Food Policy in a Warming World

Allan Hsiao* Jacob Moscona† Karthik A. Sastry‡

Princeton University Harvard University Princeton University

November 12, 2023

(most recent version here)

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 suggest that endogenizing trade policy increases climate damages by nearly 10%. Our results underscore how policy and politics affect 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 and Vincent Pons for very 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 aggressively "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 producers and consumers 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 around the world.

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. 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 combination of producer surplus, consumer surplus, and government revenue. Flexible weights across these terms capture the government's preferences for redistribution and fiscal responsibility.

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 dead-weight 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 domestic climate shocks, which we model as negative domestic supply shocks. We characterize when negative climate shocks induce pro-consumer or pro-producer policy shifts, as a function of the government's relative preference weights and the domestic elasticities of supply and demand. We show that the policy response hinges on whether the government is *constituent-* or *revenue-focused*. A constituent-focused government places higher weight on producer or consumer surplus (or both), while a revenue-focused government places higher weight on government revenue. Intuitively, the dominant concern for a constituent-focused government is that a domestic supply shortage shifts the burden of lower prices away from domestic producers and toward foreign producers, on whom the government places no welfare weight. The dominant concern for a revenue-focused government is that a domestic supply shortage is the most expensive time to subsidize imports (or the least profitable time to tax exports). Critically, these considerations differ from what determines the *level* of trade policy. A pro-producer government can subsidize production on average, but still respond in a pro-consumer fashion to an adverse shock; 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 (or less profitable) 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 because it operates through changing prices. International spillovers can reinforce the initial change in trade policy, consistent with a hypothesis in popular discourse about food policy "contagion" (Ghosal et al., 2023). 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. That is, policies across countries are stabilizing rather than amplifying at global scale. A single-country analysis would thus overstate the global effect of climate change on policy.

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. We combine gridded, global data on daily temperature realizations (Muñoz-Sabater et al., 2021) with expert-elicited estimates of the maximum growing temperature for individual plant species in order to measure the potential exposure of a given crop to extreme heat in a given country over a specific period of time (Moscona and Sastry, 2023). We use these data to construct crop-specific exposure to extreme heat for each country and each decade 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.

Before presenting the main analysis, 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.

Results. We then turn to the main results of the paper. First, we document that extreme heat exposure substantially reduces NRA. This reduction corresponds to more strongly *pro-consumer* policy. Through the lens of the model, this finding is consistent with trade policy driven by constituent focus, as governments institute policy to reduce domestic prices in response to local supply shocks. 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. Each result is consistent with the model's prediction that the magnitude of the policy response should be inversely related to the elasticity of demand.[1] 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. We also find that extreme temperature shocks reduce the absolute value of NRA, suggesting that climate change may reduce the overall level of policy distortions in the agricultural economy.

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. Our model suggests that, since we found a negative effect of domestic

[1] When splitting the NRA into components associated with different policy instruments, we find that the effects are concentrated in output-market interventions (e.g., import and export tariffs) as opposed to input-market interventions (e.g., subsidies for fertilizer or mechanical inputs).

climate shocks on NRA, we should expect to find a *positive* effect of foreign climate shocks on NRA. But as governments respond to climate change with consumer-oriented policies like export bans, qualitative accounts imply that other government may respond with their own consumer-oriented policies. Ghosal et al. (2023) refer to this scenario as food policy "contagion." This notion has led to proclamations that climate change is driving "food nationalism" and that policy responses can have "multiplier effects" that exacerbate their economic consequences (de Guzman, 2022). Unlike this prevailing narrative and consistent with our model, we find evidence of the opposite pattern. Foreign 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.

Third, we turn from studying year-to-year fluctuations in extreme heat to decade-to-decade changes in extreme heat exposure. This analysis seeks to capture the effects of longer-run climate change on agricultural policy. In principle, short-run responses could differ greatly from long-run responses, which incorporate the fact that production and patterns of trade may adapt. However, when we study the decadal response to both local and foreign extreme heat exposure, we estimate effects that are similar to our baseline estimates. These findings are consistent with our event study estimate, which suggests a degree of persistence in the effect of extreme heat exposure on trade policy.

Fourth, we test for evidence of our key model mechanism: the constituent or revenue focus of governments when responding to adverse climate shocks. A large body of work documents the existence of "political cycles," suggesting that upcoming elections may lead governments to place less emphasis on fiscal responsibility and more emphasis on redistributing to their constituents.[2] Under our proposed mechanism, we would expect our baseline results to be more pronounced in advance of upcoming elections. Consistent with this hypothesis, our findings are all substantially large 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. These estimates indicate that differences in political incentives shape the policy response to climate change.

Finally, we combine our model and empirical estimates to quantify how these policy responses affect aggregate climate damages. We simulate climate change by increasing the number of extreme heat days globally, then we compute production, consumption, and trade in equilibrium. We do so under both endogenous and exogenous trade policy. Endogenizing trade policy exacerbates climate damages, as constituent-focused governments move to shield

[2]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.

consumers and producers but at great fiscal cost. Exogenous trade policy takes trade costs as fixed and understates total welfare losses by 9%.

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).[3] 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 responds to climate shocks, and we quantify the implications for global adaptation.[4]

In studying the role of policy, we connect to a long-standing literature in international trade that studies the distributional nature of trade policy. This work studies trade policy motivated by protectionism (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), with distributional consequences both within and across borders. 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.

2 Model

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

[3] See Ortiz-Bobea (2021) for a survey.

[4] Bastos et al. (2013) study how rainfall shocks affect agricultural tariffs, and our results are consistent with their finding that rainfall shortages lead to lower agricultural import tariffs, across countries and time. We differ in our theoretical focus on redistributional motivations for distortionary trade policy, in our empirical focus on climate change more generally, and in our empirical strategy which leverages variation across sectors, countries, and time.

policy. We show that a sharp 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 policy shift or a 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 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., extremely high 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, 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 prices 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 differentiable function $P^* : \mathbb{R}^3 \to \mathbb{R}_+$ that maps (τ, ω, ω') to equilibrium prices. This function is increasing in its first argument: if the government taxes imports (or subsidizes exports) more, then the domestic price increases. We make the further assumption that P^* is differentiable in τ.

The government sets an optimal border tax $\tau^* \in \mathbb{R}$ to maximize a weighted sum of equilibrium 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 $\frac{\partial M}{\partial p}\frac{p}{m} \notin (-1, 1)$.[5]

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 is that the first-order benefit of changing τ is zero. That is, if the optimal tariff is interior,

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

The first term measures marginal redistribution between producers and consumers. In particular, 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 simplifying this expression, we define the equilibrium demand, supply, and import elasticities as

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

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

$$s_m = \frac{m}{q} \tag{2.5}$$

and observe that $s_m \in (-\infty, 1]$: negative imports correspond to net exports, but imports

[5] 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.

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:

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

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

Optimal Policy. Putting together the terms in Equation 2.3, and expressing the marginal changes in imports and prices in terms of elasticities, 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

$$\alpha^* = \frac{1}{\epsilon_m} \tag{2.8}$$

which is a familiar "inverse elasticity rule" or "Ramsey rule," obtained from setting marginal revenue equal to marginal dead-weight loss (see, e.g., Ramsey, 1927; Limão, 2017). For a net importer ($\epsilon_m > 0$), the Ramsey rule always takes the form of producer support: that is, restricting imports via a tax. For a net exporter ($\epsilon_m < 0$), the Ramsey rule takes the form of consumer support: that is, restricting exports via a tax.

We next allow the planner's weights on consumers, producers, and government revenue may differ. In this case, there is a second determinant of optimal policy: the government's desire for pecuniary redistribution among agents. To the first order, increasing the price of the product transfers surplus away from consumers and toward producers and the government. The latter two forces are proportional to the relative amounts of domestic production and imports, and the latter effect is negative if the country is a net exporter and the policy is an import subsidy. The extent of this pecuniary transfer is proportional to the price impact of marginal trade policy. That price impact is high when, in absolute value, domestic supply and demand are relatively inelastic and 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 ($\tau > 0$) if and only if*

$$\lambda^C < \lambda^P(1 - s_m) + \lambda^G s_m + \frac{\lambda^G}{\epsilon_m}((1 - s_m)\epsilon_s - \epsilon_d) \tag{2.9}$$

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$[\tau]$ decreases in λ^C and increases in λ^P. For a net importer, sign$[\tau]$ increases in ϵ_s and $|\epsilon_d|$; for a net exporter, sign$[\tau]$ decreases in ϵ_s and $|\epsilon_d|$

Proof. See Appendix A.2. □

A high weight on consumers pushes the government to set $\tau < 0$: that is, to subsidize imports or to tax exports. A high weight on producers pushes the government to set $\tau > 0$: that is, to subsidize exports or to tax imports. These comparative statics 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 (e.g., due to climate change), how does trade policy respond?

To study this tractably, we restrict to the case in which the supply, demand, and net import curves are isoelastic. 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 joint parameter restriction on government preferences and domestic elasticities of supply and demand that defines whether the government is *constituent-focused* or *revenue-focused*:

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

$$\epsilon_S(\lambda^C - \lambda^G) - \epsilon_D(\lambda^P - \lambda^G) > 0 \tag{2.10}$$

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; a *revenue-focused* government is the opposite. 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 (or minimizing domestic dead-weight loss) versus raising revenue.

Intermediate Step: Policy and the Import Share. Whenever the government has distributional concerns, 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.

Toward describing equilibrium and its comparative statics, we first describe the how the government "responds" to market conditions. Critically, there are cases in which producer assistance is increasing in, decreasing in, and invariant to the import share. These hinge on whether the government is constituent-focused, revenue-focused, or neutral.

Lemma 1 (Relative Assistance and Import Shares)**.** *Let $\alpha = A^*(s_m)$ denote the optimal producer assistance derived in Proposition 1. 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 $A^{*'} > 0$, 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 $A^{*'} < 0$, 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 $A^{*'} = 0$, or assistance is invariant to the import share.*

Proof. See Appendix A.3. □

Crucially, these properties underlying *marginal* incentives to support producers *vs.* consumers are different than those underlying *average* incentives to support producers *vs.* consumers (Corollary 1). We now review the intuition of the result, case by case.

