Food Policy in a Warming World

Allan Hsiao* Princeton
Jacob Moscona† Harvard
Karthik A. Sastry‡ Harvard

June 15, 2023

Abstract

Preliminary and incomplete. Please do not circulate.

This paper studies how climate change affects agricultural policy and how policy adjustment shapes global adaptation to climate change. We first introduce a simple model of an agricultural market in which a policymaker has preferences for redistribution between producers and consumers and access only to a single distortionary instrument, an import tariff. Depending on the shape of supply and demand curves and on the policymaker's preference, which together control countervailing incentives for redistribution and avoiding deadweight loss, a negative productivity shock (e.g., from damaging climate change) can push endogenous trade policy toward further producer bias or further consumer bias. To test these predictions empirically, we combine a new global panel dataset of crop-specific extreme heat exposure from 1980 to the present with global data on agricultural production, trade, and policy distortions. Extreme heat exposure significantly decreases domestic production, has a comparatively much smaller effect on domestic consumption, and significantly biases distortionary agricultural policy toward consumers (i.e., decreases nominal rates of assistance). Thus, governments systematically adjust distortionary agricultural policy to shield consumers from the harms of climate change. Taken together, these results highlight the critical role of policy in mediating the aggregate and distributional effects of climate change in the agricultural sector.

*Princeton Department of Economics, Julis Romo Rabinowitz Building, Princeton, NJ 08544. Email: ajhsiao@princeton.edu.

†Harvard Department of Economics, 1805 Cambridge Street, Cambridge, MA 02138. Email: moscona@fas.harvard.edu.

‡Harvard Department of Economics, 1805 Cambridge Street, Cambridge, MA 02138. Email: sastry.karthik@gmail.com.

1 Introduction

In March 2022 a major heat wave in India reduced India's wheat production by approximately 100 million tons, or 11% of expected output (Beillard and Singh, 2022). Citing food security risks, India's government issued a decision on May 13, 2022 to ban exports of all wheat. While this policy change had potential benefits for Indian consumers, it was met with hostility by farmers. Ashok Gulati, fomer chairman of India's Commission for Agricultural Costs and Prices, averred in an interview with India Today that the policy was aggressively "anti-farmer" and painted "a very sorry picture" of India's role in global commerce.[1]

This story has ingredients that we might expect to recur in the coming decades as climate change intensifies. First, increased incidence of extreme heat will further alter patterns of agricultural productivity. Second, governments will be faced with tough decisions about how to devise policy responses that balance different stakeholders' opposing interests. Third, these policies will critically mediate the effect of climate change on the agricultural economy—in particular, determining who bears the burden of climate change *within* countries, as well as the total resilience of the global food system to smooth over shocks *across* countries.

In this paper, we study the role of agricultural policy in shaping the agricultural sector's response to climate change. In particular, is the story above indicative of a broader trend over the last several decades of governments' responding to climate stress by systematically biasing agricultural policy toward consumers? And how has the intermediating effect of trade policy shaped global adaptation to climate change?

We first present a simple model that formalizes the causes and consequences of distortionary trade policy. The first goal of our theoretical analysis is to show that even with a simple framework, governments may have strong incentives to alter food policy in response to climate distress. However, the direction of this response is ambiguous. While the example from India highlights a case in which the government introduced consumer-friendly policy in response to a negative production shock, it is also possible that governments instead prop up distressed farmers by introducing producer-friendly measures. To determine how policy responds to climate distress, it is therefore essential to turn to the data. The second goal of the model is to highlight how the endogenous response of policy to climate distress mediates the impact of rising temperatures on production and welfare.

Our empirical analysis directly investigates the relationship between climate distress, production, and agricultural policy. To measure changes in climate distress, we construct

[1] https://www.indiatoday.in/india/video/dr-ashok-gulati-calls-govt-s-decision-to-ban-\export-of-wheat-as-anti-farmer-1950695-2022-05-17

a new global data set that captures trends in exposure to extreme temperature for every crop-by-country pair since 1980. We combine gridded, global data on daily temperature realizations (Muñoz-Sabater et al., 2021) with expert-elicited estimates of the maximum growing temperature for individual plant species to measure the potential exposure of a given crop to extreme heat in a given country over a specific period of time (see Moscona and Sastry, 2023). We use these data to construct crop-specific exposure to extreme heat for each country and each decade since 1980. To measure production and trade, we rely on data from the UN FAOSTAT database. Finally, to measure crop-specific agricultural policy across countries, we use data from the World Bank's "Distortions to Agricultural Incentives" project. This database reports price distortions for 80 agricultural products and 81 countries. The project was built from a large set of country-specific policy studies that investigated changes in commodity support over time. The authors then report a measure of the "nominal rate of assistance" (NRA) for each country, crop, and year, which we use as our main measure of market intervention.

