Food Policy in a Warming World

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Abstract

Do governments systematically intervene in agricultural markets in response to climate shocks? If so, what are the aggregate and distributional consequences? We construct a global dataset of agricultural policies and extreme heat exposure by country and crop since 1980. We find that extreme heat shocks to domestic production lead to increased consumer assistance. This effect is persistent, primarily implemented via border policies, and stronger in election years when politicians are particularly responsive to constituent demands. Shocks to foreign production lead to increased producer assistance, consistent with policymakers' targeting redistribution rather than price stabilization. Interpreted via a model, the estimates imply that policy responses almost fully stabilize prices in shocked markets, reducing losses to domestic consumers by 97% while increasing those to domestic producers and foreign consumers by 55% and 105%, respectively. Responsive policy exacerbates overall welfare losses from projected end-of-century climate shocks by 14%.

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1 Introduction

In March 2022, a heat wave in India's breadbasket region reduced the country's wheat production by 11 million metric tons, or 10% of expected output (Beillard and Singh, 2022). On May 13, citing concerns that elevated prices threatened food security, India's government announced a ban on wheat exports. While this policy change had potential benefits for Indian consumers, it was controversial both in India and around the world. Farmer Ranbeer Singh Sirsa, quoted in the *New York Times* on May 14, decried the government's action: "If the price wants to go up, let it settle at the international price. Who are they trying to protect now, at the cost of farmers?" (Yasir and Kim, 2022). Ashok Gulati, former chairman of India's Commission for Agricultural Costs and Prices, concurred that the policy was "anti-farmer" and "painted a very sorry picture" of India's role in global commerce (India Today, 2022). Other critics focused on the global repercussions: on the policy's announcement, global wheat prices jumped a further 6%, exacerbating food security concerns in other countries (Lockett and Fildes, 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).

These examples have three ingredients that we might expect to recur in a warming world. First, extreme heat could significantly disrupt agricultural production. Second, governments may not be passive: they could react with policies that balance different stakeholders' interests and shift the burden of climate shocks between consumers and producers. Third, these policy choices could mitigate or exacerbate the overall consequences of climate shocks, 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 climate extremes? If so, how and why? And what implications do these policy responses have for adaptation to climate change?

We begin with a model that formalizes how food policy responds to climate shocks and shapes their distributional consequences. A government sets a border tax to maximize a weighted sum of consumer surplus, producer surplus, and revenue. We derive a condition on government preferences and the elasticities of demand and supply that determines whether the preferred response to a negative productivity shock is to assist consumers by pushing down domestic prices or to assist producers by elevating domestic prices.

The government increases consumer assistance in response to the shock if it is *constituent-*

focused, or places relatively high welfare weights on consumer and producer surplus relative to government revenue. This is natural if agricultural consumption and production are concentrated among the government's supporters or if redistribution via transfers is poorly targeted. In this case, the government's main consideration is that reduced domestic supply shifts the burden of lowering prices away from domestic producers and toward foreign producers, on whom the government places no weight. This policy response cushions the blow for consumers, but exacerbates it for producers.

The government increases producer assistance in response to the shock if it is *revenue-focused*, or places relatively high welfare weights on revenue relative to constituent surplus. This may be natural if revenue is highly valued for a use outside of the agricultural economy, like enriching interest groups or paying off debt. For a revenue-focused government, the dominant concern is that a domestic supply shortage is the most expensive time to subsidize imports or the least profitable time to tax exports. This policy dampens farmers' economic exposure to shocks while intensifying that of consumers.

We finally study how these forces shape the aggregate welfare consequences of climate shocks in equilibrium. We first show that the government's optimal response to *foreign* climate shocks could amplify or dampen the effect of domestic policy responses on welfare. We next observe that policy responses to climate shocks have ambiguous distributional consequences and effects on overall efficiency. It is therefore essential to turn to the data to understand both the sign and magnitude of these effects.

To understand how food policy reacts to climate shocks and shapes their economic consequences, we compile a global data set of temperature realizations and crop-specific agricultural policy interventions since 1980. We first compute the annual exposure to extreme temperatures of every crop-by-country pair since 1980. To do this, we combine gridded, global data on daily temperature realizations from the ERA5 dataset (Muñoz Sabater et al., 2021) with expert-elicited estimates of the maximum growing temperature for individual plant species. Thus, our measure incorporates variation across time, space, and crops. Our main empirical strategy exploits the differential exposure of country-crop pairs to plausibly exogenous variation in extreme heat over time. We validate that this measure of extreme heat reduces crop-specific yields in international panel data.

We measure crop-specific agricultural policy across countries with data from the World Bank's "Distortions to Agricultural Incentives" project (Anderson and Valenzuela, 2008). This database reports the "nominal rate of assistance" (NRA), which measures percent distortions of domestic prices from international prices, for 80 agricultural products and

81 countries, covering about 85% of global agricultural production (Anderson et al., 2013). The NRA is an appealing measure for our study because it takes into account multiple policy instruments, including border taxes, quantity restrictions, and domestic production or input subsidies. We also use the specific components of the summary NRA measure, as well as independent measures of tariffs from the United Nations' Trade Analysis Information System (TRAINS) database and of other policy interventions from the Global Trade Alert (GTA) database, to identify the specific types of policy that drive our findings and to confirm our findings on independent measures of policy intervention.

Our first main result is that extreme heat exposure leads to large changes in agricultural policy in a direction that supports local consumers. These effects are particularly large for economically important staple crops. In particular, for a staple crop, a swing from the first to fourth quartile of extreme heat exposure results in a more than 30 percentage point change in NRA. Concretely, this implies that a country that initially elevates prices 30% above the international price would move to no distortion, or a country initially with no distortion would move to a 30% domestic consumer subsidy. Breaking down the NRA effects across specific policy levers, we show that our results are driven by border policy changes. We corroborate this by replicating our finding in independently collected data on tariffs (from TRAINS) and export restrictions (from GTA). We find that policy does not anticipate future changes in extreme heat, but that the contemporaneous response persists for several years. Through the lens of our model, these findings are consistent with policy being driven by constituent focus in the short- and medium-run.

Second, we investigate how extreme heat exposure in foreign countries affects agricultural policy. For each country-crop pair, we construct a measure of foreign extreme heat shocks weighted by each country's pre-period import partners. We find that adverse climate shocks to import partners lead to a more producer-oriented policy at home. Unconditional increases in global prices and global extreme-heat shocks also lead to pro-producer policy. Thus, a threat to food security originating overseas has precisely the opposite effect as one originating domestically. This finding is consistent with our model, which predicts that domestic and foreign climate shocks have opposite effects on policy because of their asymmetric distributional consequences. However, the finding is *inconsistent* with the hypothesis that the government's singular goal is to reduce price fluctuations for consumers. A further implication is that, if a heat wave jointly hits trading partners, policy responses to foreign shocks partially offset policy responses to domestic shocks. This finding pushes against narratives of food policy "contagion" (Ghosal et al., 2023)

and "multiplier effects" (de Guzman, 2022) in case studies of global food trade disruptions.

Third, we study long-run changes in climate and policy. In principle, short-run responses could differ from long-run responses if there is mean reversion in policy or adaptation via production techniques and trade (Dell et al., 2012; Burke and Emerick, 2016). We find decadal-frequency effects that are consistent with, and slightly larger than, our baseline annual-frequency estimates. Thus, governments use policy not just to respond to short-run weather fluctuations, but also to respond to long-run climate trends.

Fourth, we test the model's redistribution-focused mechanism. Motivated by existing work on political cycles, which hypothesizes that upcoming elections lead governments to place less emphasis on fiscal responsibility, we treat the timing of elections as within-country variation in the extent of constituent focus.[1] We find that the effect of extreme heat on policy is almost four times as large in magnitude during the lead-up to elections, consistent with our hypothesis and indicative of a strong influence of politics on climate adaptation. As a second strategy, we treat countries' debt-to-GDP ratio as a proxy for governments' marginal cost of fiscal irresponsibility. The effect of extreme heat on consumer assistance is muted when the debt-to-GDP ratio is high, consistent with the hypothesis that these circumstances induce revenue focus.

Finally, combining our model and empirical estimates, we quantify how policy responses shape the aggregate and distributional welfare impacts of extreme heat shocks. We begin with historical shocks within our sample from 1991 to 2010. We find that, on average, policy responses fully shielded consumers from price increases due to domestic shocks. Domestic prices increase by 1.64% when policy is fixed, but policy responses reduce this price increase to 0% and thus minimize welfare losses for domestic consumers. At the same time, policy responses worsen welfare losses for domestic producers and foreign consumers – in some cases, by more than 20 percentage points. We then extrapolate out of sample to study projected shocks from 2091 to 2100, as predicted by the GFDL-ESM4 climate model. We find that policy responses exacerbate total welfare losses from extreme heat shocks by 14%. As with historical shocks, responsive policy dampens price increases from domestic shocks, aiding consumers at the expense of producers. But projected shocks are large and widespread, and they induce policy responses that intensify baseline distortions in many markets. The endogenous emergence of trade barriers leads to worsened climate damages.

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

Our main contribution is to show that agricultural policy responds to climate shocks, shaping their aggregate and distributional effects. We build on existing work studying distortions to agricultural incentives. Others have documented these distortions around the world (Krueger et al., 1988; Johnson, 1991; Anderson, 2009; Anderson et al., 2013) and argued qualitatively that they are driven by politicians' desire to re-distribute between the producers and consumers of food (Barrett, 2013; Bates, 2014).[2] We depart from existing work by focusing on responses to climate shocks, in the short and long run, rather than political trends or static cross-country differences.[3] We show that policy responses can exacerbate existing distortions and worsen the impacts of climate shocks.

A large literature in environmental economics quantifies the impacts of climate shocks on agricultural production (see, e.g., Lobell and Field, 2007; Schlenker and Roberts, 2009; Lobell et al., 2011). Costinot et al. (2016) studies global adaptation via trade and how it can reduce projected welfare losses from climate change.[4] Others study how trade interacts with other mechanisms including crop switching (Baldos et al., 2019; Hultgren et al., 2022), land and water use (Gouel and Laborde, 2021; Carleton et al., 2022), sectoral reallocation (Rudik et al., 2022; Nath, 2023), migration (Cruz and Rossi-Hansberg, 2023; Conte, 2024), technology (Farrokhi and Pellegrina, 2023), and regulation (Shapiro, 2021; Farrokhi and Lashkaripour, 2024; Hsiao, 2024a). Each takes domestic policy distortions as fixed. We show that policy itself responds as the environment changes and that this endogenous policy response can create frictions to adaptation.[5] We quantify the implications for global resilience to the increasing volatility of a warming world.

2 Model

We present a model in which governments can intervene in agricultural markets to raise revenue and redistribute between domestic groups. We show that climate shocks can induce either consumer assistance, as would rationalize our initial example of the Indian response to the 2022 drought, or producer assistance, as would rationalize the opposite. This theoretical ambiguity motivates our subsequent empirical and quantitative analysis.

[2] A related literature studies the link between political favoritism and trade policy (e.g., Grossman and Helpman, 1994, 1995; Goldberg and Maggi, 1999; Maggi and Rodríguez-Clare, 2000; Adão et al., 2023).

[3] Bastos et al. (2013) study how rainfall affects tariffs, and Amodio et al. (2024) investigate how rainfall shortages and surpluses have affected negotiated agricultural tariff reductions. Their findings that rainfall shortages lead to lower agricultural tariffs are consistent with our first empirical result.

[4] See also Reilly and Hohmann (1993), Rosenzweig and Parry (1994), and Randhir and Hertel (2000).

[5] Similarly, Hsiao (2023) shows that endogenous government intervention complicates adaptation to rising sea levels by inducing potential moral hazard. Hsiao (2024b) takes on distributional consequences.

2.1 Set-up

We study the market for a single agricultural commodity. Consumer demand is $q = Q(p) = Q_0 p^{-\epsilon_d}$, where $Q_0 > 0$ parametrizes the level of demand, p is the price, and ϵ_d is the elasticity of demand. Domestic supply is $y = Y(p, \omega) = Y_0(\omega) p^{\epsilon_s}$, where $\omega \in \mathbb{R}$ is an adverse productivity shock, $Y_0 : \mathbb{R} \to \mathbb{R}_+$ is a decreasing function, and ϵ_s is the elasticity of supply. International net supply is $m = M(p, \omega') = M_0(\omega') p^{\epsilon_m}$, where $\omega' \in \mathbb{R}$ is an adverse foreign productivity shock, $M_0 : \mathbb{R} \to \mathbb{R}$ is a decreasing function, and ϵ_m is the elasticity of import supply. The case of $M_0 > 0$ and $\epsilon_m > 0$ corresponds to an importer and the case of $M_0 < 0$ and $\epsilon_m < 0$ corresponds to an exporter. We assume that either $\epsilon_m > \epsilon_s > 1$ or $-\epsilon_m > \epsilon_d > 1$: foreign supply or demand is more elastic than its domestic counterpart, and all curves are more than unit elastic. The former is natural if the studied country is smaller than the rest of the world. The latter ensures that the government's tax revenue is a concave function of the tax rate. We let $s = m/q \in (-\infty, 1]$ denote the import share, which is negative if the country exports.

The government imposes an *ad valorem* border tax $\alpha \geq -1$. Positive α corresponds to an import tax or export subsidy, and negative α to the opposite. The market clears at some domestic equilibrium price $p^* \in \mathbb{R}_+$ if $Q(p^*) = Y(p^*, \omega) + M\left(\frac{p^*}{1+\alpha}, \omega'\right)$. The government chooses an optimal tax α^* to maximize a weighted sum of consumer surplus, producer surplus, and government revenue.

$$\begin{aligned} \alpha^* \in \arg\max_{\alpha \in [-1, \infty)} & \left\{ \lambda^C \int_{p^*}^{\infty} Q(p)\, \mathrm{d}p + \lambda^P \int_0^{p^*} Y(p, \omega)\, \mathrm{d}p + \lambda^G \frac{\alpha}{1+\alpha} M\left(\frac{p^*}{1+\alpha}, \omega'\right) \right\} \\ \text{s.t. } & p^* = P^*(\alpha, \omega, \omega') \end{aligned} \tag{2.1}$$

where $\lambda^C, \lambda^P, \lambda^G \in \mathbb{R}_+$ specify the relative weights on each payoff component, and $P^* : \mathbb{R}^3 \to \mathbb{R}_+$ maps policy and fundamentals to the equilibrium price.[6] Because aggregate elasticities and welfare weights will be sufficient statistics for optimal policy, we are intentionally agnostic about micro-foundations. Nonetheless, Section 2.4 offers one specific interpretation in a production economy.

2.2 What Determines Trade Policy?

We first characterize optimal policy in terms of welfare weights, elasticities, and the equilibrium import share.

[6] We assume that primitives are such that this problem is globally concave in α.

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

$$\alpha^* = \frac{\tau^*}{p^* - \tau^*} = \frac{1}{\epsilon_m} \left(\frac{\lambda^G \left((1-s)\epsilon_s + \epsilon_d \right) + \epsilon_m \left(\lambda^P (1-s) + \lambda^G s - \lambda^C \right)}{\lambda^G \left((1-s)\epsilon_s + \epsilon_d \right) - \left(\lambda^P (1-s) + \lambda^G s - \lambda^C \right)} \right). \tag{2.2}$$

Moreover, α^* increases in λ^P and decreases in λ^C.

Proof. See Appendix A.1 □

First consider the utilitarian case in which $\lambda^P = \lambda^C = \lambda^G$ and, consequently, $\alpha^* = 1/\epsilon_m$. We obtain an "inverse elasticity (Ramsey) rule" that sets marginal revenue equal to marginal deadweight loss. It captures the typical terms-of-trade motivation for tariffs. For an importer, this rule implies producer support via an import tax; for an exporter, it implies consumer support via an export tax.

Beyond the utilitarian case, redistribution is an additional motivation for policy. Higher prices transfer surplus away from consumers and toward producers, while indirectly affecting import tax revenue. This pecuniary transfer scales with the price impact of trade policy. It is largest when domestic supply and demand are relatively inelastic and when the import share is high. We obtain intuitive comparative statics in the welfare weights on producers and consumers. High λ^P pushes toward helping producers by elevating domestic prices above world prices, while high λ^C pushes toward the opposite.

2.3 How Does Trade Policy Respond to Shocks?

We now study the comparative statics of optimal trade policy. We first define a key condition on government preferences and elasticities of supply and demand.

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

$$\epsilon_s(\lambda^C - \lambda^G) + \epsilon_d(\lambda^P - \lambda^G) > 0. \tag{2.3}$$

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

A constituent-focused government has a relatively high weight on consumers and producers and a relatively low weight on revenue. Such a government places high value in transferring resources to consumers and producers. A high consumer weight might be natural if food consumers are numerous and politically influential. A high producer weight

describes, in reduced form, the impact of political lobbying as modeled by Grossman and Helpman (1994). Conversely, a revenue-focused government places high value in raising government funds, perhaps to service government debt or to enrich corrupt officials. A utilitarian government with $\lambda^C = \lambda^P = \lambda^G$ is neutral. We now show our main comparative statics result:

Proposition 2 (Trade Policy and Climate Shocks)**.** *The following statements are true.*

1. *For a neutral government, α^* is invariant to ω: shocks do not affect policy.*
2. *For a revenue-focused government, α^* increases in ω: adverse shocks lead to producer assistance.*
3. *For a constituent-focused government, α^* decreases in ω: adverse shocks lead to consumer assistance.*

Proof. See Appendix A.2. □

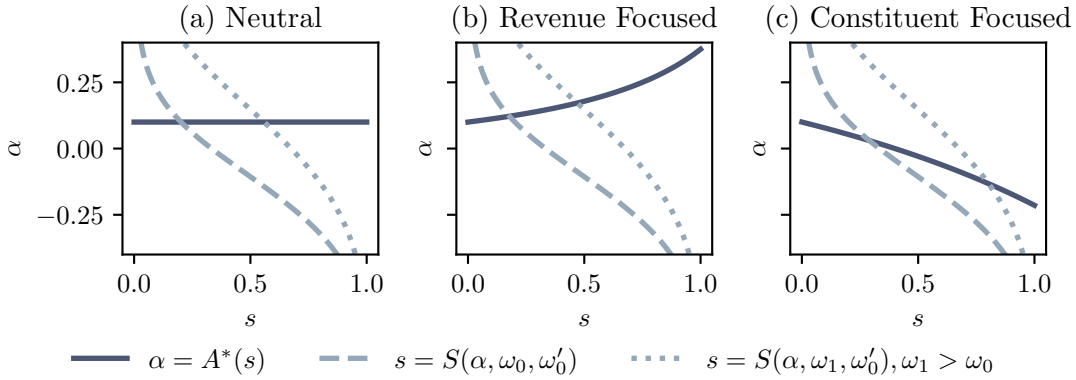
The response of policy to production shocks is determined by constituent vs. revenue focus, rather than the sign of policy α or trade balance M. That is, neither the distinction between pro-consumer and pro-producer governments nor the distinction between net importers and net exporters determines the sign of policy response to climate shocks.

