Weather Shocks Affect Trade Policy: Evidence from Preferential Trade Agreements

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Abstract

We show that weather shocks affect government trade policy decisions. We exploit variation in rainfall during the growing season within and across countries to show that weather shocks impact agricultural output and trade. Using information on tariff cuts by commodity from preferential trade agreements, we then show that weather shocks that happen during the negotiation period correlate strongly with the size of tariff cuts. When weather shocks increase (decrease) a country's capacity to produce a given crop, its government negotiates a smaller (larger) tariff cut. These results are consistent with a political economy trade model with sector-specific inputs in which the government places more weight on producers relative to consumers in its objective function. They also reveal that governments update their beliefs about domestic agricultural production capacity in response to weather shocks.

Keywords: weather shocks, climate change, agricultural trade, trade policy.

JEL Codes: F13, F14, Q17, Q54.

1 Introduction

In August 2021, the United Nations Intergovernmental Panel on Climate Change (IPCC) released its latest report.[1] It is one of the most comprehensive science review efforts in global history, summarizing eight years of research from more than 14,000 papers. The report concludes that the global water cycle and the severity of wet and dry events will intensify. Extreme ecological events that used to occur once every 10 years are now 1.7 times more likely than they were from 1850 to 1900. These changes will have dramatic consequences for agricultural production and sustainability all over the world. Shifting rainfall patterns increase soil erosion, make it harder to grow many crops, and shorten the growing season.[2] This will have a direct impact on what and how much different countries produce, with implications for what the world trades and how (Arnaud Costinot, Dave Donaldson and Cory Smith 2016). This is even more important considering that tariffs on agricultural goods are significantly higher than tariffs for non-agriculture for the vast majority of countries in the world (Jayson Beckman 2021) and even amongst WTO members (Will Martin and Aaditya Mattoo 2010).

We show that weather shocks affect agricultural output and trade, and change government trade policy decisions. Our analysis proceeds in three steps. First, we combine geographic and climate information at a very fine spatial resolution to capture the effect of extremely high and low rainfall on the capacity of each country to produce different crops. We show that negative rainfall shocks during the growing season in those areas within a country that are suitable to produce a given crop decrease domestic output, increase imports, and decrease exports of that crop. These effects are symmetric for positive rainfall shocks, which increase domestic output.

Second, we use data from two decades of Preferential Trade Agreements (PTAs) to document that these shocks to domestic production capacity correlate strongly with the size of tariff cuts.[3]

[1] Available at https://www.ipcc.ch/report/ar6/wg1/, accessed on November 17, 2021.

[2] Within countries, the impacts of changes in rainfall patterns may be very localized and affect crops differently, having heterogeneous effects on households both by region and by income level (Channing Arndt, Adam Schlosser, Kenneth Strzepek and James Thurlow 2014). Changes in temperature may also have a direct effect on agricultural production, but their impact is not clear. The consensus among climate change analysts is that rising temperatures will likely have a positive impact in colder areas by boosting agricultural productivity, but will have a negative impact in hotter areas, especially in the tropics (Paul Brenton and Vicky Chemutai 2021).

[3] With the term preferential trade agreement, we refer to *"an agreement between two or several countries to increase the free movement of goods and services across the borders of its members"* (Andreas Dür, Leonardo Baccini and Manfred Elsig, 2014).

Specifically, we relate weather shocks that occur during the negotiation period to the size of tariff cuts stipulated in each PTA. Evidence shows that when weather shocks increase the domestic capacity to produce a given crop, governments negotiate a smaller tariff cut. Negative changes in domestic capacity are instead associated with larger tariff cuts. These findings stand up to a battery of robustness checks such as using alternative cut-offs to identify extreme weather events or focusing on whether a given crop is included in the agreement in the first place as outcome. We also find that the strength of the relationship between weather shocks and tariff cuts changes according to the level of storability of different crops and is highest and most significant for the least storable crops. Our baseline estimates imply that the average tariff cut stipulated in the PTAs in our sample would have been at least two times higher – from 41% to 93% – in the absence of any weather-induced increases in production capacity during the negotiation period.

In the third and last part, we show that these findings are consistent with a standard political economy trade model with sector-specific inputs (Gene M Grossman and Elhanan Helpman 1994; Giovanni Maggi and Ralph Ossa 2020). In the model, both the optimal level of tariff and how it varies with import penetration depend on the weight the government places on producers relative to consumers in its objective function. When domestic output is higher, both the positive effect of protection on producer surplus and its negative effect on consumer surplus are larger in magnitude. If the government weighs the former more than the latter, it chooses a higher tariff. When interpreted through the lens of this model, our empirical findings suggest that governments place more weight on producers relative to consumers in their objective function.

The weather shocks that we consider are transitory. Yet, by changing the size of tariff cuts, they have permanent implications. This reveals that government officials regard changes in agricultural production that come with weather shocks as permanent to at least some extent, and update accordingly their beliefs over domestic production capacity. This is rational if they believe that climate change will make weather shocks more frequent in the future.

Our contribution to the literature is threefold. First, we contribute to the literature on the effect of climate change on agricultural production and trade.[4] Evidence shows that weather shocks negatively affect agricultural production for a variety of crops and locations around the world.[5] Other papers have looked at the effect of climate shocks on international trade.[6] Benjamin F. Jones and Benjamin A. Olken (2010) show that higher temperatures in poor countries lower agricultural exports. Robin Burgess and Dave Donaldson (2010) show that trade openness may mitigate the negative effects of weather shocks on agricultural output. We contribute to this literature by providing novel, granular evidence on the impact of weather shocks on agricultural production and trade, providing supporting evidence to the mounting concern about the effects of climate change on agricultural sustainability.

Second, our research speaks to the literature on the relationship between trade policy and climate change. On the one hand, evidence shows that trade policy has consequences for the environment (Brian R. Copeland, Joseph S. Shapiro and M. Scott Taylor 2022).[7] On the other hand, concerns about climate change are increasingly shaping trade policy. This is the case for environmental provisions, which have started to be included in trade agreements (Clara Brandi, Jakob Schwab, Axel Berger and Jean-Frédéric Morin 2020; Ryan Abman, Clark Lundberg and Michele. Ruta 2021). We provide evidence that weather shocks affect trade policy. Our theoretical discussion suggests that extreme weather events, made more severe and frequent by climate change, shape the incentives of special interest groups, which are taken into account by governments in their decision-making process.[8]

[4] A related literature focuses on the effect of economic growth and international trade on climate change and environmental sustainability documenting large effects (Brian R. Copeland, Joseph S. Shapiro and M. Scott Taylor 2022). In particular, several of these studies have tested the so-called Environmental Kuznets Curve (EKC) hypothesis (see Brian R. Copeland and M. Scott Taylor 2004 and Paul Brenton and Vicky Chemutai 2021 for a review).

[5] See M. Parry, T. Carter and N. (Eds.) Konijn (1998); Arnaud Costinot, Dave Donaldson and Cory Smith (2016); Ewen Gallic and Gauthier Vermandel (2020) among others.

[6] See for instance John Reilly and Neil Hohmann (1993) and Cynthia Rosenzweig, Martin Parry, Günther Fisher and Klaus Frohberg (1993).

[7] Joseph S Shapiro (2022) analyzes the structure of trade protection and finds that tariff and non-tariff barriers are lower in carbon-intensive industries than in clean industries. This indicates that the entire structure of trade policy is biased towards promoting trade in carbon-intensive goods. At the same time, Paul Brenton and Vicky Chemutai (2021) note that, while cutting tariffs in carbon-intensive industries without appropriate carbon policies, would lead to higher emissions and more environmental pollution, reducing this bias will have a positive effect. On the effect of trade liberalization and free trade on the environment, see also Werner Antweiler, Brian R. Copeland and M. Scott Taylor (2001); S. Managi, A. Hibiki and T. Tetsuya Tsurumi (2009); J. Cherniwchan (2017); Ryan Abman and Clark Lundberg (2020).

[8] Weather shocks may also represent a source of uncertainty, connecting our paper with the theoretical literature on trade under uncertainty (Batra and Russell, 1974; Helpman and Razin, 1978). When volatility in prices due to

Third, our analysis contributes to to the vast literature on the political economy of trade policy. The political economy view of trade is that governments are concerned with the distributional implications of their tariff choices, and subject to the pressure of special interest groups (Richard Baldwin 1987; Ngo Van Long and Neil Vousden 1991; Gene M Grossman and Elhanan Helpman 1994, 1995*a*,*b*; Kyle Bagwell and Robert W. Staiger 1999). In its simplest formulation, the government's problem is to choose the tariff level that maximizes a weighted sum of producer and consumer surplus. The greater the influence of producer lobbies, the greater the relative weight placed on producers in the government's objective function.[9] To identify such relative weight, several papers – from Pinelopi Koujianou Goldberg and Giovanni Maggi (1999) to Kishore Gawande, Pravin Krishna and Marcelo Olarreaga (2009) – have taken the theory of Gene M Grossman and Elhanan Helpman (1994) to the data using structural estimation methods.[10] Our approach is different. In the model, the relative weight attached to producers in the government's objective function determines not only the optimal level of import tariffs, but also their relationship with import penetration. When domestic output increases or imports decrease, both the positive effect of protection on producer surplus and its negative effect on consumer surplus get larger in magnitude. If the government weighs the former more than the latter, the optimal tariff increases. We build on this result and use reduced-form evidence that exploits plausibly exogenous variation in domestic production capacity and data on tariff cuts from PTAs to show that governments place more weight on producers relative to consumers in their objective function.

Finally, our paper speaks to a large literature on the political economy of agricultural and food

international trade is introduced in classical trade models most of the traditional predictions of trade theory do not hold any more or are significantly modified (Turnovsky, 1974; Helpman and Razin, 1980; Newbery and Stiglitz, 1984; Di Maio and Valente, 2013). Bernhard Dalheimer, Marc F. Bellemare and Sunghun Lim (2023) explore how both price levels and volatility affect the payoffs of consumers and producers in different ways in the context of global value chains. Our analysis focuses instead on trade policy and how uncertainty related to whether shocks affect the political economy process behind it.

[9]In this class of models, lobbying on trade policies is carried out by industry groups (Gene M Grossman and Elhanan Helpman 1995*a*) or by homogeneous or heterogeneous firms (Pravin Krishna 1998; Emanuel Ornelas 2005; Matilde Bombardini 2008). In particular, M. Blanga-Gubbay, P. Conconi, I. S. Kim and M. Parent (2020) examine how lobbying by heterogeneous firms can shape the content of trade agreements, i.e., the non-tariff provisions included in Free Trade Agreements (FTAs), while Michael Blanga-Gubbay, Paola Conconi and Mathieu Parenti (2022) document that lobbying for FTAs is dominated by large internationalized firms, which are in favor of these agreements because they allow them to access to foreign consumers and suppliers.