Our first main finding is that extreme heat exposure for specific crops significantly reduces agricultural production but has a much smaller effect on agricultural consumption. Our baseline estimates are from regression models that absorb two-way fixed effects at the country-by-decade level, country-by-crop level, and crop-by-decade level. Thus, our analysis exploits only the differential exposure of different crops *within* a country to temperature trends to identify effects on production and consumption. This approach stands in contrast to existing work, which is based purely on cross-country variation (e.g., Lobell and Field, 2007; Lobell et al., 2011). Our results also suggest a significant role of international trade for smoothing the consumption effect of climatic shocks.

Our second main finding is that increased extreme heat exposure for specific crops reduces nominal rates of assistance, or biases trade policy toward consumers. These effects are persistent over subsequent decades, but we find no evidence of anticipation. Moreover, when splitting the NRA into components associated with different policy instruments, we find that the effects are concentrated in output-market interventions (e.g., import and export tariffs) as opposed to input-market interventions (e.g., subsidies for fertilizer or mechanical inputs). Thus, the motivating example is indicative of a broader trend: in response to climate stress, countries systematically implement policy that protects consumers. Critically, this bias diminishes the extent of distortionary policy for country-crop pairs that provide net assistance to producers and exacerbates the extent of distortionary policy for country-crop pairs that provide net assistance to consumers, each of which comprise about half of our sample.

In future work, we plan to integrate these estimates into a quantitative model to shed

light on three key questions. First, what is the contribution of endogenous trade policy to the observed reduced-form effect of climate stress on production and consumption? Second, how have trading partners' policy adjustments affected global adaptation in equilibrium? Third, if we extrapolate these trends to model future reallocation to climate change, how much might endogenous distortionary policy shape our ability to achieve global food security in the coming decades?

Literature Review (Incomplete). Within the literature on the global response of the agricultural sector to climate change, our primary contribution is to focus on the role of endogenous agricultural policy, which systematically responds to climate shocks and shapes their total and distributional effects.

This focus on endogenous policy differentiates our perspective from existing literature that studies agricutural reallocation in a fixed policy environment. For example, Costinot et al. (2016) quantitatively study the importance of trade for global adaptation to climate change when trade costs are nonzero but fixed. Our analysis, by contrast, suggests that trade barriers themselves may systematically change as the climate changes.

Relatedly, Bastos et al. (2013) study how rainfall shocks affect agricultural tariffs in theory and practice. Our results are consistent with their finding that rainfall shortages lead to lower agricultural import tariffs. We differ in our theoretical focus on redistributional motivations for distortionary trade policy, and also in our empirical focus on climate change more generally. We also relate to a broader literature that studies the determinants and effects of distortionary agricultural policy (e.g., Anderson and Masters, 2009; Bates, 2014).

2 Model

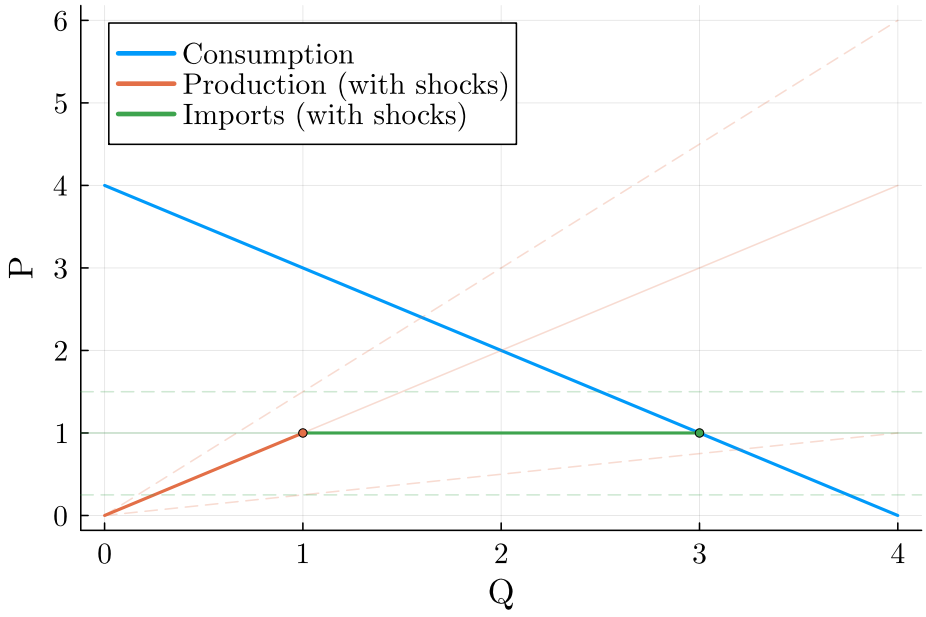
We characterize the aggregate and distributional effects of agricultural climate shocks, and we study how endogenous trade policy mediates these effects.