We prove this result in two steps, which we illustrate with a numerical example in Figure 1. First, we show that the import share is a decreasing function of the tariff: more domestic price support leads to fewer imports or more exports. Moreover, an adverse shock to domestic productivity leads to more imports for any fixed level of policy. Second, we observe that the optimal tariff can be a flat (neutral), increasing (revenue-focused), or decreasing (constituent-focused) function of the import share. The comparative statics follow from the graphical argument in Figure 1.

A revenue-focused government increases producer assistance in response to a climate shock. Intuitively, a domestic supply shortage is the most profitable time to tax imports. In taxing imports, a large importer can manipulate its terms of trade to raise revenue at the expense of foreign producers. Domestic shocks increase imports and thus strengthen this ability to manipulate terms of trade. A government whose preferences put high weight on revenue takes advantage by taxing imports more strongly. This policy response intensifies the rise in domestic prices following a domestic shock, shielding producers but exacerbating losses for consumers.[7]

[7]The same holds for net exporters. Domestic shocks reduce exports, weakening the terms-of-trade incentive to tax exports. The government responds by lowering export taxes, thereby shielding producers.

Figure 1: Trade Policy and Climate Shocks



Each panel illustrates a case from Proposition 2 in a numerical calibration. The dotted and dashed lines correspond to the condition $s = S(\alpha, \omega, \omega')$ with (dotted) and without (dashed) an adverse domestic productivity shock. The solid line corresponds to the condition $\alpha = A^*(s)$. The intersections of the dashed and dotted lines with the solid line indicate optimal policies. The parameters are $\epsilon_s = \epsilon_d = 2.5$, $\epsilon_m = 19$, $Q_0 = 3$, $Y_0(\omega) = 2e^{-\omega}$, $M_0(\omega') = e^{-\omega'}$, $\omega_1 = 1 > 0 = \omega_0$, $\omega_0' = 0$, and $\lambda^C = \lambda^P = 1$. In panels (a)-(c), we vary $\lambda^G \in \{1, 2, 0.5\}$ to span the cases.

A constituent-focused government increases consumer assistance in response to a climate shock. Intuitively, a domestic supply shortage shifts the benefits of high domestic prices from domestic to foreign producers, while the costs continue to fall on domestic consumers. The resulting incentives outweigh those on the revenue side when the government places higher weights on constituents relative to revenues. For a pro-producer government that initially taxes imports, domestic shocks reduce domestic production and thus the marginal benefit of protectionist import taxes. The government responds by lowering import taxes. This component of our argument relates to the prediction in Grossman and Helpman (1994) that higher import penetration predicts lower protection in an environment focused on producer bias.[8] For a pro-consumer government that initially subsidizes imports, domestic shocks reduce domestic consumption. With downward-sloping demand, the result is a higher marginal benefit of reducing prices with import subsidies. The government responds by raising import subsidies. In both cases, policy responses dampen the rise in domestic prices following a domestic shock, shielding consumers but exacerbating losses for producers.[9]

[8] Maggi and Rodríguez-Clare (2000) call this the "standard prediction" in models of trade and politics.

[9] The same holds for net exporters. A pro-consumer government taxes exports to assist consumers by lowering domestic prices. This policy cross-subsidizes foreign producers by raising world prices. Domestic shocks reduce exports, lowering the cross-subsidy to foreign producers and allowing the government to

We also study policy responses to foreign shocks experienced by trading partners. Consistent with our earlier definition, we say that foreign countries experience an adverse supply shock if ω' increases and, consequently, foreign net supply $M(\cdot, \omega')$ shifts down. Proposition 2 readily implies that government responses to foreign shocks have the *opposite* sign as responses to domestic shocks:

Corollary 1 (Foreign Climate Shocks)**.** *The following statements are true.*

1. *For a neutral government, α^* is invariant to ω': foreign shocks do not affect policy.*
2. *For a revenue-focused government, α^* decreases in ω': adverse foreign shocks lead to consumer assistance.*
3. *For a constituent-focused government, α^* increases in ω': adverse foreign shocks lead to producer assistance.*

Proof. See Appendix A.2. □

A decrease in foreign net supply has precisely the opposite effect on the import share as a decrease in domestic supply. Intuitively, since the logic underlying Proposition 2 concerned only the policy response to greater or lower imports, the result is exactly flipped. We take the following stark, testable implication of our theory to the data: governments whose food policy is motivated by redistribution should respond *oppositely* to climate-induced shortages that arise abroad instead of at home.

2.4 Discussion

Before proceeding, we describe three extensions of the baseline model.

Interpreting Welfare Weights. To provide an additional interpretation for aggregation and government preferences, we micro-found our setting in a production economy with households indexed by $i \in \{1, \ldots, N\}$. There are two goods, the agricultural good and "money," which acts as numeraire. Each household consumes both goods and produces the agricultural good with costly labor. Their payoff in terms of agricultural consumption $q_i \in \mathbb{R}_+$, money consumption $m_i \in \mathbb{R}$, and production $y_i \in \mathbb{R}_+$ is

$$\mathcal{U}_i = \mu_i^{\frac{1}{\epsilon_d}} \frac{q_i^{1-\frac{1}{\epsilon_d}}}{1-\frac{1}{\epsilon_d}} - f(\omega)^{-\frac{1}{\epsilon_s}} \psi_i^{-\frac{1}{\epsilon_s}} \frac{y_i^{1+\frac{1}{\epsilon_s}}}{1+\frac{1}{\epsilon_s}} + m_i, \tag{2.4}$$

better target domestic consumers. The government responds by raising export taxes. A pro-producer government subsidizes exports to assist producers by raising domestic prices. Domestic shocks reduce production, lowering the returns to price support. The government responds by reducing export subsidies. In both cases, policy responses assist domestic consumers by keeping domestic prices low.

where $\mu_i \in \mathbb{R}_+$ is a taste shifter, $\psi_i \in \mathbb{R}_+$ is a productivity shifter, and $f : \mathbb{R} \to \mathbb{R}_+$ is a decreasing function that encodes an aggregate adverse productivity shock. Their budget constraint is $px_i + m_i \leq py_i + T_i$, where T_i is a government transfer. Transfers are determined by the rule $T_i = \xi_i \mathcal{G}$, where $\xi_i \in \mathbb{R}_+$ are fixed weights and $\mathcal{G}$ is tax revenue. The import sector and government policy instrument are exactly as described earlier. The government's objective is to maximize a social welfare function $\mathcal{W} = \sum_{i=1}^{N} \lambda_i \mathcal{U}_i$ with Pareto weights $\lambda_i \in [0, 1]$ normalized such that $\sum_i \lambda_i = 1$. These micro-foundations map to our original model as follows.

Lemma 1. *The competitive equilibrium in this economy coincides with the "supply and demand" representation described above, where* $Q_0 = \sum_i^N \mu_i$ *and* $Y_0(\omega) = f(\omega) \sum_i^N \psi_i$. *The government's preferences coincide with those in Equation 2.1, with*

$$\lambda^C = \sum_{i=1}^{N} \tilde{\mu}_i \lambda_i, \qquad \lambda^P = \sum_{i=1}^{N} \tilde{\psi}_i \lambda_i, \qquad \lambda^G = \sum_{i=1}^{N} \xi_i \lambda_i \tag{2.5}$$

and where $\tilde{\mu}_i = \mu_i / (\sum_{j=1}^{N} \mu_j)$ *is household* i*'s share of domestic consumption and* $\tilde{\psi}_i = \psi_i / (\sum_{j=1}^{N} \psi_j)$ *is household* i*'s share of domestic production. If the social welfare function is utilitarian, such that* $\lambda_i = 1$ *for all* i*, then* $\lambda^C = \lambda^P = \lambda^G = 1$.

Proof. See Appendix A.3. □

Via this interpretation, consumer weight λ^C is large if the government prioritizes redistribution toward those who consume a large fraction of the agricultural good, as is natural for staple crops that sustain a large share of the population. Producer weight λ^P is large if agricultural income is evenly spread among many high-weight households (e.g., an economy with widespread small-scale farming) rather than concentrated among a few low-weight households (e.g., an economy with centralized agriculture).

Moreover, λ^G is large if government revenues reach those with high welfare weights. If government transfers are a metaphorical "leaky bucket" (Okun, 1975), such that transfers do not effectively reach their target recipients, then λ^G is low. Conversely, if governments prefer to redistribute away from participants in agricultural markets and toward a different group of agents, such as corrupt officials or other interest groups, then λ^G is high. While our analysis has presumed a balanced budget, we might also treat a high-benefit target of public funds as a reduced form for a high need to pay off outstanding government debt, and the opposite as a low (opportunity) cost of fiscal irresponsibility.

Price Stabilization and Curvature in Utility. An alternative hypothesis for why climate shocks lead to policy responses is that they directly change how "needy" certain groups are, measured by their marginal utility. Our main analysis ruled this out by assuming quasilinear payoffs, so utility was transferable across groups. To incorporate this feature, we can extend the micro-founded model such that payoffs for agent i are $v(\mathcal{U}_i)$, where $v : \mathbb{R} \to \mathbb{R}$ is a concave and differentiable function and $\mathcal{U}_i$ is as described in Equation 2.4. To a first-order approximation, the payoff of each agent is $\mathcal{W}_i \approx v'(\mathcal{U}_i)\mathcal{U}_i$, where v' is decreasing because of concavity of v. Applying this approximation in the social welfare function, our results go through with $\lambda_i v'(\mathcal{U}_i)$ as an endogenous Pareto weight that now responds to shocks.

If adverse agricultural shocks reduce payoffs for households with high consumption shares, then λ^C may decrease in response to a domestic or foreign adverse shock. Applying Proposition 1, this pushes toward consumer assistance as an optimal response to either shock. Such a response would be consistent with the intuition that governments always intervene to lower food prices during shortages. But it contrasts with the prediction from our baseline model that responses to domestic and foreign shocks have opposite signs. Our empirical analysis will document opposite-signed policy responses, offering evidence in favor of our model and against an alternative focused on curvature in utility.

Multi-Country Interactions. So far, we have studied a single country setting policy in isolation. But our results also shed light on how multiple countries' policies may interact. Consider an extension in which there are additional countries $\ell \in \{1, \ldots, L\}$, each with demand function Q_ℓ and supply function Y_ℓ. Each country levies its own distortionary producer assistance α_ℓ. Markets clear internationally. In terms of the world price p^w, equilibrium prices in each "foreign" country, p^*_ℓ, are $p^*_\ell = p^w/(1+\alpha_\ell)$. Therefore, in terms of the home country's price, p^*_ℓ, are $p^*_\ell = p^w/((1+\alpha_\ell)(1+\alpha))$. Market clearing requires global trade balance, or

$$Q(p^*) - Y(p^*, \omega) = \underbrace{\sum_{\ell=1}^{L} \left(Q_\ell \left(\frac{p^*}{(1+\alpha)(1+\alpha_\ell)} \right) - Y_\ell \left(\frac{p^*}{(1+\alpha)(1+\alpha_\ell)}, \omega_\ell \right) \right)}_{M\left(\frac{p^*}{1+\alpha}, (\omega_\ell, \alpha_\ell)_{\ell=1}^L\right)} \tag{2.6}$$

In brackets, we define the imports (or exports) curve from the perspective of the home country. In this translation, producer assistance in any foreign country is tantamount to a positive import shock. Thus, the results of Proposition 2 describe a given government's

best response to others' policy (e.g., in a Nash equilibrium of tariff setting).

The economic implications can be made concrete via a two-country ("Home" and "Foreign") example. Suppose Foreign is a net exporter and it limits exports during a climate emergency. If Home is revenue-focused, then it responds by supporting consumers or subsidizing imports. If Home is constituent-focused, then it responds by supporting producers or taxing imports. The model thus allows for feedback loops of equilibrium tariff setting. If both Home and Foreign are revenue-focused, then Home's consumer support amounts to a negative overseas shock for foreign, which pushes Foreign toward further consumer support. These interactions amplify the initial change to trade policy. If both Home and Foreign are constituent-focused, then Home's producer support leads foreign to reduce its consumer support. These interactions dampen the initial change. Moreover, in the presence of policy feedback loops of either kind, local and global shocks may propagate very differently.

3 Data, Measurement, and Descriptives

We construct a panel dataset on agricultural policy, extreme heat shocks, and other agricultural, political, and economic outcomes to study our questions of interest empirically.

3.1 Agricultural Policy

We measure distortions in agricultural markets with data from the World Bank's "Distortions to Agricultural Incentives" project (Anderson and Valenzuela, 2008; Anderson, 2009; Anderson et al., 2013). This dataset is an unbalanced panel of information about price distortions for 80 agricultural products and 82 countries from 1955 to 2011. The sample accounts for over 85% of agricultural production and employment globally, as well as within each of Africa, Asia, Latin America, and the OECD (Anderson et al., 2013). In sensitivity analysis, we also use NRA data from the Ag-Incentives project, an unofficial continuation of the DAI Project.

The key statistic of interest is the *nominal rate of assistance*, which measures the difference between domestic producer prices and prevailing "free market" prices induced by policy intervention. For crop k in country ℓ at time t,

$$\text{NRA}_{\ell kt} = \frac{p_{\ell kt} - P_{kt}}{P_{kt}} \tag{3.1}$$

where $p_{\ell kt}$ is the distorted, domestic price per unit of production, and P_{kt} is the undistorted

market price. This measure corresponds to our theoretical definition of *ad valorem* tariffs $\alpha_{\ell kt}$ if tariffs were the only policy instrument. In practice, the NRA is computed by estimating the ratio of total assistance paid to producers (in dollars) relative to the total value of production driven by policy interventions. These interventions 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).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.

The NRA is computed by compiling granular price and output data along with detailed qualitative reports about policy changes (Anderson, 2009). In addition to the aforementioned studies about the history of agricultural distortions, recent studies in economics on agricultural misallocation (Adamopoulos and Restuccia, 2014) and agricultural trade and resource use (Carleton et al., 2022) and recent studies in political science on urban-rural policy conflict (Wallace, 2013; Bates and Block, 2013) have treated the NRA as the most comprehensive available data source on agricultural policy interventions.

For our specific research question, the NRA data have two key advantages relative to other measures of agricultural policy. First, they capture policy instruments other than border taxes. For example, the NRA measure accounts for quantity restrictions in terms of the induced price wedge. This is necessary to capture non-tariff policy responses like our motivating example of India's export ban in 2022. Similarly, the NRA measure accounts for indirect assistance through input price distortions or exchange rate manipulation. This is necessary to capture agricultural assistance that substitutes for direct export subsidies, which are prohibited under World Trade Organization rules. Second, the NRA measure can capture temporary variation in trade policy that is not set by legislation. Together, these features allow us to see more relevant policy variation and to account for how governments use different instruments as complements or substitutes for one another.

Nonetheless, as an alternative and independent measure of policy, we compile data on crop-specific tariffs from the United Nations' Trade Analysis Information System (TRAINS) database by linking all relevant Harmonized System (HS) codes in the TRAINS data to individual crops in our data set. These data reduce our reliance on the modeling and imputation decisions of a single data source, at the cost of capturing just one relevant dimension of policy. We also compile data on all import and export restrictions that affect agricultural commodities from Global Trade Alert (GTA). The GTA database, intended to have comprehensive coverage since 2008, lists all sector-specific policy interventions

broken down by industry (HS code) and policy type. We identify all policy activity affecting the HS codes corresponding to crops in our analysis, and we directly measure crop-by-country-pair level changes in the total number of export- and import-restricting policies.[10] Thus, for a subset of the sample period, these data allow us to directly measure policy interventions other than tariffs, including export-restricting policies.

3.2 Extreme Heat Exposure

To measure agricultural climate shocks, we construct a global dataset of crop-level exposure to extreme heat in each country and year.

Data Inputs. Our measure of crop-specific extreme heat exposure incorporates information about the global distribution of temperature extremes, the global geography of crop production, and crop-specific sensitivity to extreme heat. This makes it possible to exploit both the fact that regions are have been differentially exposed to changes in extreme heat and the fact that, in a fixed region, crops are differentially sensitive to a given change in extreme heat exposure.

First, we measure historical temperatures with data from the ERA5 database from the European Centre for Medium-Range Weather Forecasts (Muñoz Sabater et al., 2021). This reanalysis data set combines weather observations from around the world with a model to generate gridded (0.25-by-0.25 degrees), hour-by-hour measurements since 1979.

Second, we measure the global geography of agricultural production with data 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.

Finally, we measure crop-specific temperature sensitivity with data from the United Nations Food and Agriculture Organization's *EcoCrop* database. The EcoCrop data provide information about growing conditions for 2,500 agriculturally important plants, including tolerance ranges for temperature and rainfall. The data are compiled from expert surveys and textbooks. The key piece of information for our analysis is the reported upper temperature threshold for optimal growing.[11]

[10] Export-restricting policies are those tagged as export bans, export quotas, export licensing requirements, export tariffs, export taxes, and export non-tariff barriers. Import-restricting policies include import bans, import licensing requirements, import quotas, import tariffs, and import non-tariff barriers.

[11] This database has been used in agronomics and climate science to estimate crop-specific effects of climate change (e.g., Ramirez-Villegas et al., 2013; Hummel et al., 2018) and in economics to measure exposure to crop-specific adverse conditions (Moscona and Sastry, 2023; Molina et al., 2023; Hsiao, 2024a).

Measurement. Following the methodology outlined in Moscona and Sastry (2023), which focuses just on the US, we measure crop-specific extreme heat exposure for each country-crop combination around the world as the average exposure to extreme temperatures, in degree-days, on land cultivating a given crop. Prior work has shown that extreme heat exposure is the quantitatively most important way that temperature affects output (e.g., Schlenker and Roberts, 2009) and that the temperature above which productivity falls differs across crops (Ritchie and Nesmith, 1991).[12] We partition each country ℓ into grid cells $c \in \ell$, and for each country, crop, and year we compute

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

where $\text{DegreeDays}_{ct}(x)$ returns total degree days in excess of threshold x in cell c at time t, 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. We average this variable over years and decades in different parts of our analysis.

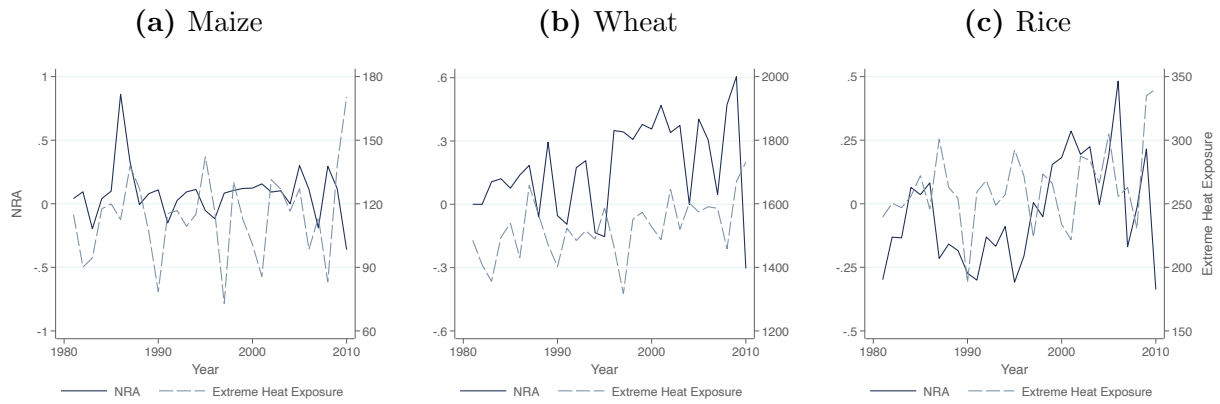
This method extends existing work on the impact of rising temperatures on global agricultural production (Lobell and Field, 2007; Lobell et al., 2011) by incorporating temperature extremes rather than averages, a larger set of crops, and crop-specific measures of temperature sensitivity. These data may be of independent interest to researchers interested in studying global trends in climate change and agricultural productivity.