[10]See also Kishore Gawande and Usree Bandyopadhyay (2000) as well as Kishore Gawande and Pravin Krishna (2003) for a review.

policy and agricultural trade (MacLaren, 1991; De Gorter and Swinnen, 2002; Swinnen, 2002). In particular, we contribute to an ongoing academic debate about the effect of political influence on agricultural protection (Gawande and Hoekman, 2006; Bullock and Coggins, 2002; Anderson, Rausser and Swinnen, 2013; Bellemare and Carnes, 2015). The key insight of our paper is that the extent of agricultural protection increases with the magnitude of rents available to local producers. Our results are also in line with previous studies arguing that protectionism in agriculture is not different from protectionism in other sectors of the economy and it conforms to key predictions of the endogenous tariff theory (Thies and Porche, 2007; Thies, 2015).

To the best of our knowledge, there are no other papers studying the effect of climate change on trade agreements. One study close to ours is Paulo Bastos, Odd Rune Straume and Jaime A. Urrego (2013), who use yearly country-level data on rainfall and tariffs on 13 agricultural products to show that lower rainfall is associated with lower tariffs. Based on an *ad-hoc* model of strategic trade policy, they interpret their results as indicating that policymakers place considerable weight on domestic producer surplus when setting import tariffs. While their findings resonate with ours, our analysis departs from that of Paulo Bastos, Odd Rune Straume and Jaime A. Urrego (2013) in several important ways. First, the weather shocks we consider are more granular as they combine geographic and climate information at very fine spatial resolution, and measure extreme rainfall realizations during the growing season of a given crop that occur in those areas within the country that are suitable to produce that crop. These measures capture both positive and negative weather shocks, and, most importantly, allow us to exploit variation across crops within countries and years. Second, by focusing on tariff cuts stipulated in PTAs, we can look specifically at the impact of weather shocks that intervene during the negotiation period, exploiting further their timing for identification. Third, we provide evidence of a complete chain of events, from weather shocks to domestic output, trade, and policy. Finally, we interpret the empirical results using a more general political economy framework, which improves the external validity of our findings.

The existing literature documents that several different factors influence the evolution of trade policy: political power, national power, past colonial ties, and geography among others. Yet, environmental factors appear not to have played a direct role (Brian R. Copeland, Joseph S. Shapiro and M. Scott Taylor 2022). Our results challenge this view by showing that climate change affects trade policy indirectly by shaping the incentives of special interest groups, and how these are ultimately reflected in tariff negotiations.

The remainder of the paper is organized as follows. Section 2 presents the data and definitions of the weather shocks. Section 3 illustrates the empirical strategy and results. Section 4 presents a political economy trade model that can rationalize the empirical findings. Section 5 concludes.

2 Data and Definitions

Our empirical analysis combines data on land suitability, rainfall, growing seasons, agricultural production and trade, and tariff cuts. This section presents all the relevant data sources and describes how we derive the rainfall shock measures that we use throughout the empirical analysis.

2.1 Data

Tariff Cuts To build our sample, we start from the set of PTAs for which information is available on the negotiated tariff cut at the agricultural commodity level. We derive this information from the Design of Trade Agreements (DESTA) database (Andreas Dür, Leonardo Baccini and Manfred Elsig 2014).[11] For each agreement, the data records the identity of partners, the year of signature and implementation, sector coverage, depth of commitments, and compliance tools. The dataset provides information on baseline tariffs and the stipulated reductions over time during the implementation period for each product at the level of 6-digit Foreign Trade

[11] In our analysis, a PTA is *"an agreement between two or several countries to increase the free movement of goods and services across the borders of its members."* This definition is in line with the WTO definition of regional trade agreements (RTAs). We prefer the use the term PTA rather than RTA for two main reasons. First, the label RTA may be misleading because these agreements are often not among countries in the same world region. This is particularly the case for our sample which considers PTAs that are mostly between high-income and low or middle-income countries. Second, since we rely on the DESTA dataset, we follow their vocabulary, which refers to PTAs, as it does all the literature that followed and uses the DESTA data.

Harmonized (HS) code, up to 12 years after implementation.[12] Tariff schedules are extracted from the officially negotiated ones listed in the appendices of the PTAs.[13] We focus specifically on agricultural products, mapping each corresponding 6-digit HS product code to the set of crops for which data exist on potential yields at the sub-national level.

Our final sample comprises all PTAs signed between 1995 and 2014 that involve at least one of the following major economies: Australia, Canada, China, Japan, United States, and for which data on the negotiated tariff cut are available at the product level.[14] These PTAs involve 72 different country pairs. The top panel of Figure 1 shows the average tariff cut in percentage by crop across these PTAs. The bottom panel of the same Figure shows instead the average tariff cut by partner country. Panel B of Appendix Table A.1 provides other summary statistics for the tariff levels and their stipulated changes. On average, agricultural tariffs fall by around 40% as a result of the PTAs in our sample, with Figure 1 showing substantial variation across crops, PTAs and countries involved.

Crop Suitability and Potential Yields We retrieve information on soil suitability and potential yields for different crops within and across countries from the Global Agroecological Zones (GAEZ) project database (IIASA/FAO 2012). Pursued jointly by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied System Analysis (IIASA), the project uses detailed agronomic-based knowledge to assess land suitability and potential yields (in tons) attainable for 42 different crops. The corresponding data are freely available online and have already been used in economics and, specifically, trade studies (Arnaud Costinot and Dave Donaldson 2012; Arnaud Costinot, Dave Donaldson, Jonathan Vogel and Iván Werning 2015; Arnaud Costinot, Dave Donaldson and Cory Smith

[12]For further information on the specifics of tariff data see Leonardo Baccini, Andreas Dür and Manfred Elsig (2018). The information pertains to *ad valorem* tariffs in all cases except for Switzerland, which uses per-unit tariffs. We show later that excluding Switzerland and its PTA with Japan entirely from our sample does not meaningfully change the results. The data also does not provide information on tariff quotas and other kind of specific tariffs.

[13]It follows that the tariff cuts we consider are *de jure* and not *de facto* since countries can still set applied tariffs that are different from the negotiated ones.

[14]We exclude the European Union because there were several instances of enlargement during this time period, i.e., 1995 to 2014. The adoption of EU-negotiated tariffs on behalf of new member states provides additional variation in tariffs, but cannot be studied within the framework of our empirical strategy, which we present below. Moreover, the tariff changes that follow from gaining EU membership status are conceptually different from those that follow from the implementation of a PTA, and we therefore do not want to consider the former in the analysis.

2016). The planet is divided into grid cells of 9km x 9km and, for each of the main crops, the data provide information on suitability and potential yield at that level. We focus on total production capacity in tons per hectare under rain-fed agriculture and low levels of inputs. These production capacity estimates are solely based on agro-climatic conditions (soil and weather characteristics) in the years 1961-1990 and are therefore exogenous to changes in the technology of agricultural production that might have intervened with the implementation of PTAs.[15]

Rainfall Rainfall data are from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset, which incorporates satellite imagery with in-situ station data to create rainfall time series at the 0.05 degree resolution grid level (Funk et al. 2015).[16] We use these data to compute monthly rainfall statistics from 1989 to 2015. To merge rainfall with suitability and potential yield data, we aggregate CHIRPS monthly rainfall statistics at the GAEZ-FAO cell level, i.e., grid cells of 9km x 9km.

Growing Seasons We identify the crop and country-specific growing seasons from the Monthly Irrigated and Rainfed Crop Areas (MIRCA2000) dataset. This dataset provides the monthly growing areas of 26 irrigated and rain-fed crops with related crop calendars for 402 spatial units around the world (Portmann, Siebert and Döll 2010). We harmonize the crop classification of this dataset to the one of the GAEZ-FAO database.

Domestic Output and Trade For each country and crop in our sample, we retrieve from FAO (2019) information on the quantity produced domestically, imported, and exported in tons. Since our shock measures are built using FAO-GAEZ data on suitability and potential yields by crop, using FAO data also for production and trade is not only internally consistent, but also minimizes issues of harmonization of crop codes and definitions across datasets.[17] We

[15]One possible limitation of our analysis is that extreme changes in local-level average weather conditions may affect the estimated measure of suitability. While we argue that this is unlikely to have happened during the relatively short period of our analysis (i.e., 20 years), this cannot be completely excluded.

[16]This dataset has been shown to outperform other land surface and rainfall model products in characterizing rainfall shocks and drought events in areas with complex topography (Awange et al. 2015; Agutu et al. 2017).

[17]The data available from FAO are supplied by governments through national publications and FAO questionnaires, and supplemented with information supplied by other national or international agencies or organizations. A potential alternative source for production and trade data is the United States Department of Agriculture's Production, Supply, and Distribution (USDA-PSD). However, we can match precisely the crops in this data with those in the FAO data only for 10 crops (out of 42), 7 of them being cereals, which means that the sample size for our

consider the same time frame of the PTAs in our sample and focus on the period from 1995 to 2014.

2.2 Identifying Weather Shocks

We identify weather shocks by leveraging information on rainfall during the growing season within and across countries over time. For each country in our dataset, we identify all the GAEZ-FAO grid cells located in the country. For each one of them, we compute the long-term monthly precipitation average and standard deviation over the entire period for which rainfall data were available at the beginning of this project, i.e. 1981 to 2017. We then obtain the following standardized rainfall measure

$$r_{cimt} = \frac{R_{cimt} - \mu_{cim}}{\sigma_{cim}} \tag{1}$$

where R_{cimt} is the amount of rainfall in cell c located in country i as recorded in month m of year t, and μ_{cim} and σ_{cim} are the monthly long-term average and standard deviation respectively in the same cell. We then define a *positive* rainfall shock dummy P_{cimt} that is equal to one if standardized rainfall are higher than 0.5, and a *negative* rainfall shock dummy N_{cimt} that is equal to one if standardized rainfall are lower than -0.5, i.e.

$$P_{cimt} = \begin{cases} 1 & \text{if} \quad r_{cimt} > 0.5 \\ 0 & \text{otherwise} \end{cases} \qquad \text{and} \quad N_{cimt} = \begin{cases} 1 & \text{if} \quad r_{cimt} < -0.5 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

As such, these dummies are equal to one if the amount of rainfall in the cell is a half standard deviation higher or lower than its monthly long-term average, thus capturing unusually high or low precipitation levels in each cell and month. We show and discuss below the results that we obtain when adopting plus and minus 0.25, 0.75, and 1 as alternative cutoffs to identify positive and negative rainfall shocks instead of the baseline value of 0.5.