To understand case 1, it is useful to consider a parameter case with $\lambda^G \gg \lambda^C, \lambda^P$. When the import share is higher, the government has higher marginal incentive to tax imports; when the import share is lower (or export share is higher), the opposite is true.[6]

To understand case 2, it is useful to consider the opposite scenario with $\lambda^G \ll \lambda^C, \lambda^P$. In this case, the government's desire to raise revenue disappears, and the incentives are most "purely" driven by redistribution. 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 which lowers the domestic equilibrium price—that is, consumer assistance. Importantly, this logic obtains *regardless* of whether distributional preferences favor consumers more or less *relative* to producers. The intuition from this case is instead about the government's incentives to favor domestic consumers or producers, who have a positive welfare weight, over *foreign* producers or consumers, who have a zero welfare weight. Thus, even a strongly producer-supporting government that sets $\alpha > 0$ may lie in case 2.

Case 3 obtains when the two forces described above cancel out. A sufficient, but not necessary, condition for case 3 is the utilitarian assumption $\lambda^G = \lambda^P = \lambda^C$.

A Simple Representation of Equilibrium. We next complete our representation of equilibrium by combining the government's optimal policy choice with the response of import shares to policy. We moreover observe several important features of the second equilibrium relationship:

Lemma 2. *A pair (α^*, s_m^*) constitutes an equilibrium if*

$$\begin{aligned} \alpha^* &= A(s_m^*) \\ s_m^* &= S(\alpha^*, \omega, \omega') \end{aligned} \tag{2.11}$$

where (i) $\frac{\partial S}{\partial \alpha} < 0$, (ii) S increases in ω, and (iii) S decreases in ω'. Moreover, under an additional technical condition which ensures equilibrium stability, (iv) $\left(\frac{\partial S}{\partial \alpha}\right)^{-1} < \frac{\mathrm{d}A^*}{\mathrm{d}s_m}$.

[6] Note that the opposite force which generates a "Laffer curve" is accounted for in the second equation of the fixed point, whereby the import share decreases in α. This force is shut down in the present thought experiment.

Proof. See Appendix A.4. □

The first three properties are entirely 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 introduced in A.4. The condition rules out the possibility that the import share falls so quickly in α, there can be a non-convergent "negative feedback loop" between policy and the import share. 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. We note that the condition to rule this out always holds in the "neighborhood" of case (iii) of Lemma 1, or in cases with "small" perturbations toward a distributional bias.

Relative Assistance and Climate Shocks. We are now equipped to show our main result of this subsection:

Proposition 2 (Relative Assistance and Supply Shocks)**.** *The following statements are true about the response of equilibrium outcomes to an adverse climate shock:*

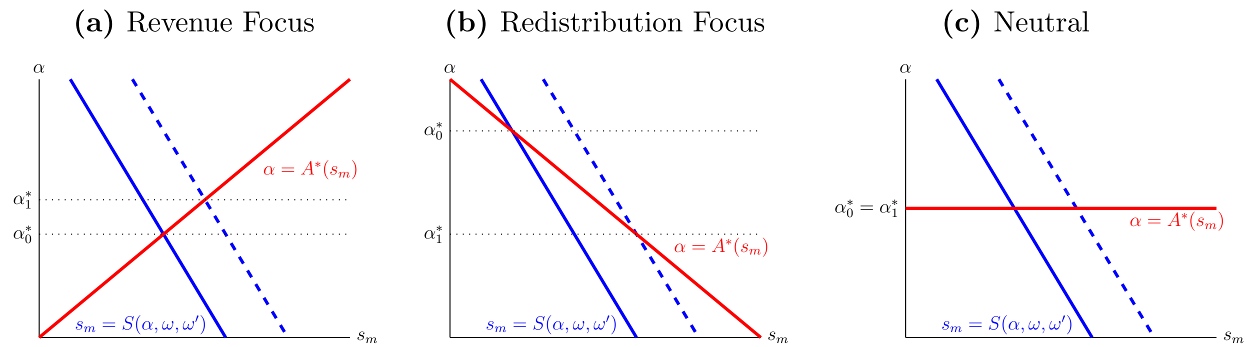
1. *If the government is revenue-focused, or* $\epsilon_S(\lambda^C - \lambda^G) - \epsilon_D(\lambda^P - \lambda^G) < 0$*, then* α^* *increases in* ω *and decreases in* ω'*.*
2. *If the government is constituent-focused, or* $\epsilon_S(\lambda^C - \lambda^G) - \epsilon_D(\lambda^P - \lambda^G) > 0$*, 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. □

That is: 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, given the properties identified in Lemmas 1 and 2. To understand the logic, we consider what happens in each case when there is an adverse domestic shock or positive foreign shock.

The revenue-focused government in case 1 of Lemma 2 an Proposition 2 wants to increase producer assistance when the import share rises. 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 (or eroding the gains) of domestic consumers.

Figure 1: Trade Policy and Climate Shocks



Each panel illustrates a case from Proposition 2, obtained from the equilibrium representation of Lemma 2. 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.

The constituent-focused government in case 2 of Lemma 2 an Proposition 2 wants to increase consumer assistance when the import share rises. 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).[7] For the opposite reason as what is cited above, this cushions the blow (or amplifies the gains) 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.

In all cases, domestic and foreign shocks have opposite effects precisely because the import share is the only relevant concern for the government. Put differently, both redistributive and tax collection motives are "scale free" in our model economy and hinge entirely on the split of surplus between domestic agents and foreigners.

2.4 Implications for Climate Adaptation

We now draw out some of the key implications of our model findings for adaptation to climate change, in the context of individual countries and the entire world.

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 consumers or by increasing assistance to producers. But does this constitute

[7] The stability condition invoked in Lemma 2 prevents the indirect effect from being so strong that it leads to an unstable equilibrium.

"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 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'.*
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'.*
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 is better than the old policy. The next statements follow from observing that consumer and producer surplus are monotone in domestic prices. These exact conclusions hinge, of course, on our disallowing government transfers of revenue directly to consumers and producers.

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 in a Warming World. So far, we have studied the problem of a single country setting trade policy in isolation. We now consider a simple two-country extension of our baseline framework. Imagine that there is now a second "foreign" country, with demand and supply functions Q' and Y', that can levy its own distortionary producer assistance τ'. Thus, equilibrium prices in the "foreign" country, $p^{*'}$, can be written in the following way as a function of equilibrium prices in the "home" country, p^*, and both the home and foreign rates of assistance:

$$p^{'*} = p^* - \tau - \tau' \tag{2.12}$$

Global trade balance requires

$$Q(p^*) - Y(p^*, \omega) = Q'(p^* - \tau - \tau') - Y'(p^* - \tau - \tau', \omega') \tag{2.13}$$

Holding fixed the foreign trade policy ω', this fits into our main model with the new net import function

$$m(p^* - \tau, \omega', \tau') = Q'(p^* - \tau - \tau') - Y'(p^* - \tau - \tau', \omega') \tag{2.14}$$

Moreover, we observe that an increase in τ', or producer assistance in the foreign country, is tantamount to a positive net imports shock. Conversely, a decrease in τ', or consumer assistance in the foreign country, is tantamount to a negative net imports shock.

A Nash equilibrium in government policy can be defined as a fixed-point between optimal symmetric choices of τ and τ', solving the respective versions of Program 2.2, with each country taking the other's policy as given. But even without full analysis of this case, we can make the following observations about the "best-response" functions of one country given a conjecture about the other's policy. Using the observation above that a positive shock to α' is tantamount to a negative shock to τ', it is clear that the cases of Proposition 2 already describe this best-response function.

This "first round effect" can be illustrated via example. Imagine that the foreign country is a net exporter to the home country 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, or an import subsidy. Under case 2 (a redistribution-focused government), the home country increases producer support, or taxes imports.

Consider now what happens if the cases are "global," or apply to both countries. Under case 1, 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 case 2, 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.

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 and, in particular, the graphical argument of Figure 1. 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

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,

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

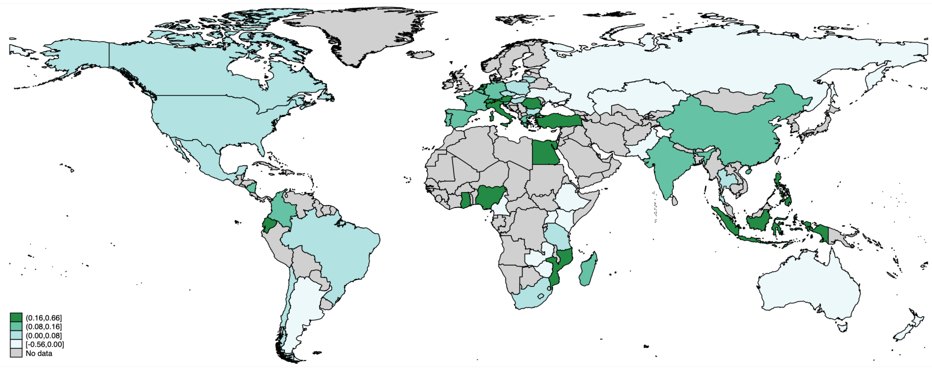
where $P^d_{\ell kt}$ is the unit value of production at a distorted price and $P^m_{\ell kt}$ is the unit value of production at an undistorted market price. In the model, this corresponds to our definition of α if we interpret $P^d_{\ell kt}$ as p^*, the domestic equilibrium price, and we interpret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

