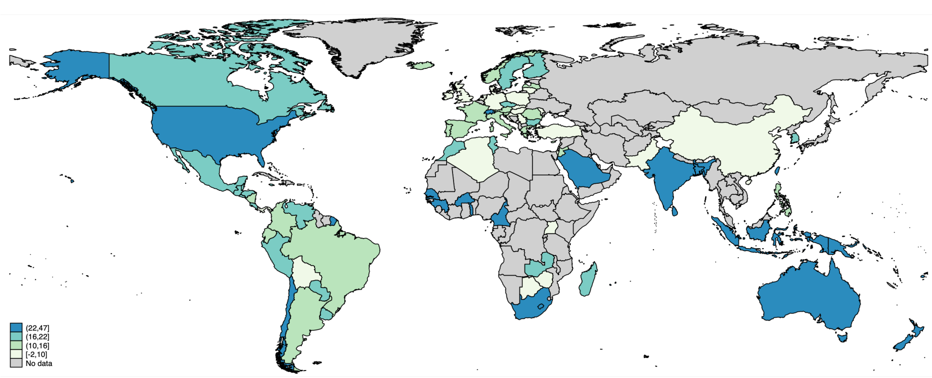
(a) Maize



(b) Wheat

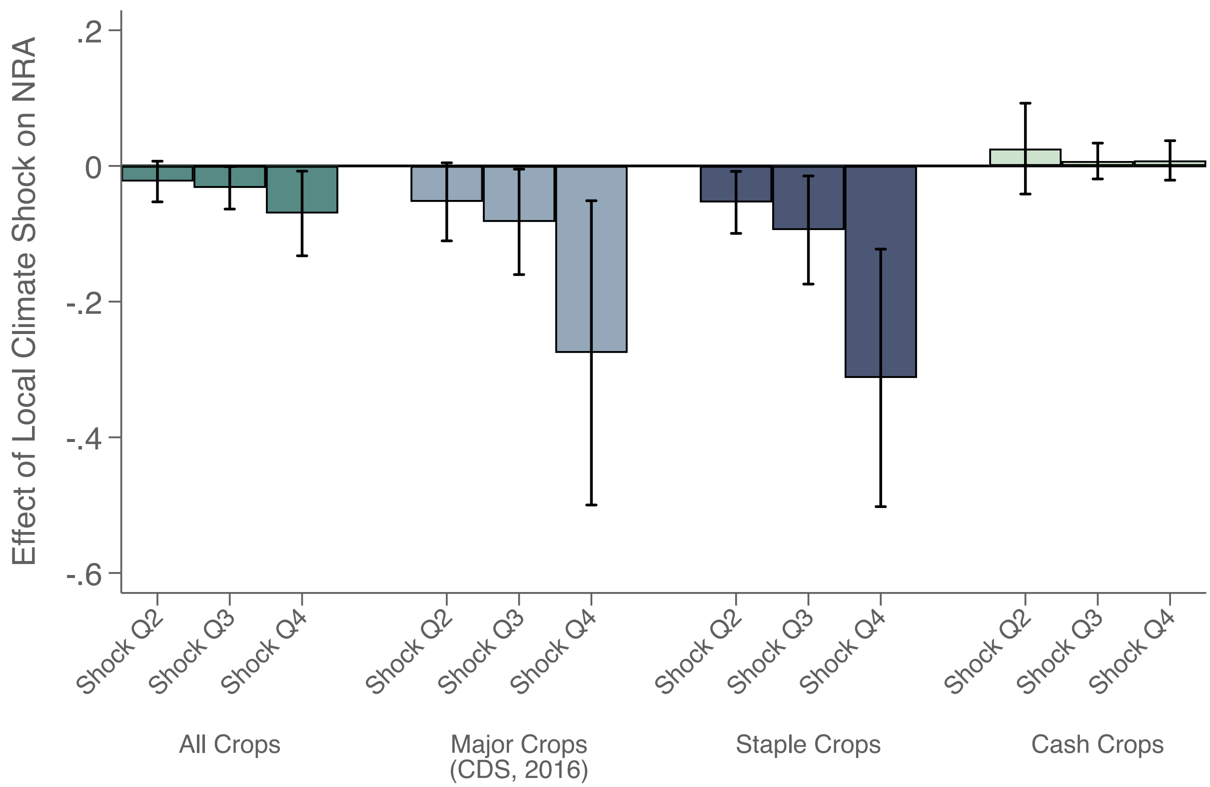


(c) Rice



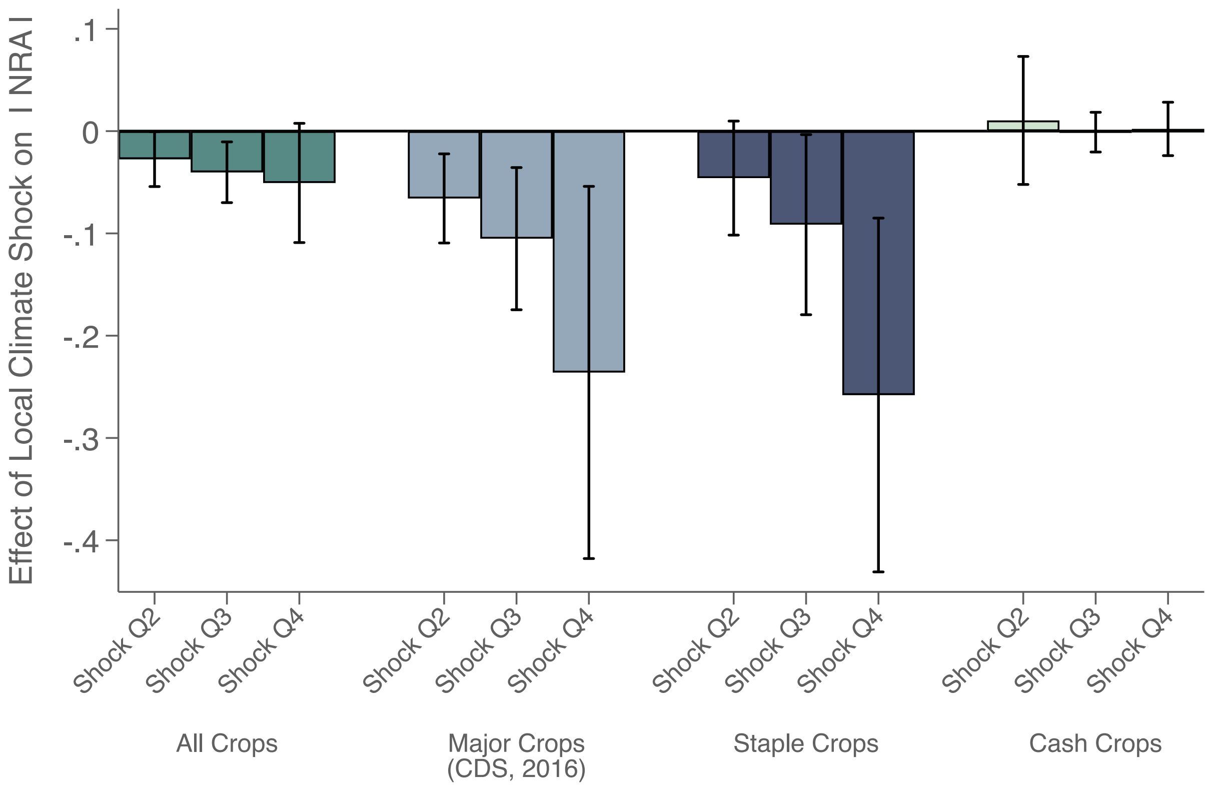
This figure displays the change in foreign import-weighted extreme heat exposure (1980s-2000s) for maize (Figure A.2a), wheat (Figure A.2b), and rice (Figure A.2c). Countries are color-coded by quartile.