We combine these rainfall shock indicators with suitability within and across countries, and

analysis would be greatly reduced.

growing calendar information across crops. Let S_{cik} be the potential production capacity or suitability of cell c in country i to produce crop k, which does not change over time. Let instead G_{cikm} be a dummy equal to one if month m belongs to the growing season of that same crop k in the same cell.[18]

The weather shock variables we employ are given by

$$\begin{aligned} \textit{Positive Shock}_{ikt} &= \sum_{c\,\in\,i}\sum_{m=1}^{12} P_{cimt} \times G_{cikm} \times S_{cik} \\ \textit{Negative Shock}_{ikt} &= \sum_{c\,\in\,i}\sum_{m=1}^{12} N_{cimt} \times G_{cikm} \times S_{cik} \end{aligned} \tag{3}$$

These measures are specific to each country, crop, and year. They encapsulate the incidence of extreme rainfall realizations that occur during the growing season of a given crop in those areas within the country that are suitable to produce that crop. Both measures are zero if no extreme rainfall is recorded in any cell in any month during the year, i.e. $P_{cimt} = N_{cimt} = 0$. They are also equal to zero if extreme rainfall happens in areas that are unsuitable to produce the crop, i.e. $S_{cik} = 0$, or they occur outside the growing season, i.e. $G_{cikm} = 0$.

We conceptualize these measures as capturing suitability-based rainfall shocks to the capacity of each country to produce a given crop. We expect high values of *Negative Shock* (i.e. negative rainfall shocks on suitable land during the growing season) to unambiguously decrease production capacity, while *Positive Shock* (i.e. positive rainfall shocks on suitable land during the growing season) can have a positive effect on agricultural output, but also a negative one in case of catastrophic outcomes (i.e., floods). The salience of these weather shock measures for domestic production capacity is an empirical question, which we take to the data using information on actual domestic output and trade.

Appendix Figures A.1 and A.2 provide a graphical representation of the variability in the weather shock measures *Positive Shock* and *Negative Shock* that we exploit in our empiri-

[18] The growing season of the same crop varies across and even within countries depending on the crop calendar. For instance, maize is cultivated in July in the northern hemisphere in Asia (e.g. Northern and North-eastern China, India, Pakistan), Southern Europe, Africa (mostly Egypt) and North America (USA, Mexico). In January, only in South-eastern China and Vietnam (Felix T. Portmann, Stefan Siebert, Christian Bauer and Petra Döll 2008).

cal analysis. Appendix Figure A.1 shows the average size of the (log) positive and negative weather shock over time across all crops and countries in our sample. Appendix Figure A.2 reports instead the mean (top) and standard deviation (bottom) of the (log) positive and negative weather shock by country across all countries and years. Taken together, they provide evidence that we have substantial variability to exploit for identification.

Appendix Table A.1 provides summary statistics for all the variables we use in the empirical analysis. Panel A shows the summary statistics for the sample used to test for the relationship between *Positive Shock*, *Negative Shock*, domestic output, and trade. In operationalizing the weather shock variables, we augment them by one and take the logarithm.[19] Panel B shows the summary statistics for the sample used to test for the relationship between the weather shock variables and tariff cuts mandated by the PTAs.

3 Empirical Strategy and Results

This section presents the empirical strategy, regression specifications, and the results that we obtain to demonstrate that weather shocks affect agricultural output and trade as well as the size of tariff cuts.

3.1 Weather Shocks, Production, and Trade

We begin our analysis by documenting that weather shocks affect agricultural domestic output and international trade. We implement the following regression specification

$$y_{ikt} = \alpha_{kt} + \phi_{it} + \beta\ \textit{Positive Shock}_{ikt} + \lambda\ \textit{Negative Shock}_{ikt} + \eta\ \textit{Suit}_{ik} + u_{ikt} \tag{4}$$

where y_{ikt} is outcome of interest – domestic output, import, or export – for crop k in country i in year t. *Positive Shock*$_{ikt}$ and *Negative Shock*$_{ikt}$ are the suitability-based weather shock measures as defined in equation (3). The α_{kt} term stands for crop $\times$ year fixed effects. These

[19] The distributions of the weather shock variables in levels is highly skewed, while this is not the case for the log distribution.

capture and net out all crop-specific time-varying determinants of production or trade volume. As such, they allow to control for differences in production technology and input usage over time that are specific to each crop but common across countries. The set of country $\times$ year fixed effects ϕ_{it} does the same for all country-specific time-varying factors, such as differences in agricultural input endowments and technology that are common to all crops within countries, as well as institutions. We also include the crop-specific country-level aggregate suitability $Suit_{ik} = \sum_{c \in i} S_{cik}$ as a control in all specifications. Notice that this is time-invariant but specific to each country and crop. u_{ikt} captures any residual determinant of the outcome of interest, which we allow to be correlated between observations belonging to the same country and year by clustering standard errors at that level. We rescale and divide the shock and suitability measures by their sample standard deviation to make reported coefficient estimates immediately interpretable as changes in the dependent variable that follow a one standard deviation increase in the independent variable of interest.

Table 2 shows the estimation results. In columns 1 to 3, we consider as dependent variable the log of domestic output. Evidence shows that positive rainfall shocks on suitable land during the growing season increase the quantity produced of a given crop. In contrast, negative shocks decrease it. The corresponding coefficient estimates are significant at the 1 and 10% levels respectively. A one standard deviation increase in *Positive Shock* (*Negative Shock*) increases (decreases) domestic output by 43% (40%). As expected, higher aggregate suitability is associated with higher domestic output. In columns 4 to 6, we consider as the dependent variable the log of imported quantities. The coefficient associated with the weather shock measures have the opposite sign than in columns 1 to 3, suggesting that a positive shock and a negative shock that affect a specific crop respectively decrease and increase imports of that crop. This effect is significant at the 1% level for negative rainfall shocks, with the estimate being much larger in magnitude than for positive rainfall shocks. Finally, columns 7 to 9 show the results when the dependent variable is the log of exported quantity. As expected, the coefficients of *Positive Shock* and *Negative Shock* have the same sign as for the case of the domestic output, and the opposite for imports. Although a positive weather shock does not significantly increase exports, a negative weather shock significantly reduces exported quantities, more than it does for the domestic output. The corresponding estimated coefficient is significant at the 10% level.

We interpret these results as indicating that the explanatory variables *Positive Shock* and *Negative Shock*, which we obtained from the interaction of rainfall, land suitability, and growing season information, are a credible source of variation in domestic production capacity, and they systematically affect agricultural trade. Evidence shows that a weather-induced increase in domestic production capacity maps into larger domestic output, lower imports, and higher exports.

A possible concern with these results is that they are obtained by linking domestic output and imported and exported quantities with shocks to production capacity that occur in the same year. In reality, the effect of these shocks may materialize with some lag. Appendix Tables A.2 and A.3 address this concern by reporting the coefficient estimates from the same regression specification, but considering two different lagged versions of *Positive Shock* and *Negative Shock*. In Table A.2, we calculate the shocks using the same formula of equation (3), but considering rainfall shocks occurred during the growing season from September of year $t-1$ to August of year t. In Table A.3, we instead simply consider rainfall shocks that occurred during the growing season in the previous year. The results are quantitatively and qualitatively similar to those reported in Table 2.

3.2 Weather Shocks and Trade Policy

Evidence from the previous section shows that weather shocks alter a country's capacity to produce and trade a given crop. We now ask if government trade policy decisions change as a result. In practice, we test if weather shocks that occur during the PTA negotiation period influence the tariff cut negotiated by partner countries.

We implement the following regression specification

$$\begin{aligned} \textit{Tariff Cut}_{ijkt} = \alpha_k + \delta_t + \phi_i + \theta_j + \beta\, \textit{Positive Shock}_{ikt-l} + \lambda\, \textit{Negative Shock}_{ikt-l} \\ + \rho\, \textit{Initial Tariff}_{ijkt} + \eta\, \textit{Suit}_{ik} + \psi\, \textit{Suit}_{jk} + v_{ijkt} \end{aligned} \tag{5}$$

where *Tariff Cut*$_{ijkt}$ is the percentage change in the tariff on crop k imposed by country i on imports from country j stipulated in the PTA signed in year t.[20] *Positive Shock*$_{ikt-l}$ and *Negative Shock*$_{ikt-l}$ are the weather shock measures for country i in some period $t-l$ before the signature year, as explained below. We let the set of crop, year, and countries fixed effects – α_k, δ_t, ϕ_i and θ_j – capture and net out average differences across crops, years, and partner countries. Because the majority of the countries in our sample take part in a single PTA, these sets of fixed effects already capture to a large extent the same variation that would be captured by PTA-specific fixed effects. We also include as additional regressors the level of tariffs before PTA implementation, *Initial Tariff*$_{ijkt}$, and the crop k aggregate suitability for each country– *Suit*$_{ik}$ and *Suit*$_{jk}$ – as additional controls.[21] v_{ijkt} captures any residual determinant of the negotiated tariff cut. We allow such residuals to be correlated between crop-level observations that belong to the same PTA by clustering standard errors at that level.

Regression specification (5) allows for possible different time lags in the effect of the weather shocks on PTA outcomes. While weather shocks have to occur before the PTA signature, it is not clear what is the appropriate time window to consider. To address this issue, we take a data-driven approach. Appendix Table A.4 shows the coefficient estimates from equation (5) that we obtain when considering positive and negative weather shocks occurring at different points in time before the PTA signature. In column 1, we consider shocks that occur in the year before the signature. In column 2, we consider the sum of shocks that occur in the previous two years. In columns 3, 4, and 5, we consider all shocks that occur in the previous 3, 5, and 7 years respectively. Above and beyond the sign and magnitude of coefficients, which we will discuss later on, results show that weather shocks that occur up to 3 years before the signature have a systematic relationship with the negotiated change in tariffs. In the following, we use this time window in estimating the parameters of equation (5).

Table 3 reports the corresponding coefficient estimates. Column 1 reports the coefficients associated with crop-specific positive and negative weather shocks during the growing season

[20]The change in tariffs is the one between baseline and the end of the PTA implementation period as recorded in the DESTA database, i.e., up to 12 years after implementation.

[21]Note that *Initial Tariff*$_{ijkt}$ has a t subscript because different PTAs are signed at different points in time, which implies that this variable is period-specific.

that occurred over the three years before the PTA signature on the tariff cut negotiated by a given country. A larger *Positive Shock*, which increases country i's production of crop k, is systematically associated with lower tariff cuts on that crop. The opposite holds for negative weather shocks: a larger *Negative Shock*, which decreases production capacity, is associated with larger tariff cuts. Point estimates are such that a one standard deviation increase in cumulated positive (negative) weather shock over the 3 years before the signature reduces (increases) the magnitude of the stipulated tariff cut by 11 (9) percentage points.[22] These estimates are significant at the 1% and 5% level, respectively. In column 2, we include as additional controls the overall (time-invariant) aggregate suitability to produce the crop for each country, which does not change the magnitude and significance of the shocks' coefficient estimates in a meaningful way.