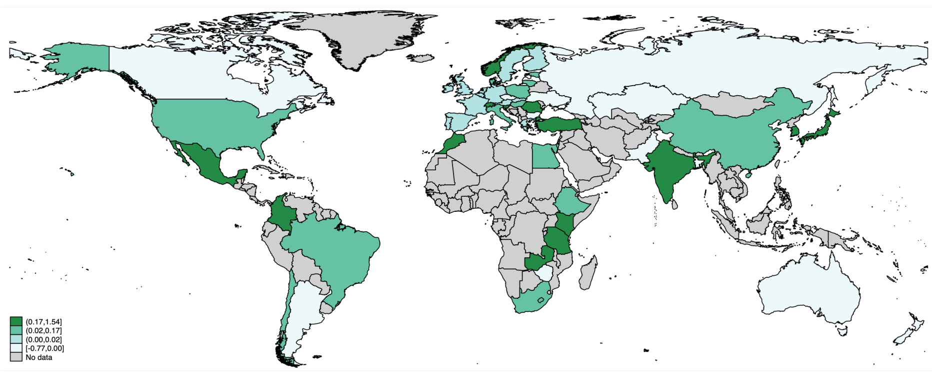
Figure 2 presents global maps of average NRA around the world from 2001-2010 for three major crops: maize, wheat, and rice. Countries are color coded by NRA quartile with darker colors corresponding to higher (i.e. more producer-oriented) NRA values. There is subtantial variation in agricultural policy, both across countries for each crop and within countries across crops. For each crop, there is a large set of countries with policy on both

Figure 2: Global Policy Variation for Select Crops

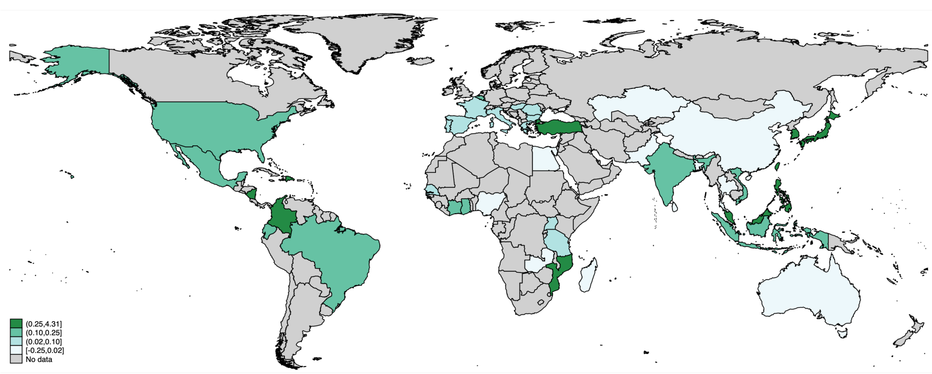
(a) Maize



(b) Wheat



(c) Rice



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.

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 big differences in how policies have changed over the last several decades. Figure 10 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 product, 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 for 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 in order 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 survey 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 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 to our data on production and trade, our dataset covers 166 countries and 126 crops. When merged to our data on agricultural policy, our dataset covers 79 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 in order to measure exposure to foreign temperature change.

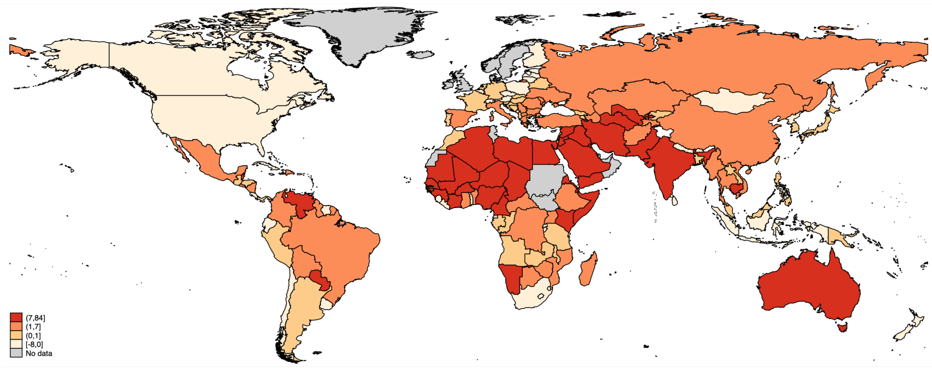
We also compile data on all election years during our sample period from the latest edition of the Database of Political Institutions (DPI), first introduced by Beck et al. (2001). The database covers elections in 180 countries from 1975-2020 and presents information about election and regime characteristics 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

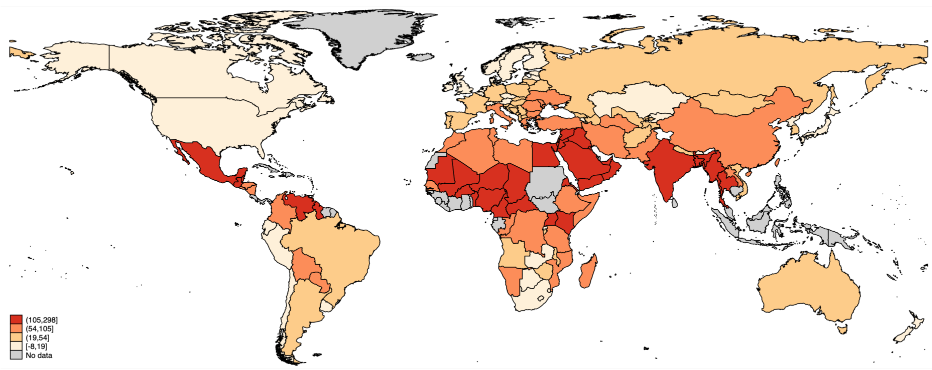
We investigate whether this measure of extreme heat exposure affects crop-specific productivity around the world. Moscona and Sastry (2023) validate, in historical panel data from

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

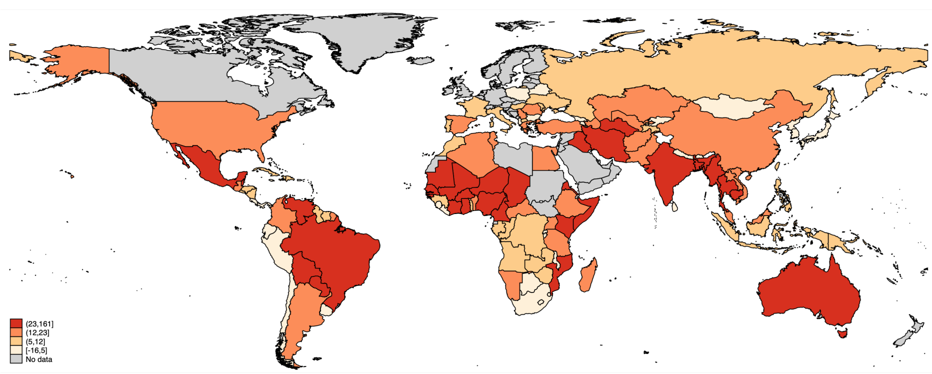
(a) Maize



(b) Wheat



(c) Rice

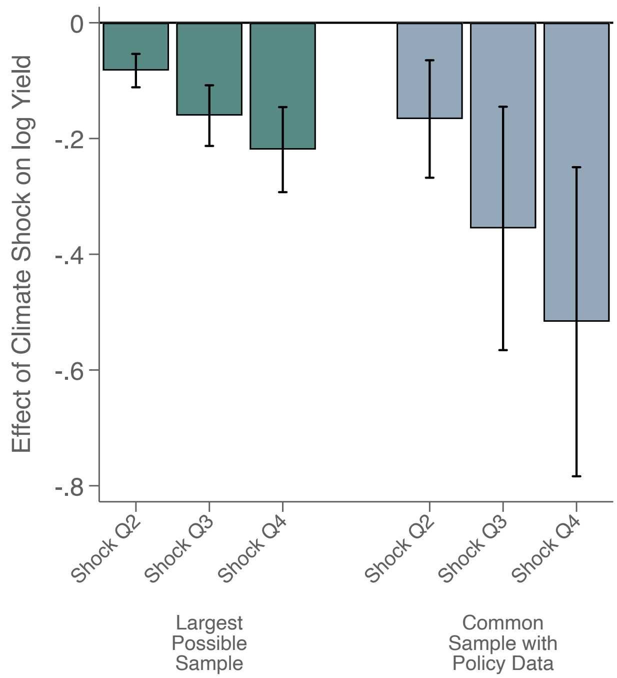


This figure displays the change in extreme heat exposure for maize (Figure 3a), wheat (Figure 3b), and rice (Figure 3c) between the 1980s and the 2010s. Countries are color coded by quartile where darker colors correspond to larger increases in extreme heat exposure.

the United States, that this measure robustly 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

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

Figure 4: Extreme Heat and Crop Yields



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.

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, 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 on this sample. Compared to the yields in the bottom extreme heat quartile, yields in the top extreme heat quartile are over 40% lower.

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

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

where $\mathrm{NRA}_{\ell kt}$ 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 $\mathrm{ExtremeExposure}_{\ell kt}$. 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.

