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Climate change increases bilateral trade costs

Maximilian Huppertz⁽¹⁾

Abstract

It is well established that climate change affects productivity, but its effects on trade costs have not been studied. I combine international trade and weather data covering 190 years. I use an augmented gravity framework to show that rising temperatures at the origin or destination country increase bilateral trade costs. Adaptation to these impacts is slow. The impact appears to be driven by the vulnerability of sea ports to climate change. Combining these results with a standard international trade model, I find that 2010s welfare would increase by 1.6% if we could undo the impact of climate change on trade cost over the preceding 100 years. Welfare gains depend not only on countries' own climate trends, but also on their neighbours' trajectories. Poor and rich countries are roughly equally harmed. Smaller economies, which are more reliant on international trade, are especially affected. Ignoring this trade cost channel and focusing only on productivity effects leads to a 9% underestimate of the welfare impact of climate change. Because it is based on a gravity framework, my methodology can easily be embedded in studies of the impact of climate change.

Key words: Climate change, international trade, sea ports, welfare impacts, adaptation.

JEL classification: Q54, Q56, F18.

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Analyses of the economic effect of climate change take trade costs as given and focus on the impact on productivity. Trade costs, however, are shaped by the same economic forces through which climate change affects productivity, such as worker productivity, and the availability of labor and capital. Does climate change, then, directly affect trade costs, just as it does other forms of economic activity? If so, does ignoring this mean we underestimate the impact of climate change?

I use trade and weather data covering 190 years to show that climate change increases bilateral trade cost. I show this using an augmented gravity framework with one simple addition: an interaction between distance and decade-to-decade changes in average temperature at the origin and destination countries. I find that climate change significantly raises trade cost. The core identification concern is that countries which see more rapid climate change are different along other dimensions as well, and would have seen trade cost increases even absent climate change. I show that my results are robust to allowing for rich heterogeneity in trade cost levels and trends based on countries' climatic environment, allaying these identification concerns.

I find that impacts are especially severe for countries with lower benchmark temperatures and countries which see especially rapid climate change. This suggests that countries can adapt to these effects, but the adaptation process is slow. I present additional reduced form results suggesting the impact is driven by maritime trade in particular. This aligns with recent research on weather impacts on ports and anecdotal evidence from policy makers and port operators.

I embed my estimates in a standard model of international trade (Eaton & Kortum, 2002) to quantify welfare impacts. I find that welfare in the 2010s would have been 1.6 percent higher if climate change had not increased trade cost over the preceding 100 years. This is due only to the resulting reduction in trade cost, shutting down any productivity impacts. Welfare gains depend not just on countries' own climate trends, but also on their neighbors' trajectories: When country i 's neighbors face more drastic climate change than i itself, it experiences a relative trade cost reduction. Reverting climate change thus benefits i less, since its relative position declines. Poor and rich countries benefit equally. Smaller economies see especially large welfare gains, because they are more reliant on international trade. Finally, I show that ignoring this trade cost channel and focusing solely on productivity leads to a nine percent underestimate of the welfare impact of climate change.

Since my reduced form results rely on a simple augmented gravity specification, the effect I find can easily be included in other studies of the impact of climate change. A broad class of trade models yields gravity equations that can be estimated using simple regression techniques outside of

costlier estimation loops. The effect I find can be incorporated into those gravity estimations and solved without any computational overhead to speak of.

I contribute to the literature on the impacts of climate change in equilibrium. Existing studies generally estimate how trade affects productivity (e.g. Costinot, Donaldson, & Smith, 2016; Cruz & Rossi-Hansberg, 2021; Desmet, Kopp, Kulp, Nagy, Oppenheimer, Rossi-Hansberg, & Strauss, 2021; Huppertz, 2024; Nath, 2020; Porteous, 2024). They model climate change counterfactuals with reduced productivity but an *unchanged* trade network. That is, while different countries (or firms) become less productive in these counterfactuals, it is no more difficult for those countries (or firms) to ship goods across the globe. I show that this is too optimistic a baseline. We should expect that under climate change, trade networks will deteriorate. Using current trade networks to assess the impact of climate change thus underestimates that impact. My results also show that the micro impacts of weather on ports (Astier, 2025; Massoni, 2025) translate into long-term climate change damages observable in decade-to-decade shifts.

Second, I contribute to the debate about the magnitude of the welfare impacts of climate change. Using a long time horizon and considerable variation in decade-level average temperatures, I can directly estimate the impact of climate change on trade cost, without having to extrapolate from weather fluctuations to climate change impacts. The welfare impacts I find for these trade cost changes are comparable in magnitude to the welfare impacts from productivity impacts found in Costinot et al. (2016) and Nath (2020), for example. They are only about ten percent of direct estimates of climate productivity damages (e.g. Burke, Hsiang, & Miguel, 2015; Ramey, Nath, & Klenow, 2025), however. They are also only about five percent of the welfare impact of one degree of warming estimated in Bilal and Känzig (2024), who use global GDP and temperature and thus combine trade cost and productivity impacts. In workhorse models of international trade, the welfare impacts of trade cost changes (the gains from trade) tend to be small relative to the impacts of productivity changes. The impacts I find are thus consistent with overall larger estimates of the impact of climate change.

Finally, my results also relate to the literature on the carbon cost of trade. Trade itself generates considerable carbon emissions (Cristea, Hummels, Puzzello, & Avetisyan, 2013; Shapiro, 2016). As a consequence, as Farrokhi and Lashkaripour (2021) point out, trade policy is one tool that could be used to curb global emissions. My results suggest that, because climate change increases trade cost, it can also reduce carbon emissions from trade. This novel channel might be important to take into account when modeling the impacts of carbon taxes, for example.

The remainder of the paper proceeds as follows: Section 1 discusses the data I use and presents descriptive statistics, Section 2 describes the gravity equation framework I use for my reduced form estimation, Section 3 presents results of the reduced form estimation, Section 4 estimates the welfare impacts of trade cost increases due to climate change and compares to productivity impacts, and Section 5 concludes.

1 Data and descriptive statistics

1.1 Data sets

This section presents the data sources I use and some descriptive statistics. I use data on trade flows from the CEPII TRADHIST (TRADHIST) database of historical international trade data (Fouquin & Hugot, 2016). These data cover yearly international bilateral trade flows from 1827 until 2014 and contain additional information necessary for estimating gravity equations. All trade flows are in nominal British pounds (GBP). I convert these to real values using data on UK GDP deflators from the Bank of England (Thomas & Dimsdale, 2017).¹

I combine these trade flows with Berkeley Earth (BKE) data on monthly average temperature (Rohde, Muller, Jacobsen, Muller, Perlmutter, Rosenfeld, Wurtele, Groom, & Wickham, 2013). The temperature data go as far back as 1753 for some areas, achieve significant global coverage starting in 1850 and full global coverage beginning in 1960. I have weather data for virtually all countries in the trade data beginning in the 1850s. I use mainly BKE’s combined land and ocean temperature data set, but augment this with their land only data set, since the latter goes further back in time.

In order to link trade and temperature data, I use country boundaries from the Global Administrative Areas database (GADM) (Global Administrative Areas, 2022). I use Python’s `xarray` and `geopandas` packages to read in BKE temperature rasters for each month and calculate averages for each country based on its GADM area. GADM covers only currently existing countries, while TRADHIST also contains information on countries which no longer exist, such as West and East Germany, for example. For those countries, I create sets of boundaries based on the GADM data and historical maps of the country. Appendix C shows these boundaries.

To investigate mechanisms, I additionally use data on container port throughput from UN Trade

¹ Especially for earlier years, TRADHIST contains trade flows from some origins and destinations which are not countries. For example, it contains information on trade flows out of colonial administrative areas or individual cities. When I use the word ‘country’ in this paper, I always also mean these kinds of non-country reporters unless otherwise specified.

and Development (UNCTAD) (United Nations Trade and Development (UNCTAD) [UNCTAD], 2025a). This contains the number of containers processed by country and year expressed in 20-foot equivalents (a measure of volume), going back to 2010. For some supplementary exercises, I further use UNCTAD data on mode of transport (UNCTAD, 2025b).

For counterfactual exercises, I need data that cover not only international but also current domestic trade flows. (I do not require past domestic trade shares.) I therefore also use the International Trade and Production Database for Estimation (ITPD) (Borchert, Larch, Shikher, & Yotov, 2021, 2022). This database covers both international and domestic trade flows for a wide range of countries.

1.2 Descriptive statistics

For the TRADHIST data, Figure 1 shows the number of countries observed by year. For each year, I count countries which appear at least once with a non-missing trade flow, since those are the only observations I can use in estimations. I separately show the number of origin and destination countries in the data, but the numbers barely diverge. The number of countries appearing in the data increases until around 1900 and stays roughly stable afterwards.

Figure 2 shows the number of observed trade flows by year. The number of flows observed per year is a lot higher after 1950. This suggests that post-1950 data give a more complete picture of each year's trade network. My main analyses rely on analyzing individual trade flows, however, so this is not a limitation for my analysis.

For the BKE data, Figure 3 shows the number of countries with non-missing weather observations by year. I count here only currently existing countries that ever appear in the TRADHIST data. I focus on a fixed set of countries to show how the BKE data attain global coverage over time — the number of countries which could appear in the graph never changes, only the number of countries which can actually be matched to weather information in any given year. For the 1750s, I have weather coverage for a little over 60 countries. This increases over time, rising sharply in the 1850s. Starting in the 1880s I have truly global weather coverage.

To look at global climate trends, Figure 4 shows area-weighted average temperature in degrees Celsius for this same set of countries across years, plus a ten year moving average. I start the figure in 1880 because I have global weather coverage starting at that time. Over time, average temperature rises from around 12.75°C in the 1880s to almost 14.5°C in the 2010s. As the moving average shows, global mean temperature increases for most years after 1900. I see an especially fast

increase and generally above-trend temperatures beginning in the 1980s.

To show the match between trade and weather data, Figure 5 shows the percentage of countries which appear in the trade data but have missing weather information across years. Prior to 1850, I am able to match between 60 and 80 percent of all trade flows. Starting in 1850, I have non-missing weather information for virtually all countries in the trade data. This is because BKE provides much better coverage starting in 1850.

2 Gravity estimation framework

This section presents the estimation framework I used for my core reduced form results. Gravity equations describe trade flows X_{nit} between an origin i and destination n during period t as (Head & Mayer, 2015)

$$X_{nit} = G_t S_{it} M_{nt} \phi_{nit}$$

where G_t captures global factors during the period, S_{it} and M_{nt} are exporter and importer specific terms, also called multilateral resistance terms (Anderson & van Wincoop, 2003), and ϕ_{nit} is a measure of trade cost between the two countries, called a bilateral resistance term.

Many international trade models yield a gravity equation of this form, with different interpretations of what the multi- and bilateral resistance terms comprise. For estimation purposes, the bilateral resistance term is often modeled as

$$\phi_{nit} = d_{ni}^{\alpha_t} e^{\mathbf{C}'_{nit} \beta_t}$$

with d_{ni} a measure of physical distance between the two countries and \mathbf{C}_{nit} a collection of bilateral variables that affect trade between the two countries, such as sharing a border or colonial history. The elasticity of trade flows with respect to distance captures a major determinant of trade cost. It varies over time to capture global changes in trade cost, e.g., innovations in shipping technology or the policy environment.

I augment this basic specification, allowing the effect of distance to vary with changes in temperature,

$$\phi_{nit} = d_{ni}^{\alpha_t + \delta_1 \Delta T_{it} + \delta_2 \Delta T_{nt}} e^{\mathbf{C}'_{nit} \beta_t} \tag{1}$$

T_{ct} is average temperature in country c during period t , and $\Delta T_{ct} \equiv T_{ct} - T_{ct-1}$ is the change from period $t - 1$ to period t . This enters in the model fully interacted with distance. To estimate this, I follow the common practice of using origin-period and destination-period fixed effects to model the multilateral resistance terms (Anderson & van Wincoop, 2003). Accordingly, I drop the level effects of ΔT_{ct} which are captured by those fixed effects.

These fixed effects are also essential for identification of the trade cost impact, because they capture any impacts of climate change on country productivity. Using only origin and destination fixed effects, rather than origin- and destination-period fixed effects, would instead risk confusing the effect of climate change on output with the effect of climate change on trade cost. Note that this specification could be applied to any trade model that yields a gravity equation, so my estimation results apply to any model in this large class.

This yields an estimating equation

$$\begin{aligned} \mathbb{E}(X_{nit} | \mathbf{D}_{nit}) &= e^{\gamma_{it} + \xi_{nt} + \log(\phi_{nit})} \\ &= \exp \left\{ \gamma_{it} + \xi_{nt} + \alpha_t \tilde{d}_{ni} + \delta_1 \tilde{d}_{ni} \Delta T_{it} + \delta_2 \tilde{d}_{ni} \Delta T_{nt} + \mathbf{C}'_{nit} \boldsymbol{\beta}_t \right\} \end{aligned} \quad (2)$$

with origin-period and destination-period fixed effects γ_{it} and ξ_{nt} , and letting \mathbf{D}_{nit} denote the set of n, i, t covariates. (Note that the global factors G_t are not separately identified from the origin-period and destination-period fixed effects, so I drop them.) To deal with instances where trade flows are equal to zero, rather than taking logs of both sides and using the resulting linear model, this is commonly estimated in its exponentiated form using pseudo-Poisson maximum likelihood estimation (PPML) (Santos Silva & Tenreyro, 2006), which I follow here.

To assess the impact of climate change, rather than year-to-year weather fluctuations, I estimate this model across decades. To do so, I calculate decadal averages of all variables for each origin-destination pair and use those in the estimation. Using decadal averages is also attractive if trade data are interpreted as a (noisy) measure of the true underlying trade network, since decadal averages are closer to the true underlying value than yearly data.

Note that, while temperatures are interacted with distance, this specification captures changes in both the fixed and variable costs of trade. In a model such as Melitz (2003), for example, ϕ_{nit} depends both on the product of both the variable and fixed costs of trade. The specification I use simply uses distance (and a few other bilateral variables) to approximate that bilateral resistance term, regardless what fraction of it is due to variable or fixed costs of trade. The thought experiment

is this: Every country is separated from every other country by a set of bilateral distances. Shipping goods requires bridging those distances, and that is costly. As a country — Germany, for example — experiences climate change, the specification I use can tell whether it becomes more costly for Germany to bridge those distances and send goods abroad. Likewise, it can tell whether it becomes more costly for other countries to bridge that distance and send goods to Germany. The model allows temperature to increase the cost of bridging a given distance, whether that is due to increased variable or fixed costs of trade.

Note also that my estimates are necessarily a lower bound on the impact of climate change on trade cost. If climate change shifted trade cost across all routes equally, this would be absorbed by the fixed effects and I would miss it here. (A shift in trade cost across the board is indistinguishable from a shift in productivity.) Instead, I have to rely on differential impacts across distance, or across some other means of separating trade routes into different groups. Letting trade cost vary across distance is perhaps the most widely used gravity setup, and it is intuitive to think that climate change could have differential impacts across routes depending on their distance. For example, this could be due to longer routes using different modes of transport. Therefore, my workhorse specification uses distance interacted with temperature to estimate the impact of climate change.

Finally, it would be interesting to think about climate change along the route between origin and destination. That route, however, is (i) unobserved and (ii) even if I observed it, it would be endogenous to climate change. Suppose, for example that extreme weather made the Suez Canal impassable. Shipping operators would then have to divert their route, for example by going around the southern coast of Africa, or they could use multi-modal transport, leading to a complicated optimal transport problem. There are only two points along the route which are not endogenous — the origin and destination. There is no way to connect Italy and India, for example, that doesn't start or end in Italy and India. My specification therefore uses the only two non-endogenous points along the route to measure climate change. These are also where all fixed cost and loading and unloading cost is accrued, a non-negligible part of the overall cost of international trade.

2.1 Identification

The core remaining identification concern is that countries which have different climatic environments, and hence see more rapid climate change, might also have different trade cost trends for other reasons. These might be due to their geographic location or sectoral make-up (hotter countries are also poorer, on average), for example. This would create a spurious correlation between decadal

temperature changes and trade flows.