Using these estimates, we can predict the percent reduction in tariffs that we would have observed in the absence of any rainfall-induced changes in production capacity over the sample period. Specifically, we take the estimates in column 2 of Table 3 as a benchmark, set the value of positive shocks equal to zero for all observations, and predict the associated counterfactual percent reduction in own tariffs. We calculate that, in the absence of any positive shocks, the average tariff cut mandated by the PTAs in our sample would have been at least two times higher – from 41% to 93%. Negative shocks are associated with higher tariff reductions. Yet, setting these equal to zero as well, we calculate that the average tariff cut would have still been higher – from 41% to 61% – in the absence of any climate-induced shocks to production capacity during the negotiation period.

3.3 Robustness and Additional Results

Our findings stand up to several robustness checks. In Table 3 column 3, we implement a *placebo* test. We construct the shock measures as before but now consider rainfall during non-growing season months. These shocks should not have any impact on a country's production capacity, trade, and the stipulated tariff cut. This is what the corresponding coefficient estimates

[22] Table 3 column 1 shows the same estimates reported in Table A.4 column 3, i.e. the ones obtained using the 3-year lag.

show. When included together with the original measures, shocks during the non-growing season exhibit no systematic relationship with the negotiated change in tariffs. In columns 4 and 5, we evaluate further the robustness of results by looking at shocks that occur in the year of the signature, when the negotiation is over, thinking about those as well as *placebos*. The corresponding coefficient estimates are very small in magnitude and insignificant, while those of the original shock measures remain unchanged in magnitude and highly significant.

In Table 4, we flip equation (5) and investigate the relationship between own shocks and the partner's negotiated tariff cut. The coefficient estimates have the opposite sign of those in Table 3. They are always significant for *Positive Shock*, and significant for *Negative Shock* in all but the most demanding specifications. Placebo estimates are always insignificant. These results are expected since own weather shocks to production capacity affect own and partner imports and exports in the opposite way.[23]

Next, we evaluate the robustness of the results to using different cutoffs to identify positive and negative rainfall shocks. We construct the *Positive Shock* and *Negative Shock* variables using alternative thresholds for the cell-specific dummies P_{cimt} and N_{cimt}, defined in equation (2). We replace the baseline cutoff value of 0.5 with three alternatives: 0.25, 0.75, and 1. This means we let the positive rainfall shock dummy P_{cimt} be equal to one if standardized rainfall are higher than 0.25, 0.75 or 1, respectively, and the negative rainfall shock dummy N_{cimt} be equal to one if standardized rainfall are lower than -0.25, -0.75, and -1, respectively. We report the results for own and partner tariff cuts in Appendix Tables A.6 and A.7. Although sometimes imprecise, the results are in line with those reported in Tables 3 and 4.

As mentioned before, our data are on *ad valorem* tariffs in all cases except for Switzerland, which applies exclusively per-unit tariffs. We therefore probe the robustness of our findings to excluding Switzerland and its PTA with Japan entirely from our sample. Appendix Tables A.8 shows that this does not meaningfully change the results.

Appendix Table A.9 investigates the extent to which the shocks we consider and their impact

[23] The results reported in Appendix Table A.5 show that also in this case it is meaningful to consider shocks that occur up to 3 years before the signature.

on tariffs are indeed crop-specific. This is important because the tariff cuts for a given crop are likely not negotiated in isolation, but together with other crops, and spillovers may occur. For comparison, columns 1 and 4 report the estimates shown in column 2 of Table 3 and Table 4 respectively. In columns 2, 3, 5, and 6 we include separately as additional regressors the average positive and negative shocks among all other crops that are part of the PTA. The estimated coefficients of the main, crop-specific shock measures remain relatively stable. This indicates that, while shocks appear to be weakly correlated across crops, those that are specific to each crop affect the negotiated tariff cut in an idiosyncratic manner. In column 2, we also find some evidence of spillovers as average positive shocks to other crops make the government less willing to reduce tariffs on a particular crop.

We then investigate whether the main results hold at the extensive margin by looking at whether the same climate and suitability-based shocks to domestic production capacity affect the likelihood of a given crop being included in the agreement in the first place, i.e., of experiencing any tariff cut. We implement the same regression specification in equation (5) but replace as the dependent variable a dummy equal to one if the crop is part of the agreement. Appendix Table A.10 shows the corresponding results, columns 1 to 3 focusing on own tariffs and columns 4 to 6 focusing on partner tariffs. The sign and significance of the estimated coefficients associated with weather shocks (and the *placebo* ones) are consistent with those shown in Tables 3 and 4.

Finally, we explore heterogeneity across crops. In theory, one would expect the salience of the shocks we consider and their impact to be different according to the level of storability of different crops. By spreading the shock of a good or bad harvest across a number of periods, storage is by its nature a shock absorber (Williams and Wright, 1991); thus we expect the effects to be smaller for more storable crops. We proceed as follows. First, we use the Indicative Crop Classification (ICC 1.1) to identify the following four crop categories: cereals, roots, oilseed crops, and fruits and vegetables. This classification is consistent with the classification of commodities used by GAEZ-FAO and FAOSTAT, our main sources of crop-level data. We can thus classify 24 out of the 42 crops we consider in either of these four categories, which can be ranked according to storability, with cereals being highly storable, fruits and vegetables being the least storable, and the other two categories in between.[24] We then implement the regression specification in equation (5) separately for each crop category. Appendix Table A.11 reports the corresponding results. In line with our expectations, we find the highest and most significant estimates of the impact of weather shocks on tariff cuts for fruits and vegetables, somewhat weaker results for oilseed crops, and non-significant estimates for cereals. Evidence thus suggests that the mechanisms we are able to pin down with our empirical strategy are salient in particular for less storable crops.

4 Conceptual Framework

In this section, we show that our findings on the relationship between weather shocks, production capacity, and tariffs can be interpreted through the lens of a simple political economy trade model with sector-specific inputs a la Gene M Grossman and Elhanan Helpman (1994). Our formalization follows closely the one in Giovanni Maggi and Ralph Ossa (2020).

4.1 Model

Consider as a benchmark the case of a small economy and $G + 1$ goods, with good 0 serving as the numeraire. The representative consumer in the economy has preferences given by

$$U = c_0 + \sum_{g \in G} u(c_g) \tag{6}$$

with $u'(\cdot) > 0$ and $u''(\cdot) < 0$, and where c_0 is the aggregate consumption of the numeraire good and c_g is consumption of good g. Given price p_g, let $d_g(p_g)$ be the corresponding demand function and $S_g(p_g)$ denote the associated consumer surplus.

The numeraire good is produced using only labor with constant returns to scale and a one-to-one input-output ratio. Production of the numeraire good is assumed to be positive and the equilibrium competitive so that the wage is equal to one. Production of each non-numeraire

[24] Amongst the crops in our analysis, cereals are: maize, wheat, sorghum, dryland rice, wetland rice, barley, rye, oat, foxtail millet, pearl millet, buckwheat; roots are: cassava, yam and cocoyam, white potato, sweet potato; oilseed crops are: soybean, oil palm, olive, groundnut, coconut; fruits and vegetables are: banana/plantain, carrot, citrus, onion, tomato.

good requires labor and a production input – such as capital or land – that is specific to each sector and has returns equal to $\pi_g(p_g)$.

The government chooses a specific tariff τ_g on imports. If tariffs are not prohibitive, it follows that $p_g = p_g^* + \tau$, where p_g^* is the world price of good g. Markets clear at equilibrium, so that the total quantity consumed $c_g = d_g(p_g)$ is equal to the sum of domestic production $y_g(p_g)$ and imports $m_g(p_g)$. Revenues from tariffs are given by $R_g(p_g) = \tau_g m_g(p_g)$.

The government sets the value of import tariff τ_g to maximize its payoff. It does so under the influence of producer lobbies that represent the interests of specific-factor owners. We can capture their influence with a bias parameter γ_g added as an extra weight attached to producer surplus by the government in its payoff. It follows that we can also interpret γ_g as the extra weight that the government places on producers relative to consumers in its objective function.

The government chooses the value of τ_g that maximizes

$$\Omega_g = (1 + \gamma_g)\pi_g(p_g^* + \tau_g) + S_g(p_g^* + \tau_g) + \tau_g m_g(p_g^* + \tau_g) \tag{7}$$

Assuming that Ω_g is concave, we can take the first-order condition and get the equilibrium condition

$$\frac{\tau_g}{p_g^* + \tau_g} = \gamma_g \left(\frac{z_g}{\varepsilon_g}\right) \tag{8}$$

where $z_g = y_g(p_g)/m_g(p_g)$ is the equilibrium ratio of domestic output to imports and $\varepsilon_g = -m_g'(p_g)p_g/m_g(p_g)$ is the elasticity of import demand.[25]

From equation (8) it follows that if $\gamma_g > 0$ then $\partial\tau_g/\partial z_g > 0$. If the government weighs producers more than consumers, optimal tariffs increase with the ratio of domestic output to imports. This is because when domestic output increases or imports decrease, both the positive effect of protection on producer surplus and its negative effect on consumer surplus get larger in magnitude. If the government weighs the former more than the latter, the optimal tariff

[25] Taking the first order condition we get $(1 + \gamma_g)\pi_g' + S_g' + m_g + \tau_g m_g' = 0$. Hotelling's lemma implies that $\pi_g' = y_g$. We also know that $S_g' = u_g' d_g' - d_g - p_g d_g' = -d_g = -(y_{ig} + m_{ig})$, so that equation (8) follows.

increases.[26]

A similar condition holds in the case of ad valorem tariffs. In this case we have $p_g = p_g^*(1+\tau_g)$ which implies that the derivative of the domestic price with respect to the tariff is equal to the world price, i.e. $p_g' = p_g^*$. The expression for government revenues also changes as they will be now equal to $R_g(p_g) = p_g^* \tau_g m_g$. The equilibrium ad valorem tariff satisfies:[27]

$$\frac{\tau_g}{1+\tau_g} = \gamma_g \left(\frac{z_g}{\varepsilon_g}\right) \tag{9}$$

As in the previous case, if $\gamma_g > 0$ then $\partial \tau_g / \partial z_g > 0$.[28]

This discussion makes it clear that the relationship between the ratio of domestic output to imports and tariffs at equilibrium is informative of the weight that the government places on producers relative to consumers in its objective function. We show in Appendix B that this result is generalizable to a setting with two large countries in which domestic and foreign producers engage in Cournot competition.[29] We show that it also holds if the home and foreign governments set tariff levels cooperatively. These versions of the model directly speak to our empirical analysis which focuses on agricultural products and tariffs on their imports across a large number of PTAs. Agricultural markets are often presented as a textbook example of a Cournot market setting since agricultural producers make production plans infrequently, and

[26]In the words of Gene M Grossman and Elhanan Helpman (1994): *"In sectors with a large domestic output, the specific factor-owners have much to gain from an increase in the domestic price, while (for a given import demand elasticity) the economy has relatively little to lose from protection when the volume of imports is low."* Giovanni Maggi and Andrés Rodríguez-Clare (2000) show how this prediction depends critically on the assumptions that trade taxes are the only policy instruments and that the government has access to non-distortionary taxation. They propose an extended model where the government is allowed to use quantitative restrictions in addition to trade taxes, and where raising public funds is costly, and show the conditions under which the relationship between import penetration and tariffs goes in the opposite direction.