2.1 A Small Open Economy

Consider a small open economy that produces and imports a given crop. Domestic consumption q^d, domestic production q^s, and imports q^m depend on ad-valorem import tax τ^m and climate shocks $\varepsilon = (\varepsilon^s, \varepsilon^m)$. The inverse demand, supply, and import curves are

$$P^d(q^d), \quad (1+\varepsilon^s)P^s(q^s), \quad (1+\tau^m)(1+\varepsilon^m)P^m.$$

Figure 1: Consumption, production, and imports



Demand is downward-sloping, supply is upward-sloping, and imports are perfectly elastic. Climate shocks ε raise production costs, affecting supply from domestic producers and imports from foreign producers. Large ε^s raises prices for domestic production, and large ε^m raises prices for imports. The government sets import tariffs τ^m that also raise prices for imports.

Total supply is given by the lower envelope of the supply and import curves. Suppose an interior solution with domestic consumption that includes both domestic production and imports.

$$q^d = q^s + q^m.$$

In this case, imports dominate the least productive domestic producers, but not the most productive domestic producers. Domestic production q^s thus proceeds until marginal cost reaches the price of imports.

$$(1 + \varepsilon^s)P^s(q^s) = (1 + \tau^m)(1 + \varepsilon^m)P^m$$

Imports q^m then satisfy the rest of domestic consumption.

$$P^d(q^s + q^m) = (1 + \tau^m)(1 + \varepsilon^m)P^m$$

Figure 1 plots a simple linear example in a baseline scenario without import tariffs or climate shocks, such that $\tau^m = \varepsilon^s = \varepsilon^m = 0$. Domestic production provides $q^s = 1$, but

past this point is dominated by imports available at price $P = 1$. Domestic consumers take advantage and import $q^m = 2$ for total consumption $q^d = 3$. When trade policy is fixed, domestic consumption remains constant in the face of climate shocks. For domestic shocks ε^s, negative shocks raises the costs of domestic production, and so imports rise. Positive shocks lower the costs of domestic production, which then displaces imports. Foreign climate shocks ε^m generate similar substitution patterns between production and imports.

2.2 Endogenous Trade Policy

We endogenize trade policy by considering social welfare that combines consumer and producer surplus with government revenue from the import tax, as given by

$$\begin{aligned} W^d &= \int_0^{q^d} [P^d(q) - P^d(q^d)]dq, \\ W^s &= (1+\varepsilon^s) \int_0^{q^s} [P^s(q^s) - P^s(q)]dq, \\ G &= \tau^m(1+\varepsilon^m)P^m q^m. \end{aligned}$$

We study distributional preferences in the form of weights $\lambda = (\lambda^d, \lambda^s)$ on consumer and producer surplus. Weights $\tilde{\lambda} = (1, 1)$ capture a benchmark of unweighted surplus.

$$W(\lambda) = \lambda^d W^d + \lambda^s W^s + G$$

Further define unweighted social welfare as $\tilde{W} = W(\tilde{\lambda})$. Given distributional preferences λ, the government responds to climate change ε by setting import tax τ^m to maximize social welfare.

$$\hat{\tau}^m(\varepsilon; \lambda) = \arg\max_{\tau^m} W(\tau^m, \varepsilon; \lambda)$$

2.3 Theoretical Results

We extend the simple linear example from figure 1 to study how endogenous trade policy influences the welfare losses from simulated climate shocks. Figures 2 and 3 illustrate for shocks to domestic production.