Figure A.3: Extreme Heat and Agricultural Policy, 1955-2011



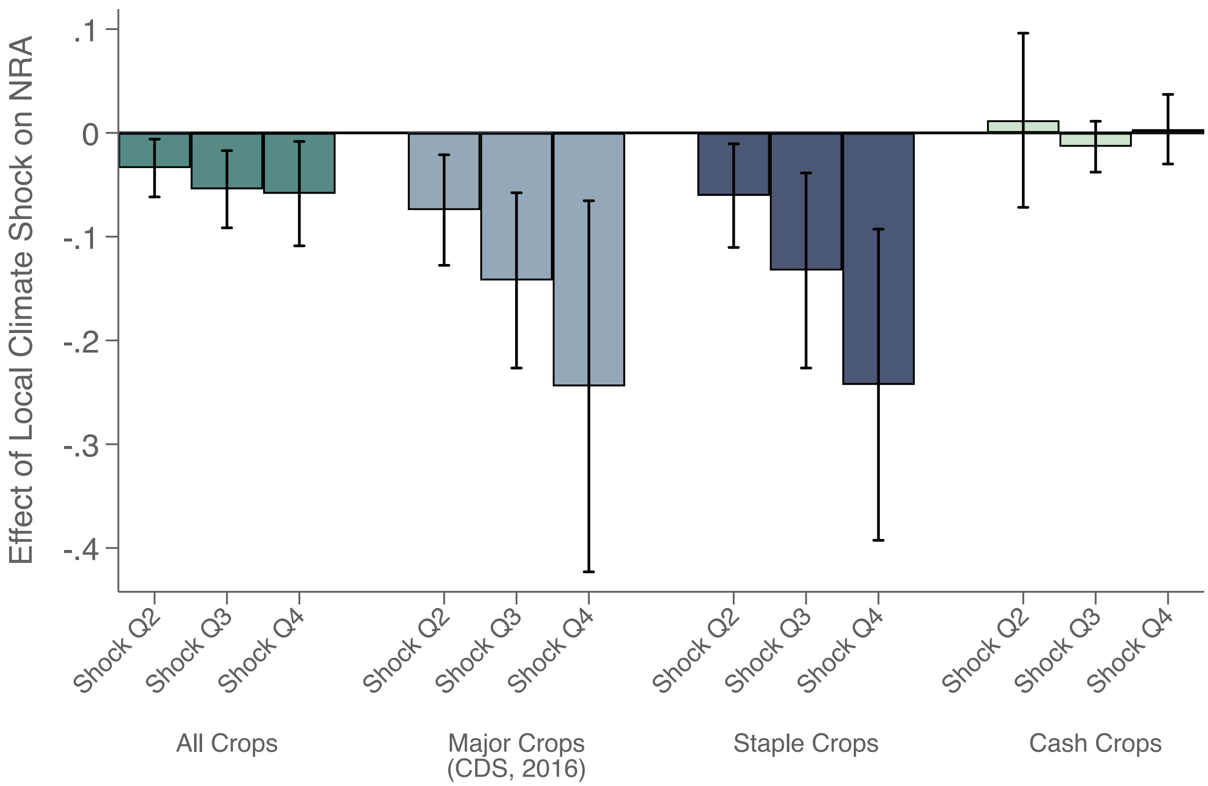
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. The sample includes all NRA and temperature data from 1955-2011. We report 90% confidence intervals.

Figure A.4: Extreme Heat and Agricultural Policy, 1980-2021 with Alternative Data



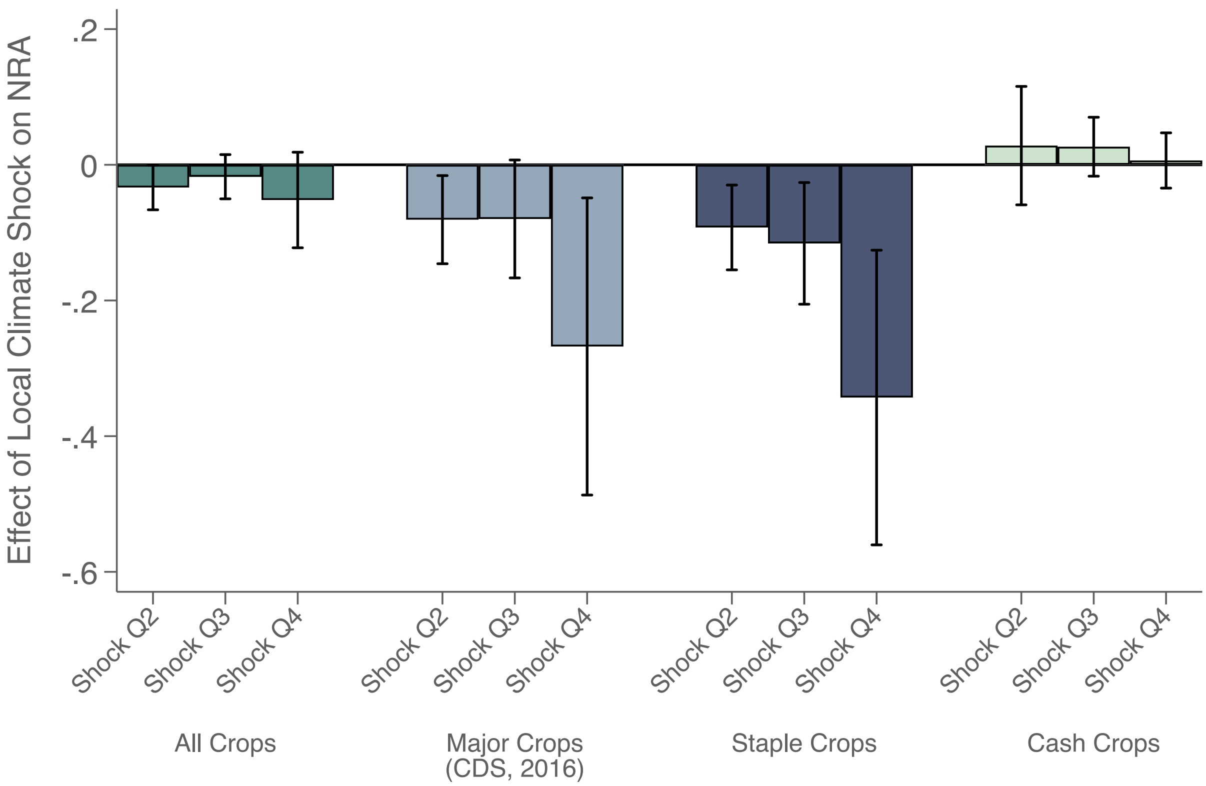
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. The sample includes all NRA and temperature from 1980 to 2021, where recent years are filled in using data from Ag-Incentives (https://www.agincentives.org/). We report 90% confidence intervals.