[27]The first order condition of the government problem becomes $(1+\gamma_g)\pi_g' p_g^* + S_g' p_g^* + p_g^* m_g + \tau_g {p_g^*}^2 m_g' = 0$ from which it follows that

$$\tau_g p_g^* = \frac{\gamma_g y_g}{-m_g'}$$

which can be rewritten as in equation (9). Note that this result maps closely to Proposition 2 in Gene M Grossman and Elhanan Helpman (1994) as they also consider ad valorem tariffs.

[28]Notice also that if the government's objective is simply to maximize revenues then the equilibrium conditions in the case of specific tariff and ad valorem tariff become respectively $\frac{\tau_g}{p_g^*+\tau_g} = \frac{1}{\varepsilon_g}$ and $\frac{\tau_g}{1+\tau_g} = \frac{1}{\varepsilon_g}$ so that, as in the basic inverse elasticity Ramsey rule, tariffs are uniquely determined by import elasticity and are independent from import penetration.

[29]This is similar to Paulo Bastos, Odd Rune Straume and Jaime A. Urrego (2013) who obtain the same results in a model of international oligopoly.

once production decisions are made it is difficult to adjust their output levels because of fixed costs or investment in specialized capacity (M.J. Osborne 2009).[30]

4.2 Discussion

Our empirical analysis shows that weather-induced positive (negative) changes in domestic production capacity that materialize during the negotiation period cause a smaller (larger) negotiated tariff cut. When interpreted through the lens of the model, these results indicate that governments place more weight on producers relative to consumers in their objective function. This interpretation is further validated by the results on the effect of weather shock on partner countries. If governments attach more weight to producers relative to consumers in their objective function, we should expect partner tariffs to change in the opposite direction with respect to own tariffs. This is exactly what our results show.

The rainfall and suitability-based shocks that we consider are transitory. Indeed, the corresponding measures are defined by looking at monthly deviations of rainfall from their long-term average at the cell level in each country. If government officials had full information about domestic production capacity, they would acknowledge the transitory nature of these shocks, and not change their behavior at the PTA negotiation table. For these shocks to have any impact, it must be the case that governments regard changes in agricultural production that come with weather shocks as permanent to at least some extent. This is rational if they believe that climate change will make weather shocks more frequent in the future. In sum, evidence suggests that governments update their beliefs over their countries' agricultural production capacity in response to weather shocks.

[30] David M. Kreps and Jose A. Scheinkman (1983) show that the Cournot equilibrium quantity is also the equilibrium production decision of oligopolistic firms in a setting where, in the first stage, they decide independently and simultaneously how much they will produce, and subsequently bring these quantities to market, each learns how much the other produced, and engage in Bertrand-like price competition.

5 Conclusion

Climate change and its effects occupy the center stage in domestic and international policy. There is an increasing awareness that extreme weather events are becoming increasingly more severe and frequent. In particular, it is projected that anthropogenic warming will lead to an increase in the intensity of extremely high and low rainfall (Lenderink and Fowler 2017). This will most likely alter agricultural production capacity and international trade.

We provide direct evidence that weather shocks impact agricultural output and trade, and affect government trade policy decisions. In doing so, they reveal that governments place more weight on producers relative to consumers in their objective function.

Our analysis combines theory and empirics. First, we show that weather shocks impact domestic output and trade. We capture these shocks using granular information on crop soil suitability within countries and rainfall during the growing season of different crops. We then show that changes in production capacity that come with weather shocks impact the size of tariff cuts stipulated in PTAs. When a positive weather shock increases domestic production capacity, governments negotiate smaller tariff cuts. This effect is symmetric for negative weather shocks, which cause larger tariff cuts. According to our estimates, the average tariff cut stipulated in the PTAs in our sample would have been at least two times higher in the absence of any rainfall-induced increases in production capacity during the negotiation period.

We make sense of these results using a simple political economy trade model with sector-specific inputs. When interpreted through its lens, our findings suggest that during trade negotiations governments place more weight on producers relative to consumers in their objective function. Our study reveals that climate change affects trade policy by shaping the incentives of special interest groups, which are ultimately reflected in government decision-making.

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Tables and Figures

Table 1: List of Preferential Trade Agreements by Country Pair

Signature Year	Partner A	Partner B	Signature Year	Partner A	Partner B
1996	Canada	Israel	2007	Japan	Indonesia
1996	Canada	Chile	2007	USA	South Korea
2000	USA	Jordan	2008	Australia	Chile
2000	USA	Vietnam	2008	Japan	Brunei (ASEAN)
2001	Canada	Costa Rica	2008	Japan	Cambodia (ASEAN)
2002	Japan	Singapore	2008	Japan	Indonesia (ASEAN)
2003	Australia	Singapore	2008	Japan	Laos (ASEAN)
2003	USA	Chile	2008	Japan	Malaysia (ASEAN)
2004	Australia	Thailand	2008	Japan	Myanmar (ASEAN)
2004	China	Brunei (ASEAN)	2008	Japan	Philippines (ASEAN)
2004	China	Cambodia (ASEAN)	2008	Japan	Singapore (ASEAN)
2004	China	Indonesia (ASEAN)	2008	Japan	Thailand (ASEAN)
2004	China	Malaysia (ASEAN)	2008	Japan	Vietnam (ASEAN)
2004	China	Myanmar (ASEAN)	2008	China	New Zealand
2004	China	Philippines (ASEAN)	2008	Canada	Peru
2004	China	Singapore (ASEAN)	2008	China	Singapore
2004	China	Thailand (ASEAN)	2008	Canada	Colombia
2004	China	Vietnam (ASEAN)	2009	Australia	Brunei (ASEAN)
2004	USA	Australia	2009	Australia	Cambodia (ASEAN)
2004	USA	Costa Rica (CAFTA)	2009	Australia	Indonesia (ASEAN)
2004	USA	Dominican Republic (CAFTA)	2009	Australia	Laos (ASEAN)
2004	USA	El Salvador (CAFTA)	2009	Australia	Malaysia (ASEAN)
2004	USA	Guatemala (CAFTA)	2009	Australia	Myanmar (ASEAN)
2004	USA	Honduras (CAFTA)	2009	Australia	Philippines (ASEAN)
2004	USA	Nicaragua (CAFTA)	2009	Australia	Singapore (ASEAN)
2004	USA	Morocco	2009	Australia	Thailand (ASEAN)
2004	USA	Bahrain	2009	Australia	Vietnam (ASEAN)
2005	Japan	Malaysia	2009	Japan	Switzerland
2005	China	Chile	2009	China	Peru
2006	China	Pakistan	2009	Canada	Jordan
2006	Japan	Philippines	2010	Canada	Panama
2006	USA	Oman	2010	China	Costa Rica
2006	USA	Peru	2011	Japan	India
2006	USA	Colombia	2011	Japan	Peru
2007	Japan	Brunei	2012	Australia	Malaysia
2007	Japan	Chile	2013	Canada	Honduras

Notes. The table lists the PTAs that we consider in our analysis. These are all PTAs signed between 1995 and 2014 that involve at least one of following major economies as partner: Australia, Canada, China, Japan, United States, and for which data on the negotiated tariff cuts are available at the product level.

Table 2: Weather Shocks, Domestic Output, and Trade

	Domestic Output			Imports			Exports		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Positive Shock	0.433***		0.426***	-0.295*		-0.244	0.180		0.157
	(0.140)		(0.139)	(0.157)		(0.154)	(0.168)		(0.167)
Negative Shock		-0.410*	-0.395*		0.731***	0.703***		-0.495*	-0.483*
		(0.211)	(0.212)		(0.235)	(0.233)		(0.256)	(0.259)
Own Crop Suitability	0.773***	1.582***	1.165***	0.271*	-0.720***	-0.463*	1.203***	1.859***	1.700***
	(0.129)	(0.198)	(0.242)	(0.156)	(0.230)	(0.269)	(0.172)	(0.257)	(0.324)
Crop × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11803	11803	11803	12136	12136	12136	11377	11377	11377
R^2	0.673	0.673	0.674	0.567	0.568	0.568	0.575	0.575	0.575

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is a crop by country and year. The dependent variable is the log of quantity produced domestically (columns 1 and 2), imported (columns 3 and 4) and exported (columns 5 and 6) in tons. Shocks are calculated using the formula in equation (3) but using alternative thresholds for the cell-specific dummies P_{cimt} and N_{cimt}, defined in equation (2). Clustered standard errors at the country-year level.