3.3 Production, Trade, Elections, and Debt

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. Data on all election years during our sample period are from the Database of Political Institutions (DPI), first introduced by Beck et al. (2001). The database covers election information and regime characteristics for 180 countries from 1975-2020. We code an indicator that equals one during the year of or immediately preceding any national election. Finally, we compile data on government debt from the International Monetary Fund's (IMF) Global Debt Database. We compute central government debt as a share of GDP at the country-year level. All remaining country-level data are compiled from the World Bank's World Development Indicators (WDI) database.

[12] Moscona and Sastry (2023) document that this crop-specific extreme heat exposure measure predicts adverse agricultural outcomes and that it outperforms comparable measures that do not account for crop-specific tolerance using historical panel data from the United States.

Figure 2: Extreme Heat and Policy for India



This figure displays extreme heat exposure and NRA over time in India for maize, wheat, and rice. The NRA is plotted on the left y-axis (dark blue solid line) and extreme heat exposure is plotted on the right y-axis (light blue dashed line).

3.4 Visualizing the Data

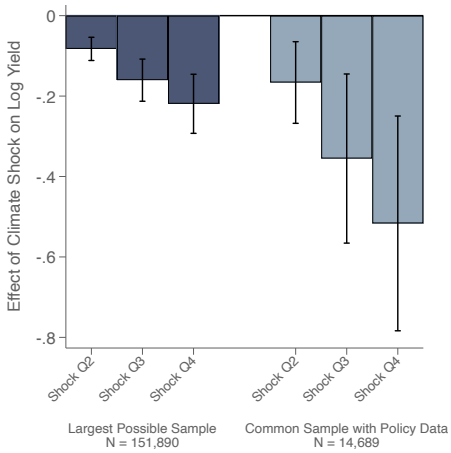
Our data on extreme heat, production and trade cover 166 countries and 126 crops. When merged with our data on agricultural policy, our dataset covers 79 countries and 61 crops.

Figure A.1 illustrates the variation in agricultural policies across countries and crops by mapping the average NRA around the world from 2001-2010 for maize, wheat, and rice. There is substantial policy variation both for fixed crops across space (e.g., some countries elevate domestic maize prices and some countries depress them) and for fixed countries across crops (e.g., Mexico's policy falls in a different quartile for each crop). Figure A.2 shows the change in NRA for each country and crop from the 1980s to the 2010s. This also reveals clear differences across crops and countries.

Figure A.3 illustrates the variable incidence of realized extreme heat by mapping changes in $\text{ExtremeHeat}_{\ell k}$ between the 1980s and the 2000s for maize, wheat, and rice. While extreme heat exposure has increased in most countries for all three crops, there is substantial variation in the magnitude of the effect. For example, Brazil is in the third quartile for maize, second quartile for wheat, and fourth quartile for rice. We will exploit this within-country, cross-crop variation in the empirical analysis.

We can also use these raw patterns in policy and climate exposure to anticipate our main analysis and findings. To follow up on our motivating anecdote about Indian policy, we plot the evolution of extreme heat exposure and NRA for Indian maize, wheat, and rice

Figure 3: Crop Yield Effects of Extreme Heat



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

in Figure 2. While extreme heat exposure has increased over time for all three crops, there are also large fluctuations from year to year that we will use for identification. Both the level of extreme exposure and the pattern over time are also very different across crops. Visually, increases in extreme heat exposure seem to coincide with declines in NRA, and drops in extreme heat exposure seem to coincide with increases in NRA. This is a first indication that adverse climate shocks may lead to more consumer-friendly policy for staple crops in India. Our main empirical analysis in Section 4 exploits variation across all countries, crops, and years to investigate this pattern systematically.

3.5 Validation: Extreme Heat Lowers Crop Yields

Before turning to the main results, we document that extreme heat exposure by our measure adversely affects productivity. To this, we estimate the following regression:

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

where $\text{yield}_{\ell kt}$ is output-per-area of crop k in country ℓ and year t, and all possible two-way fixed effects are included. $\text{ExtremeHeat}_{\ell kt}$ is defined in Equation 3.2, and we estimate

function f that encodes effects by quartile of $\text{ExtremeHeat}_{\ell kt}$. 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.

We estimate a large, negative effect of extreme heat exposure on yields (Figure 3). Compared to the yields in the bottom extreme heat quartile, yields in the top extreme heat quartile are over 20% lower. When we restrict attention to the subsample of observations for which we also have policy data, our estimates are comparable and slightly larger. Together, these estimates indicate that our measure of extreme heat exposure has substantial negative effects on agricultural productivity.

4 Empirical Results

We present our main empirical findings. First, extreme heat shocks to local production lead to large shifts in agricultural policy that favor domestic consumers. Second, adverse shocks to import partners have the opposite effect, pushing toward pro-producer policies. Third, these effects are larger when studying lower-frequency, decade-by-decade changes. Fourth, these effects are larger in scenarios when governments may plausibly care more about helping constituents in the short term and less about fiscal responsibility.

4.1 Extreme Heat Leads to Pro-Consumer Policy

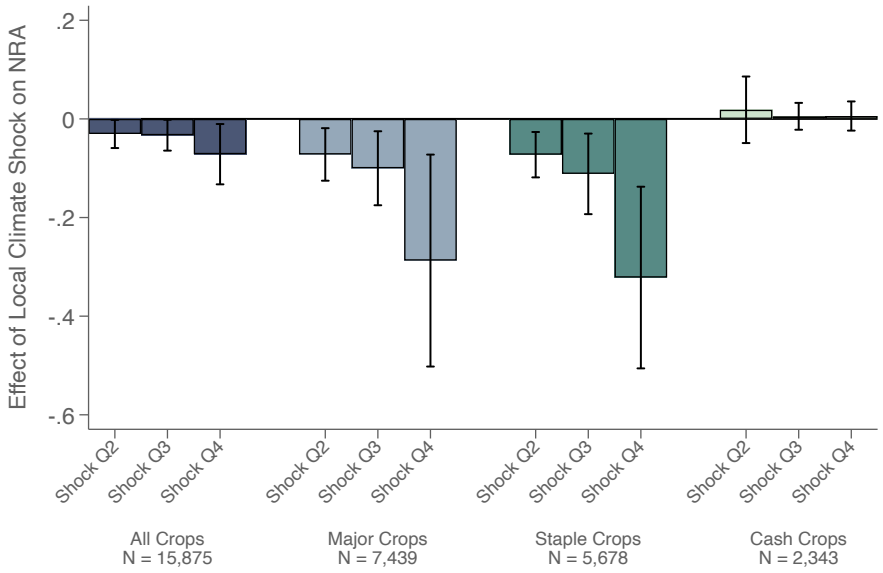
We first investigate the relationship between local extreme heat exposure and crop-specific policy. Our main estimating equation is

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

where $\text{NRA}_{\ell kt}$ is a measure of crop-specific policy for crop k in country ℓ and year t. We estimate non-parametric function g with indicators for each of the four quartiles of $\text{ExtremeHeat}_{\ell kt}$. 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 report our findings in Figure 4. Each set of three bars corresponds to estimates from a separate regression, and the coefficients are effects relative to the left-out category of first-quartile exposure.

Our first finding is that extreme heat exposure induces consumer assistance on our full sample of countries and crops (dark-blue bars). Experiencing fourth-quartile compared to

Figure 4: Policy Effects of Extreme Heat



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.

first-quartile extreme heat exposure reduces NRA by 0.072. This corresponds to a 7.2% reduction in domestic prices relative to international prices. In our panel data, such a change corresponds to 0.092 in-sample standard deviations of the NRA variable. Through the lens of the model, this finding is consistent with a *constituent-focused* government. The finding is moreover consistent with the motivating stories of the Introduction, including India's 2022 ban on wheat exports following a national drought, as well as the time-series patterns for India visualized in Figure 2. This first result confirms that such policy reactions are systematic and quantitatively large relative to the baseline cross-country and cross-crop variation in agricultural policy.

We next focus on the most economically important crops by restricting the sample to the ten crops studied by Costinot et al. (2016).[13] 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 29 percentage points or 0.37 in-sample standard deviations. Moreover, the fourth-quartile effect is substantially larger than,

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

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.[14] The third set of bars (dark-green bars) reports our estimates for staple crops, and the results closely mirror the preceding specification. We find large, negative effects of higher extreme heat exposure on policy and the effect is particularly large for the highest values of extreme heat exposure. Experiencing high (compared to low) extreme heat exposure for staple crops reduces NRA by 32 percentage points or 0.41 standard deviations. Once more, the fourth-quartile effect is statistically distinguishable from the third-quartile effect ($p < 0.01$). In contrast, we find no statistically significant evidence that extreme heat exposure affects agricultural policy for cash crops (light-green bars).

Through the lens of the model, the contrast between our results for staple crops and cash crops is consistent with the idea that staple crops are more important in terms of both consumption *and* income for households that the government prioritizes. Both would push toward greater constituent focus (see the discussion after Definition 1) and hence, according to our model prediction, a negative response of NRA to shocks. By contrast, cash crops are a source of income for a smaller set of constituents and are often consumed predominately by foreigners. Thus, governments may see interventions in cash crop markets as primarily a way to generate government revenue for other purposes.

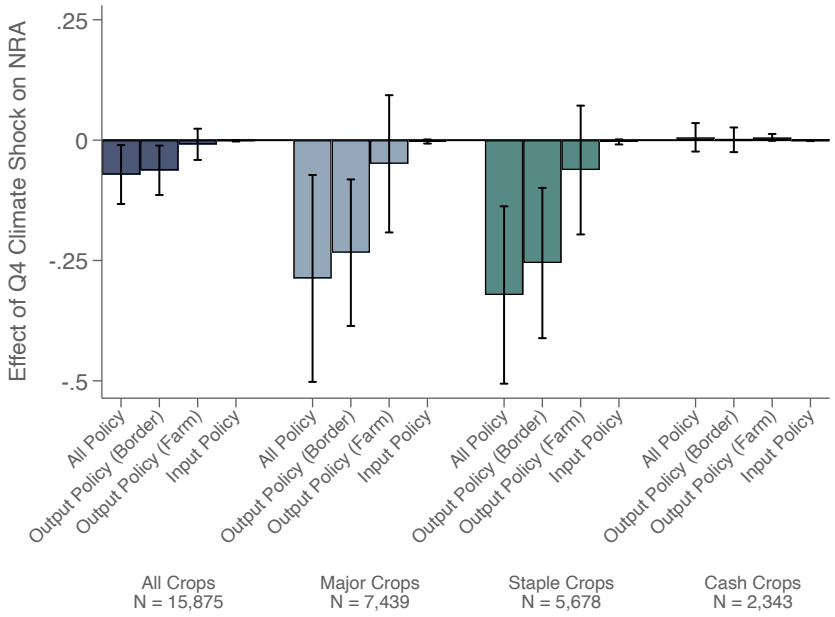
Together, these estimates suggest that exposure to extreme heat reduces NRA, leading to more consumer-oriented agricultural policy. The effects are particularly pronounced for staple crops and for the highest levels of exposure to extreme temperatures.

Policy Types and Alternative Measures. The results in Figure 4 focus on the summary NRA measure which combines all types of policy. We argued earlier that this is desirable to identify the net effect of policy. Nonetheless, it may be interesting to better understand exactly which policies drive our overall findings. For instance, our baseline results may mask partially offsetting responses of different policies.

We first estimate Equation 4.1 using each component of overall NRA as a separate dependent variable (Figure 5). We report the effect of the top quartile of extreme heat exposure; the four sets of bars report the results for the sample of all crops, major crops, staple crops, and cash crops respectively. All forms of policy move in the same direction. This helps justify our baseline strategy of bundling together all policies in the baseline

[14]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 5: Policy Effects of Extreme Heat 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, labelled below the bar. The sample of crops included in each regression is noted below each set of bars. We report 90% confidence intervals.

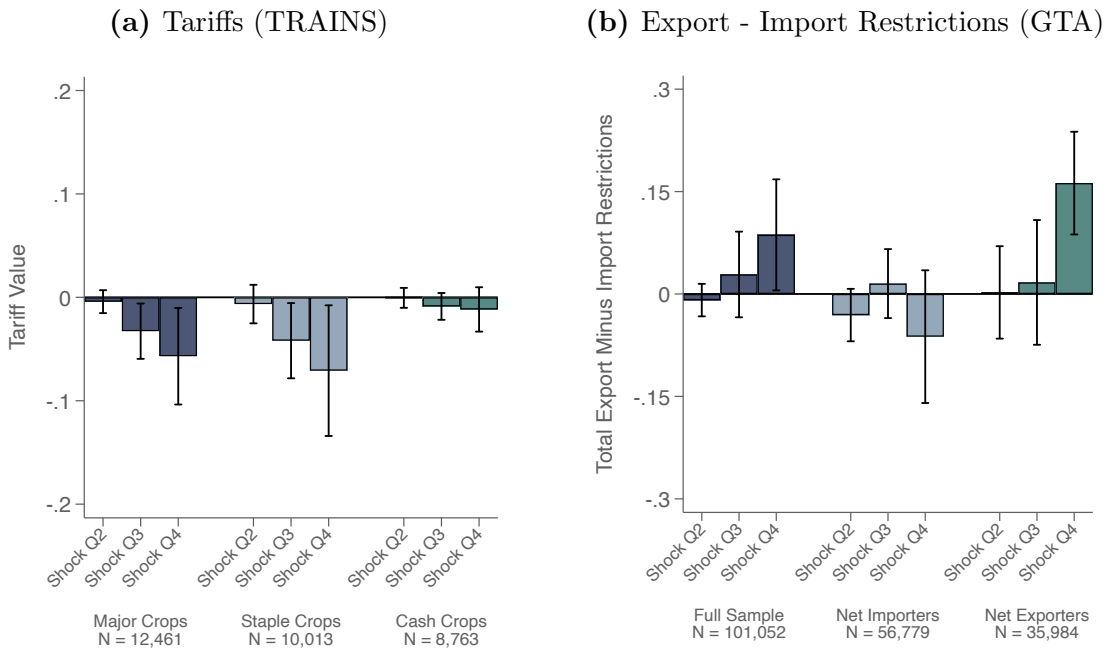
NRA measure. However, our results are primarily driven by output-related policies and, in particular, policies that affect prices at the border. By contrast, the effect is weaker for policies that affect output prices at the farm gate (e.g., output price support) and absent for policies that affect agricultural inputs (e.g., fertilizer subsidies).

We next replicate our baseline findings using measured tariffs from the TRAINS database as the outcome (Figure 6a). High exposure to extreme temperatures leads to reductions in crop-specific tariffs. Consistent with the main results, these findings are driven by staple crops and extreme heat exposure has no effect on tariff policy for cash crops (second and third set of bars). This is consistent with our finding within the NRA data that effects are concentrated within border policies.

We finally replicate our results using data on trade disruptions from the GTA database.[15]

[15]The regression specification used for these estimates is slightly different from the previous results since policy interventions are measured at the country *pair*-by-crop-by-year level. Thus, the unit of observation is a country-pair-by-crop-by-year and, in addition to all previously described two-way fixed effects, we also include country-pair-specific time trends.

Figure 6: Trade Disruption Effects of Extreme Heat

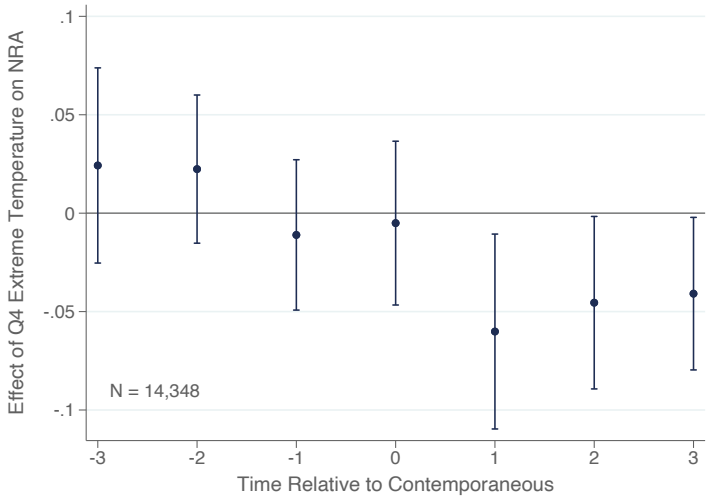


Panel (a) displays the relationship between quartiles of extreme heat exposure and crop-specific tariffs. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. Each set of three bars corresponds to estimates from a single regression. Panel (b) displays the relationship between quartiles of extreme heat exposure and crop-specific policy interventions. The unit of observation is a country-pair-crop-year and all specifications include fixed effects at the origin-crop, crop-year, and origin-destination-year levels. The outcome variable is the total number of export-restricting policies minus the total number of import-restricting policies. We report 90% confidence intervals.

In our baseline specifications, we use the count of export restrictions minus the count of import-restricting policies as the outcome.[16] We find that extreme heat exposure increases export restrictions (Figure 6b). Intuitively, the estimates are larger for crop-country pairs that tend to be exporters, defined as countries that were, on average, net exporters during the sample period (third set of bars); export restrictions are a policy lever that is only available to exporting markets. These corroborate our main finding that governments respond to climate shocks with pro-consumer policy, and are also consistent with there being an important role the export-restricting policies highlighted by recent press reports (Yasir and Kim, 2022; de Guzman, 2022; Ghosal et al., 2023).

[16]Figure A.11 shows that the results are similar using the raw count of export restrictions and an indicator for having more export- than import-restricting policies as an outcome.

Figure 7: Dynamic Policy Effects of Extreme Heat



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.

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

Figure 7 reports estimates of Equation 4.1 focusing only on the top-quartile effect and including three leads and three lags in the regression. Each coefficient can be interpreted as the effect of an extreme temperature shock in that period holding fixed temperature realizations in the contemporaneous period and all other included lags and leads.