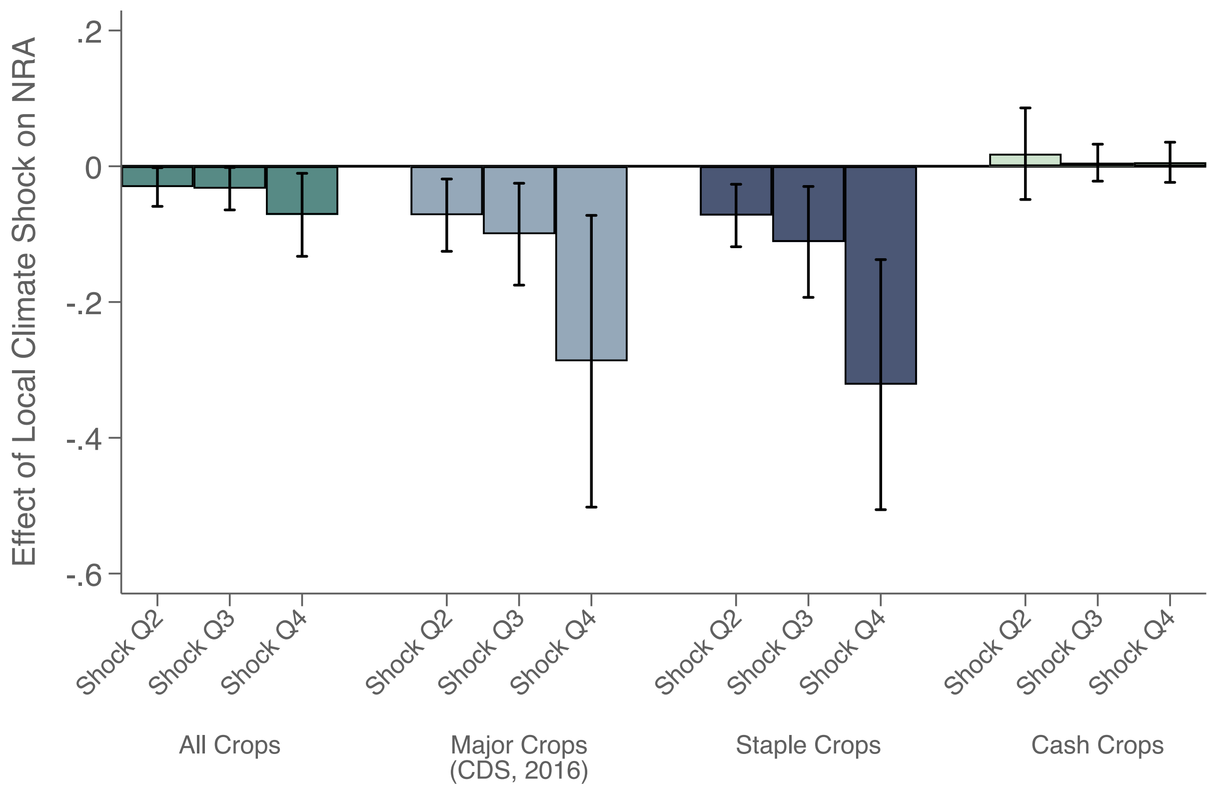
4.1 Local Temperature Extremes Lead to Pro-Consumer Policy

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 $\mathrm{NRA}_{\ell kt}$ 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 ($\mathrm{NRA}_{\ell kt}$).

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.

Figure 5: Extreme Heat and Agricultural Policy



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.

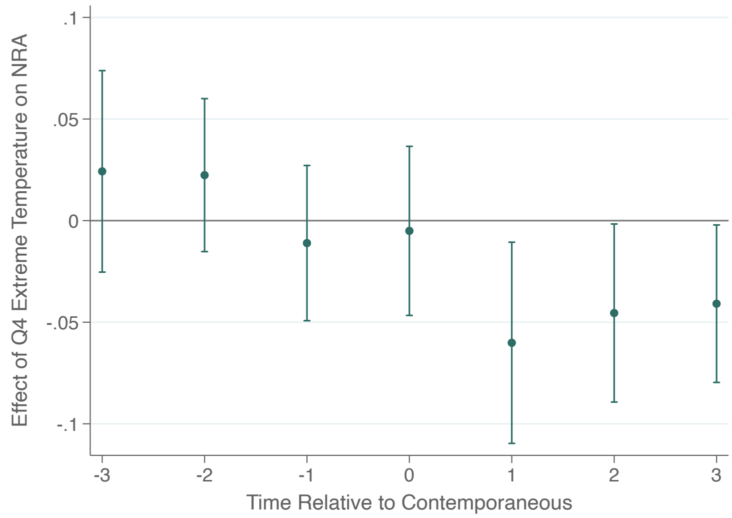
Next, we focus on the most economically important crops by restricting the sample to the ten crops that are the subject of analysis in Costinot et al. (2016).[8] Our estimates using this sub-sample (blue-grey bars) are substantially larger in magnitude: experiencing high (compared to low) extreme heat exposure reduces NRA by 0.37 standard deviations. While the second and third quartiles are both statistically significant, 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.

Finally, we compare the effect for major staple crops and major cash crops.[9] 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

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

[9]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



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.

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 ($p < 0.01$). We then turn to cash crops (light-green bars) and the effect is very different. We find no evidence that extreme heat exposure affects agricultural policy for cash crops. The effect for all quartiles is statistically indistinguishable from zero.

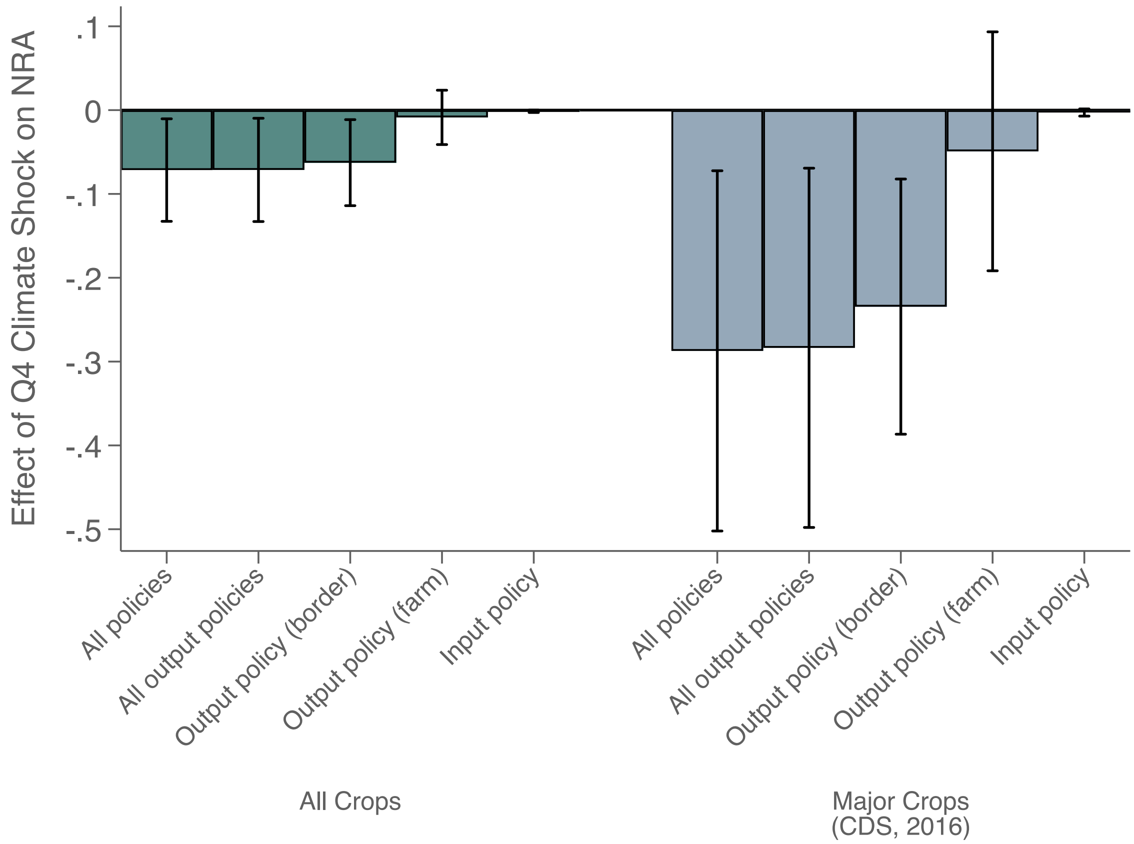
Together, these estimates suggest that exposure to extreme heat reduces NRA, leading to more consumer-oriented agricultural policy. The effects are particularly pronounced for staple crops and for the highest levels of exposure to extreme temperature.

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 rule out the possibility that our main estimates are driven by pre-existing trends and to investigate any persistence in the effect of extreme heat exposure on crop-specific policy.

Figure 6 reports estimates of Equation 4.1 focusing only on the top-quartile effect and

Figure 7: Extreme Heat and Agricultural Policy by Policy Type



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, noted 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.

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 conditional on the existence of an extreme temperature shock 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 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 (e.g. different policies could be substitutes). However, the effect is weaker for policies that affect output prices at the farm gate (e.g. output price support) and entirely 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.

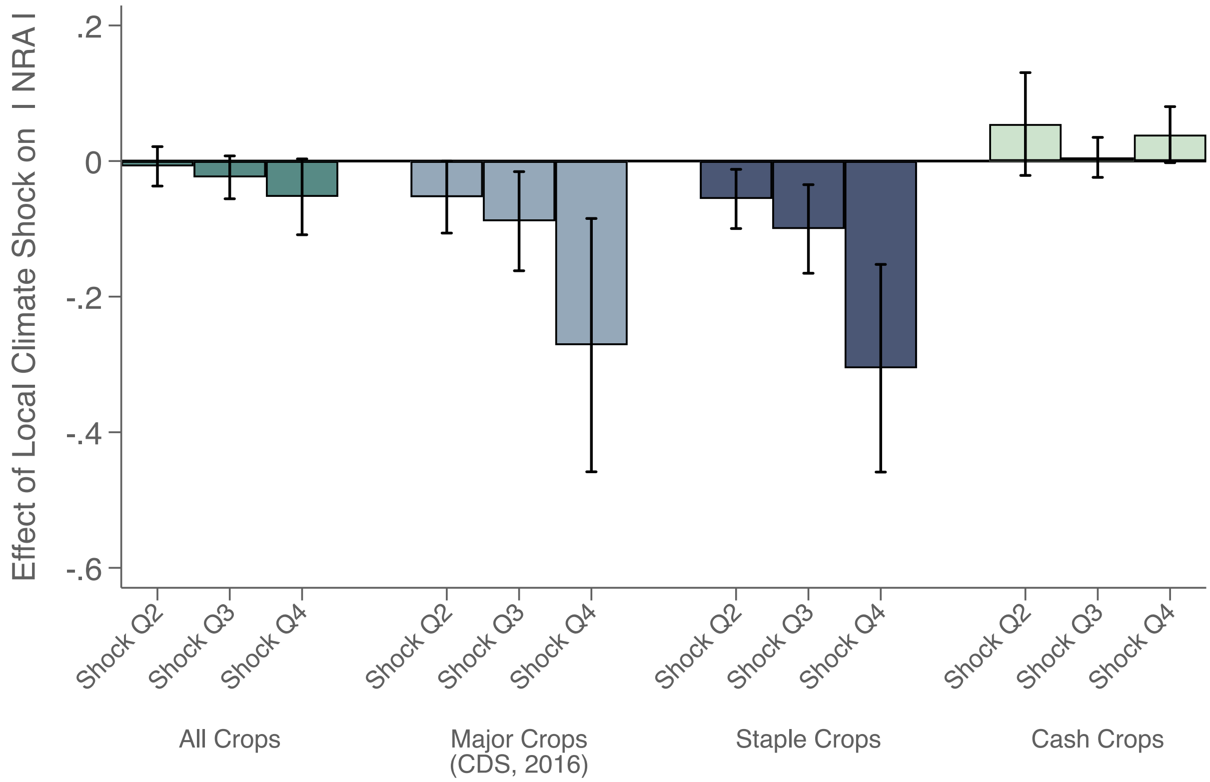
Policy Absolute Value. Our dependent variable of interest so far has been the value of NRA. A different but related question is how climate change affects the *absolute value* of NRA, or the overall level of policy distortion. The answer to this question is unclear and does not directly follow from the findings in Figure 5. While the model predicts that pro-producer and pro-consumer governments will set positive and negative values for NRA respectively, *both* types of governments reduce NRA in response to climate shocks. What this implies for the overall level of distortion is unclear and depends on whether the results are more driven by positive-NRA crop-country pairs moving closer to zero or negative-NRA crop-country pairs moving away from zero.