Table 3: Weather Shocks and Negotiated Change in Own Import Tariffs

	Own Tariff Cut (%)				
	(1)	(2)	(3)	(4)	(5)
Positive Shock	-0.111***	-0.139***	-0.141***	-0.114**	-0.106**
$(t-3, t-1)$	(0.038)	(0.042)	(0.043)	(0.049)	(0.049)
Negative Shock	0.087**	0.098**	0.090**	0.104**	0.104**
$(t-3, t-1)$	(0.039)	(0.039)	(0.040)	(0.045)	(0.044)
Positive Shock			-0.051		-0.047
Non-growing Season $(t-3, t-1)$			(0.094)		(0.095)
Negative Shock			0.077		0.076
Non-growing Season $(t-3, t-1)$			(0.092)		(0.093)
Positive Shock				-0.010	-0.013
t				(0.008)	(0.008)
Negative Shock				0.001	-0.002
t				(0.010)	(0.011)
Own Initial Tariff	0.194***	0.194***	0.194***	0.194***	0.194***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Own Crop Suitability		0.028***	0.029***	0.028***	0.029***
		(0.010)	(0.011)	(0.010)	(0.010)
Partner Crop Suitability		0.003	0.003	0.003	0.003
		(0.007)	(0.007)	(0.007)	(0.007)
Own Country FE	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035
R^2	0.641	0.642	0.643	0.642	0.643

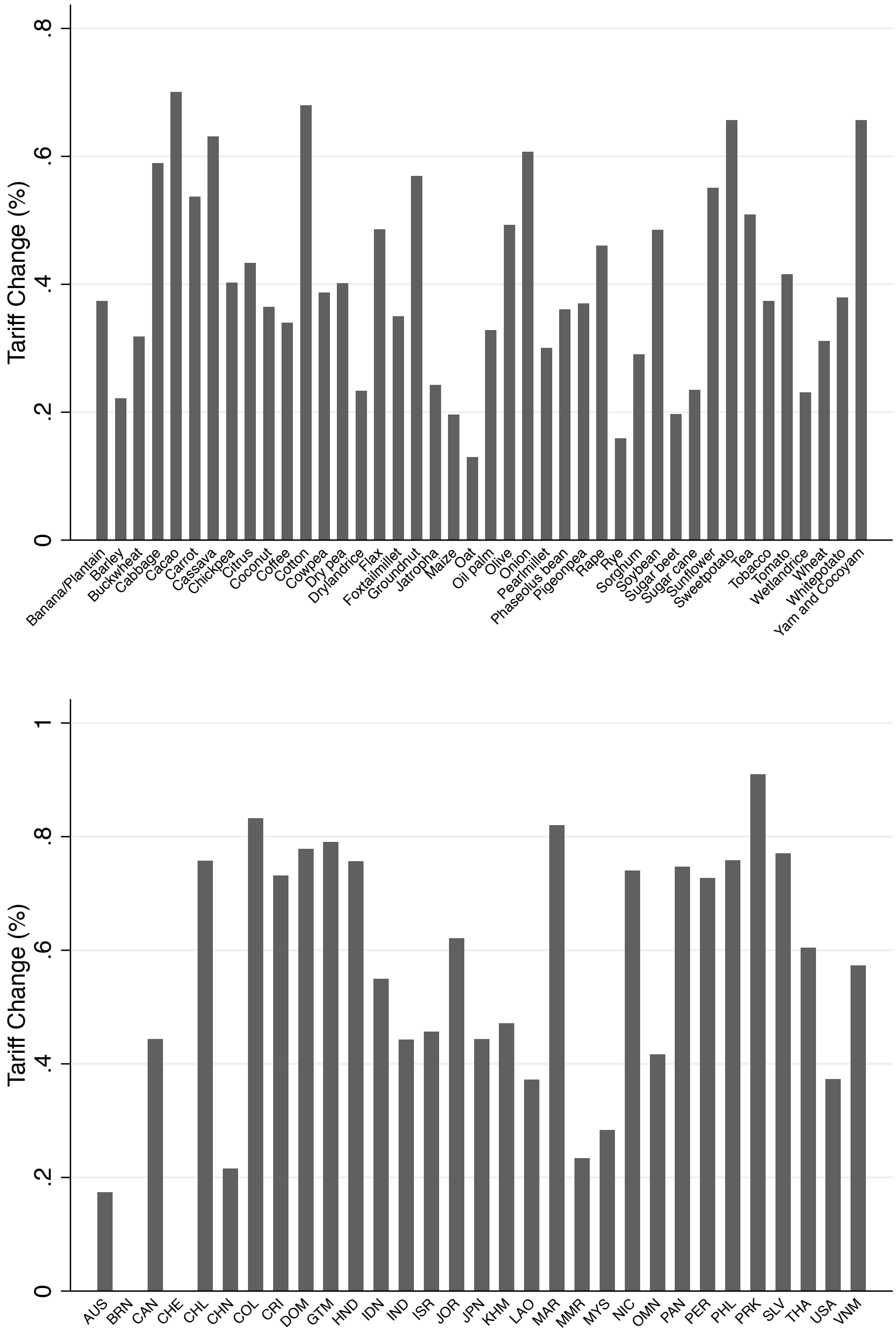
Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table 4: Weather Shocks and Negotiated Change in Partner Import Tariffs

	Partner Tariff Cut (%)				
	(1)	(2)	(3)	(4)	(5)
Positive Shock	0.086**	0.084**	0.085**	0.123**	0.125**
$(t-3, t-1)$	(0.033)	(0.036)	(0.037)	(0.051)	(0.052)
Negative Shock	-0.083**	-0.082**	-0.081**	-0.041	-0.040
$(t-3, t-1)$	(0.034)	(0.034)	(0.035)	(0.031)	(0.031)
Positive Shock			-0.014		-0.040
Non-growing Season $(t-3, t-1)$			(0.055)		(0.060)
Negative Shock			0.005		0.032
Non-growing Season $(t-3, t-1)$			(0.053)		(0.058)
Positive Shock				-0.006	-0.006
t				(0.006)	(0.006)
Negative Shock				-0.017*	-0.018*
t				(0.010)	(0.011)
Partner Initial Tariff	0.209***	0.209***	0.209***	0.209***	0.209***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Own Crop Suitability		0.002	0.002	-0.002	-0.000
		(0.011)	(0.011)	(0.011)	(0.011)
Partner Crop Suitability		0.001	0.001	0.001	0.001
		(0.006)	(0.006)	(0.006)	(0.006)
Own Country FE	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035
R^2	0.656	0.656	0.656	0.656	0.656

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated partner import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Figure 1: Average Tariff Cut by Crop and Countries



Notes. The top figure shows the average recorded percentage change in tariff by crop for the entire sample of PTAs that we consider in our analysis. The bottom figure shows instead the average tariff cut by partner country.

A Appendix: Additional Tables and Figures

Table A.1: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	Obs.
	Panel A. Domestic Production and Trade Sample				
Year	2004.542	5.767	1995	2014	14301
Domestic Production (Million Tonnes)	5.246	23.617	0	361.091	11803
Imported Quantity (Million Tonnes)	0.262	1.799	0	73.812	12143
Exported Quantity (Million Tonnes)	0.381	2.978	0	60.24	11434
Log of Positive Weather Shock	13.286	3.584	0	19.878	14301
Log of Negative Weather Shock	13.55	3.472	0	20.159	14301
Log of Positive Weather Shock (Aug$_{t-1}$,Sept$_t$)	13.293	3.573	0	19.811	14301
Log of Negative Weather Shock (Aug$_{t-1}$,Sept$_t$)	13.555	3.474	0	20.166	14301
Log of Positive Weather Shock at $t-1$	13.299	3.584	0	19.878	13557
Log of Negative Weather Shock at $t-1$	13.544	3.478	0	20.159	13557
Log of Crop Suitability	12.771	3.245	1.099	18.967	14301
	Panel B. PTA Sample				
Signature Year	2006.471	3.059	1996	2013	4035
Own Initial Tariff	9.34	18.642	0	391.2	4035
Partner Initial Tariff	8.242	20.992	0	391.2	4035
Negotiated Own Tariff	3.674	10.47	0	107.25	4035
Negotiated Partner Tariff	2.073	7.375	0	108.165	4035
% Change in Own Tariff	0.406	0.389	0	0.997	4035
% Change in Partner Tariff	0.414	0.397	0	0.997	4035
Log of Own Positive Weather Shock at $t-1$	14.53	3.231	0	19.551	4035
Log of Own Negative Weather Shock at $t-1$	14.753	3.331	0	20.156	4035
Log of Own Positive Weather Shock $(t-2, t-1)$	15.269	3.19	0	20.361	4035
Log of Own Negative Weather Shock $(t-2, t-1)$	15.476	3.299	0	20.703	4035
Log of Own Positive Weather Shock $(t-3, t-1)$	15.651	3.164	1.609	20.759	4035
Log of Own Negative Weather Shock $(t-3, t-1)$	15.939	3.258	0	21.096	4035
Log of Own Positive Weather Shock $(t-5, t-1)$	15.922	3.155	1.609	21.08	4035
Log of Own Negative Weather Shock $(t-5, t-1)$	16.229	3.284	0	21.418	4035
Log of Own Positive Weather Shock $(t-7, t-1)$	16.319	3.156	1.946	21.487	4035
Log of Own Negative Weather Shock $(t-7, t-1)$	16.656	3.27	0	21.771	4035
Log of Own Crop Suitability	14.481	2.702	1.609	19.02	4035
Log of Partner Crop Suitability	10.998	5.741	0	19.02	4035

Notes. The table reports summary statistics for all the variables we use in the empirical analysis. The top panel shows the summary statistics for the sample used to explore the relationship between rainfall and suitability-based shocks, domestic output, and imports. The bottom panel reports the summary statistics for the PTA sample, where we look at the relationship between rainfall and suitability-based shocks and negotiated tariff cut.

Table A.2: Weather Shocks, Domestic Output, and Trade
Lagged Weather Shocks: August$_{t-1}$ to September$_t$

	Domestic Output			Imports			Exports		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Positive Shock	0.443***		0.445***	-0.252		-0.213	0.079		0.060
August$_{t-1}$ to September$_t$	(0.149)		(0.147)	(0.168)		(0.164)	(0.194)		(0.193)
Negative Shock		-0.270	-0.276		0.591***	0.570***		-0.450*	-0.447*
August$_{t-1}$ to September$_t$		(0.227)	(0.229)		(0.220)	(0.219)		(0.253)	(0.254)
Own Crop Suitability	0.761***	1.445***	1.028***	0.232	-0.583***	-0.361	1.298***	1.814***	1.754***
	(0.138)	(0.211)	(0.256)	(0.168)	(0.216)	(0.259)	(0.193)	(0.255)	(0.328)
Crop × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11803	11803	11803	12136	12136	12136	11377	11377	11377
R^2	0.673	0.673	0.673	0.567	0.567	0.568	0.575	0.575	0.575

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is a crop by country and year. The dependent variable is the log of quantity produced domestically (columns 1 and 2), imported (columns 3 and 4) and exported (columns 5 and 6) in tons. Shocks are calculated using the formula in equation (3), but considering rainfall shocks and growing season months from August of year $t-1$ to September of year t. Clustered standard errors at the country-year level.