2.3.1 Distributional preferences motivate distortionary trade policy

Import taxes are zero when the government weighs consumer and producer surplus equally ($\lambda^d = \lambda^s$). Imports are supplied elastically, and so a lack of terms-of-trade effects implies that import taxes are purely distortionary. But with richer distributional preferences, the

government's desire to support consumers or producers can outweigh the costs of this distortion. A government that prioritizes producer surplus will impose import taxes to support producers against foreign competition ($\lambda^d < \lambda^s$). Conversely, a government that prioritizes consumer surplus will impose import subsidies to support consumers by increasing competitive pressure on domestic producers ($\lambda^d > \lambda^s$).

Figure 2 illustrates. A pro-producer government imposes import taxes, a pro-consumer government imposes import subsidies, and government without bias toward either allows free trade. Taxes tilt more strongly toward producers as domestic climate shocks increase the dependence of domestic producers on government support. Conversely, subsidies told more strongly toward consumers as domestic climate shocks lower the productivity of domestic production. These policy responses go beyond the direct effect of domestic climate shocks, which themselves push domestic consumption away from domestic production and toward imports.

2.3.2 Endogenous trade policy affects climate damages

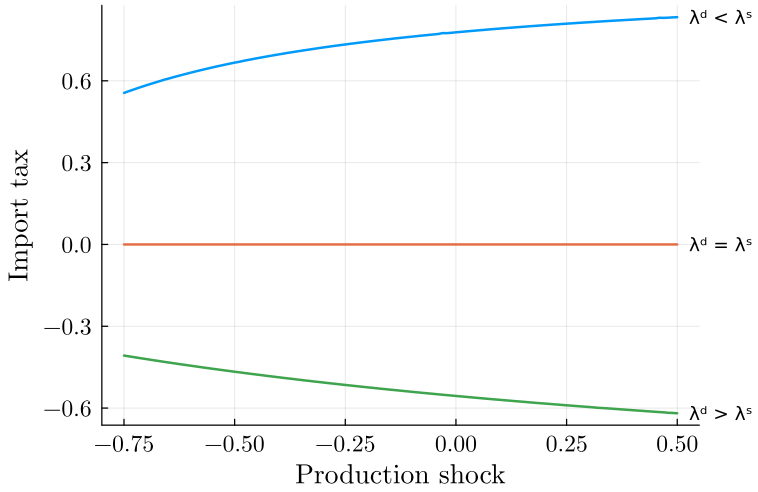
Figure 3 shows how trade policy mediates the impacts of climate shocks on both consumer and producer surplus, as well as total social welfare. We present unweighted social welfare across scenarios to allow comparison in common units. Consumer surplus remains unaffected by climate shocks when import taxes are zero ($\lambda^d = \lambda^s$) because consumers adapt by turning to imports. But producer surplus and social welfare each fall as producers suffer cost shocks.

Consider a pro-producer government that imposes import taxes ($\lambda^d < \lambda^s$). Domestic climate shocks increase the dependence of domestic producers on government support, which leads to increased import taxes. Consumers thus suffer from reduced access to inexpensive imports. But producers suffer greatly as losses from climate shocks are exacerbated by the loss of government support. Taken together, social welfare falls.

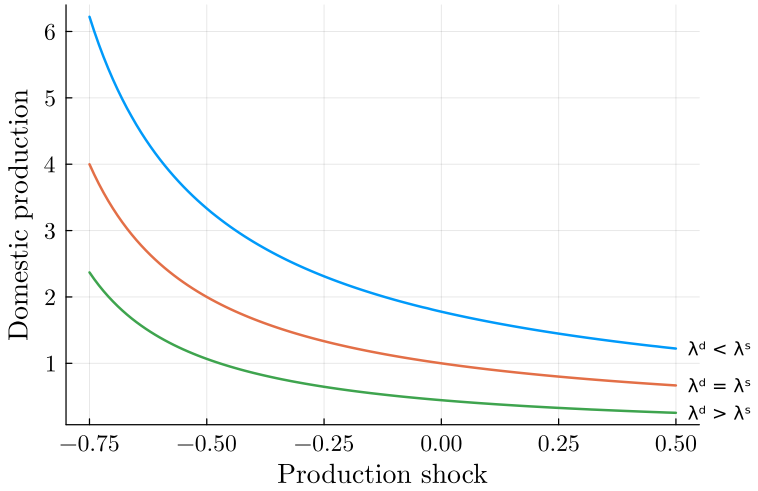
Also consider a pro-consumer government that imposes import subsidies ($\lambda^d > \lambda^s$). These subsidies increase as shocks to domestic production raise the returns to encouraging imports. Consumer surplus is thus increasing in the magnitude of climate shocks. Producers suffer, but only moderately so, as producer surplus is already low in this world with import subsidies. Even at baseline, domestic producers face intense foreign competition. Moreover, import subsidies are costly and thus result in diminishing social welfare despite increased consumer surplus.