To address this concern, I capture countries' climatic environments in three ways — using their average temperature between 1950 and 1980, temperature change between the 1900s decade and the 2000s decade, and latitude. I calculate deciles of each of these variables and interact them with distance, allowing for different levels of trade cost for countries with different climates. I also estimate a specification which adds trade cost time trends for each decile. This full specification with different trade cost levels and trends is

$$\begin{aligned} \mathbb{E}(X_{nit}|\mathbf{D}_{nit}) \\ = \exp \left\{ \gamma_{it} + \xi_{nt} + \alpha_t \tilde{d}_{ni} + \left(\sum_{D=2}^{10} \alpha_D \tilde{d}_{ni} + \tau_D t \tilde{d}_{ni} \right) + \delta_1 \tilde{d}_{ni} \Delta T_{it} + \delta_2 \tilde{d}_{ni} \Delta T_{nt} + \mathbf{C}'_{nit} \boldsymbol{\beta}_t \right\} \end{aligned} \quad (3)$$

Here, α_D allows for separate coefficients on distance — separate trade costs — for each decile D of a given measure of climatic environment, e.g., 1950–1980 average temperature. τ_D allows for separate time trends in the coefficients on distance — separate time trends of trade costs — across deciles.

Note that the specification using 1900s to 2000s climate change as a measure of climatic environment is very conservative, perhaps even overly conservative. It assumes trade cost differences between countries with different long-run climate trends are not driven by climate change (even though they might be). It then uses only the remaining decadal variation among countries with similar climate trends to estimate the impact of climate change. This inherently discards a lot of the identifying variation and limits the potential impact of climate change. Estimates from this specification are therefore a lower bound on the impact of climate change on trade cost.

2.2 Heterogeneity

I also look at heterogeneity of the impact of climate change on trade cost. As I explain below, this can help shed some light on patterns of adaptation to climate change. To do this, I modify equation (2), letting the coefficients on distance by decade and the core interaction terms vary by climatic environment,

$$\mathbb{E}(X_{nit}|\mathbf{D}_{nit}) = \exp \left\{ \gamma_{it} + \xi_{nt} + \left(\sum_{Q=1}^4 \alpha_{tQ} \tilde{d}_{ni} + \delta_{1Q} \tilde{d}_{ni} \Delta T_{it} + \delta_{2Q} \tilde{d}_{ni} \Delta T_{nt} \right) + \mathbf{C}'_{nit} \boldsymbol{\beta}_t \right\} \quad (4)$$

Here, I use similar measures of heterogeneity as I did to control for climatic environment above — 1950s–1980s average temperature and 1900s–2000s climate change. I use fewer bins, however, since

I am not just controlling for potential confounders. Instead, here I want to estimate impacts within each bin, which requires sufficient sample sizes for each bin. I therefore use quartiles Q (instead of deciles) of 1950–1980 average temperature and 1900s–2000s climate change, and estimate separate effects of climate change on trade cost for each quartile.

3 Gravity estimation results

3.1 Impact of climate change on trade cost

This section presents my core reduced form results, based on the gravity estimation framework laid out in the previous section. I estimate all regressions via PPML, using the R command `fepois` from the `fixest` package to deal with the high dimensional fixed effects involved (Bergé, 2018). I capture d_{ni} using the great circle distance between the origin and destination countries in kilometers. (While TRADHIST also contains a population-weighted distance measure, this is available only for a subset of countries and usually missing for historical countries. I therefore opt for the unweighted distance measure which is available for all countries, and show robustness to using the population-weighted distance measure.)

As temperature measures, I use the decadal mean of the yearly average of daily average temperatures in °C. Decadal temperature changes are winsorized at the 1st and 99th percentiles to guard against outliers, though this does not impact my results. Figure 6 shows a histogram of the winsorized decadal temperature changes, highlighting the source of my identifying variation. The additional bilateral controls C_{nit} contain a common language indicator, sharing a border indicator and indicators for current and past colonial relationships. Again, I take decadal means for all variables.

Figure 9 shows a coefficient plot for the coefficients of interest — those on the interaction between distance and temperature change — across a number of specifications. These include estimating (2), the climatic environment robustness checks following (3), some additional robustness checks, and a benchmark specification excluding temperature variables. Table 1 shows the results in table form, including additional coefficient estimates (for example, on log distance). Standard errors are clustered by country pair, since that is the unit at which treatment $d_{ni}\delta T_{ct}$, $c \in \{i, n\}$ is assigned. I show p -values in brackets.

The first pair of coefficients (*Basic*) is for the basic model (2). The following pairs are for the climatic environment decile regressions specified in (3). These allow the effect of distance — and

hence trade cost levels and trends — to differ by countries’ 1950–1980 average temperature decile (T_{50-80} , with *t.t.* indicating the specification with time trends), their 1900s to 2000s climate change (CC) and their latitude (Lat).

I present some additional robustness checks as well. These use population-weighted great circle distance instead of the unweighted measure (d_{popw}), drop China from the data set (*No CHN*), subset to the 1950s onwards ($t \geq '50s$), and interact the additional bilateral controls with temperature changes as well (labeled $C_{nit} \times \Delta T_{it}$, but note this interacts with both origin and destination temperature change). A final robustness check uses residualized temperatures from an autoregression, akin to Ramey et al. (2025).² This is a different approach to addressing potential spurious correlation between climate and trade cost trends by detrending temperature. Finally, the last column of Table 1 shows a benchmark model excluding temperature variables.

As expected from the gravity literature, I consistently find a negative and significant effect of distance on trade flows. My baseline specification yields that, at zero change in origin and destination temperatures, a one percent increase in distance in the 2010s decreases trade flows by 0.552 percent. The magnitude for the distance effect itself is roughly comparable to the estimates from Santos Silva and Tenreyro (2006), who find that a one percent increase in distance decreases trade flows by 0.784 percent. Figure 7 shows the coefficients on distance across decades, highlighting that there is a slight but imprecisely estimated decrease in trade cost over time. Figure 8 shows a similar figure for the benchmark model excluding temperature variables.

The novel empirical result in this paper is that temperature changes at both the origin and destination increase this negative effect of distance. That is, rising temperatures make it harder to cross a given distance — climate change hence increases trade cost. Across specifications, I consistently find negative and significant effects. Even using the most conservative specification, which allows for different trade cost levels and trends based on countries’ long-term climate change, I find that a one degree increase in temperature at the origin decreases trade flows by a further 0.053 percent. Similarly, a one degree increase in temperature at the destination decreases trade flows by an additional 0.014 percent, though the destination effect is not significant in this very

² The specification is

$$T_{it} = \left(\sum_{l=1}^3 \beta_{1l} T_{it-l} + \beta_{2l} \bar{T}_i^{50-80} T_{it-l} \right) + \gamma_i + \nu_t + \varepsilon_{it}$$

using three lags of decadal average temperature interacted with countries’ 1950–1980 average temperature, plus country and decade fixed effects. I then use residuals from this regression instead of ΔT_{it} to estimate the impact of climate change.

conservative specification. Overall, I thus find that climate change increases trade cost.³

To put these numbers into perspective, between the 1910s and the 2010s, for example, the average country saw a temperature increase of about 1.3°C. Comparing the estimated impact of temperature from the most conservative specification with the average impact of distance on trade flows, over the last 100 years, the average origin country saw the effect of distance on trade flows increase by about 12.5 percent ($\approx (1.3 \times .058)/.552$). The average destination country saw an increase of about 3.3 percent (calculated analogously).

Note that, because of the long time horizon of the data I use, these results incorporate adaptation to climate change. Since I actually observe climate change directly, rather than having to make inferences about the impact of climate change from a short period’s worth of weather data, any adaptation effects will be captured into my coefficient estimates. This is similar to the long differences used in Burke and Emerick (2016).

3.2 Patterns of adaptation to climate change

I briefly discuss countries’ ability to adapt to the impact of climate change on trade cost. To this end, I analyze how the effect of climate change on trade cost varies with climatic environment. As I explained above, I do this by estimating equation (4), a version of my main estimating equation (2) which lets the impact of climate change on trade cost vary across climatic environments. Analogous to my core robustness checks above, I consider two dimensions of climate heterogeneity. First, I assess how the impact of climate change varies across quartiles of countries’ 1950–1980 average temperature. Second, I estimate how that impact varies across quartiles of countries’ average temperature change between the 1900s and 2000s decades.

Figure 18 shows the coefficients on the temperature interactions across 1950–1980 average temperature quartiles. I see significant negative impacts in the lower two quartiles of the temperature distribution, while estimates for the upper two quartiles are much noisier. This suggests that the same temperature change is especially detrimental to countries that are adapted to colder climates, and thus see a larger relative change.

³ Theoretically, it is possible that climate change could decrease trade cost across all distances but less so for longer distance trade. That would also generate a negative coefficient on longer-distance trade. I would then misinterpret this as an increase in trade cost, instead of a lower decrease. This is highly unlikely, however, due to the evidence on mechanisms I discuss below. I present evidence for several channels through which climate change could increase trade cost. There is no evidence I am aware of for channels that would systematically decrease trade cost. The one channel through which it might decrease trade cost for certain country pairs in the future is an ice-free Northwest Passage. Brancaccio, Kalouptsi, and Papageorgiou (2020) explore this in a counterfactual. This would, if anything, tend to benefit longer-distance trade more, though. Furthermore, it has not happened yet and would only apply to certain routes. On balance, therefore, a negative impact is overwhelmingly more likely.

Figure 19 shows the corresponding coefficient estimates across quartiles of 1900s–2000s temperature change. One might expect that countries which see faster climate change have more of an incentive to adapt to it. If this incentive leads to actual adaptation, these countries would then see smaller impacts. I find, however, that the upper two quartiles — countries which see relatively rapid climate change — see clear negative impacts, while I find no significant impact on the lower two quartiles. It seems, therefore, that countries have a harder time dealing with rapid changes in their climatic environment.

Together, these results suggest that adaptation to the impact of climate change on trade cost is relatively slow. Warmer countries see less of an impact from decade to decade climate change, which suggests that in the long run, countries were able to adapt to their climatic environment. Countries seem unable, however, to adapt to rapid climate change in real time. This is concerning given the increasing pace of climate change, which makes future climate change especially hard to adapt to. Furthermore, we can expect to be in a unstable climatic environment for the foreseeable future, which could lead to countries being continuously less well adapted to this changing environment than they historically were to a more stable climate.

3.3 Mechanisms

My results of course raise the question: Why would climate change affect trade cost? The most obvious mechanism is that shipping and receiving goods is an industrial task much like many others: It involves both manual and cognitive labor. It is well established that weather shocks and climate change affect the productivity of both of these kinds of labor and of industrial firms more generally (Adhvaryu, Kala, & Nyshadham, 2019; Carleton & Hsiang, 2016; Huppertz, 2024; Nath, 2020; Somanathan, Somanathan, Sudarshan, & Tewari, 2021; Zhang, Dêschenes, Meng, & Zhang, 2018). Through the same channels that climate change affects manufacturing firms, it can also affect the efficiency of dock and freight operations. Brancaccio et al. (2020), for example, point out the endogeneity of transportation cost and of port efficiency in particular.

As I mentioned in Section 2, the sign of the estimated coefficients provides suggestive evidence as to which kinds of trade are most affected. A significant and negative coefficient suggests that the impact of climate change is larger for longer-distance trade cost. One salient difference between short and long distance trade is the mode of transportation — longer distance predominantly uses maritime shipping, rather than land or even air freight. Maritime trade could be at a higher risk from climate change because of its dependence on ports.

The basic argument is that sea ports tend to be relatively few per country, and they are exposed to a range of weather hazards. Because climate change makes those hazards more frequent, climate change would also affect sea ports. This would be especially detrimental to the cost of maritime trade. Land freight, by contrast, is relatively decentralized: Producers can load goods onto trucks at their production facility, and trucks can use the entire road network to reach their destination. This makes it relatively resilient against adverse weather events affecting specific roads or production locations — other roads or locations can function as substitutes. Because maritime trade does not have this degree of flexibility, climate change would have a larger impact on it.⁴

To support the argument that maritime trade is driving my results, I first discuss the impact of adverse weather events on ports, as reflected in recent research and discussed by practitioners and policy makers. I then show patterns in my data suggesting that maritime trade in particular is driving the impact of climate change on trade cost.

3.3.1 Weather impacts on ports

Recent work shows that adverse weather events, such as storms, increase port congestion and decrease port efficiency (Astier, 2025; Massoni, 2025). As climate change makes these events more frequent, it can thus affect port efficiency in the longer term. I do not have port efficiency data going back long enough to estimate decade to decade impacts of climate change on ports. I do, however, replicate the impact of weather on port efficiency these papers find. I use data on container port throughput from UNCTAD to estimate

$$\Delta \log(\text{TEU}_{it}) = \beta_1 \Delta T_{it} + \beta_2 \bar{T}_i^{50-80} \Delta T_{it} + \gamma_i$$

⁴ Longer distance trade also uses air freight more commonly, and airports are exposed to weather hazards in a similar way to sea ports. I focus on maritime trade rather than air freight as the mechanism for two reasons. First, I use long-run historic data, and air freight used to be much less common than it is now (indeed, nonexistent for part of my sample). Second, maritime shipping is more important for longer-distance trade today. Figure 10 shows the share of total trade transported by sea and air freight across countries for the years 2016–2019, weighted by the weight transported, based on UNCTAD transport mode data. Figure 11 shows an analogous figure weighted by value. Though air freight clearly transports higher value-to-weight goods, it transports a much lower share of goods. Figure 12 shows trade shares for maritime and air freight across distance deciles, with Figure 13 the analogous value-weighted figure. (Note the level shares may be understated somewhat due to some trade being classified as ‘other’ or ‘non-specified’ modes.) Again, maritime shipping transports a larger share of goods, and an increasing share of goods across distance compared to a relatively flat pattern for air freight. Overall, the relative recency of air freight and larger trade volume of maritime trade lead me to consider maritime shipping as the likely mechanism underlying my results. I cannot rule out, however, that climate impacts on air freight also play a role. I also have no interest in doing so — it is a potential mechanism, and could be explored further in the future.

Note that t denotes years here, not decades. The outcome is country i 's container port throughput in year t , expressed in twenty-foot equivalents (TEU), i.e., a measure of freight volume processed. I use year-to-year temperature changes ΔT_{it} as my measure of temperature shocks. The impact is allowed to vary by countries' 1950–1980 average temperature.

Figure 14 shows the marginal effect of temperature shocks across 1950–1980 average temperature, as well as a histogram of 1950–1980 average temperature. The impact is negative for most countries and significant especially for hotter countries. Here, of course, I cannot control for productivity differences using country fixed effects. Instead, Figure 15 shows a version of this model controlling for changes in GDP per capita. This is an endogenous regressor, so results are harder to interpret. Even in this specification, however, I find a negative effect for most countries, though with a significant positive impact on the coldest countries. Overall, these results are in line with recent work on the impact of severe weather on ports. This weather impact provides a channel for climate change to affect ports.

As an additional piece of evidence, note that policy makers are concerned about climate change impacts on ports. UNCTAD notes that sea ports are especially affected by rising sea levels and the associated increased risk of storm surges (Asariotis, 2021). The Environmental Defense Fund finds that Hurricane Katrina caused USD 2.2 billion in damages to US port infrastructure, and that climate change increases the frequency and severity of such storms. Furthermore, they find that inland flooding or droughts disrupt the connections between domestic producers, consumers and international ports, making ports less useful as connections to the rest of the world. Finally, heat waves have already led to multi-day port shutdowns, for example, in Melbourne, Australia in 2009 (Van Houtven, Gallaher, Woollacott, & Decker, 2022).

Finally, shipping companies and port operators themselves are wary of climate change, and engaging in costly actions to deal with it. Two examples are, first, Maersk, one of the largest international freight operators. They recently engaged the Zurich Insurance Group (specifically its risk management consulting arm) to help plan how to climate-proof ports Maersk operates (McAllister, 2024). “‘In the past decade, we have seen coastal flooding at our terminal in Port Elizabeth, New Jersey; flooding at our Salalah terminal in Oman; a cyclone hit our Pipavav terminal in India; and regular exposure to tropical windstorms to our terminals in Miami, Florida, and Mobile, Alabama,’ says Lars Henneberg, VP, Head of Risk Management at Maersk.” Second, the Port of Long Beach enacted a Climate Adaptation and Resiliency Plan as far back as 2016. This plan again highlights the risks posed by storm surges, sea level rise, flooding, and heat waves (Port

of Long Beach, 2016).

3.3.2 Maritime trade drives trade cost impacts

I find a number of results which are consistent with the idea that climate change especially affects the cost of maritime trade, which then drives the overall results. First, Table 2 shows results for gravity estimations similar to my main specification (2), but using alternatives to distance to measure bilateral trade cost.