There is no evidence of pre-existing trends: the coefficient estimates on all the leading values are small in magnitude and indistinguishable from zero. These estimates suggest that governments do not shift policy in anticipation of *future* changes in extreme heat. Moreover, the effect of an extreme temperature shock on policy persists for several years. An adverse temperature shock reduces NRA for the subsequent three years, with the largest effect taking place in the year following the shock year. This finding is not driven by persistence in the shock itself, since the regression includes the contemporaneous extreme heat shock (as well as all leading and lagged values) on the right-hand side.

Country-Level Estimates and Cross-Crop Interactions. Our baseline estimates exploit variation in temperature and policy not only across countries and over time, but also across *crops* within the same country. There are several advantages to this approach. First, the country-crop-year is level at which policy is set and the relevant unit for measuring exposure to climate shocks. Second, as illustrated by Figures A.1 and A.3, there is substantial variation in both policy and extreme heat exposure across crops and within countries. Finally, the country-by-year fixed effects in our baseline specification make it possible to fully absorb any country-level trends or shocks that might spuriously co-vary with policy or temperature. This is an especially salient concern for our study, as there are significant time trends in NRA (Anderson et al., 2013) and in planetary warming.

Nonetheless, it is useful to study trends at the country level to investigate how the crop-country-year estimates aggregate. These estimates could be larger than our baseline estimates if governments are more responsive to high overall exposure to extreme heat, rather than high exposure for a single crop, since this increases overall hardship for consumers. They could be smaller in absolute value if politicians face a political budget that makes it harder to change policy across multiple commodities at the same time. Moreover, country-level policy averages could capture policy levers that are absorbed by the inclusion of country-year fixed effects (e.g., exchange rate manipulation).

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

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

The estimates are reported in Figure A.5. While the estimates are less precise than our main results, they point to a negative relationship between country-level extreme heat exposure and weighted country-level NRA. Consistent with our main findings, these estimates are driven by border market policies, and we estimate slightly larger and more precise effects focusing on the first lag of the extreme heat shocks. Finally, these estimates are quantitatively comparable to the estimates from the country-crop-year specification, indicating that cross-crop interactions do not seem to have a large effect on average.

Sensitivity Analysis. We conduct a series of sensitivity checks to probe the robustness of our findings. First, we reproduce our baseline result using all NRA data from

1955-2011 (Figure A.6). 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 and more complete policy data; however, the results are very similar if we use the back-filled version of the ERA temperature data. Second, we show that the results are also similar if we extend the sample to more recent years using alternative data on nominal rates of assistance from Ag-Incentives (Figure A.7).[17] Third, we show that our baseline results are similar if we individually drop each decade in the analysis, suggesting that our results are not driven by specific temperature or policy events (Figures A.8 to A.10).

4.2 Foreign Extreme Heat Leads to Pro-Producer Policy

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

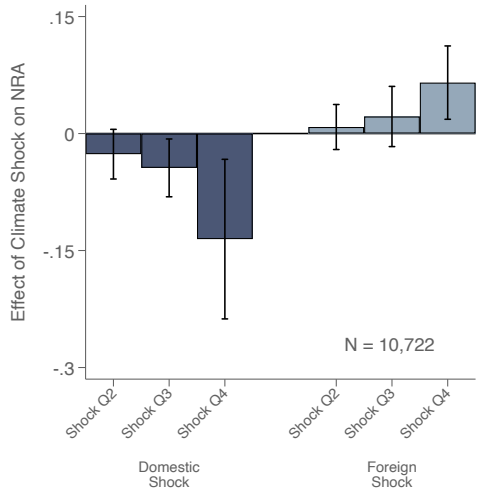
To systematically investigate how policy reacts to foreign climate shocks in the data, we measure the extreme heat exposure experienced by import partners as

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

where $\text{ImportShare}_{\ell' \to \ell k}$ is the share of imports of crop k to ℓ that are from ℓ'. This measure captures the exposure of each country-crop to foreign climate shocks, weighted by import shares. Figure A.4 maps the change in $\text{ForeignExtremeHeat}_{\ell kt}$ from the 1980s to the 2010s for maize, wheat, and rice, revealing substantial variation across countries and crops. In Figure A.13, we validate this measure of foreign extreme temperature

[17] This is not 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 re-construct them. When we estimate a regression that includes both, we include an Ag-Incentives indicator interacted with all two-way fixed effects in order to capture average differences due to methodology.

Figure 8: Policy Effects of Domestic and Foreign Extreme Heat



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 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.

exposure by showing that it has a large, positive effect on measured crop prices.[18]

To investigate the effect of both local and importer temperature extremes on agricultural policy, we estimate an augmented version of Equation 4.1 that includes both the local and the foreign temperature shocks.

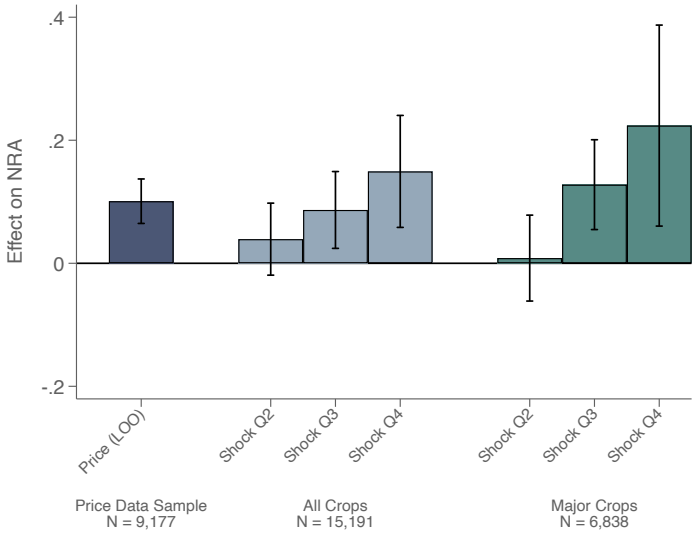
$$\text{NRA}_{\ell kt} = g(\text{ExtremeHeat}_{\ell kt}) + h(\text{ForeignExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt} \qquad (4.4)$$

Functions g and h are spanned by quartile indicators. We include all two-way fixed effects.

Estimates of Equation 4.4 are displayed in Figure 8. The left three bars show the effect of each quartile in local extreme exposure. Consistent with the baseline results, we continue to find negative effects of local extreme heat exposure on NRA after also conditioning on foreign extreme heat exposure. The right three bars show the effect of foreign extreme heat exposure. Higher foreign extreme heat exposure is associated with an increase in NRA (i.e., more producer-friendly policy). That is, if food shortages

[18] We estimate the relationship between the production-weighted global price for each crop (leaving out the country in question) and show that higher values of $\text{ForeignExtremeHeat}_{\ell kt}$ are associated with higher crop prices, conditional on country-year and country-crop fixed effects.

Figure 9: Policy Effects of Global Prices and Extreme Heat



The first panel of this figure shows the relationship between agricultural policy and the global (production-weighted, leave-one-out) average price. The second and third panels of this figure display the relationship between policy and quartiles of global (production-weighted, leave-one-out) extreme heat exposure. The unit of observation is a country-crop-year and all country-year and crop-country fixed effects are both included. We report 90% confidence intervals.

arise due to international rather than domestic shocks, they induce the opposite policy response. These effects are smaller in absolute value than the effect of local extreme heat exposure, suggesting a stronger response to local climate distress. Nevertheless, our estimates are precise enough to rule out negative effects of foreign temperature effects and are inconsistent with the "contagion of food restrictions" view of global food policy.

In our main analysis of foreign exposure, we exploit precise variation in shocks to import partners and estimate a regression model with crop-by-time fixed effects. This approach has the advantage of partialling out other possible crop-level trends, like global crop demand shocks. A possible disadvantage is that we ignore a large portion of common variation in world prices. To investigate how other sources of world price variation affect policy, we estimate a variant of Equation 4.4 in which we remove the crop-by-time fixed effect and simply include the leave-one-out production-weighted average price of each crop on the right-and side (first panel of Figure 9). Consistent with the result in Figure 8, we estimate a positive and significant relationship between the "world price" and NRA. Since, for a variety of reasons, the world price is an endogenous object, we also estimate the effect of the leave-one-out, production-weighted average of global extreme heat exposure, again

after excluding the crop-by-time fixed effects (second and third panels of Figure 9). These estimates also indicate that global negative production shocks lead to producer assistance, confirming our original finding.

The opposite effects of domestic and foreign shocks are consistent with our model, in which domestic and foreign shocks had asymmetric distributional effects from the perspective of the government. These findings are inconsistent with a view of the world in which all food security concerns induce the same policy response, for instance if they arise purely from elevated consumer needs when food is scarce and prices are high (see Section 2.4 for the theoretical argument).

4.3 Longer-Run Effects

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

To investigate this, we collapse our data to the decade-level and estimate versions of Equation 4.1 in which the unit of observation is a country-crop-decade triplet. The independent variables of interest are the number of years during the decade with high (fourth-quartile) *local* exposure to extreme heat and the number of years during the decade with high *foreign* exposure to extreme heat. These estimates are reported in Table 1. In the first column, we focus on the full sample of crops and only include local extreme heat exposure. Consistent with the yearly analysis, we estimate a negative and significant effect. Each additional year of extreme heat exposure reduces the decade's average NRA by about 0.04 standard deviations and ten years of extreme heat exposure (which occurs in about 5% of the sample) reduces the decade's average NRA by about 0.4 standard deviations. A full decade of extreme heat exposure would induce a 24% pro-consumer wedge in domestic prices relative to international prices. This is larger than our year-on-year estimate from Figure 4.

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)

Table 1: Decade-Level Policy Effects of Extreme Heat

	(1)	(2)	(3)	(4)	(5)
	Dependent variable is NRA				
	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)		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

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.

statistically significant. We can also rule out sizeable negative effects that would be consistent with international policy "contagion." In the next two columns, following our preceding analysis, 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.

We finally use the decadal analysis to shed further light on how governments use different policy tools as substitutes for one another. One explanation for our earlier finding that border policies respond more to output or input-based policies (Figure 5) is that the former can be adjusted quickly, while the latter two are more sticky. Moreover, only border policies can contemporaneously mediate the impact of shocks after production decisions have already been made. Thus, we may find effects on different types of policy at the decade level. Table A.1 repeats our estimates from Table 1 for each policy type. As in the yearly analysis, we find that the results are primarily driven by border policies; however, there also seems to be some movement in input-based policies, suggesting that governments have additional policy levers at their disposal over longer time horizons.

Table 2: Policy Effects of Extreme Heat by Election Year

	(1)	(2)	(3)	(4)
	Dependent variable is NRA			
	Full Sample	Major Crops	Staple Crops	Cash Crops
Q2 Extreme Heat x No Election	-0.0429*	-0.0724	-0.0509	-0.0259
	(0.0222)	(0.0445)	(0.0390)	(0.0486)
Q3 Extreme Heat x No Election	-0.0138	-0.0788	-0.0561	-0.0182
	(0.0236)	(0.0654)	(0.0719)	(0.0163)
Q4 Extreme Heat x No Election	-0.0172	-0.0948	-0.104	-0.0126
	(0.0374)	(0.101)	(0.0946)	(0.0216)
Q2 Extreme Heat x Election	-0.0120	-0.0689**	-0.0820**	0.0680
	(0.0172)	(0.0315)	(0.0316)	(0.0600)
Q3 Extreme Heat x Election	-0.0363	-0.110**	-0.145**	0.0217
	(0.0230)	(0.0543)	(0.0627)	(0.0223)
Q4 Extreme Heat 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

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.

4.4 Mechanisms and Heterogeneity

All of our findings suggest that the "constituent-focused" case from Proposition 2 holds *on average* across markets. To investigate this mechanism directly, we exploit elections as a positive shock to concerns about constituents relative to fiscal responsibility. A large literature on political cycles has documented that upcoming elections reduce fiscal responsibility and to lead to policies designed to win the support of constituents (e.g. Alesina and Roubini, 1992; Akhmedov and Zhuravskaya, 2004). Therefore, under our proposed mechanism, we would expect all of our baseline results to be exacerbated when there is an upcoming election.

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.[19] 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 ($p = 0.03$). The model would predict also a similar intensification for the response to *foreign* shocks. In Appendix Table A.2, we confirm that the *positive* effect of *foreign* extreme heat exposure on NRA is larger in magnitude during election years.

We use a different strategy to investigate whether countries that are focused on avoiding revenue loss would respond to climate shocks with less extreme consumer-oriented policy. Specifically, we use each government's accumulated debt-to-GDP ratio as a rough proxy for the government's ability to forego fiscal revenue in order to shield constituents from climate shocks. Table A.3 reports estimates from an augmented version of Equation 4.1 that includes interaction terms between extreme heat exposure and the central government debt-to-GDP ratio in each country-year. The first column includes our full sample of crops and the remaining columns focus only on the set of ten major crops. The negative effect of extreme heat exposure is substantially diminished when central government debt is high, and in two of the four estimates it flips sign. The estimates are qualitatively similar in column 3, when we control flexibly for central government debt interacted with country-by-crop fixed effects, and in column 4, when we control for extreme heat exposure interacted with the *change* in government debt, in order to account for year-to-year changes in fiscal policy or incumbent political orientation.

Together, 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 their economic consequences.

We finally explore heterogeneity in our main results across a range of additional dimensions. These results are summarized in Figure A.12, where each set of three bars reports the effect of each extreme heat quartile interacted with the indicated country-level characteristic. The first set of bars conveys that we do not find that the results differ for more vs.

[19] 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.

less democratic countries, proxied using their average Polity score. Constituent-focused policy when it comes to food provision is not restricted to democratic regimes, indicating that even authoritarian governments do not use staple food price manipulation, which has potentially large effects on popular contentment, for revenue extraction. We also do not find that the results differ for countries with higher total or per-capita GDP, suggesting that the main findings are not driven by larger (smaller) or richer (poorer) countries.

Turning to the size of different interest groups within the country, we do not find evidence of heterogeneity with respect to the overall size of the agricultural economy (proxied using agriculture's share of GDP), but we do find that all results are more pronounced for countries with a higher urban population share. This finding indicates that governments are perhaps especially responsive to the demands of urban constituents, consistent with accounts that urban residents can most effectively lobby or threaten the legitimacy of incumbents (e.g. Bates, 2014).

5 Counterfactuals

We combine our empirical estimates and model to quantify how endogenous agricultural policy shapes the aggregate and distributional welfare effects of extreme heat shocks. We consider both historical (in-sample) and projected (out-of-sample) shocks.

5.1 Quantification

Model. We describe a multi-crop, multi-country model for quantification. For countries ℓ, crops k, and years t, we specify isoelastic demand and supply curves

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

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

for quantities $(q_{\ell kt}, y_{\ell kt})$, intercepts $(q^0_{\ell kt}, y^0_{\ell kt})$, and elasticities (ϵ_d, ϵ_s) of demand and supply. Damage function f captures production losses from domestic extreme heat shocks. Government policy is given by

$$\alpha_{\ell kt} = \alpha^0_{\ell kt} + g(\text{ExtremeHeat}_{\ell kt}) + h(\text{ForeignExtremeHeat}_{\ell kt}). \tag{5.3}$$

Policy functions g and h capture policy responses to domestic and foreign extreme heat shocks. Government policy acts as an *ad valorem* tariff, with domestic prices $p_{\ell kt} = (1 + \alpha_{\ell kt})P_{kt}$ and world prices P_{kt}. Equilibrium world prices P^*_{kt} clear world markets by

crop and year.

$$\sum_{\ell} q_{\ell kt}(P^*_{kt}; \alpha_{\ell kt}) = \sum_{\ell} y_{\ell kt}(P^*_{kt}; \alpha_{\ell kt}) \quad \forall\ k, t \tag{5.4}$$

Measurement. We measure consumption $q_{\ell kt}$, production $y_{\ell kt}$, NRA policy $\alpha_{\ell kt}$, and world prices P_{kt} by year from 1991 to 2010.[20] We restrict attention to countries and crops for which we have data on policy, and we interpret these data as generated by a realized equilibrium of our model.[21] We also measure domestic extreme heat shocks $\text{ExtremeHeat}_{\ell kt}$ and foreign shocks $\text{ForeignExtremeHeat}_{\ell kt}$. We calibrate elasticities $\epsilon_d = 2.82$ and $\epsilon_s = 2.46$ based on estimates from Costinot et al. (2016).[22]

Section 3.5 estimates damages f as the quartile effects of extreme heat shocks. Section 4 similarly estimates policy responses g and h with Equation 4.4, as presented in Figure 8. Directly using our regression estimates allows us to proceed without estimating underlying government preferences and, more generally, to accommodate alternative models that also generate the empirical patterns we document for nominal rates of assistance. Finally, we recover intercepts $(q^0_{\ell kt}, y^0_{\ell kt}, \alpha^0_{\ell kt})$ as residuals to fit the observed data, and we hold these quantities fixed in counterfactuals.

Shocks and Policy. We study historical and projected extreme heat shocks relative to a baseline without shocks. We observe historical shocks $\omega = \{\text{ExtremeHeat}_{\ell kt}\}$ in our sample from 1991 to 2010, and we construct baseline shocks ω_0 by setting extreme heat exposure in every year to its in-sample minimum for each country-crop pair. We estimate projected extreme heat shocks $\hat{\omega}$ for the decade from 2091 to 2100, drawing on extreme heat projections from the Geophysical Fluid Dynamics Laboratory's Earth System Model (GFDL-ESM4).[23] We compute within-day exposure by 0.25-degree cell to temperatures above any given cutoff level, then we aggregate by country and year to obtain projected shocks by country, crop, and year. Appendix Figure A.14 plots historical and projected shocks against baseline shocks. Historical shocks are only modestly larger than baseline shocks, and projected shocks are roughly twice as large as baseline shocks. Finally, we apply Equation 4.3 to obtain foreign exposure to baseline, historical, and projected shocks.

For policy responses, we observe historical government policies $\alpha = \{\alpha_{\ell kt}\}$. Equation

[20] While our baseline sample begins in 1980, prices from the FAO are not available before 1991.

[21] We compute unmodeled net production for the study sample as total production less total consumption in each year, and we hold these net quantities fixed in counterfactuals.

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

[23] We take central model forecasts from NASA's Global Daily Downscaled Projections, corresponding to the SSP 4.5 pathway for global greenhouse gas concentrations. The data are available at https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp-cmip6.

5.3 gives baseline policies α_0 as a function of baseline domestic and foreign shocks, as constructed above. Similarly, Equation 5.3 gives projected policies $\hat{\alpha}$ as a function of projected domestic and foreign shocks.

Welfare. As welfare measures, we consider consumer surplus, producer surplus, and government revenue.

$$\mathcal{C}_{\ell kt} = \frac{q_{\ell kt} p_{\ell kt}}{\epsilon_d - 1}, \quad \mathcal{P}_{\ell kt} = \frac{y_{\ell kt} p_{\ell kt}}{\epsilon_s + 1}, \quad \mathcal{G}_{\ell kt} = \alpha_{\ell kt} P_{kt} (q_{\ell kt} - y_{\ell kt}) \tag{5.5}$$

We define total welfare as the equal-weighted sum of these terms, noting that governments may not seek to maximize this utilitarian objective function.

$$\mathcal{W}_{\ell kt} = \mathcal{C}_{\ell kt} + \mathcal{P}_{\ell kt} + \mathcal{G}_{\ell kt} \tag{5.6}$$

Given shocks ω and policies α, we solve for equilibrium prices and quantities with Equations 5.1 and Equation 5.2. Shocks directly affect production by Equation 5.2. We can then compute welfare measure $W(\alpha, \omega)$ for any $W \in \{\mathcal{W}, \mathcal{C}, \mathcal{P}, \mathcal{G}\}$, defining aggregate welfare measures as unweighted sums over countries, crops, and years.