Figure 8 displays estimates analogous to Figure 5 except that the outcome variable is the *absolute value* of NRA. While the estimates are (intuitively) smaller in magnitude than those in Figure 5, they suggest that extreme heat exposure, on average, shifts NRA values toward zero. This is driven both by the fact that a majority of crop-country pairs start the period with pro-consumer policy and the fact that the marginal effect of extreme heat exposure is larger on this sub-sample.[10] There is some (weak) evidence of the opposite pattern for cash crops; however, the effect is much smaller in magnitude than the negative effect for staple crops. Far from causing the breakdown of trade, a conclusion that has occasionally been drawn from a handful of extreme cases, these findings suggest that on average extreme heat exposure reduces policy barriers to trade by one measure.

Sensitivity Analysis. We conduct a series of sensitivity checks in order to probe the robustness of our baseline estimates. First, we reproduce our baseline findings using all

[10]During the pre-analysis period, the average NRA for just 29% of crop-country pairs is below zero.

Figure 8: Extreme Heat and Agricultural Policy, Absolute Value



This figure displays the relationship between quartiles of extreme heat exposure and the absolute value of 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.

NRA data from 1955-2011 (Figure 12). 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[11] and re-estimate our baseline specification on this combined sample, which increases the sample size by about 25%.[12] Reassuringly,

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

[12]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, interact an indicator that equals one if the outcome data came from Ag-Incentives with all the two-way fixed effects.

the results are very similar (Figure 13). 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 14 to 16.

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. A range of anecdotal accounts suggest 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 several examples where countries restricted exports following export restrictions enacted by their trading partners.[13] Our model, however, suggests that the opposite pattern should be the one we observe in the data. Proposition 2 implies that policy should move in the *opposite* direction in response to foreign shocks compared to local shocks.

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

$$\text{ForeignExtremeExposure}_{\ell kt} = \sum_{\ell' \neq \ell} \text{ImportShare}_{\ell' \to \ell k} \cdot \text{ExtremeExposure}_{\ell' kt} \tag{4.2}$$

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 11 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 that includes both the local and the foreign temperature shocks.

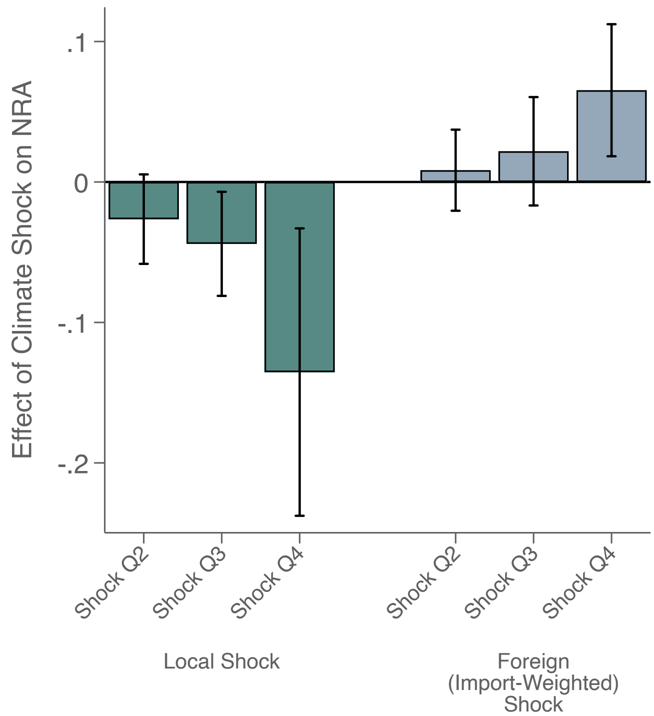
$$\text{NRA}_{\ell kt} = g(\text{ExtremeExposure}_{\ell kt}) + h(\text{ForeignExtremeExposure}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt} \tag{4.3}$$

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

Estimates of Equation 4.3 are displayed in Figure 9. The left three bars show the effect

[13] 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 [...] Elsewhere, a drought in Spain took its toll on olive oil production. As European buyers turned to Turkey, olive oil prices soared in the Mediterranean country, prompting authorities there to restrict exports" (Ghosal et al., 2023).

Figure 9: Local vs. Foreign Extreme Heat Shocks



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.

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, consistent with a stronger response to local climate distress.[14] 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.

[14] Of course, we cannot rule out that the smaller effect of foreign extreme heat shocks is driven, in part, by greater measurement error in our construction of the shocks.

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, the sign of which was theoretically ambiguous. 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 set of issues, 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. In order to investigate this mechanism directly, and to test Prediction 3 of the model, we use elections as a positive shock to concerns about redistribution 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).

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

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.

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.[15] 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 ($p = 0.03$).

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.

[15]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

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.

5 Counterfactuals

We investigate how endogenous agricultural policy affects climate damages by combining our empirical estimates with a multi-country, multi-crop version of our model.

5.1 Simulating Climate Change and Agricultural Policy

For countries ℓ and crops k, we specify demand and supply curves of simple log-linear form

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

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

We approximate the government's policy function, as derived in Proposition 1, as a non-parametric function of extreme heat exposure, both locally and for import partners.

$$\alpha_{\ell k} = \alpha^0_{\ell k} + g(\text{ExtremeExposure}_{\ell k}) + h(\text{ForeignExtremeExposure}_{\ell k}) \tag{5.3}$$

Imports are $m_{\ell k} = q_{\ell k} - y_{\ell k}$. 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 take functions f, g, and h, which capture extreme heat effects by quartile, to be as estimated in Equations 3.3 and 4.3. We back out $(q^0_{\ell k}, y^0_{\ell k}, \alpha^0_{\ell k})$ from the data, and we treat these values as constants. We set $\epsilon_d = 2.82$ and $\epsilon_s = 2.46$ based on long-run estimates from Costinot et al. (2016).[16]

We simulate climate change by adding 100 degree days to all values of $\text{ExtremeExposure}_{\ell k}$ and $\text{ForeignExtremeExposure}_{\ell k}$, then computing a new equilibrium. We focus on staple crops with data from 2000 to 2010, which we average across years.[17] Climate change affects supply and NRA through

$$\text{ExtremeExposure}^{\text{CC}}_{\ell k} = \text{ExtremeExposure}_{\ell k} + 100 \tag{5.4}$$

and $\text{ForeignExtremeExposure}^{\text{CC}}_{\ell k}$, which we define similarly. Equilibrium world prices p_k then adjust to clear global markets.

$$\sum_{\ell} q_{\ell k}(p_k) = \sum_{\ell} y_{\ell k}(p_k) \quad \forall\ k \tag{5.5}$$

where crop markets clear independently. We evaluate welfare effects on consumer surplus, producer surplus, and government revenue.

$$\mathcal{C}(p_{\ell k}) = \frac{q^0_{\ell k}}{1-\epsilon_d} p_{\ell k}^{1-\epsilon_d} \tag{5.6}$$

$$\mathcal{P}(p_{\ell k}) = \frac{y^0_{\ell k}}{1+\epsilon_S} p_{\ell k}^{1+\epsilon_s} \exp\left[f(\text{ExtremeExposure}_{\ell k})\right] \tag{5.7}$$

$$\mathcal{R}(p_k) = \frac{\alpha_{\ell k}}{1+\alpha_{\ell k}} p_k m_{\ell k} \tag{5.8}$$

[16] We take estimates $\theta = 2.46$ and $\kappa = 2.82$ from Costinot et al. (2016) Table 2.

[17] We average values from 2000 to 2010 to make sure that the results are not driven by any single year or extreme observation. For NRA and production, we compute predicted values under climate change in each year, then we average over these values. We focus on the NRA subsample for each crop, and we compute net production as total production less total consumption for this subsample. We hold this net supply fixed in counterfactuals. Stated differently, we compute net consumption for the non-NRA subsample, and we hold this net demand fixed in counterfactuals.

Table 3: Welfare Effects of Extreme Heat (%)

Trade policy	Total	CS	PS	G
Endogenous	-3.89	-3.36	-3.13	-48.72
Endogenous, domestic only	-4.19	-3.80	-3.04	-52.47
Endogenous, foreign only	-3.15	-3.25	-4.03	24.26
Exogenous	-3.55	-3.67	-3.81	8.68

Columns show percentage changes in total social welfare, consumer surplus, producer surplus, and government revenue. Each row describes the impact of increased extreme heat exposure under a policy regime. Endogenous policy allows NRA to respond to domestic and foreign exposure both, to domestic exposure alone, or to foreign exposure alone. Exogenous policy fixes NRA at observed values.

noting that tariff $\tau_{\ell k} = \frac{\alpha_{\ell k}}{1+\alpha_{\ell k}} p_k$ by Equation 3.1.