The first column uses an indicator which is equal to one if the only connection between the origin and destination is via the ocean. All trade between these country pairs thus has to use maritime shipping. As might be expected, since this sea-only trade indicator is correlated with distance, I find similar patterns to my main results — climate change at the origin, especially, significantly increases the cost of trade for country pairs which are forced to use maritime shipping. The second column of the table instead uses a long distance indicator. This is one if the distance between the origin and destination country is equal to or larger than the median distance between country pairs that have only an ocean-based connection.

The pattern I find is similar, but note that the coefficient on the long distance-climate change interaction is now no longer significant. That is, the coefficient on sea-only trade in the first column captures something that this purely distance based indicator misses. This suggests that maritime trade, rather than generic long distance trade, is driving the results. This is of course a very conservative way to assess the impact of maritime trade — plenty of country pairs have a land route between them, but due to the length of that route maritime trade is preferable. This specification ignores those routes and treats them the same as other, shorter and more attractive land routes.

As a less conservative approach to isolating the impact on maritime trade, I conduct two sets of ‘donut hole’ estimations. First, I use the fact that maritime trade becomes more attractive not only with distance, but also with the number of land borders which would need to be crossed in order to go from the origin to the destination via a land route. This is because border crossings incur fixed costs (Anderson & van Wincoop, 2003). I calculate, for each origin-destination pair, the number of land borders which would have to be crossed to get from one to the other. (For country pairs with no land based connection, the number is infinite, $\text{Land borders}_{ni} = \infty$.)

I then estimate regressions similar to my main specification (2), but using an indicator which is zero if the origin and destination are neighbors ($\text{Land borders}_{ni} = 1$) and one if the number of land borders between the origin and destination is at least a minimum gap size b ($\text{Land borders}_{ni} \geq b$),

for $b = 2, 3, \dots, 10$. Country pairs which are not neighbors and have fewer than b land borders in between them (i.e., $\text{Land borders}_{ni} \in (1, b)$) are discarded. (These countries are in the donut hole.)

I thus compare country pairs with progressively costlier land trade routes (where maritime trade is hence more attractive) to neighboring country pairs. If it is true that climate change especially affects maritime trade, I would expect to see negative coefficients on the interaction between the minimum gap size indicator and origin and destination temperature change. If maritime trade is indeed much more attractive once a certain number of land borders separate two countries, I would further expect these coefficients to remain roughly stable as I increase the minimum gap size b beyond that threshold.

Figure 16 shows the estimated coefficients on the interaction between minimum gap size for each estimation and origin and destination temperatures. At only two land borders I do not yet see a difference, but coefficients become progressively more negative and are significant once four land borders would need to be crossed. Note that, though confidence intervals become wider (because larger donut holes mean fewer total observations), coefficients remain fairly stable across larger minimum gap sizes.

I thus find that I see a significant increase in trade cost for country pairs where maritime trade is more attractive. Consistent with the idea that maritime trade is preferable once a threshold number of borders have to be crossed, this difference becomes more pronounced up to a point, but then stays relatively stable. This suggests I am not picking up some kind of correlate of distance, but rather a differential impact on maritime as opposed to land based trade.

To again highlight that this is not simply because larger gap sizes mean larger distances, Figure 17 shows results for a similar estimation, but using indicators for the distance between origin and destination being equal to or greater than a given distance decile $d = 2, 3, \dots, 5$. Here, coefficients again show only a much noisier version of the maritime trade based analysis — I find significant and negative effects for some, but not all comparisons. This suggests that maritime trade picks up a pattern in the data that, while correlated with distance, picks up something that distance misses.

Impacts on ports, and through those maritime trade, are thus a plausible mechanism behind my main results. This is consistent with (i) the coefficient estimates I find in my main results (maritime trade is also longer-distance trade), (ii) recent research on the impact of weather on ports, policymakers' concerns regarding the vulnerability of sea ports to climate change and port operators' costly adaptation efforts, and (iii) additional reduced form analyses showing that where maritime shipping is more attractive (or even the only option) I clearly see a differential impact on trade cost.

4 Welfare impacts

I now use a workhorse model of international trade to assess the welfare implications of my reduced form results. To work towards welfare implications, note that my gravity results allow me to estimate the change in ϕ_{nit} we would observe if we moved to the climate of a different decade $s \neq t$. I can do this by plugging temperature changes between decade s and t into the specification for the bilateral resistance term (1) to obtain a counterfactual ϕ'_{nit} , using primes to denote counterfactual quantities. As a simple, illustrative example, consider the basic distance-based specification (2). Using hats to denote the ratio of counterfactual to observed quantities, the change in the bilateral resistance term would be

$$\hat{\phi}_{nit} \equiv \frac{\phi'_{nit}}{\phi_{nit}} \stackrel{(1)}{=} d_{ni}^{\delta_1(T_{is}-T_{it})+\delta_2(T_{ns}-T_{nt})} \quad (5)$$

Importantly, all non-temperature covariates remain constant — I simply estimate the change in bilateral resistance stemming from the changed temperature variables.

To estimate the change in bilateral resistance terms, I use a specification that is consistent with maritime trade being the main driver of the impacts I observe. I estimate the impact of climate change on trade for countries with at least four land borders between them, compared to trade between direct neighbors. This is similar to the coefficient in Figure 16 for $b = 4$. I now also allow for the impact of trade cost to vary by origin and destination 1950–1980 average temperature. This allows countries’ climatic environment to drive their reactions to climate change. Using a measure of average temperature to do this is common in the literature on climate impacts on productivity (e.g. Burke et al., 2015; Ramey et al., 2025). I estimate

$$\begin{aligned} & \mathbb{E}(X_{nit} | \mathbf{D}_{nit}) \\ &= \exp \left\{ \gamma_{it} + \xi_{nt} + \alpha_t b_{ni}^4 + \delta_1 b_{ni}^4 \Delta T_{it} + \gamma_1 b_{ni}^4 \bar{T}_i^{50-80} T_{it} + \delta_2 b_{ni}^4 \Delta T_{nt} + \gamma_2 b_{ni}^4 \bar{T}_n^{50-80} \Delta T_{nt} \right\} \end{aligned} \quad (6)$$

Here, b_{ni}^4 is an indicator for the minimum number of land borders between n and i being four or greater. I estimate this using only direct neighbors and countries with at least four land borders between them, like for the donut hole specification above. This creates a clear comparison between likely maritime and likely non-maritime routes. I omit the additional controls \mathbf{C}_{nit} since they do not affect my main results.

Figures 20 and 21 show the marginal effect of origin and destination temperature across 1950–

1980 average temperature. I find consistently negative impacts, with some variation across 1950–1980 average temperature but not necessarily significant differences. I can back out the change in bilateral resistance from these results, similar to (5). (For neighboring countries and those with two or three land borders between them, I assume there is no impact of climate change on trade cost.)

To go from the changes in bilateral resistance to an implied welfare impact, I need to specify a model of international trade. This is necessary because I have to discipline how wages and prices adjust in this counterfactual. I use the well-established model of Eaton and Kortum (2002) to estimate the 2010s welfare change when I undo the impact of climate change since previous decades. Under the Eaton and Kortum (2002) model, the bilateral resistance term is equal to $\phi_{nit} = \tau_{nit}^{-\theta}$ where τ_{nit} is a measure of how difficult it is to ship goods from i to n and $\theta > 0$ measures productivity dispersion in the Fréchet distribution of technology underlying the Eaton and Kortum (2002) model.

To estimate welfare impacts, I rewrite the model in changes (Dekle, Eaton, & Kortum, 2008). The core object I need to estimate welfare impacts are trade shares $\pi_{nit} = X_{nit}/X_{nt}$, where $X_{nt} \equiv \sum_{i=1}^N X_{nit}$ is the destination country's total expenditure for decade t . The change in trade shares $\hat{\pi}_{nit} \equiv \pi'_{nit}/\pi_{nit}$ resulting from a change $\hat{\tau}_{nit} \equiv \tau'_{nit}/\tau_{nit}$ is

$$\hat{\pi}_{nit} = \frac{\hat{A}_{it}(\hat{\tau}_{nit}\hat{w}_{it})^{-\theta}}{\sum_{k=1}^N \pi_{nkt}\hat{A}_{kt}(\hat{\tau}_{nkt}\hat{w}_{kt})^{-\theta}} \quad (7)$$

Here, $\hat{A}_{it} \equiv A'_{it}/A_{it}$ is the change in country i 's productivity for period t (also from the Fréchet distribution underlying technology) and $\hat{w}_{it} \equiv w'_{it}/w_{it}$ is the change in country i 's wage for period t . The resulting welfare change, letting $\hat{\pi}_{nit} \equiv \pi'_{nit}/\pi_{nit}$ denote the change in own trade share and W_{it} country i 's welfare in decade t , is

$$\hat{W}_{it} \equiv \frac{W'_{it}}{W_{it}} = \hat{A}_{it}^{\frac{1}{\theta}} \hat{\pi}_{iit}^{-\frac{1}{\theta}} \quad (8)$$

4.1 Welfare impact of climate change through the trade cost channel

For now, I focus on the impact of climate change on trade cost only, keeping technology unchanged ($\hat{A}_{it} = 1$). Then, the welfare change simply becomes the change in own trade share raised to a negative power — if own trade share decreases, welfare increases.

It is straightforward to back out $\hat{\tau}_{nit}$ from the estimates of $\hat{\phi}_{nit}$. I can then solve the system of equations (7) for wage changes \hat{w}_{it} that equate counterfactual trade deficits and surpluses with those observed in the data (ensuring goods market clearing in the counterfactual). The resulting

counterfactual trade shares π'_{nit} enable me to calculate welfare changes for each country from (8). Following Dekle et al. (2008), I set the only unknown parameter $\theta = 8.28$. Finally, solving the model requires choosing a normalization. I fix world GDP at its 2010s value.

I use the 2010s as my reference period. Because this estimation requires domestic trade shares, which the TRADHIST database lacks, I use the ITPD data on trade shares for the 2010s to measure π_{nit} . I then calculate welfare changes resulting from a shift to each previous decade’s climate. I do this for all previous decades from the 1880s onwards, since I have global weather coverage beginning at that time. Figure 22 shows the population-weighted mean welfare change across decades, as well as the 5th and 95th percentile of welfare changes. (Appendix Table 4 shows the same information in table form.)

Looking at the results for the 1910s, I estimate that the average country would see a 1.6 percent increase in welfare if we reverted trade cost increases due to climate change over the last 100 years. This is a relatively sizeable effect, comparable to estimates of the impact of climate change based on field-level or firm-level data (Costinot et al., 2016; Nath, 2020) but compatible with direct country-level estimates of the productivity impact (Bilal & Känzig, 2024; Burke et al., 2015; Ramey et al., 2025). I discuss this comparison to productivity impacts in more detail below.

The welfare impact of trade cost changes tends to be larger when switching to earlier climates. This is because temperatures increase over time and reverting to an earlier period’s climate thus results in a larger temperature change. For example, the mean welfare increase for the earliest decade, the 1880s, is estimated to be 1.8 percent, whereas for the 1950s I estimate an average welfare increase of 1.2 percent. For the most recent decade, the 2000s, I estimate an 0.2 percent welfare increase, on average. Across decades, almost all countries see an increase in welfare — the 5th percentile of welfare changes is consistently positive. At the 95th percentile, welfare impacts are as high as 5.5 percent in the 1880s counterfactual.⁵

4.2 Drivers and distribution of welfare gains

Figure 23 shows a map of welfare gains across countries for the 1910s counterfactual. There is considerable heterogeneity across the globe, with larger gains in southern, western and northern Africa, Argentina, northern Latin America and Central America, the Arabian Peninsula, and south-eastern Asia. Australia, Iceland and Ireland also have somewhat larger gains than other rich

⁵ Appendix Figure 35 and Appendix Table 5 show versions of these results without population weights. As I discuss below, larger economies benefit less from trade cost reductions, so the unweighted average welfare changes and percentiles are somewhat higher.

countries. What determines who gains more from undoing the trade cost impact of climate change?

The most obvious factor are climate trends: I would expect that countries which see more climate change or whose neighbors see more climate change would benefit more from undoing those changes. Figure 24 shows welfare changes in the 1910s counterfactual across countries' own temperature change between period the 1910s and the 2010s. Figure 25 shows welfare changes across the inverse distance weighted change in other countries' change in temperatures, which is calculated as

$$\text{Inverse distance weighted change}_{it} \equiv \frac{1}{\sum_{n \neq i} d_{ni}} \sum_{n \neq i} d_{ni} \Delta T_{nt}$$

where ΔT_{nt} is country n 's change in temperature between period t and the 2010s. This measures climate change in the rest of the world, but weighted towards countries' neighbors. Interestingly, both measures of climate trends are somewhat negatively correlated with welfare gains.

These temperature measures are, of course, correlated. Figure 26 highlights this, showing inverse distance weighted temperature changes across countries' change in own temperature between the 1910s and 2010s. That correlation could mask how own and others' climate trends affect welfare gains. To disentangle their effects, Table 3 shows results for regressions of welfare impacts \hat{W}_{it} across periods on country characteristics. These regressions include period fixed effects to analyze correlates of welfare change within period. Standard errors are clustered at the country level, but note that these welfare outcomes are generated regressors, which I ignore here. I treat these results as interesting suggestive evidence for directions of change, not as a true test for significantly different welfare effects.

The first column again highlights that, somewhat surprisingly, countries' own temperature change is negatively correlated with welfare gains. The second column shows that inverse distance weighted change is also negatively correlated with countries' own welfare changes. Column three combines the two and shows that once I take both changes into account, countries' own temperature changes are only weakly negatively correlated with welfare changes. Surrounding countries' temperature changes, however, are still strongly negatively correlated with welfare gains. The fourth column shows that when controlling for 1950–1980 average temperature change (which drives heterogeneity in trade cost impacts), the correlations become weaker, but own trends now have the expected (positive) sign and neighbors' trends retain the negative sign.

The negative impact of neighbors' temperatures may seem counterintuitive, but there is a simple explanation. When country i and its neighbor j both see large temperature changes, they both see

rising trade cost and become less attractive trade hubs. Reversing that change benefits both. When only j sees climate change, both countries still see an *absolute* increase in trade cost. Country i , however, sees a reduction in *relative* trade cost — i ’s cost of exporting and importing falls relative to that of j . This relative cost reduction benefits i . Reversing climate change lowers absolute trade cost for both countries, but *increases* i ’s relative cost. That makes reversing climate change less beneficial for i . The key takeaway is the importance of considering neighbors’ climate trends, not just countries’ own climate trends.

To understand the distribution of gains across economies of different sizes, Figure 27 shows the estimated welfare impacts of returning to the climate of the 1910s across countries’ 2010s log GDP. Larger economies tend to benefit less from reversing the impact of climate change on trade cost. As Figure 28 shows, however, welfare gains are essentially uncorrelated with GDP per capita. That is, rich and poor countries are roughly equally affected by the trade cost impacts of climate change.

That larger economies benefit less is not surprising — they are less reliant on international trade, since they have larger domestic markets. (See Figure 29, which shows that larger economies tend to have higher own trade shares.) To show that this is driving the difference in welfare gains by GDP, the fifth column of Table 3 shows a regression of welfare gains on log 2010s GDP. Across periods, GDP and welfare gains are strongly negatively correlated. The sixth column of Table 3 additionally controls for countries’ 2010s own trade share. Once I take that into account, larger economies actually benefit more from trade cost decreases. Not surprisingly, though, a larger own trade share is correlated with lower welfare gains, because international trade is less important for the economy. The final column of the table again controls for the 1950–1980 average temperature, which does not change results much. All told, larger economies benefit less from undoing climate change impacts on trade cost because they are less reliant on international trade.

4.3 Comparing trade cost and productivity channels

As mentioned above, the welfare gains I find are sizable — the average 1910s welfare gain of 1.6 percent is comparable in magnitude to estimates of the welfare effects of climate change through agricultural and overall productivity (Costinot et al., 2016; Nath, 2020). It is only about ten percent, however, of the direct estimates of the productivity impact of climate change, depending on the exact specification (e.g. Burke et al., 2015; Ramey et al., 2025), and about five percent of the global welfare loss from one degree of global warming found in Bilal and Känzig (2024).

To compare welfare impacts through the productivity and trade cost channels, I estimate the

impact of climate change on productivity with a setup similar to Ramey et al. (2025). I use decade to decade variation, however, to line up with the trade cost estimation and my focus on climate change. I use GDP data from TRADHIST to be consistent with those results. I estimate

$$\Delta \log(y_{it}) = \beta_1 \Delta T_{it} + \beta_2 \bar{T}_i^{50-80} \Delta T_{it} + \gamma_i + \varepsilon_{it} \quad (9)$$

where y_{it} is country i 's average GDP per capita during decade t , as a measure of productivity. I allow for the effect of temperature to vary with 1950–1980 average temperature. I do not include lagged impacts since existing estimates of the impact of weather shocks on GDP have not gone beyond a ten year horizon, and I am working on a decadal scale. Figure 30 shows the marginal effect of temperature shocks across 1950–1980 average temperature. I find consistently negative impacts of decadal temperature changes on productivity, though with less negative impacts in colder countries.