For historical extreme heat, we compute $W(\alpha, \omega)$ from observed shocks and policies. We then consider two counterfactuals: $W(\alpha_0, \omega_0)$ without shocks and $W(\alpha_0, \omega)$ with shocks but not the associated policy responses. We take $W(\alpha_0, \omega_0)$ as baseline and compute welfare losses under responsive and unresponsive policy.

$$\Delta W^R = \frac{W(\alpha, \omega) - W(\alpha_0, \omega_0)}{W(\alpha_0, \omega_0)}, \quad \Delta W^U = \frac{W(\alpha_0, \omega) - W(\alpha_0, \omega_0)}{W(\alpha_0, \omega_0)} \tag{5.7}$$

For projected extreme heat, we consider two further counterfactuals: $W(\hat{\alpha}, \hat{\omega})$ with projected shocks and policies and $W(\alpha_0, \hat{\omega})$ with projected shocks but not the associated policy responses. We again take $W(\alpha_0, \omega_0)$ as baseline and compute welfare losses under responsive and unresponsive policy.

$$\Delta \hat{W}^R = \frac{W(\hat{\alpha}, \hat{\omega}) - W(\alpha_0, \omega_0)}{W(\alpha_0, \omega_0)}, \quad \Delta \hat{W}^U = \frac{W(\alpha_0, \hat{\omega}) - W(\alpha_0, \omega_0)}{W(\alpha_0, \omega_0)} \tag{5.8}$$

5.2 Historical Extreme Heat

How has government policy shaped the impacts of historical extreme heat shocks? Columns 1 and 2 of Table 3 report price and welfare effects under unresponsive and responsive pol-

icy. Panel A considers the full sample, while Panels B, C, and D study three subgroups: those that experience extreme heat shocks domestically, those that experience extreme heat shocks through foreign spillovers, and those that do not experience shocks at all.

For markets affected by domestic shocks (Panel B), responsive policy limits the effect of extreme heat on domestic prices. Domestic prices rise by 1.64% with unresponsive policy, but they rise by 0% with responsive policy. The reason is that responsive policy assists consumers precisely by keeping domestic prices low. As a result, responsive policy almost entirely offsets consumer surplus losses, reducing them from 2.89% to 0.08%. In doing so, it intensifies losses for producers, who suffer production losses without the partially offsetting benefit of higher equilibrium prices. Producer surplus losses increase from 9.43% with unresponsive policy to 14.58% with responsive policy. The opposite effects hold for the complementary set of markets that do not experience domestic shocks. For these foreign markets, consumer surplus losses increase from 1.40% to 2.87%, while producer surplus gains increase from 2.52% to 5.22% (Appendix Table A.4).

For markets affected by foreign shocks (Panel C), responsive policy has the opposite effects. It exacerbates domestic price increases from 1.32% to 2.51%, worsening losses for consumers from 2.30% to 4.51%. Producers benefit, however, with a 2.99% loss becoming a 0.76% gain. Producers profit not only from producer aid but also from reduced foreign competition, as foreign shocks and policy responses each undercut foreign producers.

For markets unaffected by any shock (Panel D), responsive policy globally worsens total welfare losses from 0.35% to 0.49%. Higher prices reduce consumer surplus in these markets, with partially offsetting positive effects on producer surplus. Policy responses to climate shocks thus affect all countries, including "bystanders" that are not themselves affected by shocks, either domestically or through trade linkages.

We document that governments systematically use policy to reallocate surplus between producers and consumers in response to shocks. Figure 10 plots these distributional effects across markets, again highlighting that policy tends to aid consumers but hurt producers in response to domestic shocks, while the opposite holds for foreign shocks. We find significant heterogeneity in these effects across markets, with responsive policy magnifying effects on consumers and producers by more than 20 percentage points in some markets, and in the most extreme cases by nearly 40 percentage points.

Panel A considers global effects. Responsive policy slightly dampens the total welfare losses from extreme heat shocks, which fall from 1.55% to 1.52% as policy adjusts in response to these shocks. Losses are modestly larger for both consumers and producers,

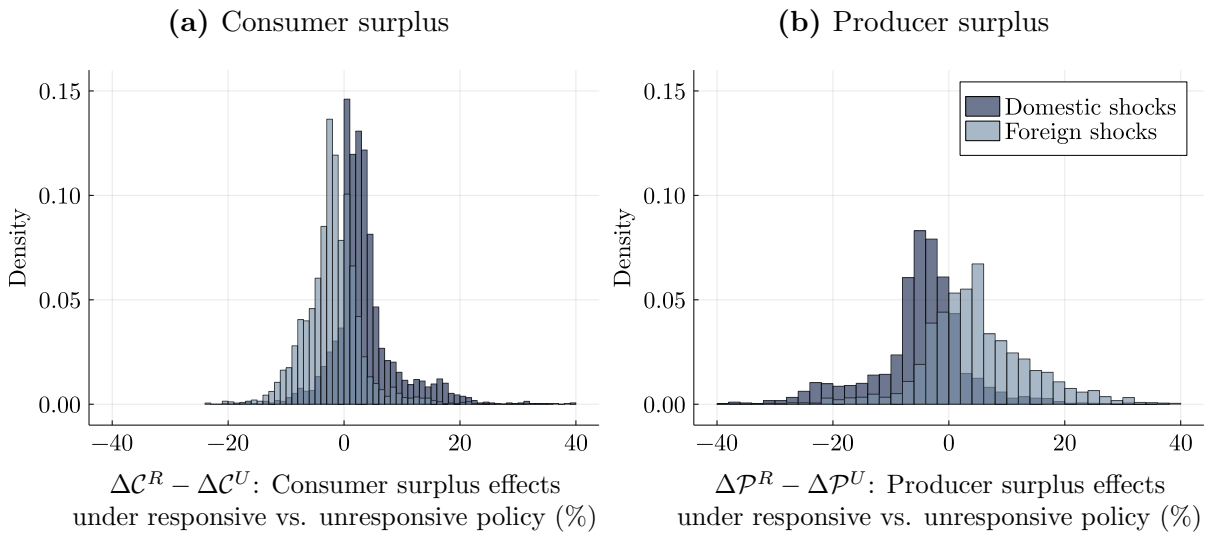
Table 3: Price and Welfare Effects of Extreme Heat and Policy

	(1)	(2)	(3)	(4)
	Historical extreme heat		Projected extreme heat	
	Unresponsive policy	Responsive policy	Unresponsive policy	Responsive policy
Panel A: All markets				
Domestic price (%)	1.07	1.06	2.56	2.65
Consumer surplus (%)	-1.87	-1.99	-4.43	-4.34
Producer surplus (%)	-2.03	-2.32	-4.24	-3.23
Total welfare (%)	-1.55	-1.52	-4.14	-4.73
Panel B: Domestic shocks				
Domestic price	1.64	0.00	2.78	2.16
Consumer surplus	-2.89	-0.08	-4.81	-3.38
Producer surplus	-9.43	-14.58	-6.70	-7.95
Total welfare	-3.74	-3.64	-4.97	-5.68
Panel C: Foreign shocks				
Domestic price	1.32	2.51	2.77	3.60
Consumer surplus	-2.30	-4.51	-4.77	-6.05
Producer surplus	-2.99	0.76	-4.51	-1.33
Total welfare	-1.39	-0.85	-4.30	-4.36
Panel D: No shocks				
Domestic price	0.67	0.83	1.36	2.37
Consumer surplus	-1.20	-1.46	-2.41	-4.07
Producer surplus	2.21	2.62	4.78	8.52
Total welfare	-0.35	-0.49	-1.40	-2.06

We compute effects in percentage terms relative to baseline. We compare unresponsive policy fixed at baseline levels and responsive policy that adjusts as observed. Panel A aggregates over all countries, crops, and years. Welfare measures are summed, while price measures are averaged weighting by baseline total welfare. Domestic prices are world prices net of NRA policy. Panels B, C, and D aggregate over countries, crops, and years that experience (B) domestic shocks, (C) foreign shocks, and (D) neither shock. For historical (projected) extreme heat, panel B contains 33% (78%) of country-crop-year observations, weighting by baseline total welfare. Panel C contains 31% (75%), and panel D 48% (10%). Categories B and C overlap in part.

but government revenue rises to offset these losses. Figure 11 isolates the welfare impacts of policy responses to domestic and foreign shocks, with price and surplus effects in Appendix Table A.5. Policy responses to domestic shocks exacerbate welfare losses by 30%, while those to foreign shocks reduce welfare losses by 31%. These forces bal-

Figure 10: Consumer and Producer Surplus Effects of Extreme Heat and Policy



We compute surplus effects in percentage terms of historical extreme heat shocks relative to a baseline without shocks. Each observation is a country-crop-year "market" subject to a domestic shock, foreign shock, both, or neither. Dark blue shading indicates observations with a domestic shock, while light blue indicates those with a foreign shock. Positive values denote surplus gains (or smaller losses) under responsive policy relative to unresponsive policy.

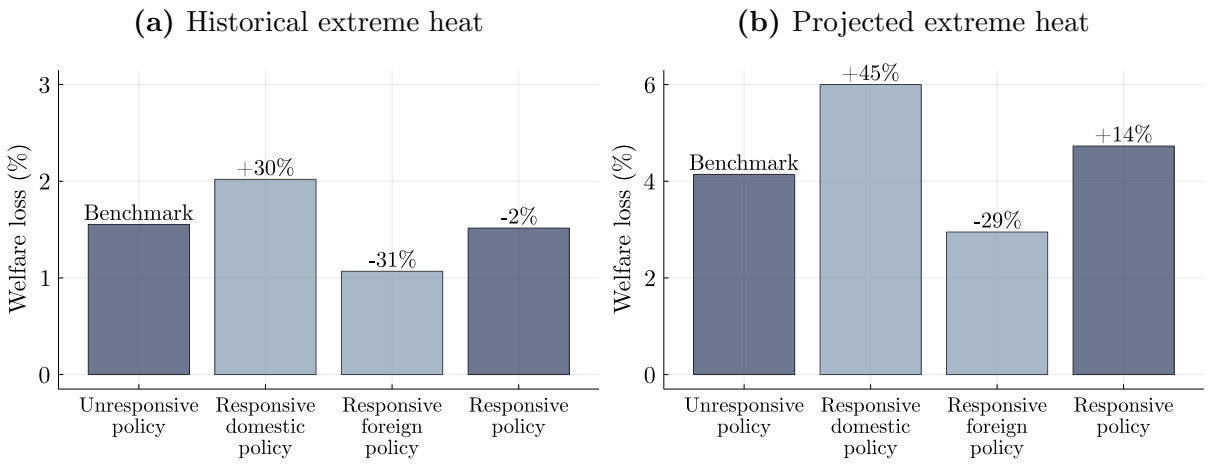
ance for historical shocks, such that welfare losses are similar under unresponsive and responsive policy. International interactions offset—rather than propagate—the negative consequences of policy responses to domestic shocks.

We note that net impacts on global utilitarian welfare are ambiguous *ex ante* for two reasons. First, governments need not maximize utilitarian welfare, and indeed our theoretical model suggests that they do not. By Proposition 2, utilitarian welfare maximization is inconsistent with our empirical finding that policy responds to climate shocks. Second, foreign policy responses can either amplify or offset domestic policy responses. Popular narratives of policy escalation highlight the former possibility, but we instead find that foreign responses are stabilizing and serve to dampen global welfare losses.

5.3 Projected Extreme Heat

How does government policy shape the welfare impacts of projected extreme heat shocks? Columns 3 and 4 of Table 3 report price and welfare effects. For markets that experience domestic shocks (Panel B), responsive policy limits the rise in domestic prices to 2.16%, relative to 2.78% under unresponsive policy. As before, this dampened impact on domestic

Figure 11: Welfare Effects of Extreme Heat by Policy Response



For historical and projected extreme heat shocks, we compute welfare losses in percentage terms relative to baseline. The dark blue bars correspond to the total welfare effects in Panel A of Table 3. Welfare effects sum over all countries, crops, and years with equal weighting. Unresponsive policy is fixed at baseline levels. The light blue bars isolate policy responses to domestic and foreign shocks, respectively. Responsive policy captures the full response to all shocks. Annotations mark percentage changes relative to the benchmark of unresponsive policy.

prices implies smaller losses for consumers but larger losses for producers. For markets that experience foreign shocks (Panel C), the opposite holds. Domestic prices rise by 3.60% under responsive policy, relative to 2.77% under unresponsive policy. Consumers are worse off, and producers better off. For markets that remain unshocked (Panel D), there are notable equilibrium effects as projected shocks affect many markets and induce widespread policy responses. These responses worsen price increases from 1.36% to 2.37%, even as these markets do not themselves experience shocks or changes in policy.

Panel A presents global effects. Endogenous policy exacerbates aggregate total welfare losses by 14%. Responsive policy dampens losses for both consumers and producers on average, but policy action is costly and causes total welfare losses to rise from 4.14% under unresponsive policy to 4.73% under responsive policy. Figure 11 isolates the impacts of policy responses to domestic and foreign shocks. Policy responds strongly to domestic shocks, exacerbating welfare losses by 45% to reach a total welfare loss of 6%. This force dominates, as policy responses to foreign shocks only dampen welfare losses by 29%. Responsive policy worsens welfare losses on net.

These total welfare losses depend on how climate shocks interact with baseline distor-

Table 4: Policy Distortion Effects of Extreme Heat

		(1) Historical	(2) Projected
		Increases $\lvert\alpha\rvert$	Increases $\lvert\alpha\rvert$
Baseline distortion is:	Positive ($\alpha > 0$)	18%	33%
	Negative ($\alpha \leq 0$)	23%	58%

We categorize country-crop-year observations by whether the baseline price distortion α is positive or negative. We then compute the percentage of observations for which the price distortion grows larger in magnitude following either historical or projected extreme heat shocks.

tions in the agricultural sector. Table 4 categorizes observations based on the relationship between baseline levels of policy distortion and whether these distortions grow larger in magnitude under responsive policy. Distortions grow larger with much greater frequency under projected shocks relative to historical shocks. In the top row, 33% of producer-aiding markets increase producer aid under projected shocks, while only 18% do so under projected shocks. In the bottom row, 58% of consumer-aiding markets increase consumer aid under projected shocks, while 23% do so under historical shocks. These larger distortions are consistent with the larger total welfare losses that we find with projected shocks and responsive policy. That is, projected shocks lead to policy responses that exacerbate baseline distortions, and in turn exacerbate welfare losses.

The same argument holds across years for historical shocks. Appendix Figure A.15 plots total welfare effects from 1991 to 2010 against the share of markets that experience larger policy distortions under responsive policy. Welfare effects are heterogeneous across years, with responsive policy improving welfare by more than one percentage point in some years and reducing welfare by the same magnitude in other years. Furthermore, years in which responsive policy reduces welfare are years in which responsive policy increases baseline distortions, with a correlation of -0.51. That is, responsive policy diminishes welfare when it increases distortions, and it enhances welfare when it decreases distortions.

The Broader Context of Climate Adaptation. We extrapolate out of sample to consider extreme heat at the end of this century, while applying damage and policy functions estimated in sample. Implicitly, we assume that long-run adaptation along other margins, including crop choice and technology, does not significantly alter the estimated relationships between extreme heat, production, and policy. In this sense, we aim to

emphasize the role of policy in shaping welfare losses under large, widespread shocks, rather than offering definitive predictions for climate adaptation over the long run.

Our analysis also suggests that endogenous agricultural price distortions may influence other margins of adaptation. Climate adaptation via crop switching (Hultgren et al., 2022), sectoral reallocation (Nath, 2023), spatial reallocation (Costinot et al., 2016; Cruz and Rossi-Hansberg, 2023; Dingel et al., 2023; Balboni, 2024; Conte, 2024), and agricultural innovation (Moscona and Sastry, 2023; Moscona, 2024) relies crucially on incentives embedded in agricultural prices. Government intervention that reduces these prices domestically, as we find, may sharpen incentives for producers to migrate or switch economic activities, while also reducing the market size for innovations that assist producers. Better understanding how government intervention affects adaptation mechanisms and their interactions is an important avenue for further research.

6 Conclusion

While international leaders proclaim that "food security rests on trade" (Gurria and da Silva, 2019), a growing number of examples suggest that governments are willing to alter food policy and restrict trade in response to climate shocks. These policy responses can lead to "shortages of essential foods" and price spikes around the world, potentially exacerbating the economic effects of climate shocks (Ghosal et al., 2023).

We study how this phenomenon affects global adaptation to climate change. Theoretically, we show how distributional concerns can motivate distortionary agricultural policy. The sign of policy's response to shocks is *ex ante* ambiguous and hinges on the government's relative preferences for constituent well-being and government revenue.

Turning to the data, we find that domestic extreme heat exposure shifts policy in a pro-consumer direction. Foreign extreme heat exposure has the opposite effect and stabilizes the global impact of temperature on policy. The results are most pronounced during elections, when politicians may be especially attuned to constituent demands.

Finally, we combine theory and data to understand how responsive policy shapes global adaptation. In sample, policy is effective at shielding consumers in the most affected areas, at the cost of amplifying damages for producers in affected areas and for consumers in the rest of the world. When we extrapolate our results to study end-of-century climate change, we find that responsive policy amplifies total damages by 14% because policy responses increase distortions and deadweight loss on net. Climate change affects economic policy, and economic policy in turn affects the consequences of climate change.

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Online Appendix: Food Policy in a Warming World

A Omitted Proofs

A.1 Proof of Proposition 1

For convenience, we re-parameterize the problem so that the choice variable is the additive price wedge τ which satisfies $p^* - \tau = p^*/(1+\alpha)$. Program 2.1 becomes

$$\begin{aligned} \tau^* \in \underset{\tau \in (-\infty, p^*]}{\arg\max} & \left\{ \lambda^C \int_{p^*}^{\infty} Q(p)\,\mathrm{d}p + \lambda^P \int_0^{p^*} Y(p,\omega)\,\mathrm{d}p + \lambda^G \tau M\left(\frac{p^*}{1+\alpha}, \omega'\right) \right\} \\ \text{s.t. } & p^* = P^*(\tau, \omega, \omega') \end{aligned} \tag{A.1}$$

where, in some abuse of notation, we still use P^* to denote the equilibrium mapping from policy and shocks to domestic prices. 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:

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

Re-arranging, and suppressing the evaluations, we obtain

$$\frac{\partial p^*}{\partial \tau} = -\frac{\frac{\partial M(p)}{\partial p}}{\frac{\partial Q(p)}{\partial p} - \frac{\partial Y(p)}{\partial p} - \frac{\partial M(p)}{\partial p}} = -\frac{\epsilon_m s}{-\epsilon_d \left(1 - \frac{\tau}{p^*}\right) - \left((1-s)\epsilon_s \left(1 - \frac{\tau}{p^*}\right) + s\epsilon_m\right)} \tag{A.3}$$

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.