We study how agricultural policy influences these welfare effects of climate change. By Equation 5.3, NRA under climate change is

$$\begin{aligned} \alpha_{\ell k}^{\mathrm{CC}} = \alpha_{\ell k} &+ g(\mathrm{ExtremeExposure}_{\ell k}^{\mathrm{CC}}) - g(\mathrm{ExtremeExposure}_{\ell k}) \\ &+ h(\mathrm{ExtremeExposure}_{\ell k}^{\mathrm{CC}}) - h(\mathrm{ExtremeExposure}_{\ell k}) \end{aligned} \tag{5.9}$$

First, we evaluate welfare effects given this change. Second, we isolate the role of domestic shocks with $g(\cdot)$ and $h(\cdot) = 0$ in turn. Third, we consider exogenous policy with $g(\cdot) = h(\cdot) = 0$, such that NRA is fixed at its observed values.

5.2 Implications for Global Adaptation

Table 3 shows welfare losses from climate change under each policy regime. Under fully endogenous trade policy, our climate change scenario leads to a 3.89% decrease in total surplus, with comparable losses from consumers and producers in percentage terms. This loss is higher for endogenous policy driven solely by domestic shocks, with much larger losses for consumers, while the opposite holds for endogenous policy driven solely by foreign shocks. This result aligns with our previous assertion that foreign policy responses partially offset domestic policy responses, such that cross-country interactions are globally stabilizing. Moreover, endogenous trade policy leads to much larger losses than exogenous trade policy. Assuming exogenous trade policy would understate total welfare losses by 9%.

Turning to distributional effects, we find that climate damages are softened for both consumers and producers, but at great fiscal cost. In our calibration, consumers and producers *both* benefit because of global equilibrium effects, despite the typically zero-sum nature of market interventions. Consumers benefit directly from pro-consumer policy, while producers benefit because the climate- and policy-induced shortage increases global prices enough to help on net. Appendix Table 4 shows how effects differ by countries' income: under endogenous trade policy, higher-income countries do more to protect consumers, lower-income countries do more to protect producers, and both incur large fiscal costs in intervening.

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. Together, these results highlight how climate change affects economic policy, and how economic policy in turn mediates the consequences of climate change.

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.

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 1

By direct calculation, we have that

$$\frac{\mathrm{d}A^*(s_m)}{\mathrm{d}s_m} = \frac{\left(\lambda^G(\epsilon_s - \epsilon_d) - \lambda^C\epsilon_s + \lambda^P\epsilon_d\right)(1+\epsilon_m)\lambda_G}{\epsilon_m\left(\lambda^G\left((1-s_m)\epsilon_s - \epsilon_d\right) - \left(\lambda^P(1-s_m) + \lambda^G s_m - \lambda^C\right)\right)^2} \tag{A.15}$$

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.

A.4 Proof of Lemma 2

First, we observe that

$$S(\alpha,\omega,\omega') = 1 - \frac{Y(P^*(\alpha,\omega,\omega'),\omega)}{Q(P^*(\alpha,\omega,\omega'))} \tag{A.16}$$

We now derive the properties in turn.

Property (i). From market clearing,

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

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

$$S(\alpha,\omega,\omega') = \frac{M\left(\frac{P^*(\alpha,\omega,\omega')}{1+\alpha},\omega'\right)}{Q(P^*(\alpha,\omega,\omega'))} \tag{A.18}$$

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

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

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

$$\frac{S(\alpha,\omega_1,\omega')}{S(\alpha,\omega_0,\omega')} = \left(\frac{P^*(\alpha,\omega_1,\omega')}{P^*(\alpha,\omega_0,\omega')}\right)^{-\epsilon_m-\epsilon_d} \tag{A.20}$$

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,

$$\frac{\partial S}{\partial \alpha} = -\frac{(1-s_m)\epsilon_s + s_m\epsilon_m - \epsilon_d}{(1+\alpha)(1-s_m)s_m\epsilon_m(\epsilon_s-\epsilon_d)} < 0 \tag{A.21}$$

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:

$$\left(\frac{\partial S}{\partial \alpha}\right)^{-1} - \frac{\mathrm{d}A^*}{\mathrm{d}s_m} = K\left(\epsilon_s(\lambda^C-\lambda^G) - \epsilon_d(\lambda^P-\lambda^G) - \frac{((1-s)\epsilon_s-\epsilon_d)((1-s)\epsilon_s+s\epsilon_m-\epsilon_d)(\lambda^C+(1-s)\epsilon_s-\epsilon_d)\lambda^G-(s\lambda^G+(1-s)\lambda^P)}{s_m\epsilon_m(1-s_m)(\epsilon_s-\epsilon_d)}\right) \tag{A.22}$$

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

$$\epsilon_s(\lambda^C-\lambda^G)-\epsilon_d(\lambda^P-\lambda^G) < \frac{((1-s)\epsilon_s-\epsilon_d)((1-s)\epsilon_s+s\epsilon_m-\epsilon_d)(\lambda^C+(1-s)\epsilon_s-\epsilon_d)\lambda^G-(s\lambda^G+(1-s)\lambda^P)}{s_m\epsilon_m(1-s_m)(\epsilon_s-\epsilon_d)} \tag{A.23}$$

the claim follows.

A.5 Proof of Proposition 2

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 1), 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 $s_{m,1}^*$, $f(s_{m,1}^*) = 0$.

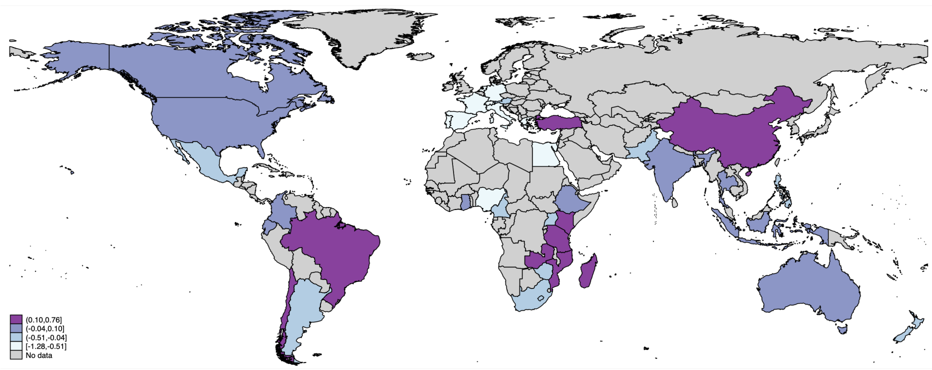
Therefore, $s^*_{m,1} \geq s^*_{m,0}$, provided that an equilibrium exists (which has been established earlier). Since A^* is increasing, then $\alpha^*_1 = A(s^*_{m,1}) \geq \alpha^*_0$.

2. Since $A(s_m)$ is strictly decreasing (Lemma 1), 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 1). Thus, $\alpha^*_1 = \alpha^*_0$.