I then back out implied technology changes \hat{A}_{it} , using that in the model, GDP per capita is

$$y_{it} \equiv \frac{w_{it}}{\mathcal{P}_{it}} = \Gamma \left(\frac{\theta - \sigma + 1}{\theta} \right)^{\frac{1}{\sigma-1}} \left(\frac{A_{it}}{\pi_{iit}} \right)^{\frac{1}{\theta}}$$

where \mathcal{P}_{it} is the optimal CES price index, Γ indicates the Gamma function and π_{iit} is country i 's own trade share during decade t . In general, this depends on all countries' temperature shocks through the trade network. This is reflected in the denominator of (7), showing that changes in trade shares depend on all countries' shocks. In autarky, however, which I can approximate by taking trade cost to infinity, I have $d_{nit} \rightarrow +\infty \forall i, n \neq i$ and $\pi_{iit} \rightarrow 1$. Then, $\hat{y}_{it} = \hat{A}_{it}^{\frac{1}{\theta}}$. The reduced form (9) estimates $\log(\hat{y}_{it})$, and I can back out $\hat{A}_{it} = \exp\{\theta \log(\hat{y}_{it})\}$.

The insight that trade between countries creates a problem with this estimation is due to, and brought out in much more generality in, Astier, Barrows, Cael, and Ollivier (2025). They show that productivity regressions of this form suffer from a stable unit treatment value assumption violation, rendering them generally invalid. They also find, however, that these regressions do better for past climate change than for projecting out into the future. I rely on this finding, and the fact that these estimations are widespread in the literature, to use (9) as my productivity benchmark. Very importantly, note that my trade cost regressions control for shocks at all origins and destinations using fixed effects and thus control for changes via the trade network. They therefore do not suffer from this problem.

I can now estimate three different counterfactuals — undoing the impact of climate change (i) *only* on trade cost, as above, (ii) *only* on productivity, and (iii) on *both* trade cost and productivity. This

allows me to compare the welfare implications of both channels and assess whether we meaningfully underestimate the welfare impact of climate change when we focus exclusively on productivity.

Figure 31 shows average welfare gains across these three counterfactuals for the 1910s climate. I break the welfare gains up by small (below median 2010s GDP) and large economies. Gains from increased productivity alone are considerably larger than gains from trade cost alone, as would be expected from most trade models. Welfare gains from the combined counterfactual are also appreciably larger, however, than those from the productivity-only counterfactual. This is especially true for smaller economies, which see a larger additional welfare gain from the combined counterfactual. Overall, this shows that focusing on productivity alone means underestimating the welfare impacts of climate change.

To quantify how large the underestimate is, Figure 32 shows a histogram of the welfare gain ratio between the combined and productivity only counterfactual. That is, this shows the welfare gain from undoing both trade cost and productivity impacts divided by the welfare gain from only undoing productivity impacts. The average country has about a nine percent larger welfare gain from also undoing trade cost changes. Figure 33 shows a histogram of the difference between the two welfare changes, rather than the ratio. The average welfare gain difference is about two percentage points, which is slightly larger than the average welfare gain through trade cost alone. The two channels are thus somewhat complementary.⁶

As discussed above, the welfare impact of climate change varies depending on countries' trade openness as well as their exposure to climate change. Figure 34 shows a world map of the welfare gain ratio, highlighting the global distribution of additional welfare gains. Again, especially smaller economies gain more, but the UK and Ireland also stand out compared to continental Europe, for example. Both of these countries are relatively open to international trade.

This simple exercise suggests that, while productivity is the main driver of climate impacts, ignoring the novel trade cost channel I study here leads to an appreciable underestimate of the overall effect. This underestimate is larger, and thus more important to take into account, for smaller economies, including rich countries which are especially open to trade.

⁶ Of course, reducing trade cost and increasing productivity at the same time would always lead to an impact larger than the sum of its parts. Due to the heterogeneity by 1950–1980 average temperature, however, it would have been possible for the estimates to produce any pattern of additional gains, including a negative correlation between trade cost and productivity changes.

5 Conclusion

I show, using an augmented gravity specification, that decade-to-decade temperature change at the origin or destination country increase bilateral trade cost. Adaptation to these impacts seems slow. The effect appears to be driven by impacts on maritime trade, potentially because sea ports are especially vulnerable to extreme weather events and hence to damages from climate change.

The welfare impacts of this are considerable: Using the Eaton and Kortum (2002) model, I find that average welfare during the 2010s would have been about 1.6 percent higher if climate change had not increased trade cost over the preceding 100 years. Welfare gains depend not only on countries' own climate trends, but also on their neighbors' trajectories: When country i 's neighbors face more drastic climate change than i itself, country i experiences a relative trade cost reduction. Reverting that change thus benefits i less, since its relative position declines.

Poor and rich countries benefit equally. Benefits are especially large for smaller economies, though, which are more reliant on international trade. A simple counterfactual exercise shows that ignoring the trade cost channel I highlight leads to a nine percent underestimate of the welfare impact of climate change.

Since I only rely on an augmented gravity specification, the effect of climate change on trade cost I demonstrate in this paper can easily be included in estimations of the overall impact of climate change. This is especially true for estimations based on the broad class of trade models that allow for gravity estimation to be solved separately from the rest of the model. There, the impact on trade cost can be estimated independently of the model and then incorporated into counterfactuals via simple hat algebra. This does not cause much computational overhead. I thus hope that this simple methodology will aid future analyses of the impact of climate change.

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Tables

Table 2: Mechanisms behind main results

Variable	Sea only trade	Long distance trade
Sea only _{ni} × 2010s	−0.564 [0.000]	
Sea only _{ni} × ΔT _{it}	−0.165 [0.004]	
Sea only _{ni} × ΔT _{nt}	−0.036 [0.507]	
Long distance _{ni} × 2010s		−0.443 [0.000]
Long distance _{ni} × ΔT _{it}		−0.101 [0.107]
Long distance _{ni} × ΔT _{nt}		−0.028 [0.626]
Sea only _{ni} ⊗ decade	Yes	No
Long distance _{ni} ⊗ decade	No	Yes
C _{nit} ⊗ decade	Yes	Yes
Origin-decade FE	Yes	Yes
Destination-decade FE	Yes	Yes
Observations	326,747	326,747
Clusters	28,993	28,993

Note: The outcome are decade-level average trade flows from country i to country n , winsorized at the 99th percentile. The estimation uses pseudo-Poisson maximum likelihood (PPML) to accommodate zero trade flows. Sea only_{ni} is an indicator for there being no overland connection between the origin and destination countries. Since the coefficient on that variable is allowed to vary across decades, I only report the coefficient for the latest period, Sea only_{ni} × 2010s. Long distance_{ni} is an indicator for the distance between the origin and destination being greater than or equal to the average distance between country pairs that only have an ocean-based connection (that is, pairs which have Sea only_{ni} = 1). Again, I only report the coefficient for the latest period. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in °C. Temperature changes are winsorized at the 1st and 99th percentiles. C_{nit} contains a common language indicator, sharing a border indicator and two indicators for current and past colonial relationships, taking decadal means for all variables within each origin-destination pair. Decades t are the decades from 1820 to 2020. Standard errors clustered by country pair, p -values in brackets.

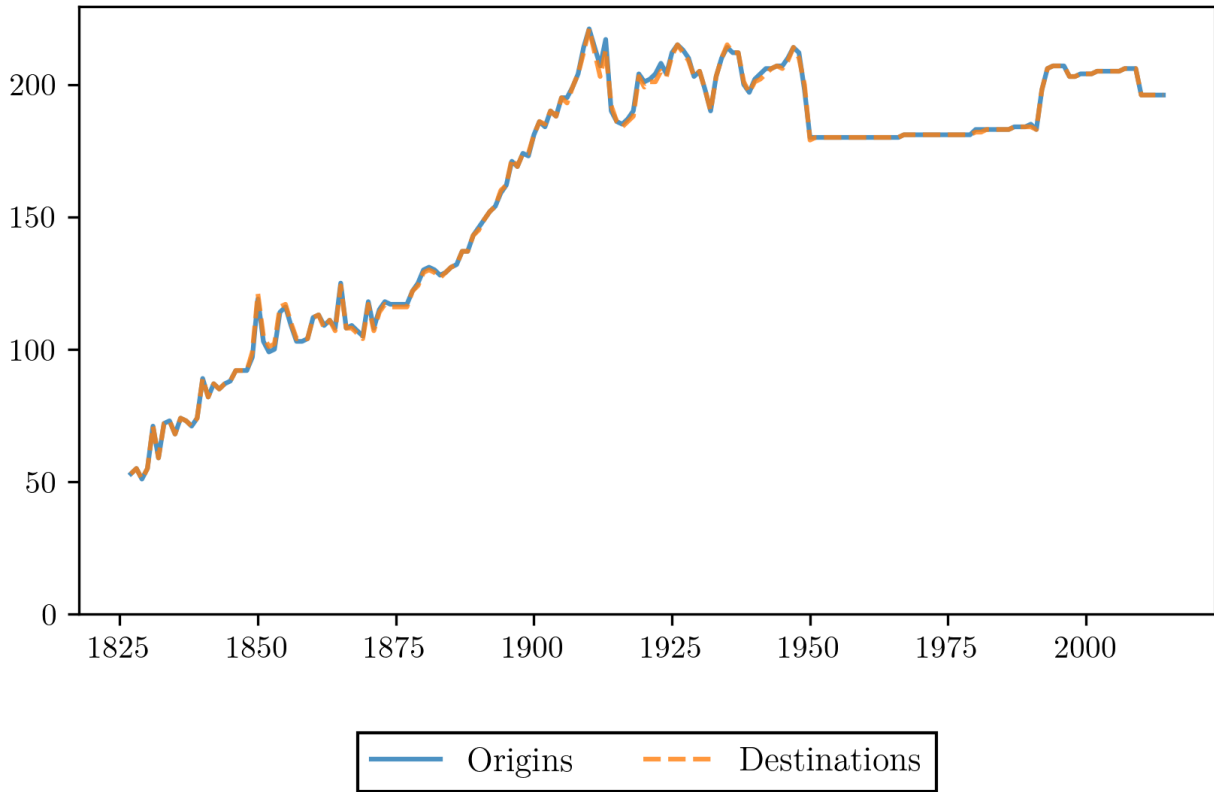
Table 3: Correlates of welfare changes

Variable	\hat{W}_{it}	\hat{W}_{it}	\hat{W}_{it}	\hat{W}_{it}	\hat{W}_{it}	\hat{W}_{it}	\hat{W}_{it}
Own ΔT	-1.661 [0.000]		-0.111 [0.873]	0.310 [0.630]			
Inverse distance weighted ΔT		-4.729 [0.000]	-4.512 [0.007]	-1.521 [0.367]			
Log 2010s GDP					-0.233 [0.000]	0.112 [0.048]	0.198 [0.001]
2010s own trade share (%)						-0.060 [0.000]	-0.054 [0.000]
1950s-'80s \bar{T}				0.112 [0.000]			0.078 [0.000]
Decade FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The outcome \hat{W}_{it} is the welfare change for country i under decade t 's climate counterfactual. *Own ΔT* is a country's change in temperature between each decade and the 2010s, whereas the *inverse distance weighted ΔT* for country i is the average change in all other countries' temperatures, weighted by the inverse of their distance to i . *1950s-'80s \bar{T}* is countries' average temperature from the 1950s to the 1980s. Standard errors clustered by country, p -values in brackets.

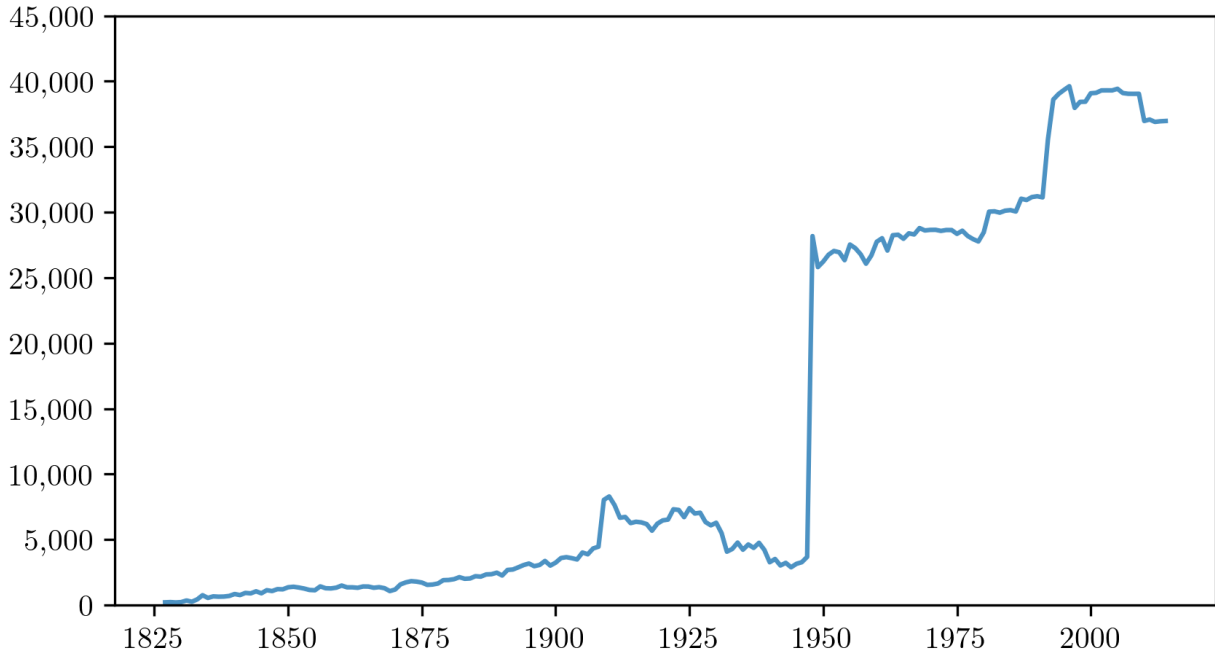
Figures

Figure 1: Trade data country counts by year



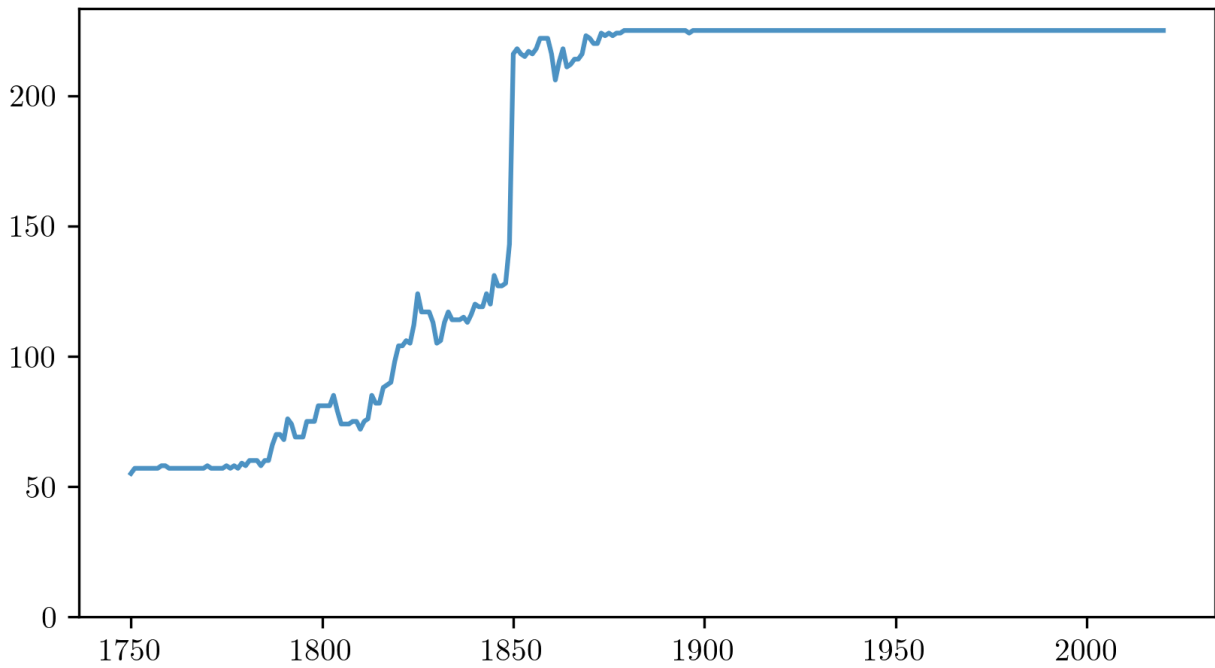
Note: The figure shows the number of countries observed in the TRADHIST trade data by year. I subset to observations with non-missing trade flows and distance information.