Table A.3: Weather Shocks, Domestic Output, and Trade
Lagged Weather Shocks: Year $t-1$

	Domestic Output			Imports			Exports		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Positive Shock	0.431***		0.422***	-0.253		-0.211	0.038		0.015
$t-1$	(0.139)		(0.137)	(0.165)		(0.160)	(0.177)		(0.176)
Negative Shock		-0.430**	-0.415*		0.609**	0.586**		-0.458*	-0.457*
$t-1$		(0.215)	(0.216)		(0.247)	(0.245)		(0.248)	(0.249)
Own Crop Suitability	0.772***	1.598***	1.186***	0.236	-0.597**	-0.375	1.332***	1.819***	1.804***
	(0.129)	(0.202)	(0.244)	(0.166)	(0.239)	(0.278)	(0.179)	(0.249)	(0.317)
Crop $\times$ Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country $\times$ Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11212	11212	11212	11529	11529	11529	10828	10828	10828
R^2	0.674	0.674	0.674	0.567	0.567	0.567	0.576	0.576	0.576

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is a crop by country and year. The dependent variable is the log of quantity produced domestically (columns 1 and 2), imported (columns 3 and 4) and exported (columns 5 and 6) in tons. Shocks are calculated using the formula in equation (3), but considering rainfall shocks and growing season months in the previous year. Clustered standard errors at the country-year level.

Table A.4: Weather Shocks and Negotiated Change in Own Import Tariffs
Alternative Time Windows for Weather Shocks

	Own Tariff Cut (%)				
	(1)	(2)	(3)	(4)	(5)
Positive Shock $t-1$	-0.066*** (0.018)				
Negative Shock $t-1$	0.043** (0.018)				
Positive Shock $(t-2, t-1)$		-0.101*** (0.022)			
Negative Shock $(t-2, t-1)$		0.078*** (0.022)			
Positive Shock $(t-3, t-1)$			-0.111*** (0.029)		
Negative Shock $(t-3, t-1)$			0.087*** (0.030)		
Positive Shock $(t-5, t-1)$				-0.054** (0.027)	
Negative Shock $(t-5, t-1)$				0.029 (0.027)	
Positive Shock $(t-7, t-1)$					-0.039 (0.028)
Negative Shock $(t-7, t-1)$					0.014 (0.028)
Own Initial Tariff	0.194*** (0.006)	0.194*** (0.006)	0.194*** (0.006)	0.194*** (0.006)	0.194*** (0.006)
Own Country FE	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035
R^2	0.641	0.642	0.641	0.641	0.641

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.5: Weather Shocks and Negotiated Change in Partner Import Tariffs
Alternative Time Windows for Weather Shocks

	Partner Tariff Cut (%)				
	(1)	(2)	(3)	(4)	(5)
Positive Shock $t-1$	0.043*** (0.016)				
Negative Shock $t-1$	-0.040** (0.016)				
Positive Shock $(t-2,t-1)$		0.051*** (0.019)			
Negative Shock $(t-2,t-1)$		-0.048** (0.019)			
Positive Shock $(t-3,t-1)$			0.086*** (0.029)		
Negative Shock $(t-3,t-1)$			-0.083*** (0.029)		
Positive Shock $(t-5,t-1)$				-0.011 (0.028)	
Negative Shock $(t-5,t-1)$				0.015 (0.028)	
Positive Shock $(t-7,t-1)$					0.007 (0.029)
Negative Shock $(t-7,t-1)$					-0.003 (0.029)
Partner Initial Tariff	0.209*** (0.006)	0.209*** (0.006)	0.209*** (0.006)	0.209*** (0.006)	0.209*** (0.006)
Own Country FE	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035
R^2	0.656	0.656	0.656	0.655	0.655

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated partner import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.6: Weather Shocks and Negotiated Change in Own Tariff Cut
Different Cut-offs To Measure Rainfall Shocks

	Own Tariff Cut (%)					
	Cut-off = 0.25		Cut-off = 0.75		Cut-off = 1	
	(1)	(2)	(3)	(4)	(5)	(6)
Positive Shock	-0.120**	-0.153**	-0.065***	-0.082***	-0.054**	-0.066***
$(t-3, t-1)$	(0.055)	(0.059)	(0.024)	(0.036)	(0.022)	(0.023)
Negative Shock	0.096*	0.111*	0.040	0.042	0.028	0.025
$(t-3, t-1)$	(0.055)	(0.057)	(0.024)	(0.027)	(0.021)	(0.022)
Own Initial Tariff	0.194***	0.194***	0.194***	0.194***	0.194***	0.194***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Own Crop Suitability		0.028***		0.024**		0.023**
		(0.010)		(0.011)		(0.009)
Partner Crop Suitability		0.003		0.002		0.002
		(0.007)		(0.007)		(0.007)
Own Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035	4035
R^2	0.641	0.642	0.641	0.642	0.641	0.642

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3) but using alternative thresholds for the cell-specific dummies P_{cimt} and N_{cimt}, defined in equation (2). Clustered standard errors at the country-year level. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.7: Weather Shocks and Negotiated Change in Partner Tariff Cut
Different Cut-offs To Measure Rainfall Shocks

	Partner Tariff Cut (%)					
	Cut-off = 0.25		Cut-off = 0.75		Cut-off = 1	
	(1)	(2)	(3)	(4)	(5)	(6)
Positive Shock	0.109**	0.107**	0.048**	0.046**	0.056***	0.054***
$(t-3, t-1)$	(0.045)	(0.050)	(0.018)	(0.021)	(0.016)	(0.018)
Negative Shock	-0.106**	-0.105**	-0.044**	-0.044**	-0.052***	-0.052***
$(t-3, t-1)$	(0.046)	(0.047)	(0.018)	(0.018)	(0.016)	(0.016)
Own Initial Tariff	0.209***	0.209***	0.209***	0.209***	0.209***	0.209***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Own Crop Suitability		0.001		0.003		0.003
		(0.011)		(0.011)		(0.011)
Partner Crop Suitability		0.001		0.002		0.002
		(0.006)		(0.006)		(0.006)
Own Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035	4035
R^2	0.656	0.657	0.656	0.656	0.656	0.657

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated partner import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3) but using alternative thresholds for the cell-specific dummies P_{cimt} and N_{cimt}, defined in equation (2). Clustered standard errors at the country-year level. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.8: Weather Shocks and Negotiated Change in Own Tariff Cut
Robustness to Excluding Switzerland-Japan PTA

	Own Tariff Cut (%)				
	(1)	(2)	(3)	(4)	(5)
Positive Shock	-0.108***	-0.134***	-0.136***	-0.110**	-0.102**
$(t-3, t-1)$	(0.038)	(0.042)	(0.043)	(0.049)	(0.049)
Negative Shock	0.083**	0.092**	0.085**	0.098**	0.098**
$(t-3, t-1)$	(0.039)	(0.039)	(0.040)	(0.046)	(0.045)
Positive Shock			-0.056		-0.052
Non-growing Season $(t-3, t-1)$			(0.094)		(0.096)
Negative Shock			0.081		0.081
Non-growing Season $(t-3, t-1)$			(0.092)		(0.094)
Positive Shock				-0.010	-0.013
t				(0.008)	(0.008)
Negative Shock				0.001	-0.002
t				(0.011)	(0.011)
Own Initial Tariff	0.194***	0.194***	0.194***	0.194***	0.194***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Own Crop Suitability		0.026**	0.028**	0.027***	0.028**
		(0.010)	(0.011)	(0.010)	(0.010)
Partner Crop Suitability		0.001	0.001	0.001	0.001
		(0.007)	(0.007)	(0.007)	(0.007)
Own Country FE	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	3978	3978	3978	3978	3978
R^2	0.640	0.641	0.641	0.641	0.641

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.9: Weather Shocks and Negotiated Tariff Cut Across Crops

	Own Tariff Cut (%)			Partner Tariff Cut (%)		
	(1)	(2)	(3)	(4)	(5)	(6)
Positive Shock	-0.139***	-0.074*	-0.103**	0.084**	0.067*	0.071*
$(t-3, t-1)$	(0.042)	(0.043)	(0.041)	(0.036)	(0.034)	(0.041)
Negative Shock	0.098**	-0.009	0.073*	-0.082**	-0.055	-0.074*
$(t-3, t-1)$	(0.039)	(0.041)	(0.037)	(0.034)	(0.034)	(0.038)
Avg. Pos. Shock Other Crops		-1.214***			0.312	
$(t-3, t-1)$		(0.231)			(0.219)	
Avg. Neg. Shock Other Crops			0.314			-0.109
$(t-3, t-1)$			(0.216)			(0.136)
Own Initial Tariff	0.194***	0.194***	0.194***			
	(0.011)	(0.011)	(0.011)			
Partner Initial Tariff				0.209***	0.209***	0.209***
				(0.013)	(0.013)	(0.013)
Own Crop Suitability	0.028***	0.024**	0.025**	0.002	0.003	0.003
	(0.010)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)
Partner Crop Suitability	0.003	-0.001	0.003	0.001	0.002	0.001
	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Own Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035	4035
R^2	0.642	0.648	0.643	0.656	0.656	0.656

Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.10: Weather Shocks and Negotiated Tariff Cut
Results Along the Extensive Margin

	Any Own Tariff Cut {0,1}			Any Partner Tariff Cut {0,1}		
	(1)	(2)	(3)	(4)	(5)	(6)
Positive Shock	-0.101**	-0.106**	-0.111**	0.166***	0.167***	0.169***
$(t-3, t-1)$	(0.043)	(0.046)	(0.047)	(0.053)	(0.056)	(0.056)
Negative Shock	0.073*	0.079*	0.077*	-0.159***	-0.162***	-0.160***
$(t-3, t-1)$	(0.043)	(0.043)	(0.043)	(0.054)	(0.055)	(0.055)
Positive Shock			0.082			-0.029
Non-growing Season $(t-3, t-1)$			(0.100)			(0.078)
Negative Shock			-0.054			0.013
Non-growing Season $(t-3, t-1)$			(0.099)			(0.076)
Own Initial Tariff	0.227***	0.227***	0.228***			
	(0.017)	(0.017)	(0.017)			
Partner Initial Tariff				0.252***	0.253***	0.252***
				(0.016)	(0.016)	(0.016)
Own Crop Suitability		0.003	0.000		-0.000	0.001
		(0.013)	(0.014)		(0.013)	(0.013)
Partner Crop Suitability		0.010	0.010		-0.006	-0.006
		(0.009)	(0.009)		(0.007)	(0.007)
Own Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4035	4035	4035	4035	4035	4035
R^2	0.567	0.567	0.567	0.646	0.646	0.646

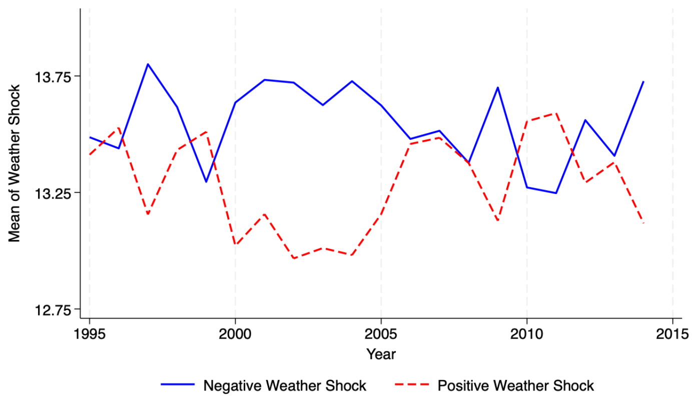
Notes. (* p-value$<$ 0.1; ** p-value$<$0.05; *** p-value$<$0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3). Shocks during the growing season are calculated by only considering months during the growing season of the crop. Non-growing season shocks are calculated by only considering months during the non-growing season. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Table A.11: Weather Shocks and Negotiated Change in Own Tariff Cut Heterogeneity Across Crops