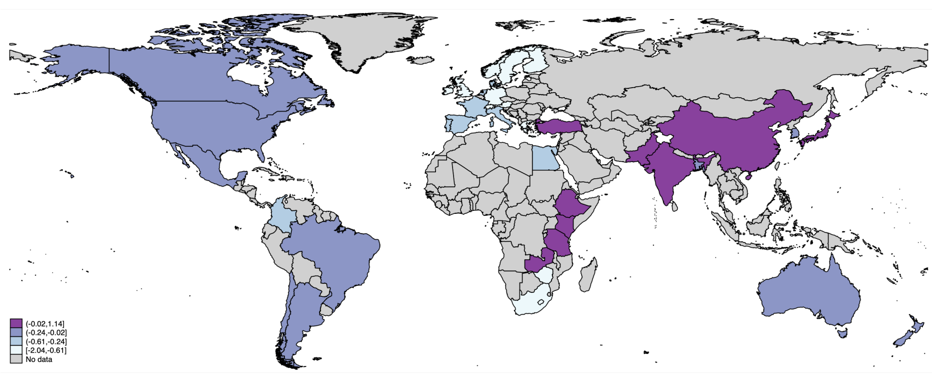
B Additional Figures and Tables

Figure 10: Global Changes in Policy for Select Crops

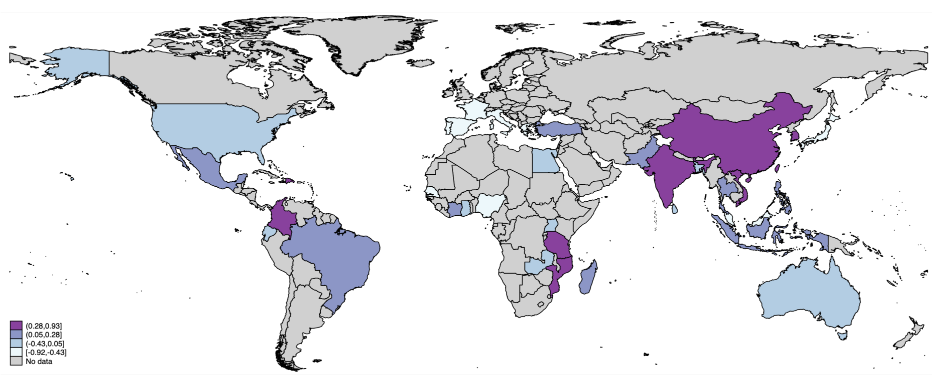
(a) Maize



(b) Wheat



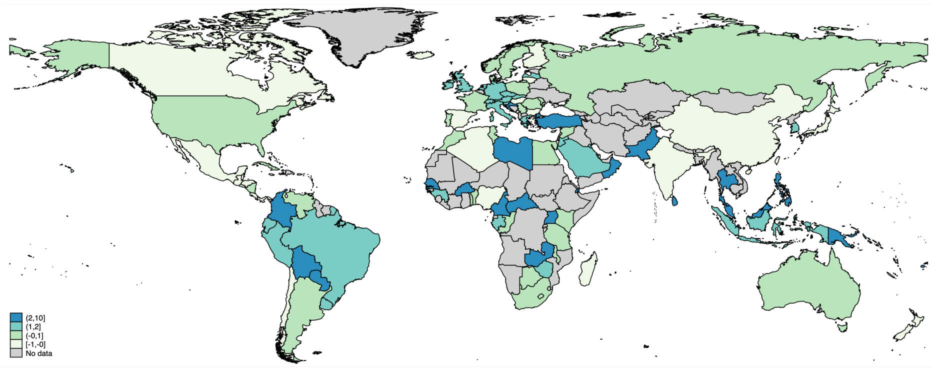
(c) Rice



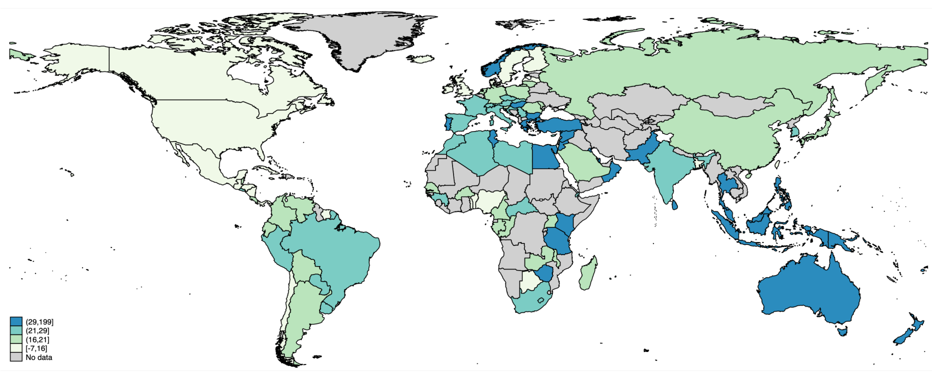
This figure displays the change in NRA (1980s-2000s) for maize (Figure 10a), wheat (Figure 10b), and rice (Figure 10c). Countries are color coded by quartile where darker colors correspond to larger values of NRA change.

Figure 11: Global Changes Exposure to Foreign Extreme Temperatures

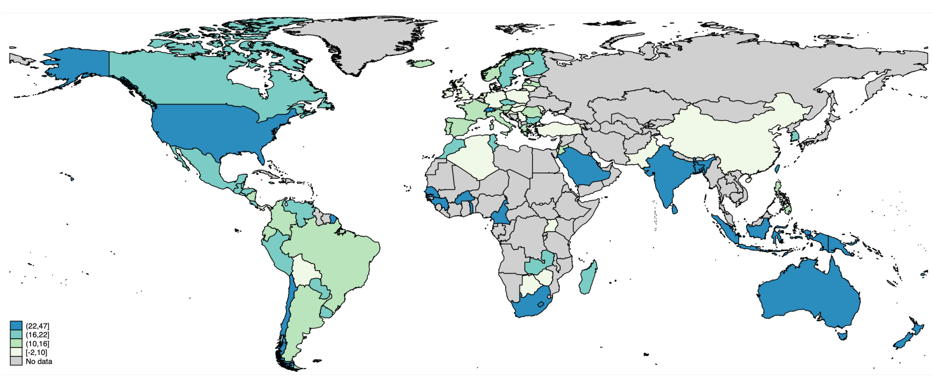
(a) Maize



(b) Wheat

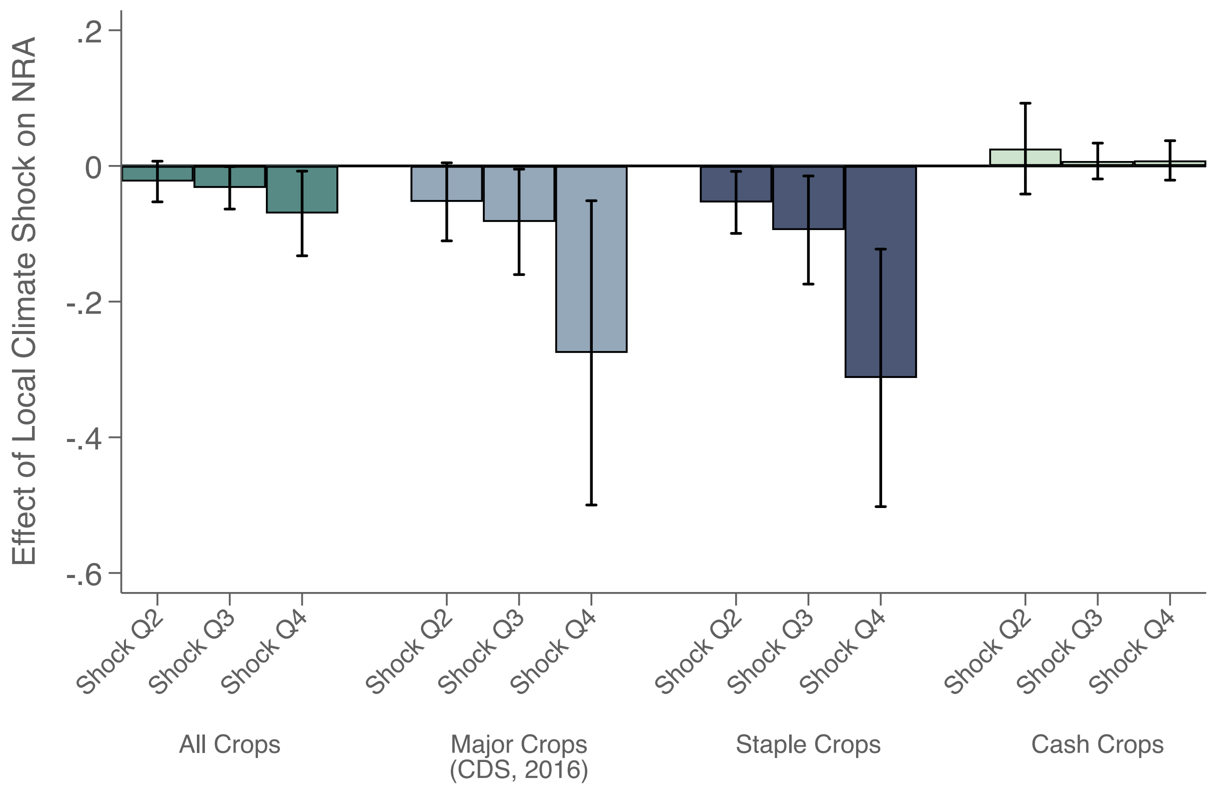


(c) Rice



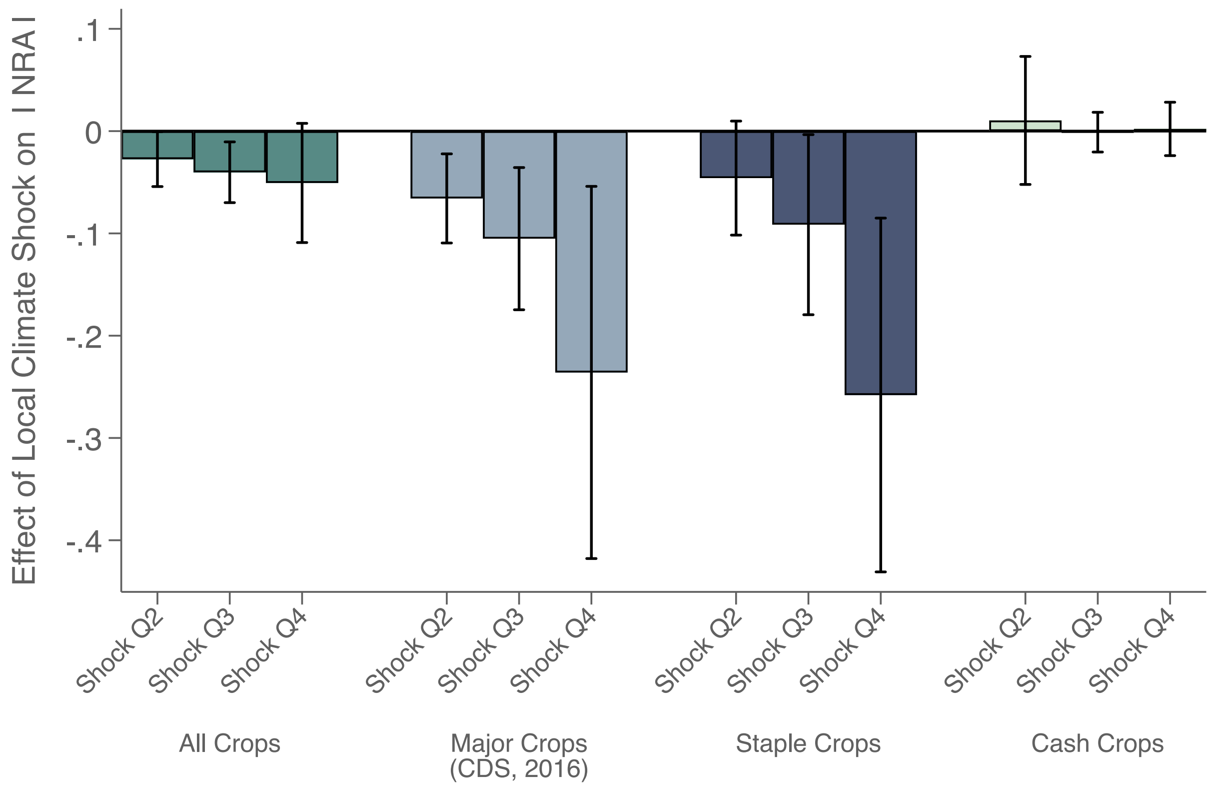
This figure displays the change in foreign import-weighted extreme heat exposure (1980s-2000s) for maize (Figure 11a), wheat (Figure 11b), and rice (Figure 11c). Countries are color coded by quartile.