Figure 2: Trade flow counts by year



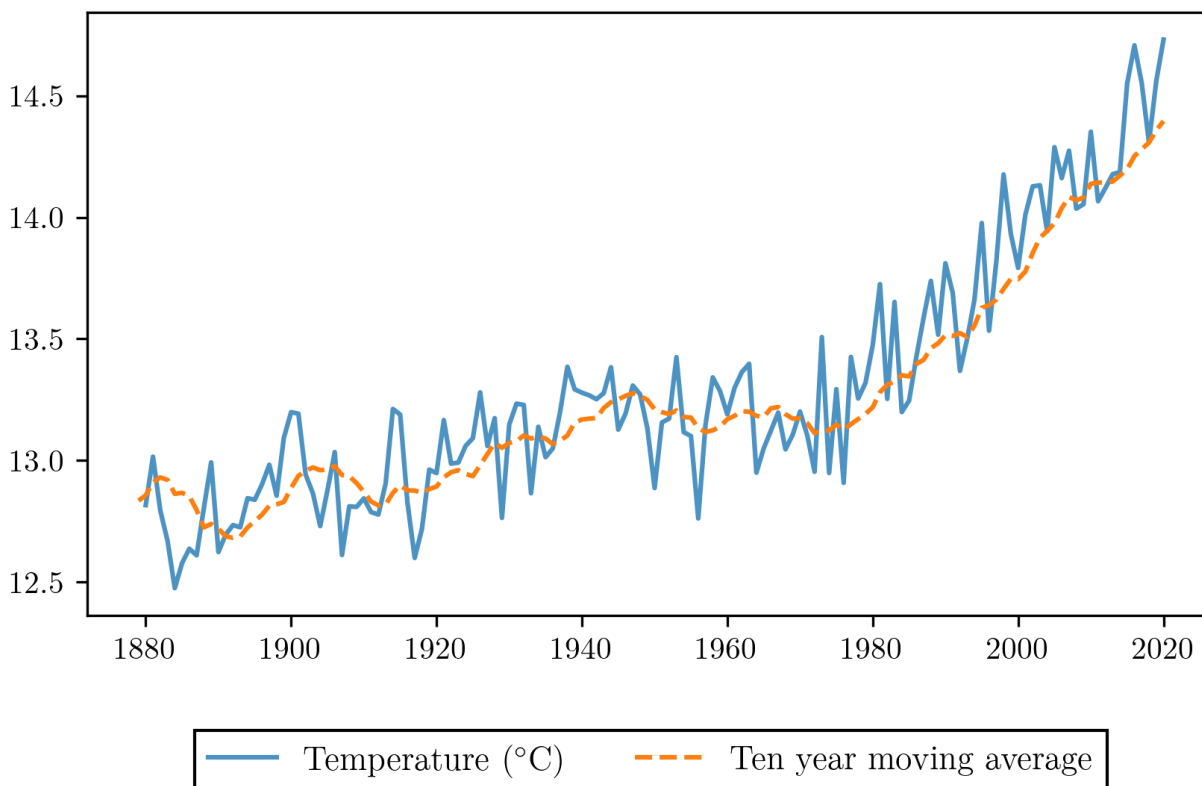
Note: The figure shows the number of trade flows observed in the TRADHIST trade data by year. I subset to observations with non-missing trade flows and distance information.

Figure 3: Weather observation counts for current countries by year



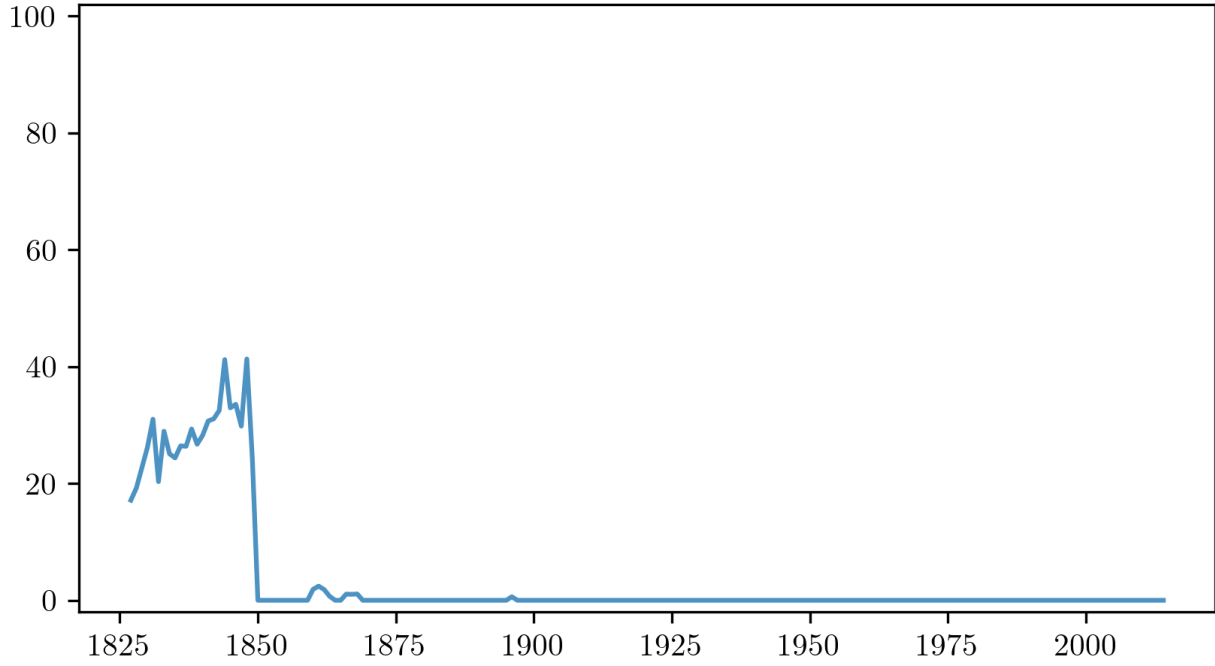
Note: The figure shows the number of countries with non-missing weather observations by year. I subset to countries which currently exist and ever appear in the TRADHIST trade data. (For example, in this plot, I include Germany, which currently exists and appears in the trade data, but not the former West and East Germany, which do appear in the trade data but no longer exist.) The number of countries in the sample therefore does not change over time.

Figure 4: Average temperature ($^{\circ}\text{C}$) by year



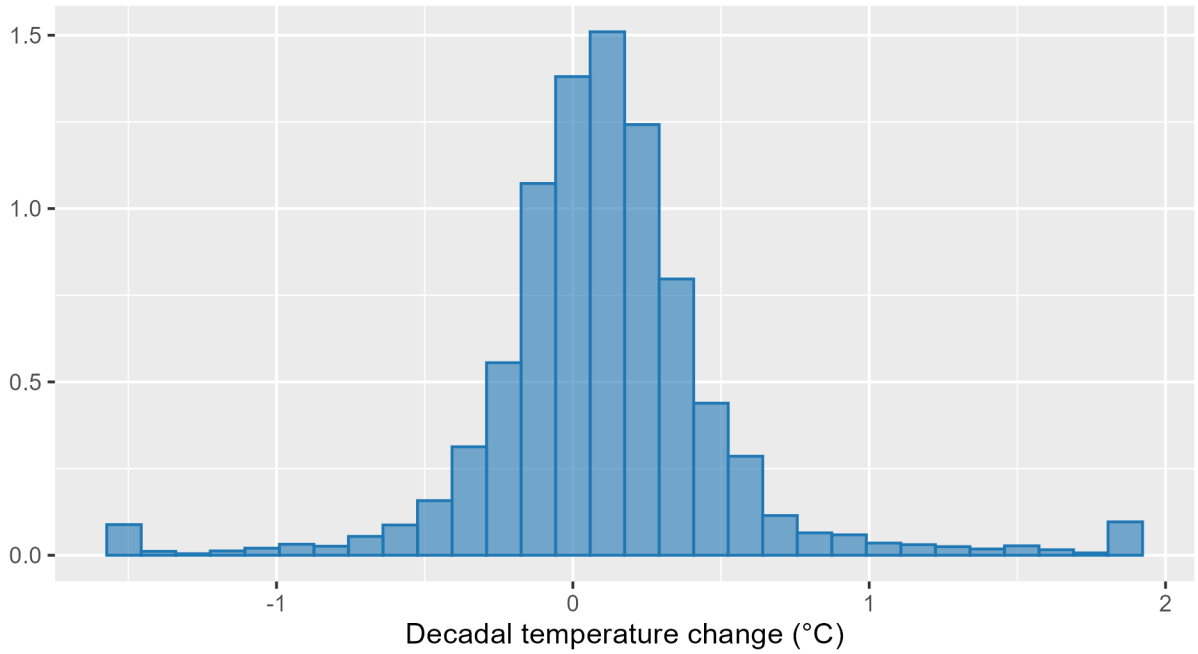
Note: The figure shows the average temperature across years, weighted by country area. The figure starts in 1880, where I have global weather coverage. I subset to countries which currently exist and ever appear in the TRADHIST trade data. (For example, in this plot, I include Germany, which currently exists and appears in the trade data, but not the former West and East Germany, which do appear in the trade data but no longer exist.) The number of countries in the sample therefore does not change over time.

Figure 5: Unmatched trade flows (percent) by year



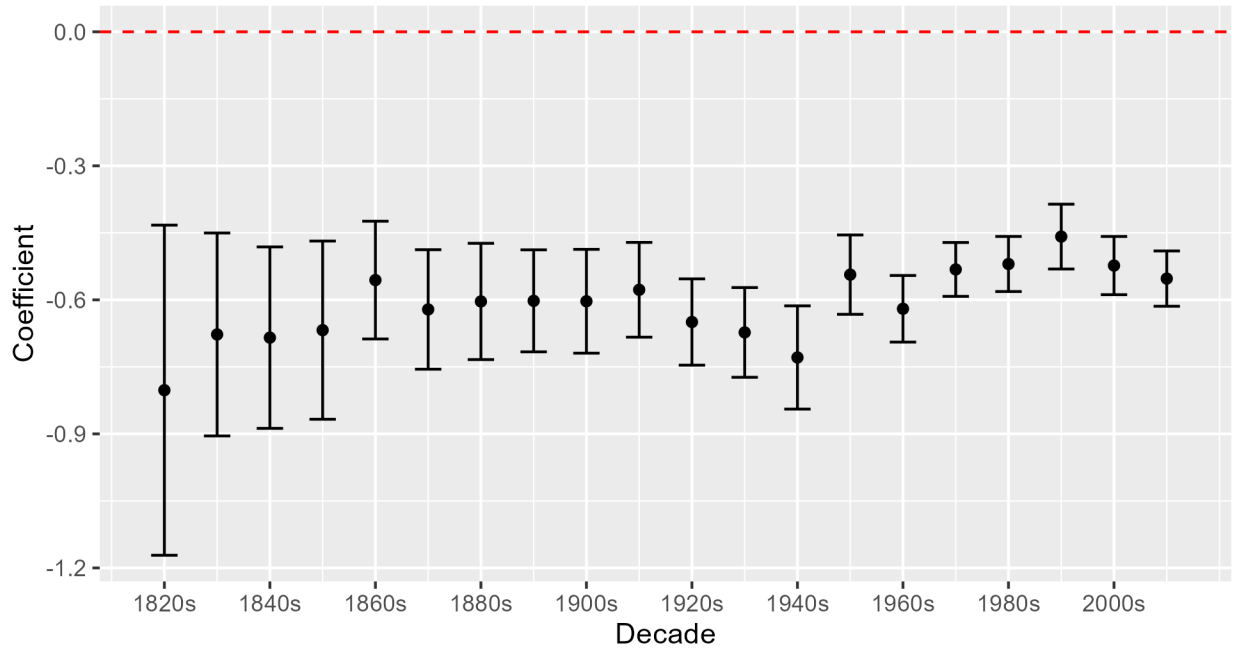
Note: The figure shows the percent of TRADHIST trade observations which cannot be matched to weather information by year. I subset to observations with non-missing trade flows and distance information.

Figure 6: Decadal temperature changes



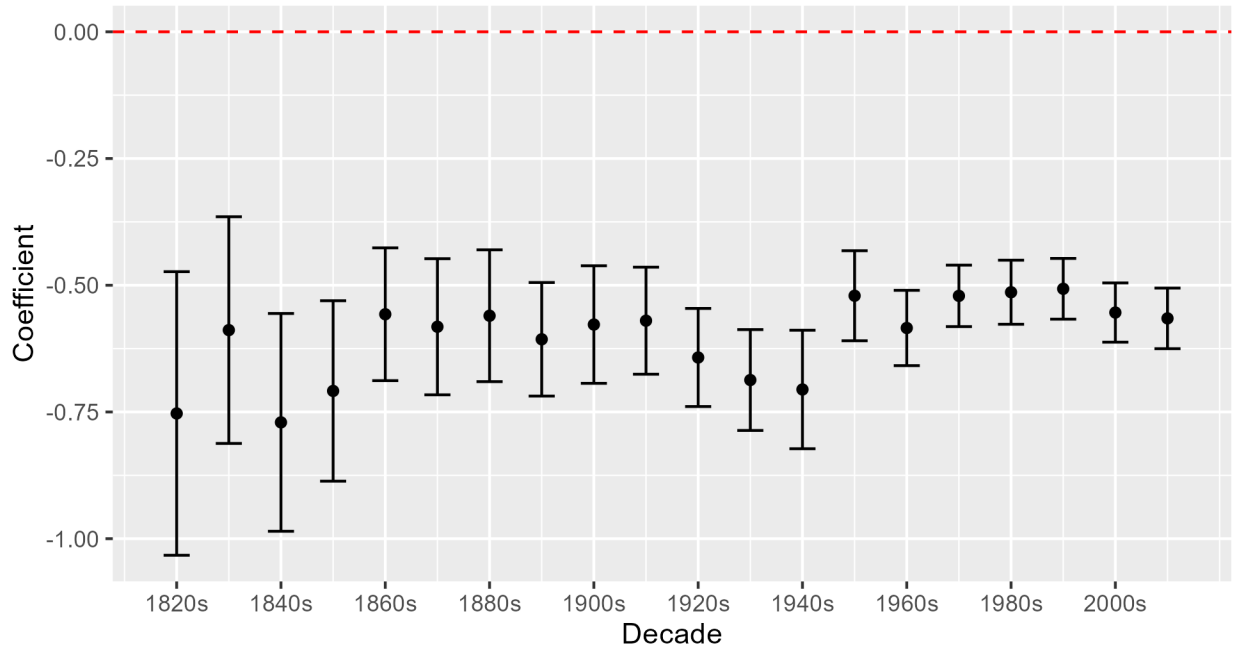
Note: The figure shows the distribution of decadal temperature changes across all countries and decades. As in my gravity estimations, decadal temperature changes are winsorized at the 1st and 99th percentiles.