	Own Tariff Cut (%)							
	Cereals		Roots		Oilseed Crops		Fruits and Vegetables	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Positive Shock	0.033	0.113	-0.252	-0.185	-0.180*	-0.166	-0.839***	-0.875***
	(0.062)	(0.071)	(0.188)	(0.178)	(0.107)	(0.109)	(0.166)	(0.175)
Negative Shock	-0.089	-0.116*	0.275	0.142	0.204*	0.226**	0.924***	0.884***
	(0.061)	(0.068)	(0.204)	(0.190)	(0.109)	(0.109)	(0.174)	(0.181)
Own Initial Tariff	0.121***	0.114***	0.254***	0.256***	0.283***	0.285***	0.203***	0.206***
	(0.024)	(0.025)	(0.035)	(0.034)	(0.025)	(0.026)	(0.023)	(0.022)
Own Crop Suitability		-0.073***		0.102**		-0.040		0.093**
		(0.019)		(0.041)		(0.035)		(0.039)
Partner Crop Suitability		0.028		-0.010		0.004		-0.001
		(0.020)		(0.028)		(0.017)		(0.032)
Own Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Partner Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Crop FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	912	912	403	403	440	440	539	539
R^2	0.569	0.580	0.769	0.775	0.759	0.760	0.779	0.781

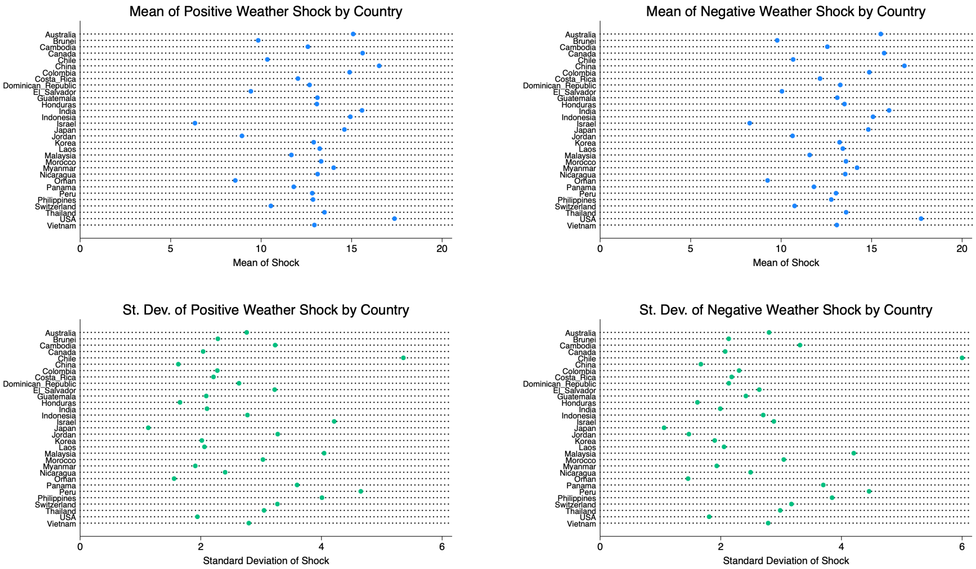
Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) The unit of observation is crop by PTA. The dependent variable is the percentage difference in negotiated own import tariffs between baseline and 12 years after the implementation of the PTA. Shocks are calculated using the formula in equation (3) but using alternative thresholds for the cell-specific dummies P_{cimt} and N_{cimt}, defined in equation (2). Clustered standard errors at the country-year level. Suitability and shock variables are in log. Clustered standard errors at the country pair-year level.

Figure A.1: Mean of Weather Shock Variables Through Time



Notes. The figure shows the average size of the (log) positive and negative weather shocks over time across all crops and countries in our sample.

Figure A.2: Weather Shock Variables Statistics by Country



Notes. The figures report the mean (top) and standard deviation (bottom) of the (log) positive and negative weather shocks by country across all countries and years in our sample.

B Theory Appendix

We here show that the main theoretical result of Section 4 is generalizable to a setting with two large countries in which domestic and foreign producers engage in Cournot competition. We show that it also holds if the home and foreign government sets tariff levels cooperatively.

Consider two countries, home (H) and foreign (F), and two goods, N and M, with good N serving as numeraire. Both goods are produced in both countries by single independent producers using inputs that are specific to each good. The marginal cost of producing good N is equal to one in both countries. The home producer of good M has marginal cost equal to c while the foreign producer has marginal cost equal to one. It follows that c also measures the inverse comparative advantage of country H in producing good M.

The representative consumer in country H has preferences given by $U = C_N + u(C_M)$. We assume $u(C_M) = vC_M - \frac{C_M^2}{2}$, where v is a positive parameter. The analysis that follows focuses on good M, exchanged in country H at price p. The corresponding demand curve is $D(p) = v - p$ and consumer surplus is $S(p) = u(D(p)) - pD(p) = D^2(p)/2$.

The home government chooses a specific tariff τ on imports. If tariffs are not prohibitive, it follows that $p = p^* + \tau$, where p and p^* are the prices charged by the domestic and foreign producer respectively. The quantities produced are given by q and q^* respectively. At equilibrium, the marginal utility of the representative consumer equals the market price, and the total quantity consumed is equal to the total quantity produced so that $v - q - q^* = p = p^* + \tau$.

The domestic and foreign producers engage in Cournot competition. They take each other's produced quantity as given and choose the level of q and q^* respectively that maximize their profits

$$\begin{aligned} \Pi &= pq - cq = (v - q - q^*)q - cq \\ \Pi^* &= p^*q^* - q^* = (v - \tau - q - q^*)q^* - q^* \end{aligned} \tag{1}$$

Taking the first order conditions and solving the system of two equations in two unknowns we get

$$q(\tau, c, v) = \frac{v - 2c + 1 + \tau}{3} \qquad q^*(\tau, c, v) = \frac{v - 2(1 + \tau) + c}{3} \tag{2}$$

Notice that for a given level of tariff the ratio of domestic output to imports $z = q/q^*$ decreases with c (increases with comparative advantage).

We can now plug the equilibrium quantities into the profit functions of the domestic and foreign producer and get

$$\Pi(\tau, c, v) = \left(\frac{v - 2c + 1 + \tau}{3}\right)^2 \qquad \Pi^*(\tau, c, v) = \left(\frac{v - 2(1+\tau) + c}{3}\right)^2 \tag{3}$$

We can also plug the equilibrium quantities in the consumer surplus to get

$$S(t, c, v) = \frac{(2v - c - 1 - \tau)^2}{18} \tag{4}$$

Non-cooperative Equilibrium Consider first the case in which the home government sets the level of tariff in isolation. Let γ be the weight bias parameter that captures the influence that producer lobbies have on the government. The government objective function is

$$\Omega(\tau, c, v) = (1+\gamma)\Pi(\tau, c, v) + S(\tau, c, v) + R(\tau, c, v) \tag{5}$$

and the optimal choice of tariff is given by the level of τ that maximizes it. It can be shown that[31]

$$\text{sign}\left\{\frac{\partial \tau}{\partial c}\right\} = \text{sign}\left\{(1+\gamma)\frac{\partial^2 \Pi(\tau, c, v)}{\partial \tau \partial c} + \frac{\partial^2 S(\tau, c, v)}{\partial \tau \partial c} + \frac{\partial^2 R(\tau, c, v)}{\partial \tau \partial c}\right\} \tag{6}$$

From the equilibrium expressions above we get

$$\frac{\partial^2 R(\tau, c, v)}{\partial \tau \partial c} = \frac{1}{3} \qquad \frac{\partial^2 \Pi(\tau, c, v)}{\partial \tau \partial c} = -\frac{4}{9} \qquad \frac{\partial^2 S(\tau, c, v)}{\partial \tau \partial c} = \frac{1}{9} \tag{7}$$

[31]The first order condition that implicitly defines τ is given by $\frac{\partial \Omega(\tau,c,v)}{\partial \tau} = 0$. Applying the implicit function theorem we get

$$\frac{\partial \tau}{\partial c} = -\frac{\frac{\partial^2 \Omega(\tau,c,v)}{\partial \tau \partial c}}{\frac{\partial^2 \Omega(\tau,c,v)}{\partial \tau^2}}$$

where $\partial^2 \Omega(\tau, c, v)/\partial \tau^2 < 0$ from which it follows that sign $\{\partial \tau/\partial c\} = $ sign $\{\partial^2 \Omega(\tau, c, v)/\partial \tau \partial c\}$.

Which we can substitute in equation (6). It follows that if $\gamma > 0$ then $\partial\tau/\partial c < 0$. An increase in the comparative advantage of home producers (lower c) both increases the ratio of domestic output to imports z and increases the equilibrium tariff τ, consistent with the main result of Section 4.

Cooperative Equilibrium In the cooperative equilibrium, home and foreign governments cooperatively choose the pair (τ, τ^*) of respective import tariffs that maximizes their joint payoff as given by

$$\Omega(\tau, c, v) + \Omega^*(\tau^*, c, v^*) \tag{8}$$

Assuming that the foreign country also attaches a positive weight bias γ to producers, the cooperative equilibrium choice of τ is the one that – omitting the irrelevant joint payoff components – maximizes

$$(1+\gamma)\Pi(\tau, c, v) + S(\tau, c, v) + R(\tau, c, v) + (1+\gamma)\Pi^*(\tau, c, v) \tag{9}$$

The only difference with respect to the non-cooperative case is that the objective function now includes the producer surplus of the foreign producer in the domestic market, which depends on τ. It can be easily shown that, consistent with Giovanni Maggi and Ralph Ossa (2020), the equilibrium level of tariffs in the cooperative equilibrium is lower than the non-cooperative equilibrium level, provided that v or c are high enough.

Following the same procedure as above, it can be shown that if $\gamma > -1/2$ then $\partial\tau/\partial c < 0$, again consistent with the main result of Section 4. In this case, however, a moderately negative producer weight bias is already sufficient for tariffs to increase with comparative advantage. This is because in choosing τ the government internalizes the negative impact of import tariffs on profits made by the foreign producer in the domestic market.