A necessary condition for optimality of an interior tariff is that the first-order benefit of changing τ is zero. That is,

$$0 = \frac{\partial P^*(\tau, \omega, \omega')}{\partial \tau}\left(-\lambda^C x + \lambda^P y\right) + \lambda^G m + \lambda^G \tau \frac{\partial M(p^* - \tau, \omega')}{\partial p}\left(\frac{\partial P^*(\tau, \omega, \omega')}{\partial \tau} - 1\right) \tag{A.4}$$

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

measure the marginal changes in government revenue.

We next re-arrange Equation A.4 in the following way:

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

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

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

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

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

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

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

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

$$\frac{\tau}{p^*} = \frac{\lambda^P(1-s) - \lambda^C}{\lambda^G((1-s)\epsilon_s + \epsilon_d)} + \frac{1}{\epsilon_m}\left(1 - \frac{\tau}{p^*}\right) + \frac{s}{(1-s)\epsilon_s + \epsilon_d} \tag{A.9}$$

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

$$\frac{\tau}{p^*} = \frac{\epsilon_m}{\epsilon_m + 1}\left(\frac{\lambda^P(1-s) + \lambda^G s - \lambda^C}{\lambda^G((1-s)\epsilon_s + \epsilon_d)}\right) + \frac{1}{\epsilon_m + 1} \tag{A.10}$$

Equation 2.2 follows by defining

$$\alpha = \frac{\tau}{p^* - \tau} \tag{A.11}$$

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

$$\frac{1}{\epsilon_m}\left(\frac{\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)+\epsilon_m\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)}{\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)-\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)}\right)>-1 \tag{A.12}$$

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

$$\frac{s\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)+s\epsilon_m\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)}{\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)-\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)}>-\epsilon_m s \tag{A.13}$$

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

$$\begin{aligned} s\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)+&s\epsilon_m\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)> \\ &-\epsilon_m s\left(\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)-\left(\lambda^P(1-s)+\lambda^G s-\lambda^C\right)\right) \end{aligned} \tag{A.14}$$

Or

$$s\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right)>-\epsilon_m s\lambda^G\left((1-s)\epsilon_s+\epsilon_d\right) \tag{A.15}$$

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

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

We finally show the comparative statics by direct calculation:

$$\begin{aligned} \frac{\partial\alpha^*}{\partial\lambda^C}&=-\frac{1+\epsilon_m}{\epsilon_m}\frac{(\epsilon_d+(1-s)\epsilon_s)\lambda^G}{(\lambda^C+(\epsilon_d-s+(1-s)\epsilon_s)\lambda^G-(1-s)\lambda^P)^2}\leq 0 \\ \frac{\partial\alpha^*}{\partial\lambda^P}&=\frac{1+\epsilon_m}{\epsilon_m}\frac{\lambda^G(1-s)((1-s)\epsilon_s+\epsilon_d}{(\lambda^C+(\epsilon_d-s+(1-s)\epsilon_s)\lambda^G-(1-s)\lambda^P)^2} \end{aligned} \tag{A.16}$$

where, in both inequalities, we use that $\epsilon_m\notin[-1,0]$, so $(1+\epsilon_m)/\epsilon_m>0$.

A.2 Proof of Proposition 2 and Corollary 1

We first and state and prove two auxiliary Lemmas:

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

$$\begin{aligned} \alpha^* &= A(s^*) \\ s^* &= S(\alpha^*, \omega, \omega') \end{aligned} \tag{A.17}$$

where (i) $\frac{\partial S}{\partial \alpha} < 0$*, (ii)* S *increases in* ω*, (iii)* S *decreases in* ω'*, and (iv)* $\alpha = A(s^*)$ *crosses* $\alpha = S^{-1}(s^*; \omega, \omega')$ *once from below.*

Proof. Property (i): From market clearing,

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

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

$$S(\alpha, \omega, \omega') = \frac{M\left(\frac{P^*(\alpha,\omega,\omega')}{1+\alpha}, \omega'\right)}{Q(P^*(\alpha, \omega, \omega'))} \tag{A.19}$$

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

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

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

$$\frac{S(\alpha, \omega_1, \omega')}{S(\alpha, \omega_0, \omega')} = \left(\frac{P^*(\alpha, \omega_1, \omega')}{P^*(\alpha, \omega_0, \omega')}\right)^{-\epsilon_m + \epsilon_d} \tag{A.21}$$

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,

$$\frac{\partial S}{\partial \alpha} = -\frac{(1-s)s\epsilon_m(\epsilon_s + \epsilon_d)}{(1-s)\epsilon_s + s\epsilon_m + \epsilon_d} \frac{1}{(1+\alpha)} < 0 \tag{A.22}$$

where the inequality uses $s\epsilon_m > 0$ and $\alpha > -1$ (interiority). If $\frac{\mathrm{d}A^*}{\mathrm{d}s} \geq 0$, then the claim follows from the fact that the government's problem is globally concave and there must

exist a solution. If $\frac{\mathrm{d}A^*}{\mathrm{d}s} < 0$, then we make the following "boundary conditions" argument. First, $\lim_{s\to 1} S^{-1}(s^*;\omega,\omega') = -\infty$: that is, the policy that supports an import share of 1 is unbounded consumer assistance. Second, $\lim_{s\to 1} A(s) > -\infty$: an import share of 100% corresponds to a well-defined policy. Because of the uniqueness of the optimal policy and concavity of the objective, A and S^{-1} must cross exactly once. If A crossed S^{-1} once from above, and $A(1) > \lim_{s\to 1} S^{-1}(1)$, then it would have to be the case, by continuity, that they cross at least once more. This contradicts the uniqueness of the optimal policy. □

Lemma 3 (Relative Assistance and Import Shares)**.** *The following statements are true:*

1. *If the government is revenue-focused, or* $\epsilon_s(\lambda^C-\lambda^G)+\epsilon_d(\lambda^P-\lambda^G) < 0$*, then* $A^{*'} > 0$*, 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. By direct calculation, we have that

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

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

We prove the cases in turn, combining the statements of Proposition 2 and Corollary 1. For all cases, we observe that for $\omega_1 \geq \omega_0$ and $\omega_1' \leq \omega_0'$, 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 $\alpha \mapsto S^{-1}(s,\omega,\omega')$ is decreasing for any ω,ω'.

1. Since $A(s)$ is strictly increasing (Lemma 3), then $f(s) = S^{-1}(s,\omega_1,\omega_1') - A^*(s)$ 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 $A(s)$ is strictly decreasing (Lemma 3), then $f(s) = S^{-1}(s, \omega_1, \omega_1') - A^*(s)$ crosses the origin once from above 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) and is unique. Since A^* is decreasing, then $\alpha^*_1 = A(s^*_{m,1}) \leq \alpha^*_0$.
3. In this case, $A(s)$ is constant (Lemma 3). Thus, $\alpha^*_1 = \alpha^*_0$.

A.3 Proof of Lemma 1

We first solve for household level choices. Given quasi-linearity, we can substitute for money in the household's objective and write

$$\mathcal{U}_i = \mu_i^{\frac{1}{\epsilon_d}} \frac{q_i^{1-\frac{1}{\epsilon_d}}}{1-\frac{1}{\epsilon_d}} + p(y_i - x_i) + T_i - f(\omega)^{-\frac{1}{\epsilon_s}} \psi_i^{-\frac{1}{\epsilon_s}} \frac{y_i^{1+\frac{1}{\epsilon_s}}}{1+\frac{1}{\epsilon_s}} \tag{A.24}$$

Taking the first-order condition in terms of consumption q_i yields $\mu_i^{\frac{1}{\epsilon_d}} x_i^{-\frac{1}{\epsilon_d}} = p$, which re-arranges to the demand curve $x_i = \mu_i p^{-\epsilon_d}$. Total demand in the economy is $\sum_{i=1}^N x_i = (\sum_{i=1}^N \mu_i) p^{-\epsilon_d} =: Q_0 p^{-\epsilon_d}$, proving the desired representation of the demand curve. We furthermore note that $\tilde{\mu}_i := \mu_i / \sum_j \mu_j = x_i / \sum_{j=1}^N x_j$. Finally, the component of households' payoff deriving directly from consumption is

$$\mathcal{C}_i := \mu_i^{\frac{1}{\epsilon_d}} \frac{q_i^{1-\frac{1}{\epsilon_d}}}{1-\frac{1}{\epsilon_d}} - p x_i = \frac{1}{1-\frac{1}{\epsilon_d}} \mu_i p^{1-\epsilon_d} - \mu_i p^{1-\epsilon_d} = \frac{\mu_i}{\epsilon_d - 1} p^{1-\epsilon_d} \tag{A.25}$$

Taking the first-order condition in terms of production yields $p = f(\omega)^{-\frac{1}{\epsilon_s}} \psi_i^{-\frac{1}{\epsilon_s}} y_i^{\frac{1}{\epsilon_s}}$, which re-arranges to the individual supply curve $y_i = f(\omega) \psi_i p^{\epsilon_s}$. Total supply in the economy is $\sum_{i=1}^N y_i = f(\omega)(\sum_{i=1}^N \psi_i) p^{\epsilon_s} =: Y_0 p^{\epsilon_s}$, proving the claimed representation of aggregate supply. Finally, the component of households' payoff deriving directly from production is

$$\mathcal{P}_i := p y_i - (\psi_i f(\omega))^{-\frac{1}{\epsilon_s}} \frac{y_i^{1+\frac{1}{\epsilon_s}}}{1+\frac{1}{\epsilon_s}} = \frac{\psi_i f(\omega)}{1+\epsilon_s} p^{1+\epsilon_s} \tag{A.26}$$

We next show the equivalence of the government objective. Consumer surplus in the

economy, at domestic price p^*, is

$$\begin{aligned}\mathcal{C} &= \int_{p^*}^{\infty} \sum_{i=1}^{N} \mu_i p^{-\epsilon_d} \, \mathrm{d}p = \sum_{i=1}^{N} \int_{p^*}^{\infty} \mu_i p^{-\epsilon_d} \, \mathrm{d}p \\ &= \sum_{i=1}^{N} \left[\frac{1}{1-\epsilon_d} \mu_i p^{1-\epsilon_d} \right]_{p^*}^{\infty} = \frac{1}{\epsilon_d - 1} p^{1-\epsilon_d} \sum_{i=1}^{N} \mu_i \end{aligned} \tag{A.27}$$

A similar calculation yields that producer surplus is

$$\begin{aligned}\mathcal{P} &= \int_{0}^{p^*} \sum_{i=1}^{N} \psi_i f(\omega) p^{\epsilon_s} \, \mathrm{d}p = \sum_{i=1}^{N} \int_{0}^{p^*} \psi_i f(\omega) p^{\epsilon_s} \, \mathrm{d}p \\ &= \sum_{i=1}^{N} \left[\frac{1}{1+\epsilon_s} \psi_i f(\omega) p^{1+\epsilon_s} \right]_{0}^{p^*} = \frac{1}{1+\epsilon_s} f(\omega) p^{1+\epsilon_s} \sum_{i=1}^{N} \psi_i \end{aligned} \tag{A.28}$$

We finally observe that

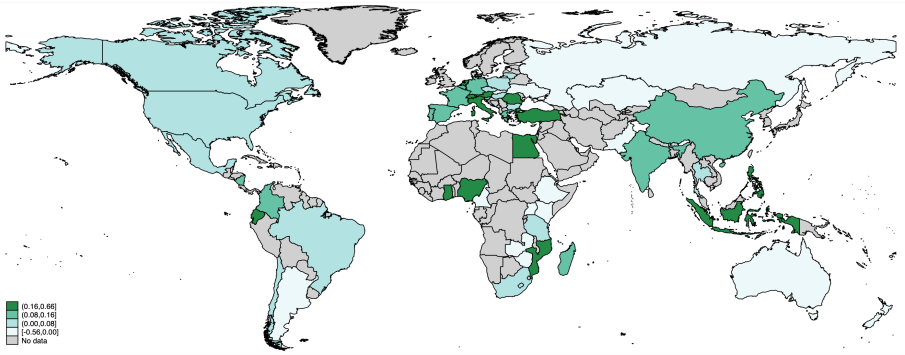
$$\begin{aligned}\mathcal{W} &= \sum_i \lambda_i \mathcal{U}_i = \sum_i \lambda_i (\mathcal{C}_i + \mathcal{P}_i + T_i) \\ &= \sum_i \lambda_i \left(\frac{\mu_i}{\epsilon_d - 1} p^{1-\epsilon_d} + \frac{\psi_i}{1+\epsilon_s} f(\omega) p^{1+\epsilon_s} + \xi_i \mathcal{G} \right) \\ &= \sum_i \lambda_i \left(\frac{\mu_i}{\sum_{j=1}^N \mu_j} \frac{\sum_{j=1}^N \mu_j}{\epsilon_d - 1} p^{1-\epsilon_d} + \frac{\psi_i}{\sum_{j=1}^N \psi_j} \frac{\sum_{j=1}^N \psi_j}{1+\epsilon_s} f(\omega) p^{1+\epsilon_s} + \frac{\xi_i}{\sum_{j=1}^N \xi_j} \left(\sum_{j=1}^N \xi_j \right) \mathcal{G} \right) \\ &= \sum_i \lambda_i \left(\frac{\mu_i}{\sum_{j=1}^N \mu_j} \mathcal{C} + \frac{\psi_i}{\sum_{j=1}^N \psi_j} \mathcal{P} + \frac{\xi_i}{\sum_{j=1}^N \xi_j} \mathcal{G} \right) \\ &= \left(\sum_i \lambda_i \tilde{\mu}_i \right) \mathcal{C} + \left(\sum_i \lambda_i \tilde{\psi}_i \right) \mathcal{P} + \left(\sum_i \lambda_i \xi_i \right) \mathcal{G} \end{aligned} \tag{A.29}$$

where the first line uses the definition of $\mathcal{U}_i$, the second substitutes in the expressions derived above for $(\mathcal{C}_i, \mathcal{P}_i)$ plus the transfer rule, the third re-arranges, the fourth uses the definitions of $(\mathcal{C}, \mathcal{P}, \mathcal{G})$,a nd the last combines terms. This, combined with the observation that $\mathcal{W} = \lambda^C \mathcal{C} + \lambda^P \mathcal{P} + \lambda^G \mathcal{G}$, completes the proof.

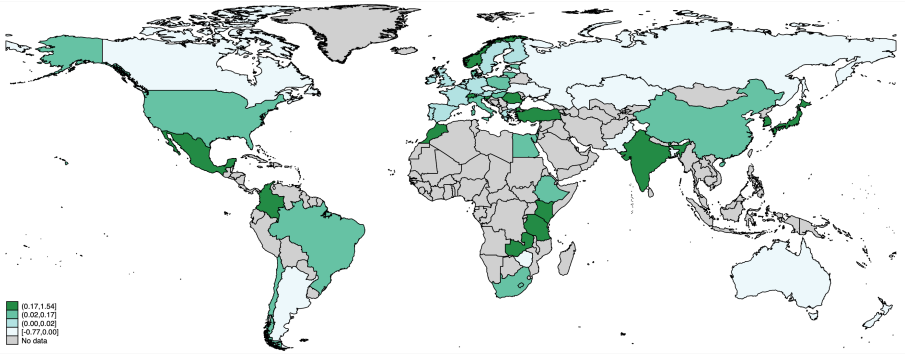
B Additional Figures and Tables

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

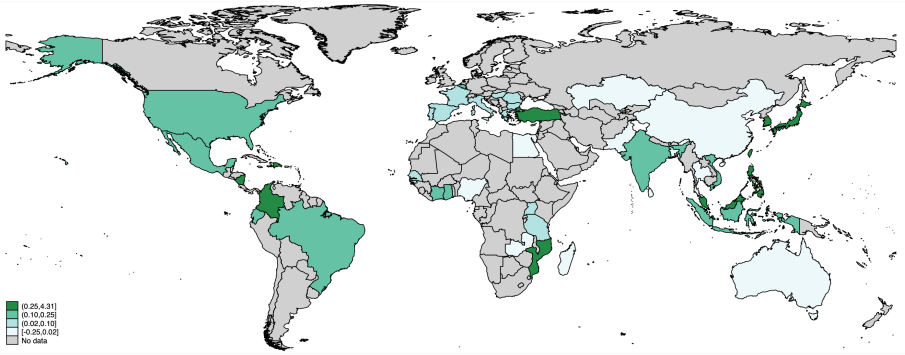
(a) Maize



(b) Wheat



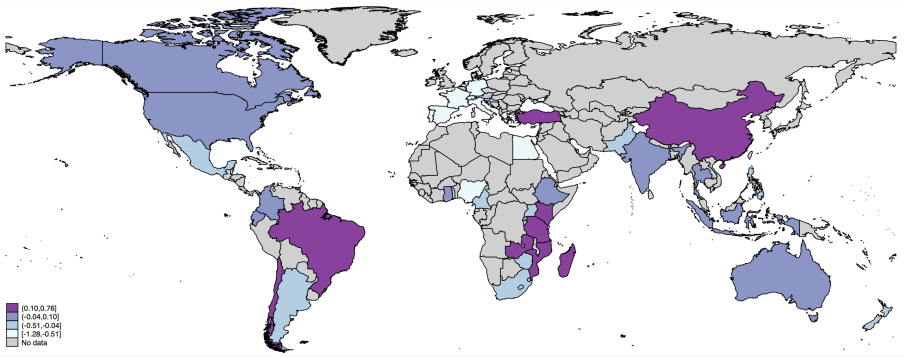
(c) Rice



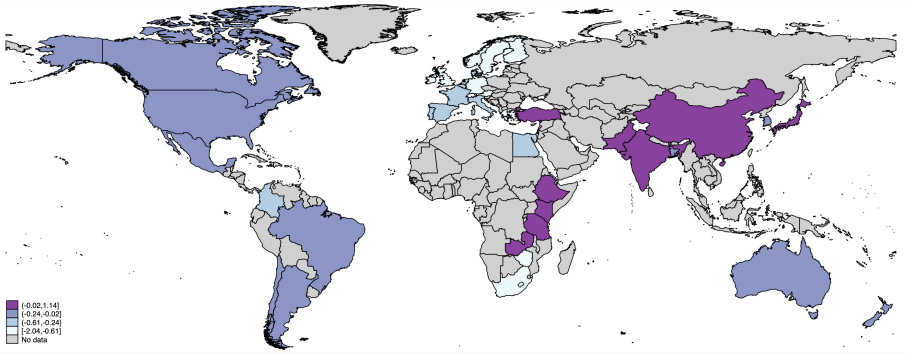
This figure displays the value of NRA for maize, wheat, and rice averaged from 2001 to 2010. Countries are color-coded by quartile, where darker colors correspond to larger values.