Figure 7: Coefficients on log distance across decades



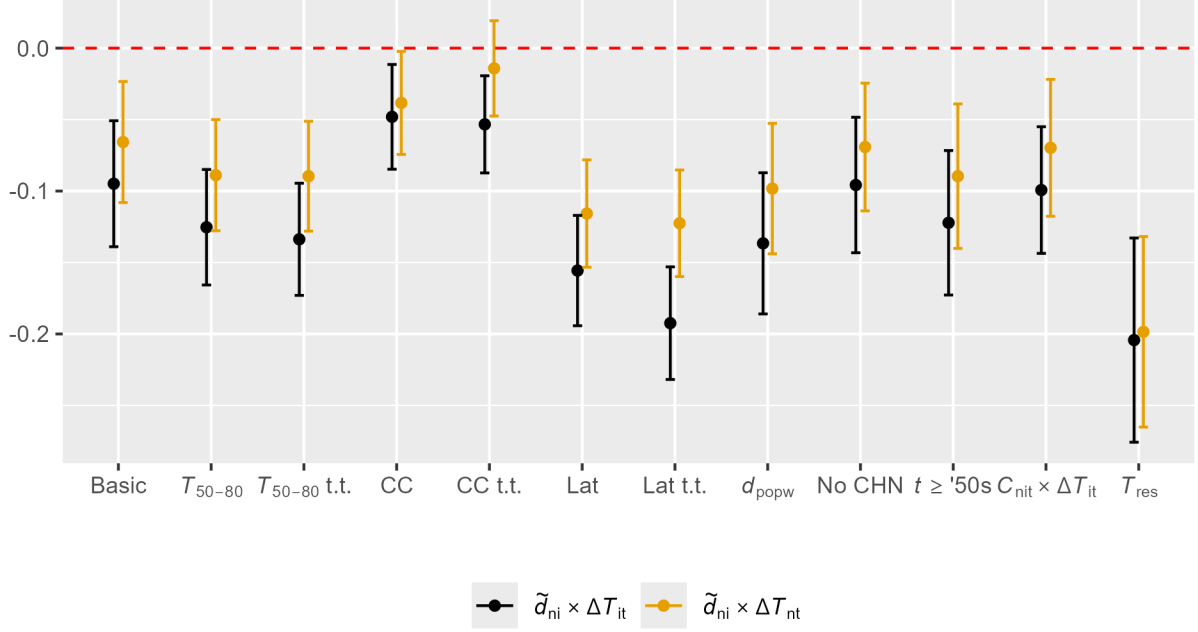
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Coefficients are for distance between origin-destination pairs interacted with decade indicators. Vertical lines and whiskers indicate 90 percent confidence intervals. Other coefficients in the model, including those on origin and destination temperature, do not vary across decades.

Figure 8: Coefficients on log distance across decades (benchmark excluding temperature variables)



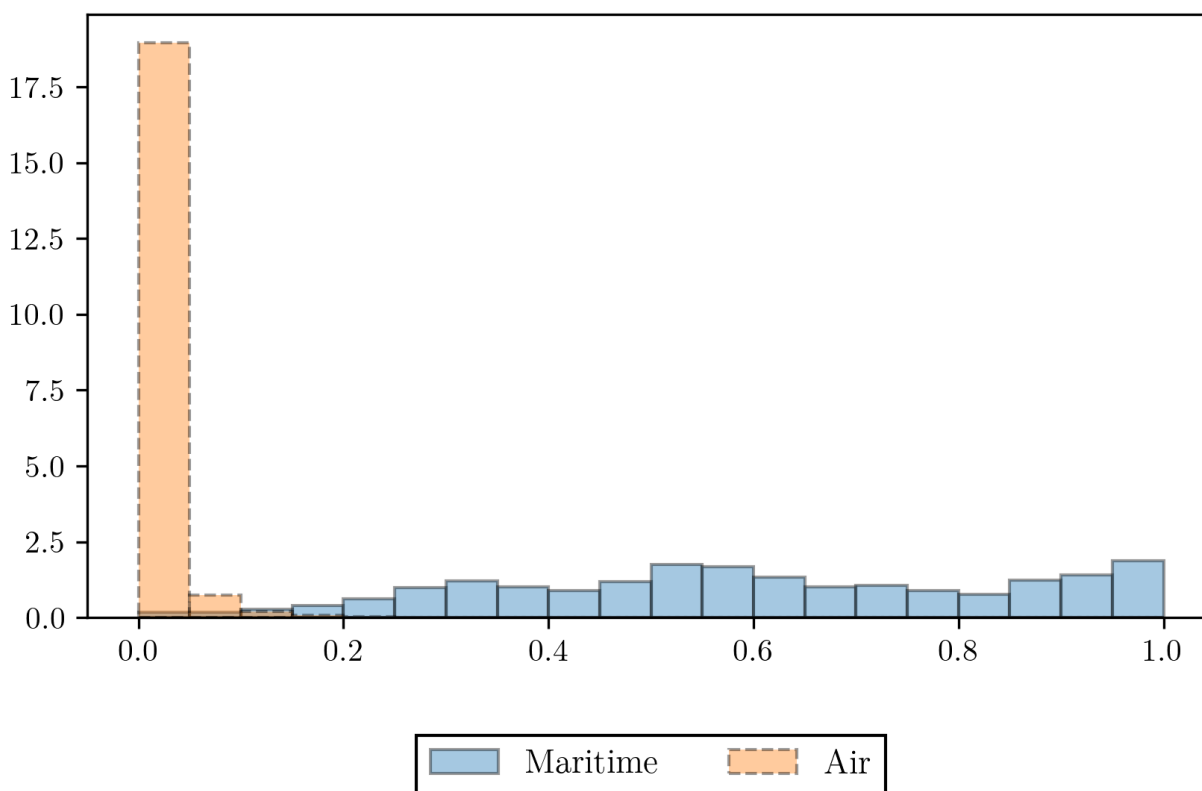
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Coefficients are for distance between origin-destination pairs interacted with decade indicators. Vertical lines and whiskers indicate 90 percent confidence intervals. This benchmark specification does not include origin and destination temperatures.

Figure 9: Coefficients on temperature interactions across specifications



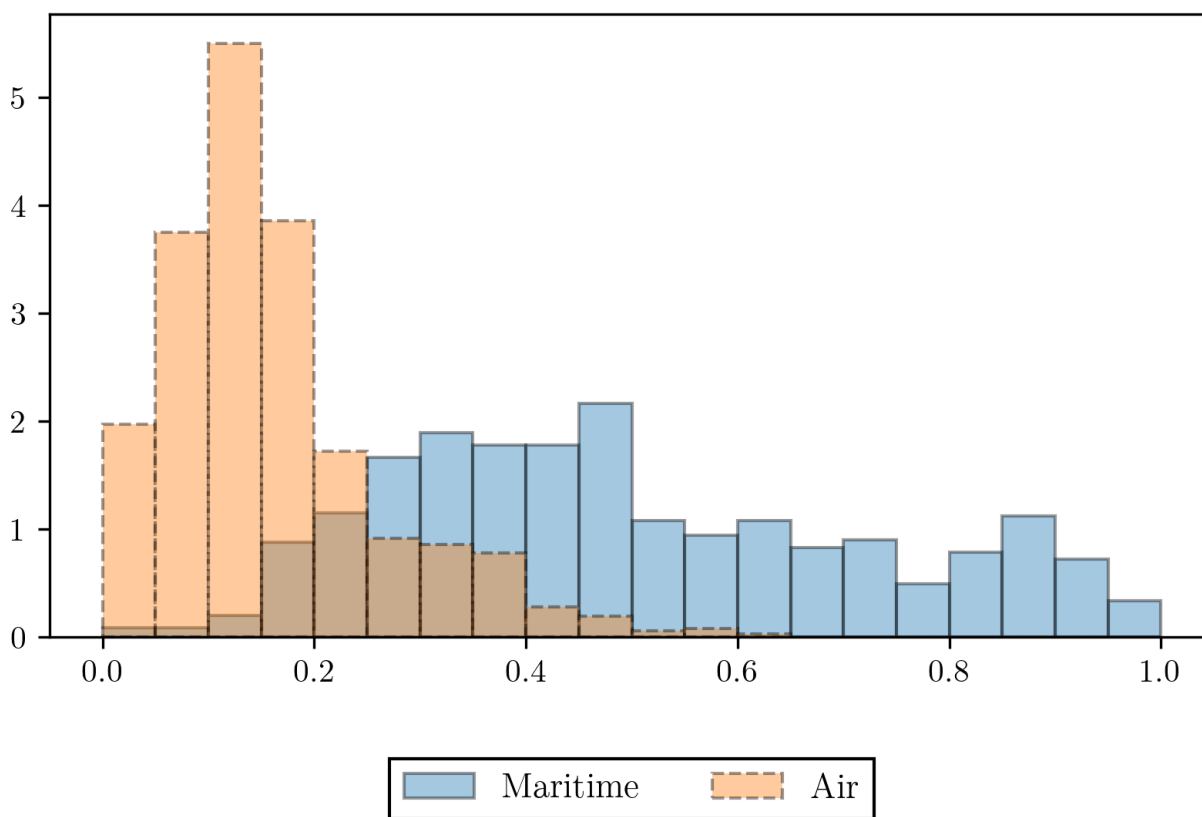
Note: The outcome are decade-level average trade flows from country i to country n , winsorized at the 99th percentile. The estimation uses pseudo-Poisson maximum likelihood (PPML) to accommodate zero trade flows. $\tilde{d}_{ni} \equiv \log(d_{ni})$ is the log of the great circle distance d_{ni} between the origin and destination countries in km. Since the coefficient on that variable is allowed to vary across decades, I only report the coefficient for the latest period, $\tilde{d}_{ni} \times 2010s$. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in $^{\circ}C$. Temperature changes are winsorized at the 1st and 99th percentiles. C_{nit} contains a common language indicator, sharing a border indicator and two indicators for current and past colonial relationships, taking decade means for all variables within each origin-destination pair. Decades t are the decades from 1820 to 2020. $T_{50-80} decile_c$ is country c 's decile of average temperature between the 1950s and 1980s. $CC decile_c$ is country c 's decile of average temperature change (i.e., climate change) between the 1900s and 2000s decades. $Lat. decile_c$ is country c 's decile of latitude. Models with these decile controls include separate trade cost levels and, for the *t.t.* version, trade cost time trends for each decile. d_{popw} uses population-weighted great circle distance instead of the unweighted measure (this is missing for countries which no longer exist, so the observation count is lower). *No CHN* drops China from the estimation sample. $t \geq '50s$ only uses decades from the 1950s onwards. *Full interaction* interacts temperatures not only with distance, but also with the variables included in C_{nit} . *Residual T* uses temperature residuals obtained from an AR(3) estimation with heterogeneity by 1950s–1980s average temperature, similar in spirit to Ramey, Nath, and Klenow (2025). Standard errors clustered by country pair. Vertical lines and whiskers indicate 90 percent confidence intervals.

Figure 10: Maritime and air trade shares across countries, 2016–2019, weight-weighted



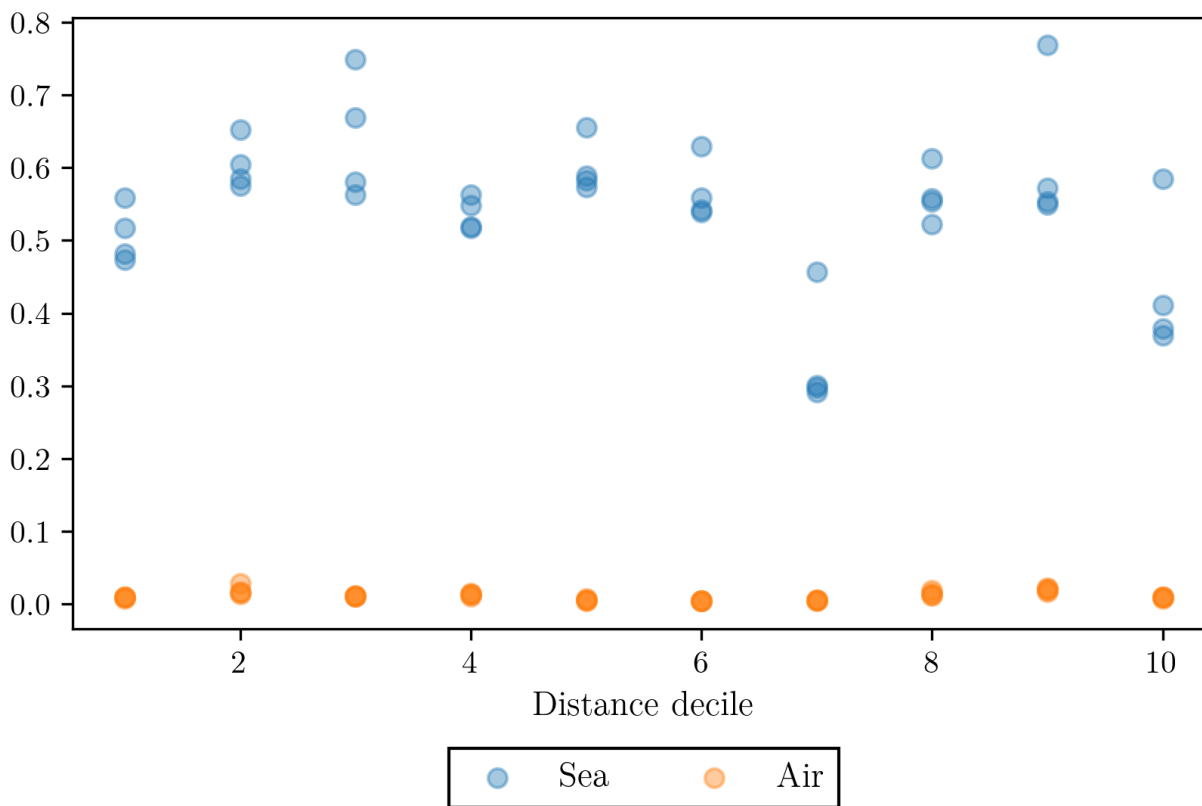
Note: This histogram shows the weight-weighted share of maritime and air trade, i.e., what fraction of the total weight of goods traded each mode transports, across countries.

Figure 11: Maritime and air trade shares across countries, 2016–2019, value-weighted



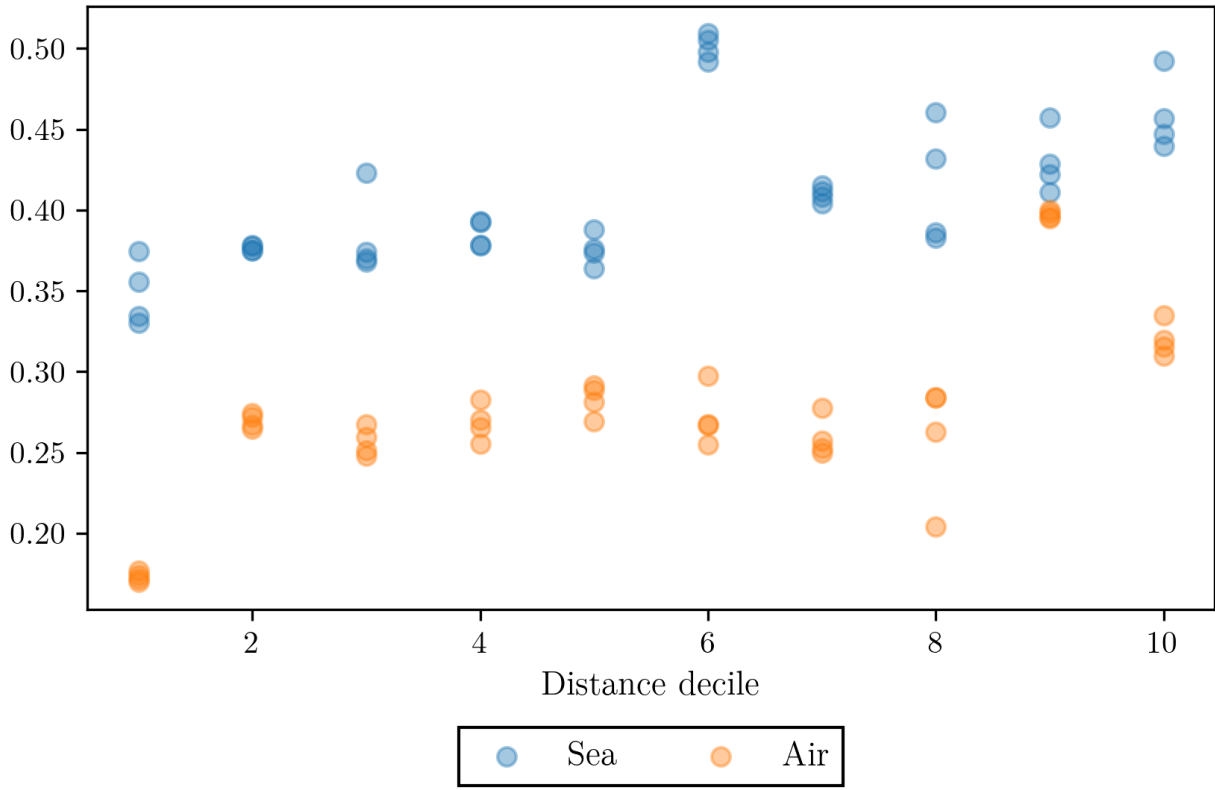
Note: This histogram shows the value-weighted share of maritime and air trade, i.e., what fraction of the total value of goods traded each mode transports, across countries.