Figure 2: Climate shocks ε^s on domestic production

(a) Import tax τ^m



(b) Production q^s



(c) Import q^m

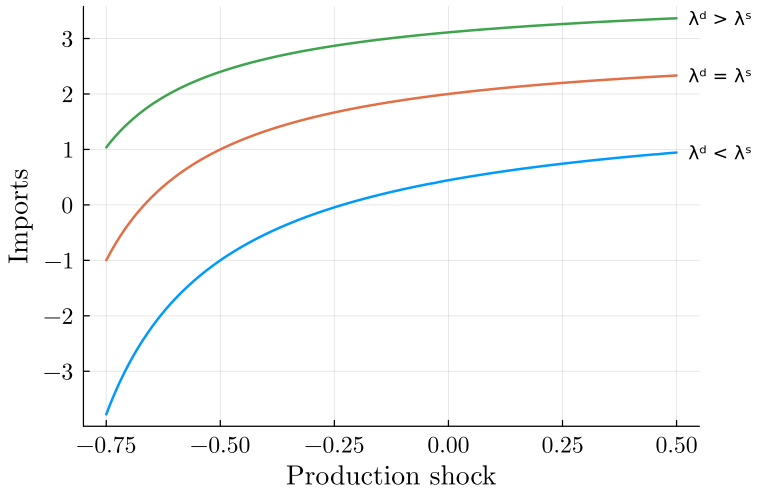
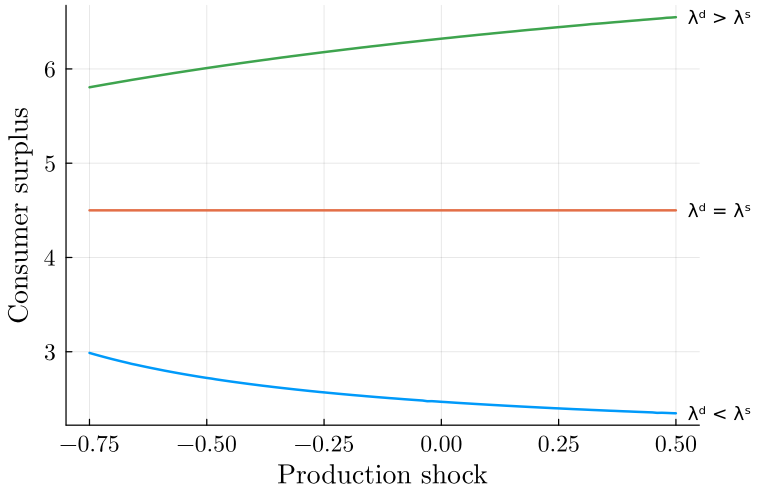
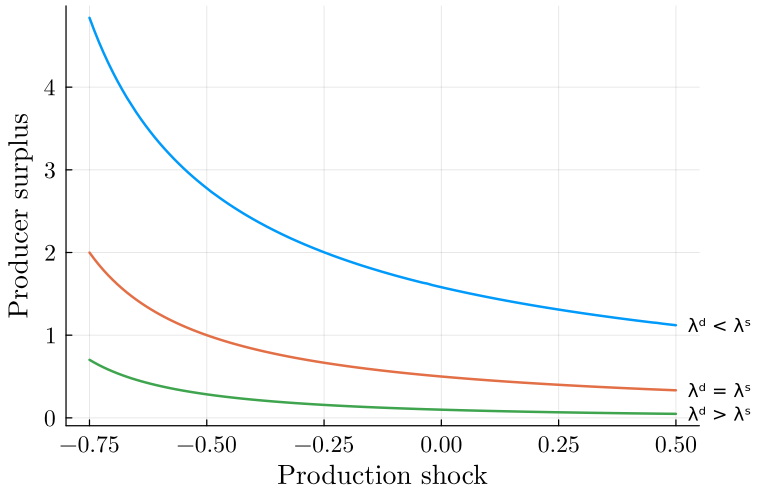