Figure 12: Extreme Heat and Agricultural Policy, 1955-2011



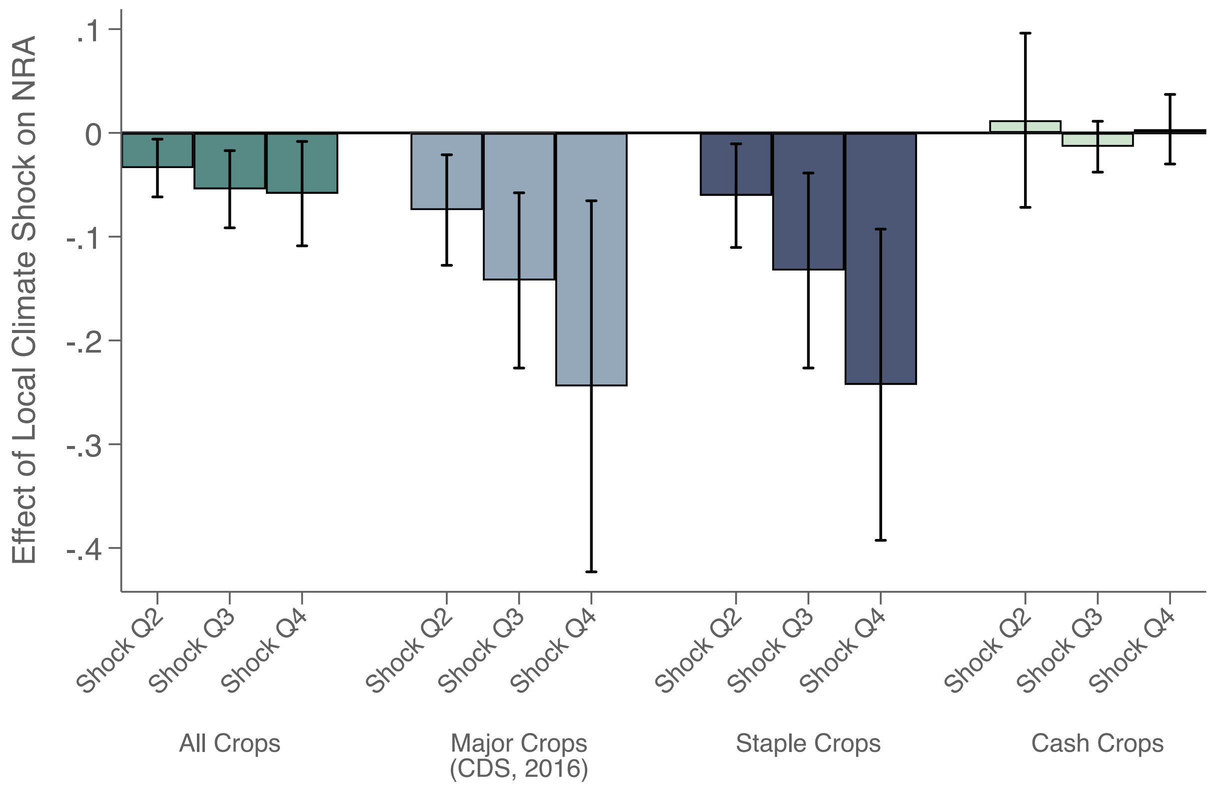
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each 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 13: Extreme Heat and Agricultural Policy, 1980-2021 with Alternative Data



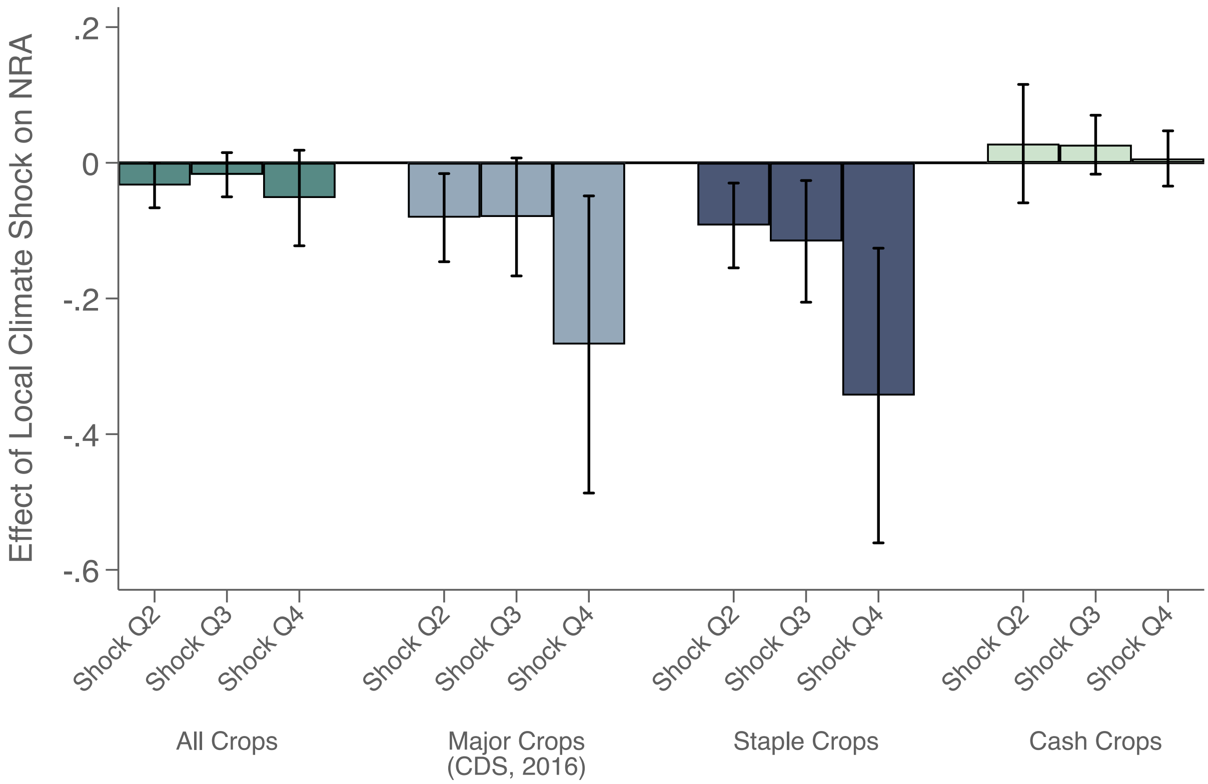
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each 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 14: Extreme Heat and Agricultural Policy Excluding 1980s



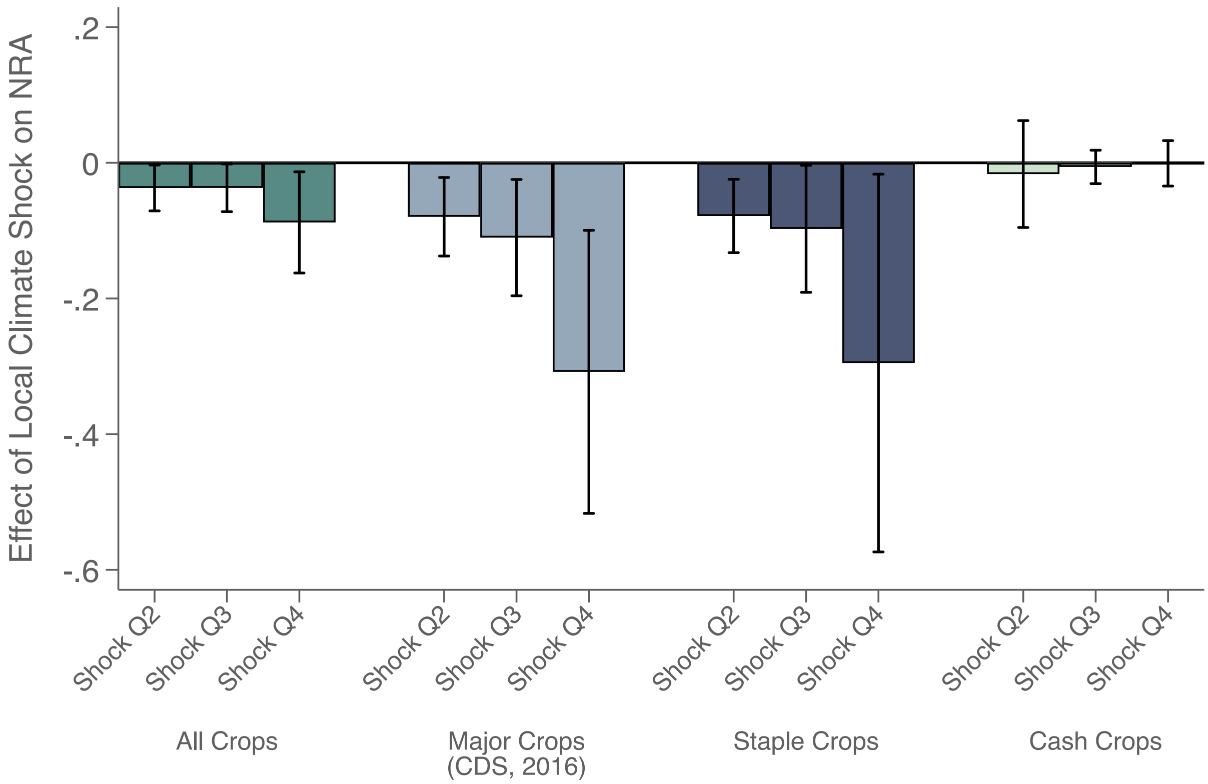
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. The sample of crops included in each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

Figure 15: 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 16: 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.

Table 4: Welfare Effects of Extreme Heat by Income (%)

	Higher-income				Lower-income			
Trade policy	Total	CS	PS	G	Total	CS	PS	G
Endogenous	-5.08	-3.46	-7.07	-36.10	-3.17	-3.29	-0.64	-53.63
Endogenous, domestic only	-5.22	-3.70	-7.29	-26.84	-3.58	-3.86	-0.35	-62.44
Endogenous, foreign only	-4.63	-3.81	-6.75	19.21	-2.26	-2.92	-2.32	26.23
Exogenous	-4.77	-4.07	-6.93	28.39	-2.83	-3.43	-1.84	1.01

Columns show percentage changes in total social welfare, consumer surplus, producer surplus, and government revenue for countries with above- and below-median income. Each row describes the impact of increased extreme heat exposure under a policy regime. Endogenous policy allows NRA to respond to domestic and foreign exposure both, to domestic exposure alone, or to foreign exposure alone. Exogenous policy fixes NRA at observed values.