Figure 12: Maritime and air trade shares across distance deciles, 2016–2019, weight-weighted



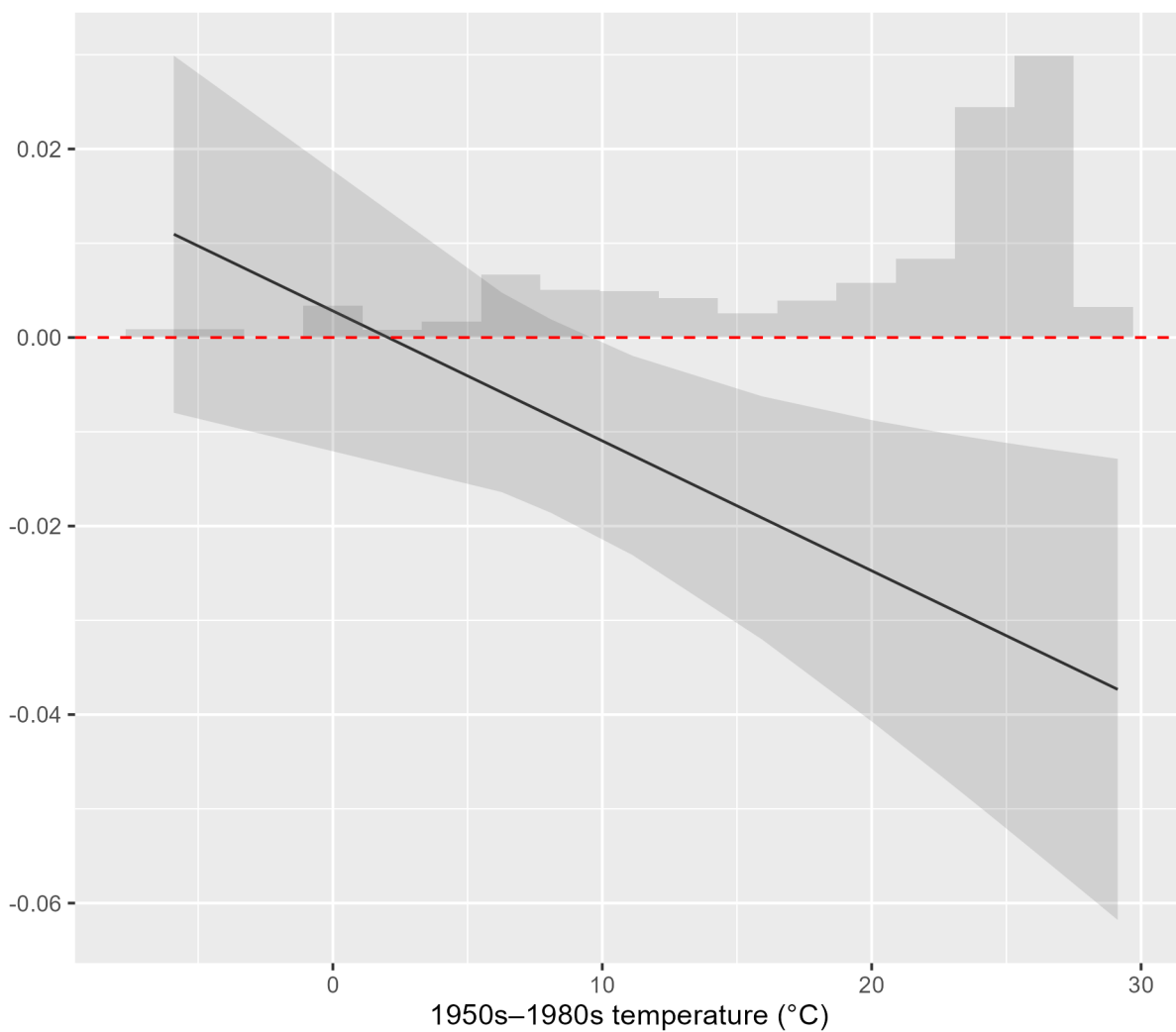
Note: This histogram shows the weight-weighted share of maritime and air trade, i.e., what fraction of the total weight of goods traded each mode transports, across distance deciles. (Deciles are across distances for all trade connections, unweighted.)

Figure 13: Maritime and air trade shares across distance deciles, 2016–2019, value-weighted



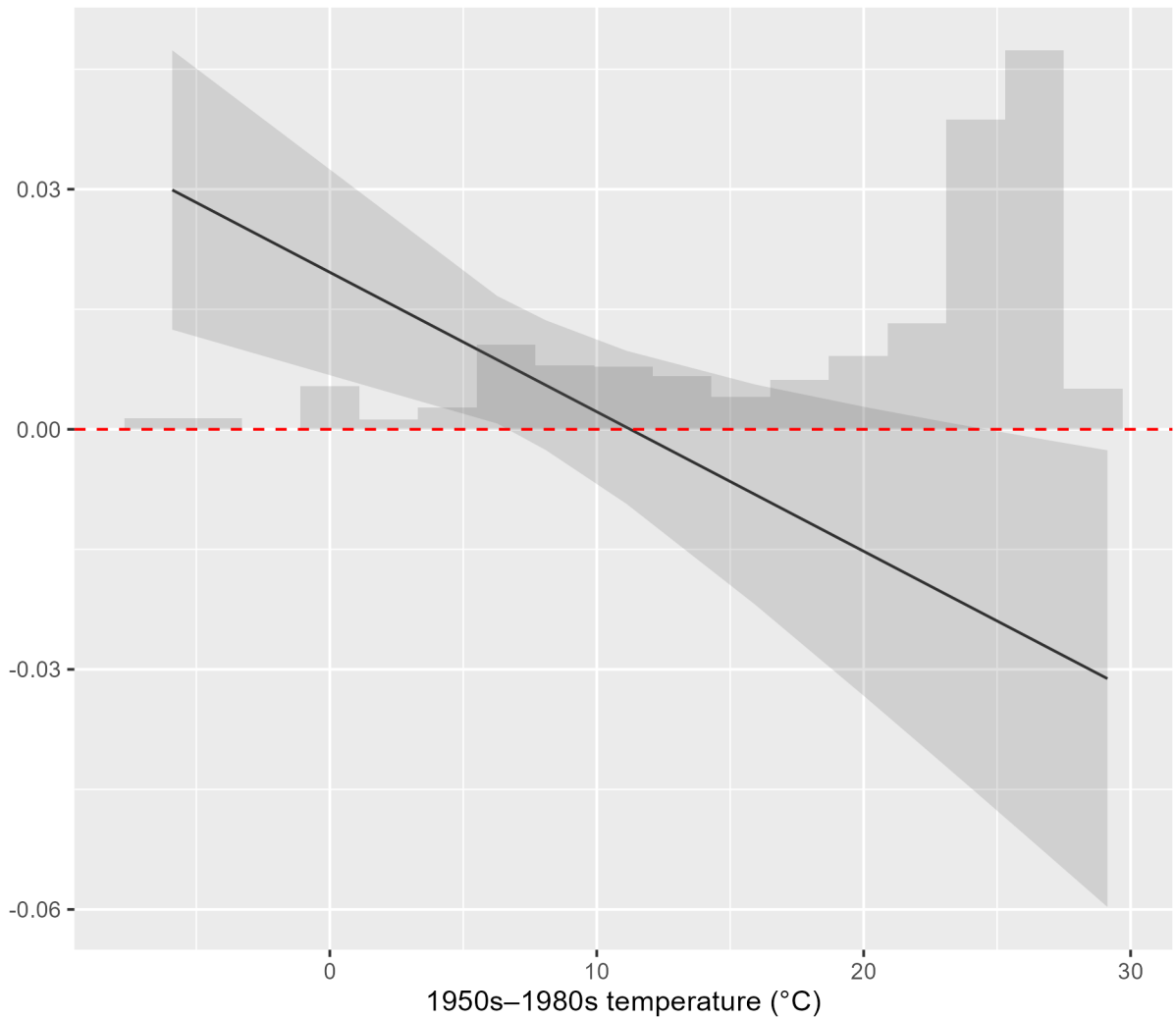
Note: This histogram shows the value-weighted share of maritime and air trade, i.e., what fraction of the total weight of goods traded each mode transports, across distance deciles. (Deciles are across distances for all trade connections, unweighted.)

Figure 14: Marginal effect of year-to-year weather shocks on container port throughput



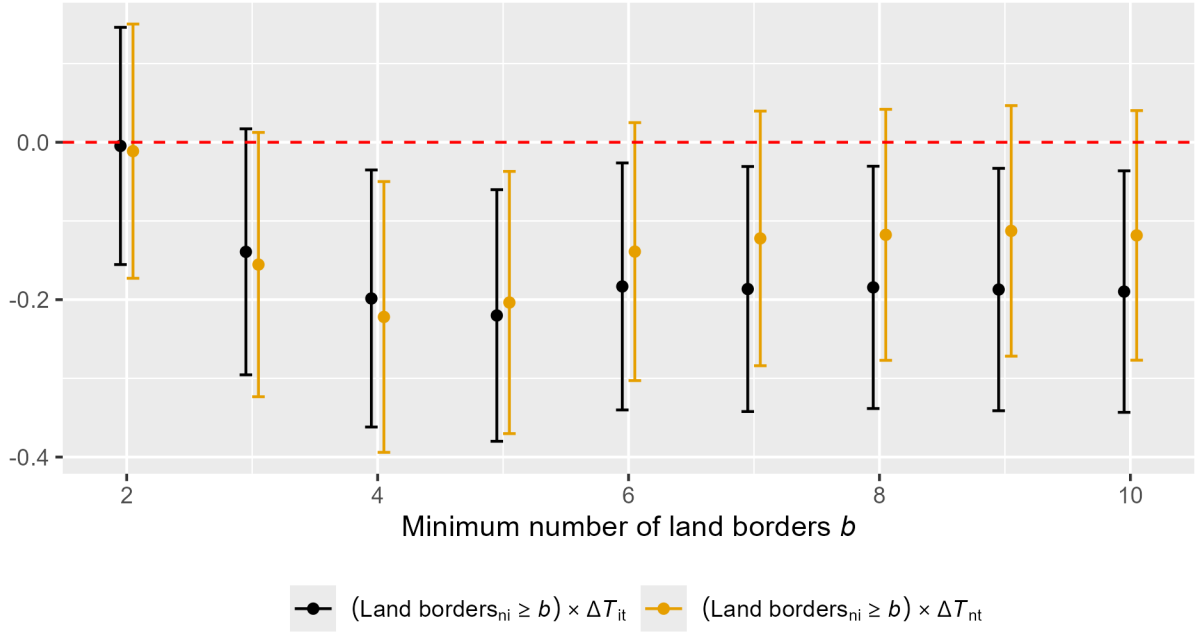
Note: Results are from a regression of log change in container port throughput on temperature changes and country fixed effects. The effect of temperature varies with countries' 1950–1980 average temperature. This graph shows the marginal effect of temperature shocks across 1950–1980 average temperature. The graph also shows a histogram of 1950–1980 average temperature. The shaded area indicates a 90 percent confidence interval.

Figure 15: Marginal effect of year-to-year weather shocks on container port throughput, controlling for change in GDP p.c.



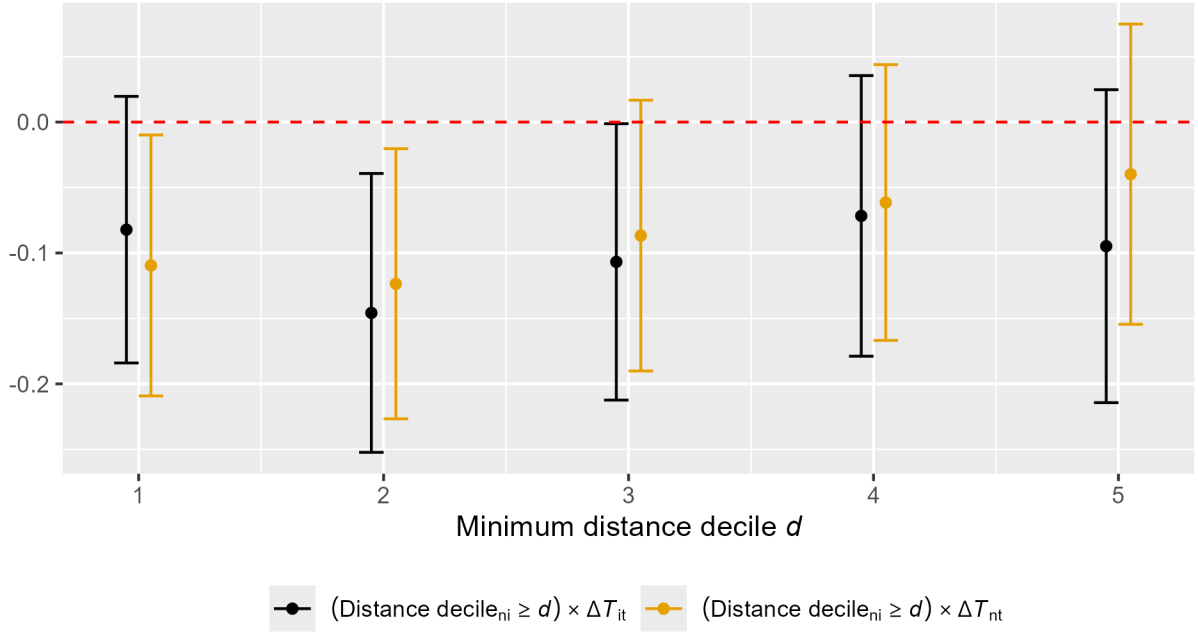
Note: Results are from a regression of log change in container port throughput on temperature changes and country fixed effects, controlling for changes in log GDP per capita. The effect of temperature varies with countries' 1950–1980 average temperature. This graph shows the marginal effect of temperature shocks across 1950–1980 average temperature. The graph also shows a histogram of 1950–1980 average temperature. The shaded area indicates a 90 percent confidence interval.

Figure 16: Land border crossing donut hole estimation



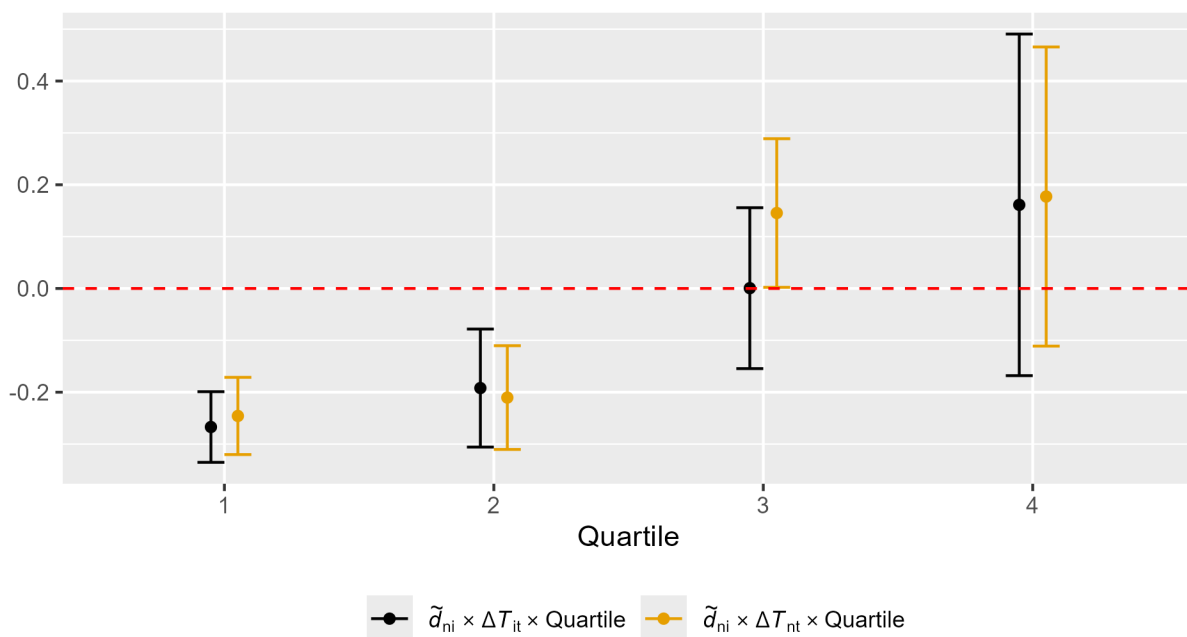
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Gap_{ni} is an indicator; it is equal to one if the number of countries that need to be crossed to get, via a land route, from the origin to the destination country is greater than or equal to the indicated gap size. It is equal to zero if the two countries are neighbors. For all other country pairs (those in the donut hole), the indicator is missing — they are discarded. Each coefficient is from a separate estimation for a different donut hole size. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in $^{\circ}\text{C}$. Temperature changes are winsorized at the 1st and 99th percentiles. Vertical lines and whiskers indicate 90 percent confidence intervals.