Figure 3: Climate shocks ε^s on domestic production

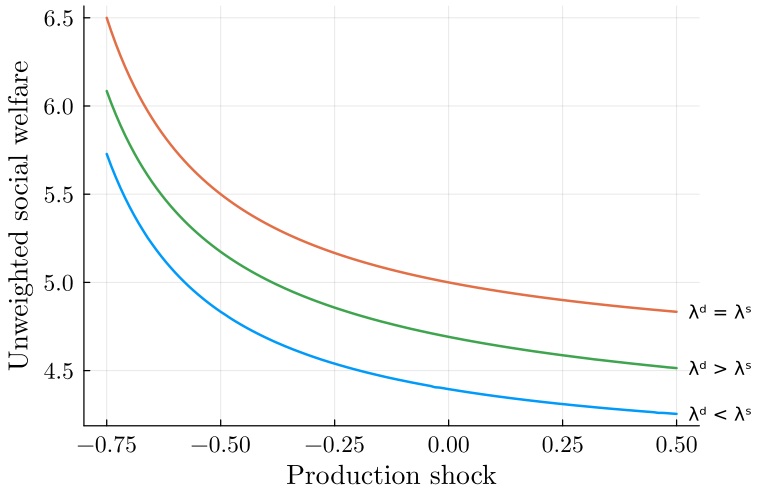
(a) Consumer surplus W^d



(b) Producer surplus W^s



(c) Unweighted social welfare $\tilde{W}$



2.4 From Theory to Data: Main Predictions

We now distill the model's predictions into *two testable predictions*, which will form the backbone of our empirical analysis.

The first prediction concerns the effect of extreme heat on agricultural production:

Prediction 1. *Extreme heat shocks at home decrease production.*

To map this prediction to the data, we need to measure extreme-heat shocks for specific agricultural products (e.g., crops) and validate their negative effects on production. This will require us to introduce a novel strategy to construct a global panel dataset extreme-heat exposure for extreme-heat exposure for a large panel of (staple and non-staple) crops.

The second prediction hones in how climate shocks affect trade policy, as the government re-optimizes its tariff:

Prediction 2. *Extreme heat shocks affect trade policy.*

In the model, this prediction holds as long as the government has some distributional preferences (i.e., $\lambda^d \neq \lambda^s$). Thus, in the context of the model, validation of Prediction 2 constitutes a rejection of this case. Moreover, in our numerical examples, the sign of the response was related to the bias of distributional preferences. If an extreme-heat shock increases the import subsidy (i.e., makes policy more "consumer friendly"), then the government favors consumers ($\lambda^d > \lambda^s$). If an extreme-heat shock decreases the import subsidy (i.e., makes policy more "producer friendly"), then the government favors producers ($\lambda^d < \lambda^s$). As a first empirical exercise, we will check the sign and magnitude of this relationship between extreme-heat and trade policy *on average* over our full panel of countries, crops, and time periods.

The sign Prediction 2 has important implications for the welfare consequences of climate change. If damaging climate shocks induce "consumer-friendly" policies in a given country, then policy response relatively shifts surplus from producers to consumers domestically. The effects on the rest of the world are the opposite. Producers in the rest of the world benefit from an increased ability to sell in a new market. Consumers in the rest of the world may suffer from increased prices. If damaging climate shocks induce "producer-friendly" policies in a given country, the sign of the previous logic flips: this is relatively beneficial for domestic producers and foreign consumers, and relatively harmful for domestic consumers and foreign producers.

3 Data and Measurement

3.1 Agricultural Policy: Nominal Rates of Assistance

To measure price distortions in agricultural markets, we use data from the World Bank's "Distortions to Agricultural Incentives" project. This dataset is an unbalanced panel of information about price distortions for 80 agricultural products and 81 countries from 1955 to 2011.

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

$$\text{NRA}_{\ell kt} = \frac{P^d_{\ell kt} - P^m_{\ell kt}}{P^m_{\ell kt}} \tag{1}$$

where $P^d_{\ell kt}$ is the unit value of production at a distorted price and $P^m_{\ell kt}$ is the unit value of production at an undistorted market price. Of course, both P^d and P^m are unobserved, model-based objects.

In practice, the NRA is computed by measuring the ratio of total assistance paid to producers (in dollars) relative to the total value of production. These sources of assistance include: market price support, payments to producers based on output, payments to producers based on inputs, and payments to producers based on other indicators (e.g., area cultivated). The first category by itself captures purely the gap between international and domestic prices, which maps to the import tax in the model. Because it is measured in price terms, this component of NRA also measures in price units the effects of non-price trade policies (e.g., quotas). The latter three components capture additional forms of producer support which, in practice, may substitute for trade policy.

3.2 Global Panel Data on Extreme-Heat Exposure

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

Data Inputs. Our strategy requires three main data inputs, described below.