Figure A.5: Extreme Heat and Agricultural Policy Excluding 1980s



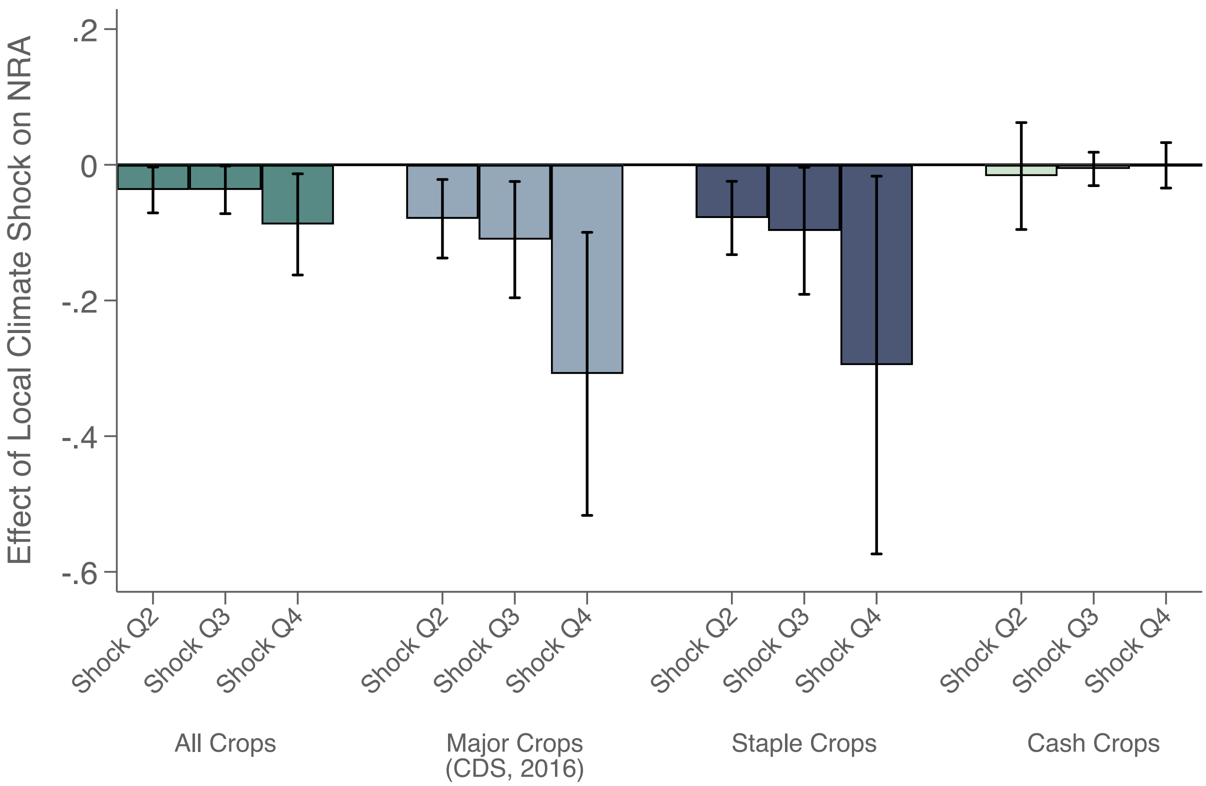
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. The 1980s are excluded from the sample. We report 90% confidence intervals.

Figure A.6: Extreme Heat and Agricultural Policy Excluding 1990s



This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. The 1990s are excluded from the sample. We report 90% confidence intervals.

Figure A.7: Extreme Heat and Agricultural Policy Excluding 2000s



This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each regression is noted below each set of bars. The 2000s are excluded from the sample. We report 90% confidence intervals.