Figure A.2: Global Changes in Policy for Select Crops

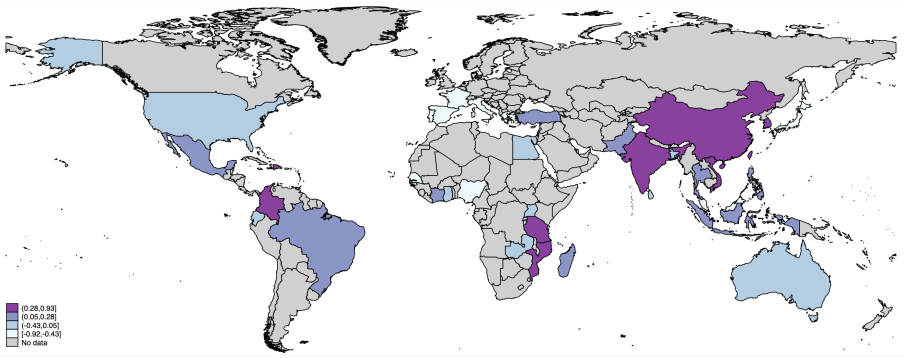
(a) Maize



(b) Wheat



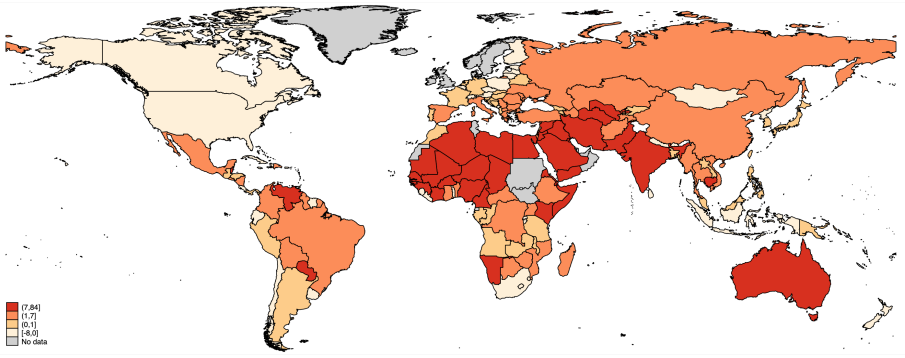
(c) Rice



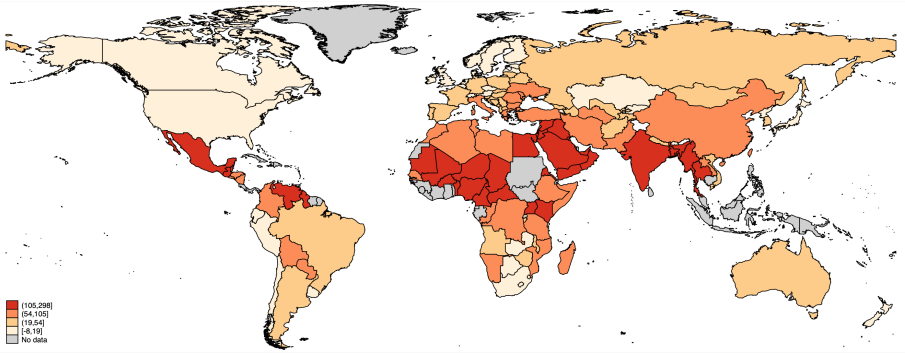
This figure displays the change in NRA for maize, wheat, and rice between the 1980s and the 2000s. Countries are color-coded by quartile, where darker colors correspond to larger values.

Figure A.3: Global Changes in Extreme Heat for Select Crops

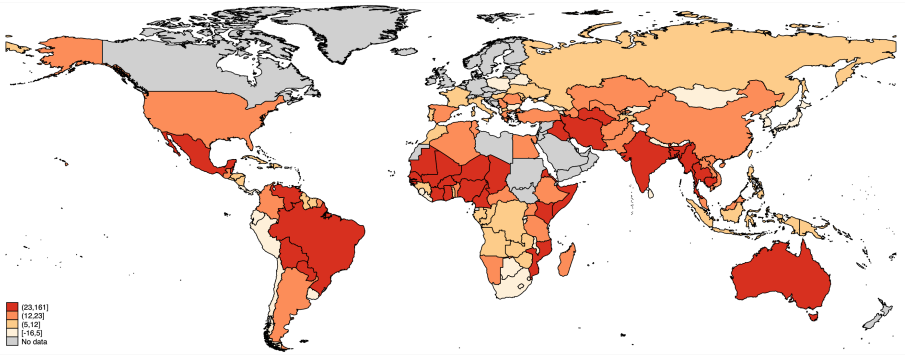
(a) Maize



(b) Wheat



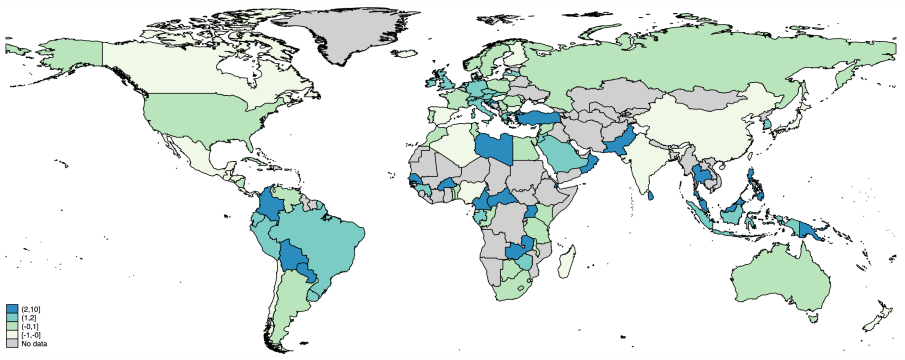
(c) Rice



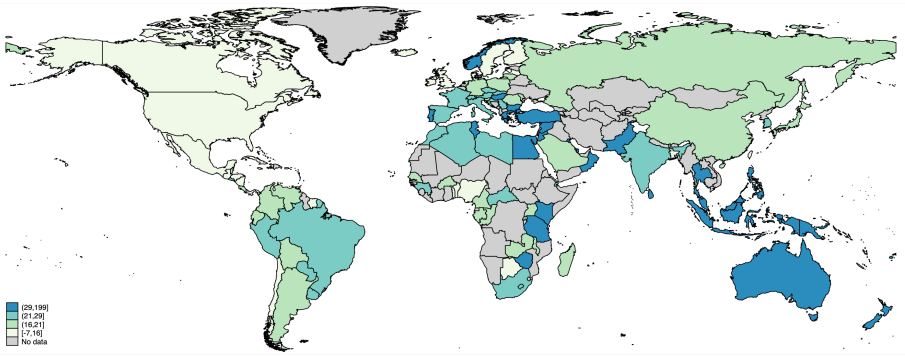
This figure displays the change in extreme heat exposure for maize, wheat, and rice between the 1980s and the 2010s. Countries are color-coded by quartile, where darker colors correspond to larger values.

Figure A.4: Global Changes Exposure to Foreign Extreme Temperatures

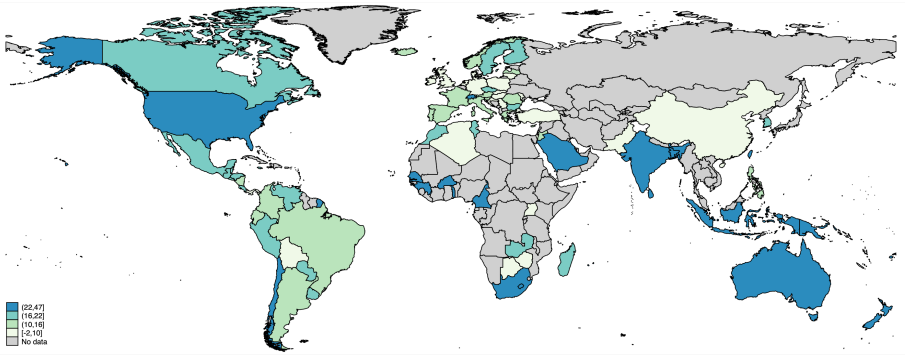
(a) Maize



(b) Wheat

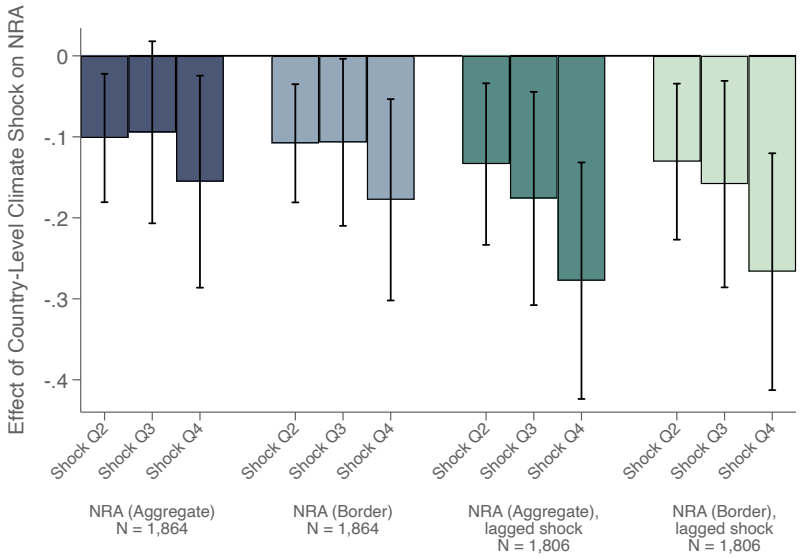


(c) Rice



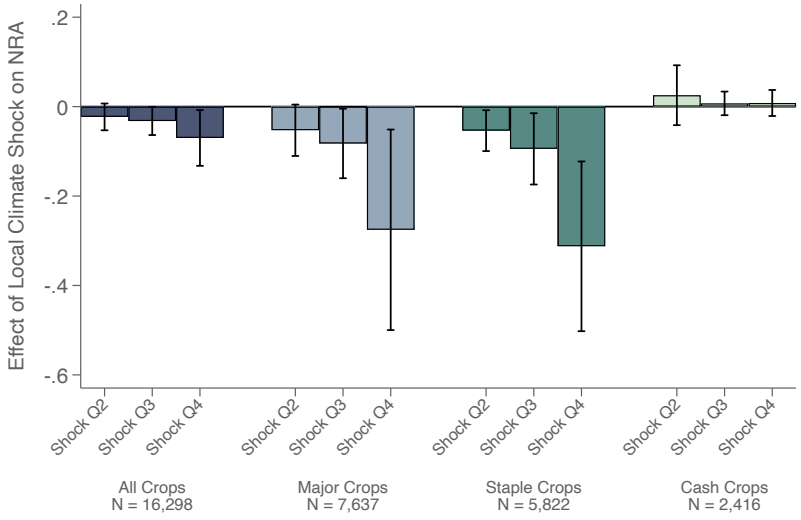
This figure displays the change in foreign import-weighted extreme heat exposure for maize, wheat, and rice between the 1980s and the 2010s. Countries are color-coded by quartile, where darker colors correspond to larger values.

Figure A.5: Policy Effects of Extreme Heat by Country-Year



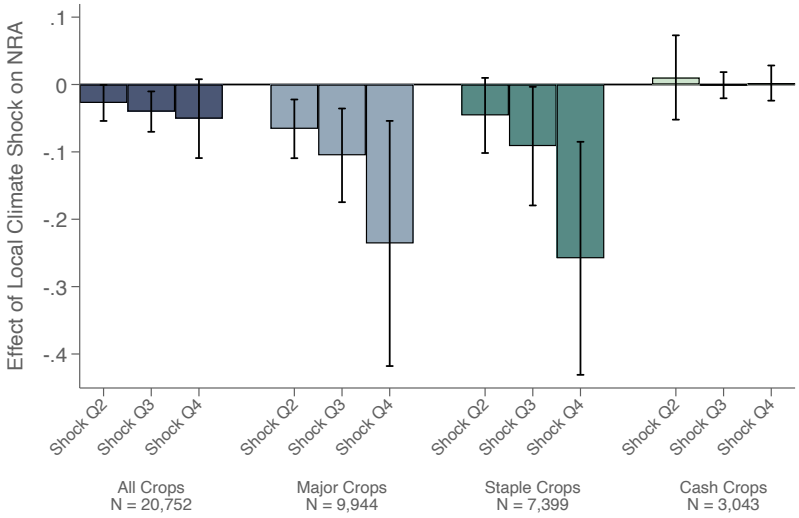
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-year and both country and year fixed effects are included. We report 90% confidence intervals.

Figure A.6: Policy Effects of Extreme Heat (1955-2011)



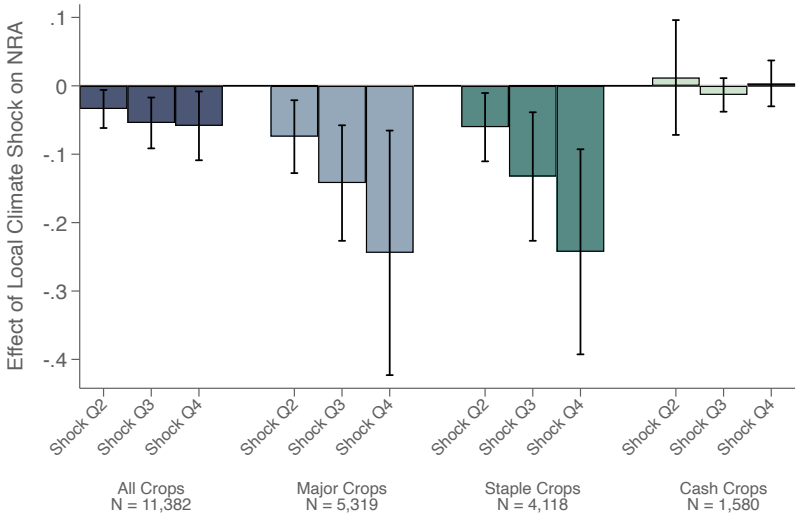
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. The sample of crops included in each regression is noted below each set of bars. We report 90% confidence intervals.

Figure A.7: Policy Effects of Extreme Heat with Alternative Data (1980-2021)



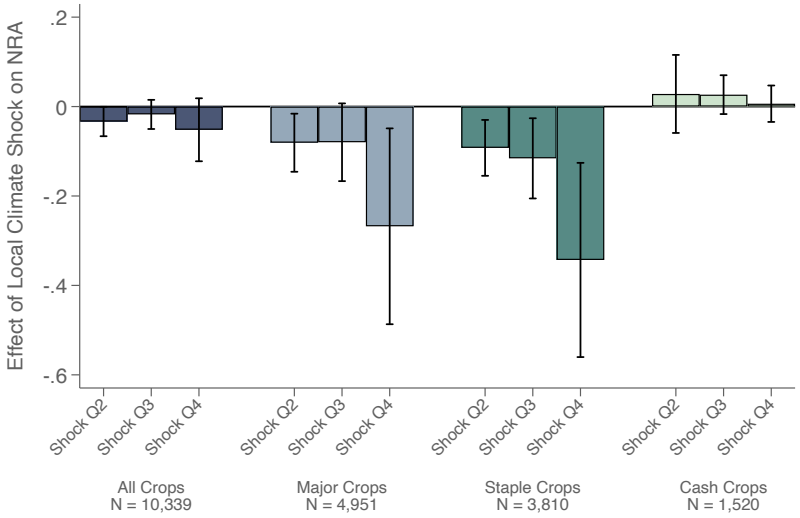
This figure displays the relationship between quartiles of extreme heat exposure and NRA. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. The sample includes all NRA and temperature from 1980 to 2021, where recent years are filled in using data from Ag-Incentives. We report 90% confidence intervals.

Figure A.8: Policy Effects of Extreme Heat Excluding 1980s



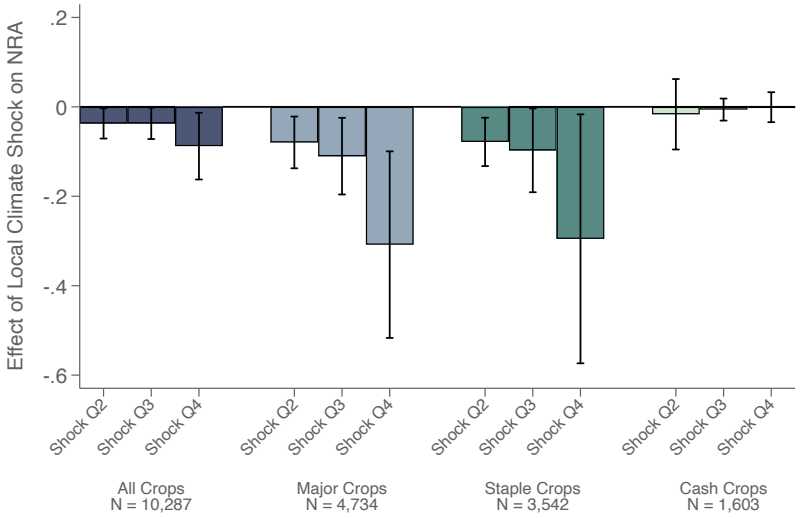
This figure displays the relationship between quartiles of extreme heat exposure and NRA in a regression that excludes all observations in the 1980s. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. The sample of crops included in each regression is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

Figure A.9: Policy Effects of Extreme Heat Excluding 1990s



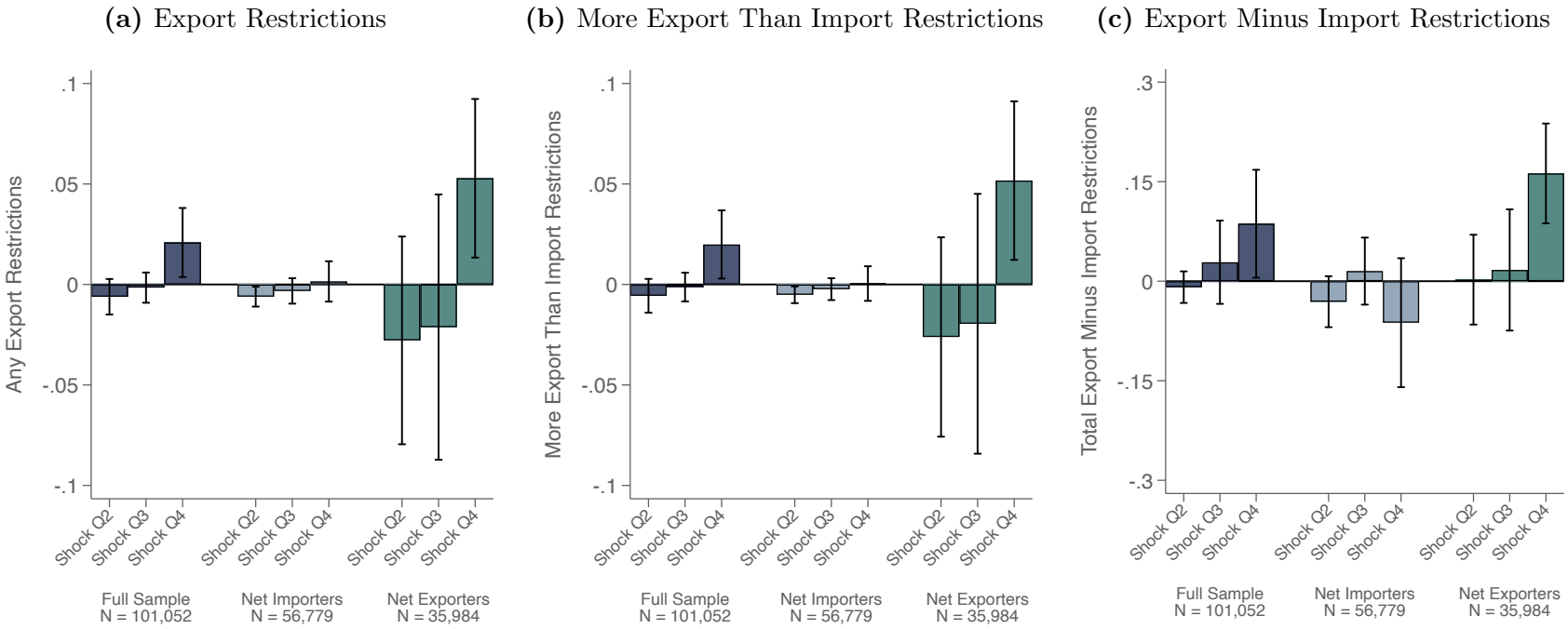
This figure displays the relationship between quartiles of extreme heat exposure and NRA in a regression that excludes all observations in the 1990s. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. The sample of crops included in each regression is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