The first are global historical estimates of temperature from Muñoz-Sabater et al. (2021). This is the fifth-generation data set produced by the European Centre for Medium-Range Weather Forecasts, in collaboration with the European Commission and Copernicus Climate Change Service. It is a reanalysis data set that combines weather observations from around the world with model data in order to generate a complete global gridded temperature data set at the hourly level with a grid size of 0.25 degrees. The data are reported from 1979 to the present, and we focus on four decadal periods (the 1980s, the 1990s, the 2000s, and the 2010s).

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

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

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

$$\text{ExtremeExposure}_{\ell kt} = \sum_{c \in \ell} \frac{\text{Area}_{ck}}{\sum_{c' \in \ell} \text{Area}_{c'k}} \cdot \text{DegreeDays}_{ct}(T_k^{max}) \tag{2}$$

where $\text{DegreeDays}(x)$ returns total degree days in excess of threshold x, T_k^{max} is the maximum optimal growing temperature for crop k from EcoCrop, and Area_{ck} is the area growing crop k in cell c from the EarthStat data. Moscona and Sastry (2023) validate, in historical panel data from the United States, that this measure of extreme exposure robustly predicts

adverse agricultural outcomes and, moreover, outperforms comparable measures that do *not* take crop-specific tolerance into account.

When merged to our data on production and trade, our dataset covers 166 countries and 126 crops. When merged to our data on agricultural policy, our dataset covers 79 countries and 61 crops.

3.3 Production and Trade

We finally take data on production, exports, and imports at the crop by country by year level from the UN FAO Stat database. We construct decadal variables by averaging. We impute consumption values using the identity Consumption = Production + Imports - Exports, ignoring storage.

4 Empirical Results

In this section, we report our two main empirical results. Our first result is that crop-specific extreme temperature exposure reduces crop-specific output. This validates our global panel data set for extreme-heat exposure and documents that extreme-heat exposure, as we measure it, has meaningfully reduced output during the past several decades. We also show that extreme heat affects production greatly in excess of consumption, suggesting that countries significantly use trade to smooth over shocks.

Our second result is that extreme heat exposure reduces nominal rates of assistance—that is, it tilts trade policy away from assisting producers (e.g., via import tariffs or input subsidies) and toward assisting consumers (e.g., via import subsidies or export tariffs). This suggests that governments systematically use policy to shield consumers against the greatest damage of climate change, but in so doing shift additional burden onto domestic producers.

4.1 Estimating Equation

Our main estimating equation for the empirical analysis is:

$$y_{\ell kt} = \beta \cdot \text{ExtremeExposure}_{\ell kt} + \alpha_{\ell t} + \gamma_{\ell k} + \delta_{kt} + \epsilon_{\ell kt} \tag{3}$$

where the unit of observation is a country-crop-decade triplet. $\text{ExtremeExposure}_{\ell kt}$ is defined above in Section 3.2. As outcome variables $y_{\ell kt}$, we use both measures of crop-specific output and crop-specific policy across countries (see Sections 3.1 and 3.3). We include all possible two way fixed effects in all specifications: country-by-decade fixed effects (capturing any

Table 1: Extreme Heat and Agricultural Production

Dependent variable:	(1) log Output	(2) log Consumption	(3) log Output / Consumption	(4) log Area	(5) log Output / Area
Extreme Temperature	-0.129**	-0.0136	-0.116***	-0.112*	-0.00646
	(0.0618)	(0.0488)	(0.0409)	(0.0585)	(0.0281)
Country x Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country x Crop Fixed Effects	Yes	Yes	Yes	Yes	Yes
Crop x Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	24,140	24,093	24,008	23,750	23,750
R-squared	0.967	0.968	0.873	0.968	0.971

Notes: The unit of observation is a country-crop-decade triplet. All possible two-way fixed effects are included in all specifications, and the outcome variable is listed at the top of each column. Standard errors are clustered by country and *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

country-level trends), crop-by-decade fixed effects (capturing any crop-level trends), and country-by-crop fixed effects (capturing all average differences between county-crop pairs around the world). Our coefficient of interest is β, which captures the impact of exogenous changes in extreme heat exposure on output and policy.

4.2 Extreme Heat and Agricultural Production

Column 1 of Table 1 reports the estimate of β when the outcome variable is log of crop-specific output. Extreme temperature as we measure it has a negative and significant impact on output. The coefficient estimate suggests that the median value of extreme heat exposure in the sample reduced output by 5%; extreme heat exposure at the 75th percentile reduced output by 23%. Thus, rising temperatures have had large, negative effects on production.