Figure A.10: Policy Effects of Extreme Heat Excluding 2000s



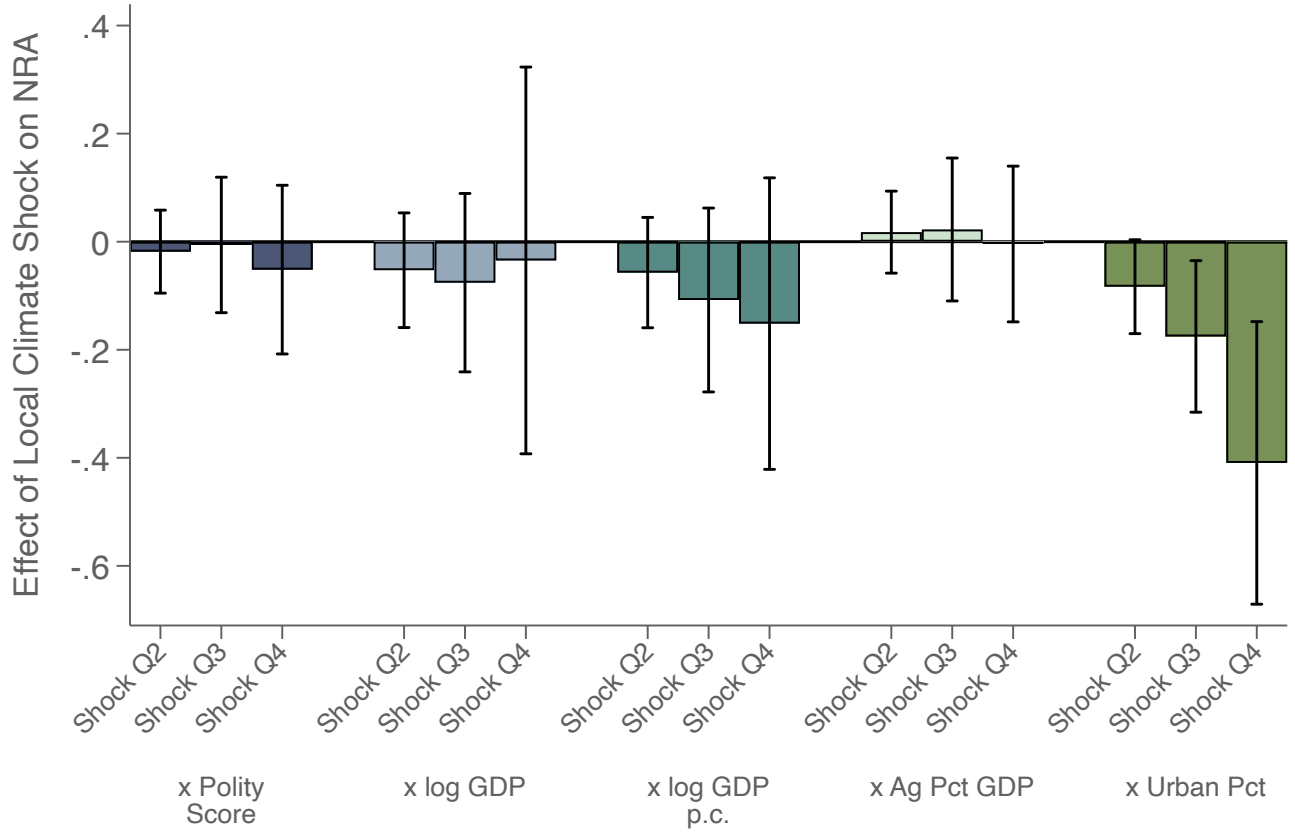
This figure displays the relationship between quartiles of extreme heat exposure and NRA in a regression that excludes all observations in the 2000s. The unit of observation is a country-crop-year and all possible two-way fixed effects are included. The sample of crops included in each regression is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

Figure A.11: Global Trade Alert Policy Effects of Extreme Heat (2008-2019)



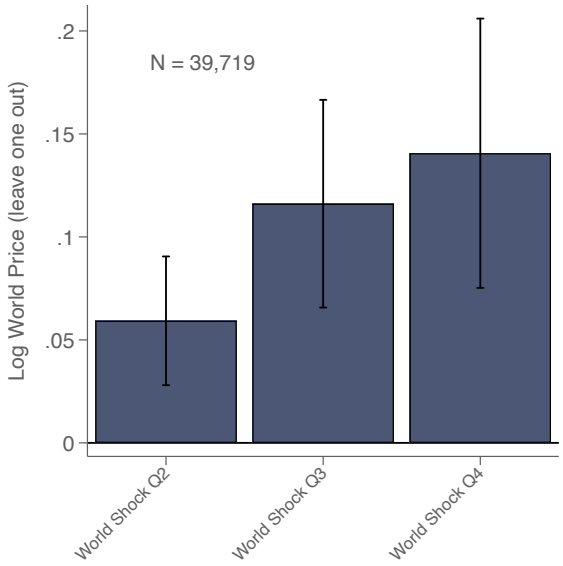
This figure displays the relationship between quartiles of extreme heat exposure and crop-specific policy interventions measured using the Global Trade Alert (GTA) database (https://www.globaltradealert.org/). The unit of observation is a country-pair-crop-year and all specifications include fixed effects at the origin-crop, crop-year, and origin-destination-year levels. In Figure A.11a the outcome variable is an indicator that equals one if there are any export-restricting policies; in Figure A.11b it is an indicator that equals one if there are more export-restricting than import-restricting policies; and in Figure A.11c it is the total number of export-restricting policies minus the total number of import-restricting policies. Since the GTA database begins in 2008, the sample period for all estimates is 2008-2019. We report 90% confidence intervals.

Figure A.12: Heterogeneous Policy Effects of Extreme Heat



This figure displays the effect of interaction terms between quartiles of extreme heat exposure and a series of country-level characteristics on 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 and reports the effect of the interaction term between the marked quartile of extreme heat exposure and the characteristic listed along the x-axis. All characteristics were standardized to be in common units in terms of their mean and standard deviation and are measured at the country-year level. The direct effects of quartiles of extreme heat exposure were also included in each specification. We report 90% confidence intervals.

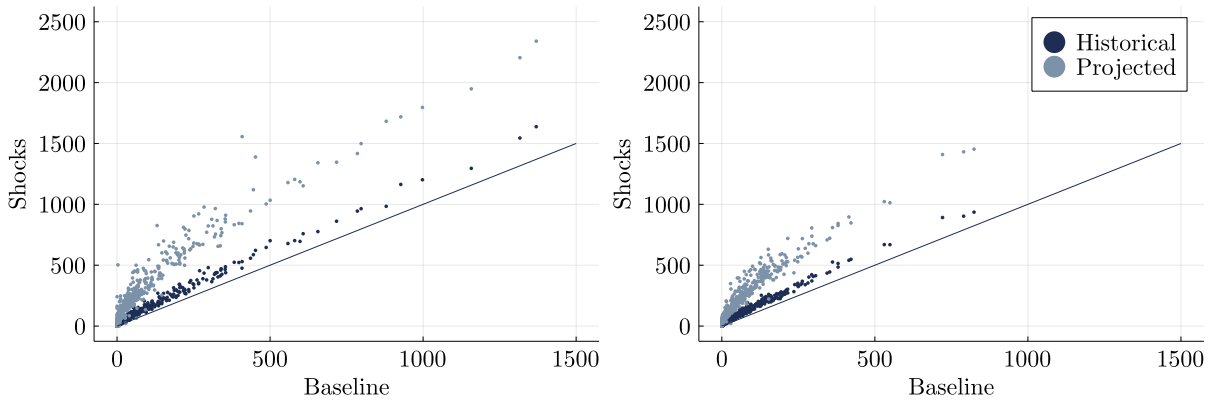
Figure A.13: World Price Effects of Extreme Heat



This figure displays the relationship between quartiles of foreign (import-weighted) extreme heat exposure and the (leave-one-out) production-weighted global price for each crop. The unit of observation is a country-crop-year and all country-year and crop-country fixed effects are both included. We report 90% confidence intervals.

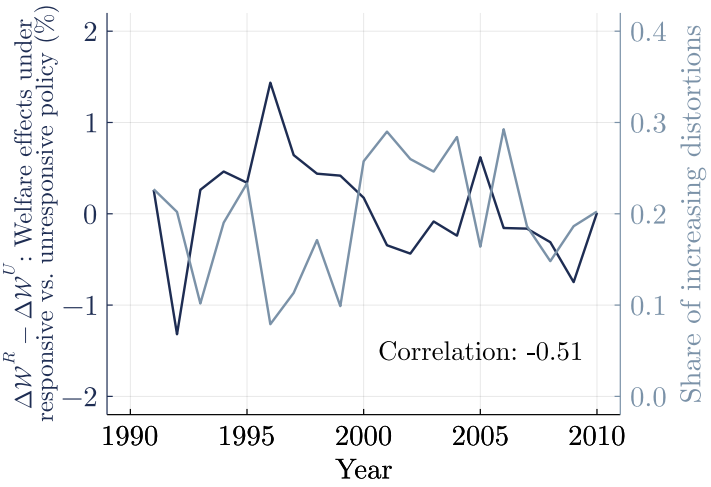
Figure A.14: Domestic and Foreign Extreme Heat

(a) Domestic shocks **(b)** Foreign shocks



We plot extreme heat exposure shocks by country-crop pair. The left figure shows domestic shocks and compares baseline values to historical and projected values. The right figure shows foreign shocks, which we define as shocks to import partners. Baseline values are the minimum shocks observed historically from 1991 to 2010. Historical values are the average shocks for the same period, where we average over annual observations for each country-crop. Projected values are from the GFDL-ESM4 model for the decade from 2091 to 2100. The solid lines are 45° lines.

Figure A.15: Total Welfare Effects of Extreme Heat and Policy



We compute total welfare effects in percentage terms of historical extreme heat shocks relative to a baseline without shocks. The dark blue line (left scale) plots welfare gains under responsive policy relative to unresponsive policy. The light blue line (right scale) plots the share of markets in which responsive policy increases the absolute value of NRA, such that pre-existing distortions grow in magnitude. We present aggregate statistics that weight by baseline total welfare.

Table A.1: Decade-Level Policy Effects of Extreme Heat by Policy Type

	(1)	(2)	(3)	(4)	(5)
	Dependent variable is NRA				
	All Policy	Output Policy	Output Policy (Border)	Output Policy (Farm)	Input Policy
Years of Extreme Heat (Local)	-0.0252**	-0.0251**	-0.0204**	-0.00468	-0.00108*
	(0.0110)	(0.0111)	(0.00897)	(0.00471)	(0.000572)
Years of Extreme Heat (Foreign)	0.0179*	0.0180*	0.0131***	0.00491	-0.000330
	(0.00969)	(0.00968)	(0.00463)	(0.00727)	(0.000617)
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	1,951	1,951	1,951

The unit of observation is a country-crop-decade triplet. The dependent variable is the NRA measure 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.

Table A.2: Policy Effects of Domestic and Foreign Extreme Heat by Election Year

	(1)	(2)	(3)	(4)
	Dependent variable is NRA			
	Full Sample	Major Crops	Staple Crops	Cash Crops
Q2 Extreme Heat x No Election	-0.0249	-0.0541	-0.0571	-0.00193
	(0.0299)	(0.0375)	(0.0406)	(0.0835)
Q3 Extreme Heat x No Election	-0.0114	-0.0853	-0.0949	0.0278
	(0.0387)	(0.0661)	(0.0716)	(0.149)
Q4 Extreme Heat x No Election	-0.0996	-0.155	-0.164	0.0448
	(0.0698)	(0.0974)	(0.104)	(0.155)
Q2 Extreme Heat x Election	-0.0234	-0.0908***	-0.0727**	0.112
	(0.0196)	(0.0280)	(0.0317)	(0.216)
Q3 Extreme Heat x Election	-0.0576**	-0.0991**	-0.0792*	0.0267
	(0.0258)	(0.0377)	(0.0456)	(0.196)
Q4 Extreme Heat x Election	-0.145**	-0.340**	-0.344**	0.00355
	(0.0695)	(0.163)	(0.171)	(0.211)
Q2 Foreign Extreme Heat x No Election	-0.0434	-0.0742**	-0.0713*	0.0907
	(0.0280)	(0.0302)	(0.0375)	(0.0777)
Q3 Foreign Extreme Heat x No Election	-0.0458	-0.0915	-0.111*	0.0646
	(0.0332)	(0.0570)	(0.0608)	(0.156)
Q4 Foreign Extreme Heat x No Election	0.0343	-0.00657	-0.0226	-0.0453
	(0.0437)	(0.0788)	(0.0787)	(0.150)
Q2 Foreign Extreme Heat x Election	0.0499**	0.0797**	0.0943**	-0.0457
	(0.0233)	(0.0350)	(0.0406)	(0.201)
Q3 Foreign Extreme Heat x Election	0.0718**	0.0605	0.0705	0.106
	(0.0318)	(0.0365)	(0.0445)	(0.200)
Q4 Foreign Extreme Heat x Election	0.0557	0.123**	0.134**	0.0159
	(0.0412)	(0.0575)	(0.0613)	(0.184)
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	10,711	5,580	4,905	741

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.

Table A.3: Policy Effects of Extreme Heat by Central Government Debt

	(1)	(2)	(3)	(4)
	Dependent variable is NRA			
	Full Sample	Major Crops	Major Crops	Major Crops
Q2 Extreme Heat	-0.0403	-0.0768	-0.151**	-0.0925*
	(0.0343)	(0.0515)	(0.0728)	(0.0548)
Q3 Extreme Heat	-0.0620	-0.122*	-0.323**	-0.142**
	(0.0514)	(0.0683)	(0.123)	(0.0623)
Q4 Extreme Heat	-0.163**	-0.399***	-0.614***	-0.434***
	(0.0712)	(0.146)	(0.180)	(0.150)
Q2 Extreme Heat x Central Govt Debt	0.0366	-0.00497	0.0784	-0.00673
	(0.0510)	(0.0739)	(0.105)	(0.104)
Q3 Extreme Heat x Central Govt Debt	0.110	0.0648	0.314*	0.0646
	(0.103)	(0.101)	(0.179)	(0.0977)
Q4 Extreme Heat x Central Govt Debt	0.261**	0.327***	0.675***	0.370**
	(0.129)	(0.119)	(0.248)	(0.147)
Country x Year Fixed Effects	Yes	Yes	Yes	Yes
Crop x Year Fixed Effects	Yes	Yes	Yes	Yes
Country x Crop Fixed Effects	Yes	Yes	Yes	Yes
Country x Crop Fixed Effects x Central Govt Debt	No	No	Yes	No
Interactions with change in debt	No	No	No	Yes
Observations	13,544	6,260	6,260	6,020

The unit of observation is a country-crop-year. Central government debt is the dept to GDP ratio in the country year, as measured by the International Monetary Fund (IMF). 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.

Table A.4: Price and Welfare Effects of Extreme Heat and Policy

	(1)	(2)	(3)	(4)
	Historical extreme heat		Projected extreme heat	
	Unresponsive policy	Responsive policy	Unresponsive policy	Responsive policy
Panel A: No domestic shocks				
Domestic price	0.78	1.60	1.77	4.44
Consumer surplus	-1.40	-2.87	-3.16	-7.57
Producer surplus	2.52	5.22	6.00	16.47
Total welfare	-0.46	-0.45	-1.17	-1.30
Panel B: No foreign shocks				
Domestic price	0.95	0.40	1.96	-0.11
Consumer surplus	-1.67	-0.76	-3.46	0.68
Producer surplus	-1.61	-3.69	-3.41	-9.19
Total welfare	-1.63	-1.82	-3.68	-5.81

We compute effects in percentage terms relative to baseline. We compare unresponsive policy fixed at baseline levels and responsive policy that adjusts as observed. Panels A and B aggregate over countries, crops, and years without (A) domestic and (B) foreign shocks. Welfare measures are summed, while price measures are averaged weighting by baseline total welfare. Domestic prices are world prices net of NRA policy. For historical (projected) extreme heat, panel A contains 67% (22%) of country-crop-year observations, weighting by baseline total welfare, and panel B contains 69% (25%). Categories A and B overlap in part.

Table A.5: Price and Welfare Effects of Extreme Heat by Policy Response

	(1) Unresponsive policy	(2) Responsive domestic policy	(3) Responsive foreign policy	(4) Responsive policy
Panel A: Historical extreme heat				
Domestic price (%)	1.07	1.15	0.98	1.06
Consumer surplus (%)	-1.87	-2.12	-1.74	-1.99
Producer surplus (%)	-2.03	-1.93	-2.40	-2.32
Total welfare (%)	-1.55	-2.02	-1.07	-1.52
Panel B: Projected extreme heat				
Domestic price	2.56	2.91	2.33	2.65
Consumer surplus	-4.43	-4.85	-3.93	-4.34
Producer surplus	-4.24	-2.56	-4.80	-3.23
Total welfare	-4.14	-6.00	-2.95	-4.73

We compute effects in percentage terms relative to baseline. Unresponsive policy is fixed at baseline levels, while responsive policy adjusts as observed. Panels A and B consider (A) historical and (B) projected extreme heat shocks. The second and third columns isolate policy responses to domestic and foreign shocks, respectively. The last column is the full policy response to all shocks. Each panel aggregates over all countries, crops, and years. Welfare measures are summed, while price measures are averaged weighting by baseline total welfare. Domestic prices are world prices net of NRA policy.