We next investigate the impact of extreme temperature exposure on consumption (column 2). Unlike production, consumption is unaffected by changes in extreme heat exposure; the effect that we estimate is both small in magnitude and statistically indistinguishable from zero. Consistent with the results from columns 1 and 2, column 3 shows that extreme temperature exposure has a large negative effect on the ratio of output to consumption. Thus, countries use international trade to smooth consumption in response to local adverse climate shocks.

Output could decline in response to more extreme temperature because producers shift away from planting more adversely-affected crops, because those crops produce less per acre, or a combination of the two. In column 4, the outcome variable is (log of) land area and in column 5, it is (log of) output per area. Extreme heat has a large, negative effect on area

Table 2: Extreme Heat and Agricultural Policy

Dependent Variable:	(1)	(2)	(3)	(4)
	Nominal Rate of Assistance		Nominal Rate of Assistance (Output)	Nominal Rate of Assistance (Input)
Extreme Temperature, future decade		-0.0243		
		(0.0655)		
Extreme Temperature	-0.106**		-0.109**	0.000861
	(0.0504)		(0.0515)	(0.00246)
Country x Year Fixed Effects	Yes	Yes	Yes	Yes
Country x Crop Fixed Effects	Yes	Yes	Yes	Yes
Crop x Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,895	1,568	1,895	1,895
R-squared	0.904	0.935	0.904	0.899

Notes: The unit of observation is a country-crop-decade triplet. All possible two-way fixed effects are included in all specifications, and the outcome variable is listed at the top of each column. Standard errors are clustered by country and crop and *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

and a much smaller negative effect on yields, suggesting that the effects on output are driven predominately by shifting specialization.

4.3 Extreme Heat and Agricultural Policy

We next investigate the impact of extreme heat exposure on agricultural policy. Column 1 of Table 2 reports estimates of Equation 3 in which $\text{NRA}_{\ell kt}$ is the dependent variable. We estimate a negative and significant effect, indicating that on average, governments shift toward more consumer-friendly policy in response to negative domestic production shocks. This relationship is not driven by pre-existing trends in agricultural policy: when we include the leading value of extreme temperature exposure on the right hand side of the regression, it has no impact on our measure of crop-specific policy (column 2).

Columns 3-4 distinguish between policy affecting agricultural output and policy affecting inputs to agricultural production (e.g. fertilizer). We find that the result from column 1 is driven exclusively by output-related policy.

5 Discussion and Next Steps

We study the role of agricultural policy in mediating the effect of temperature stress on the agricultural economy. Theoretically, we use a simple model to show how distributional concerns can motivate distortionary agricultural policy and how the response of this policy to climatic productivity shocks is ambiguous. Toward measuring these effects empirically, we construct a new global panel dataset of crop-specific extreme heat shocks since 1980 and combine these data with data on production, trade, and policy distortions, as measured by nominal rates of assistance. We find that consumption responds much more smoothly to heat stress than production, and that extreme heat systematically induces consumer-friendly policy in the form of lower nominal rates of assistance.

Next steps will consider a two-country version of the theoretical model, with imports for country one given by residual supply for country two. This residual supply in turn depends on country two's own trade policy and climate shocks. We can then characterize global welfare, including as a function of bilateral trade policy set in equilibrium. Expanding the model beyond two countries will allow us to estimate distributional preferences for each country with data on country-specific trade policy, as captuted by our data on nominal rates of assistance. Given these estimated distributional preferences, we can then simulate the aggregate and distributional effects of climate change over the coming centuries, both with and without endogenous trade policy as a barrier to adaptation.

References

Anderson, K. and Masters, W. A. (2009). *Distortions to agricultural incentives in Africa*. World Bank Publications.

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

Bates, R. H. (2014). *Markets and states in tropical Africa: the political basis of agricultural policies*. Univ of California Press.

Beillard, M. J. and Singh, S. K. (2022). Extreme temperatures scorch indian wheat production. Attaché Report (GAIN) IN2022-0045, USDA Foreign Agricultural Service. Available at https://www.fas.usda.gov/data/india-india-extreme-temperatures-scorch-indian-wheat-production.

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

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

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

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

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

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

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

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

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., et al. (2021). Era5-land: A

state-of-the-art global reanalysis dataset for land applications. *Earth System Science Data*, 13(9):4349–4383.

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

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