Figure 17: Distance decile donut hole estimation



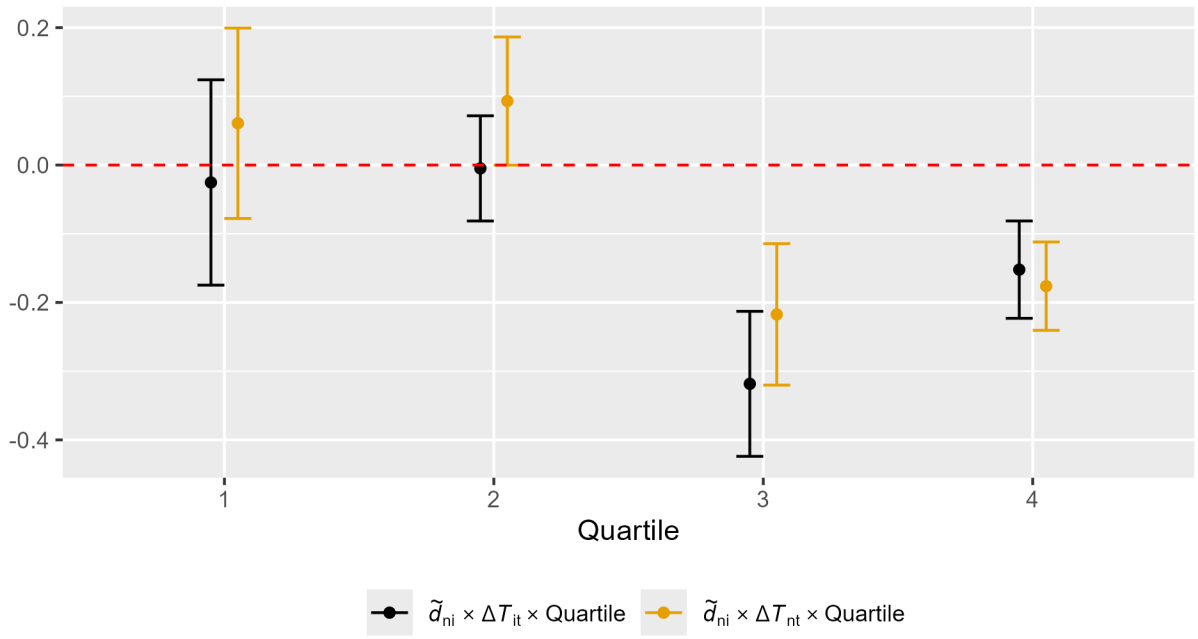
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Distance decile_{ni} is an indicator; it is equal to one if the distance between the origin to the destination country is greater than or equal to the indicated distance decile. It is equal to zero if the two countries are closer to each other than the first distance decile. For all other country pairs (those in the donut hole), the indicator is missing — they are discarded. Each coefficient is from a separate estimation for a different donut hole size. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in $^{\circ}\text{C}$. Temperature changes are winsorized at the 1st and 99th percentiles. Vertical lines and whiskers indicate 90 percent confidence intervals.

Figure 18: Coefficients on temperature interactions across 1950–1980 average temperature quartiles



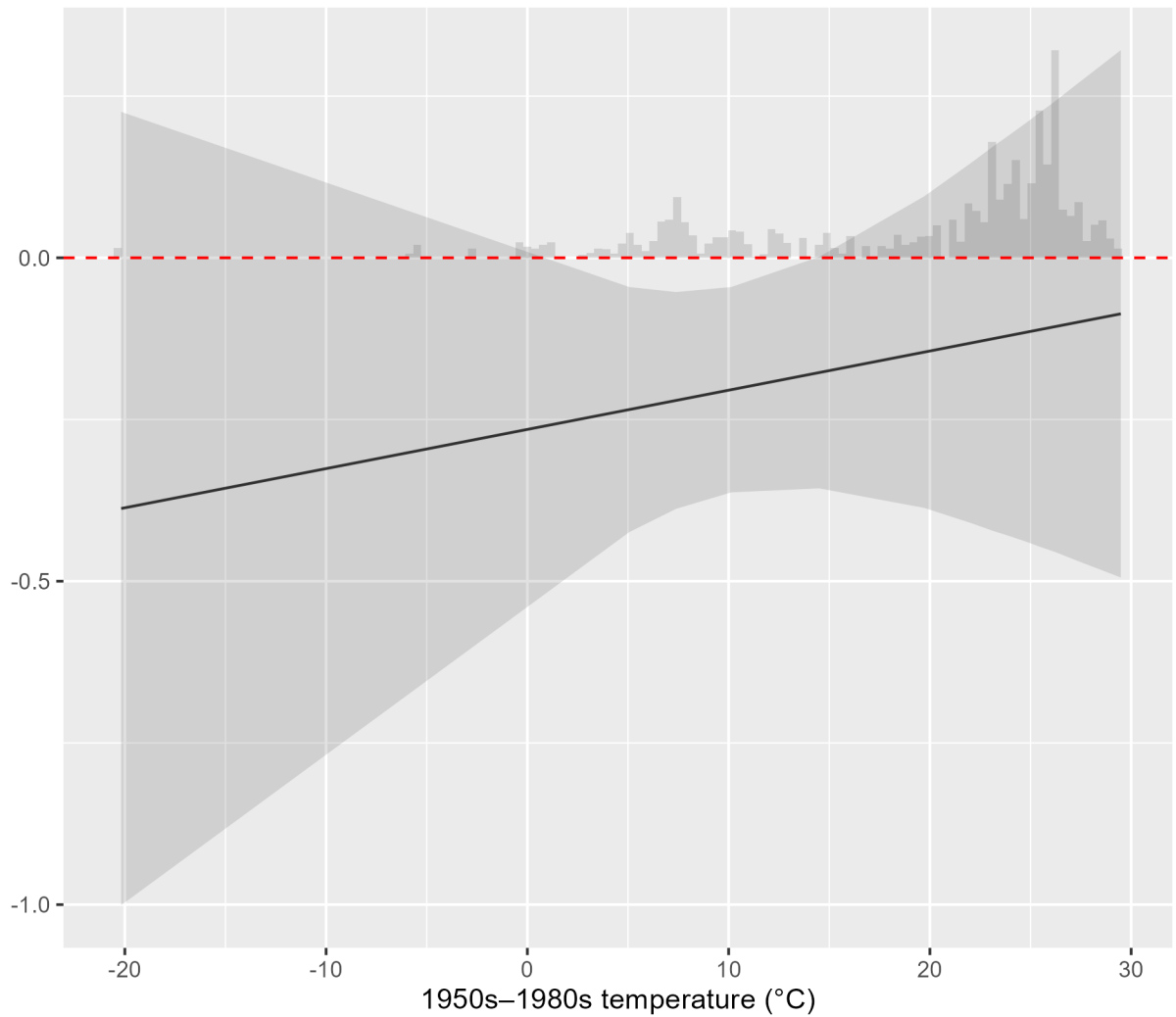
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. $\tilde{d}_{ni} \equiv \log(d_{ni})$ is the log of the great circle distance d_{ni} between the origin and destination countries in km. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in $^{\circ}\text{C}$. Temperature changes are winsorized at the 1st and 99th percentiles. *Quartiles* are country quartiles of countries' average temperature between the 1950s and 1980s. Vertical lines and whiskers indicate 90 percent confidence intervals.

Figure 19: Coefficients on temperature interactions across 1900s–2000s climate change quartiles



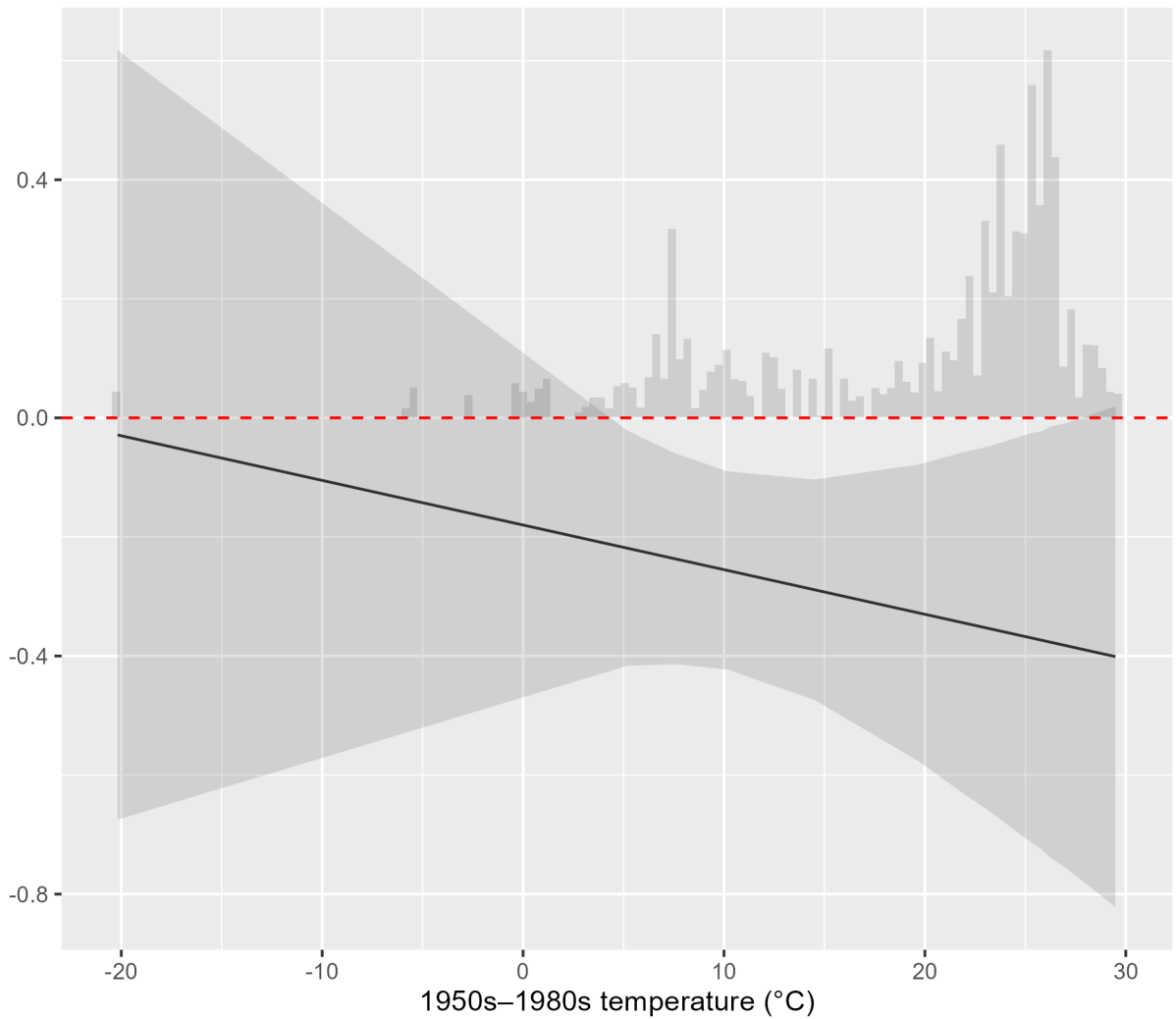
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. $\tilde{d}_{ni} \equiv \log(d_{ni})$ is the log of the great circle distance d_{ni} between the origin and destination countries in km. ΔT_{ct} is the change in decadal mean temperature in country c between decades t and $t - 1$ in $^{\circ}\text{C}$. Temperature changes are winsorized at the 1st and 99th percentiles. *Quartiles* are country quartiles of countries' average temperature change (i.e., climate change) between the 1900s and 2000s decades. Vertical lines and whiskers indicate 90 percent confidence intervals.

Figure 20: Marginal effect of origin temperature on trade cost, donut hole specification using four or more land borders



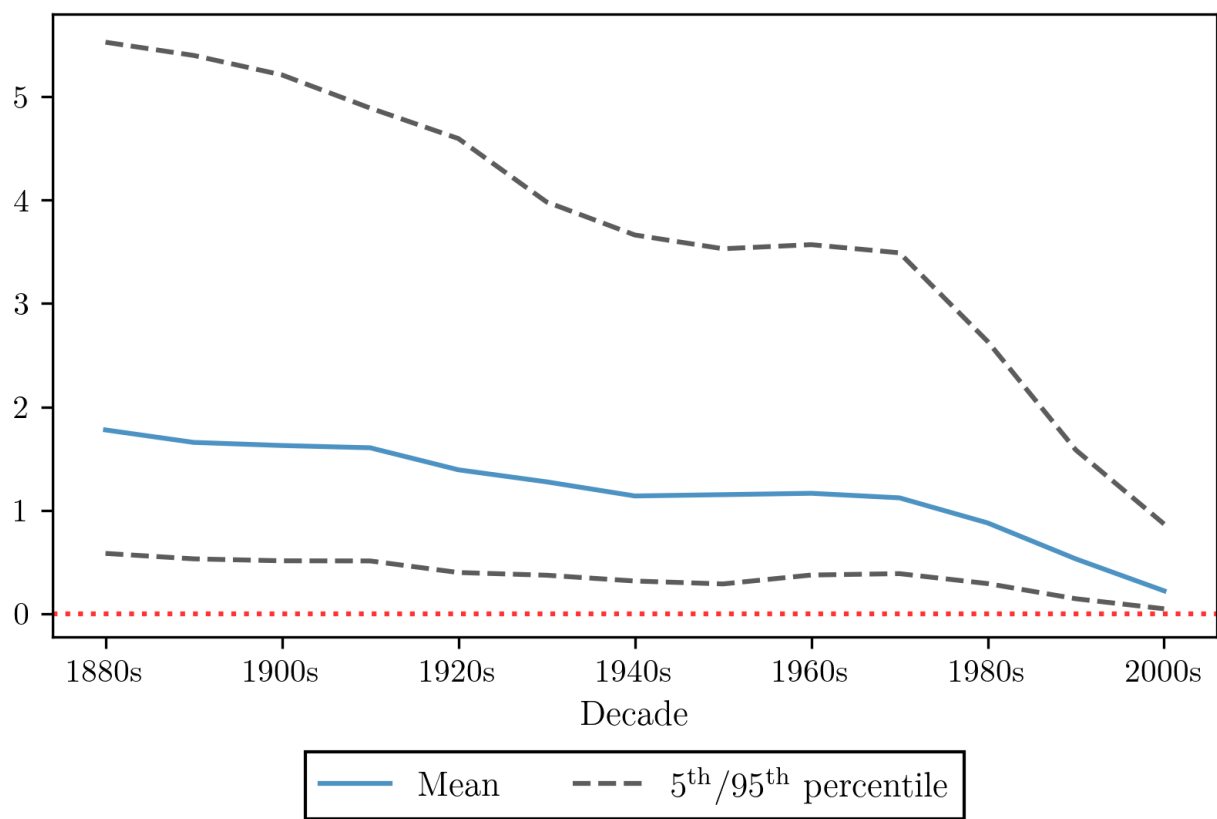
Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Decadal temperature changes are interacted with an indicator for four or more land borders between countries, compared to neighboring countries. I include a further triple interaction between the land border indicator, temperature changes and countries' average temperature between the 1950s and 1980s. This graph shows the marginal effect of origin temperature changes across 1950–1980 average temperature. The graph also shows a histogram of 1950–1980 average temperature. Temperature changes are winsorized at the 1st and 99th percentiles. The shaded area indicates a 90 percent confidence interval.

Figure 21: Marginal effect of destination temperature on trade cost, donut hole specification using four or more land borders



Note: Results are from a gravity estimation for decade-level average trade flows between countries, estimated via Poisson pseudo-maximum likelihood to deal with zero flows. Decadal temperature changes are interacted with an indicator for four or more land borders between countries, compared to neighboring countries. I include a further triple interaction between the land border indicator, temperature changes and countries' average temperature between the 1950s and 1980s. This graph shows the marginal effect of destination temperature changes across 1950–1980 average temperature. The graph also shows a histogram of 1950–1980 average temperature. Temperature changes are winsorized at the 1st and 99th percentiles. The shaded area indicates a 90 percent confidence interval.

Figure 22: Population-weighted summary statistics for welfare change (percent) across decades



Note: The mean and percentiles use 2010s population as weights.

Figure 23: Welfare change (percent) in 1910s climate counterfactual across countries

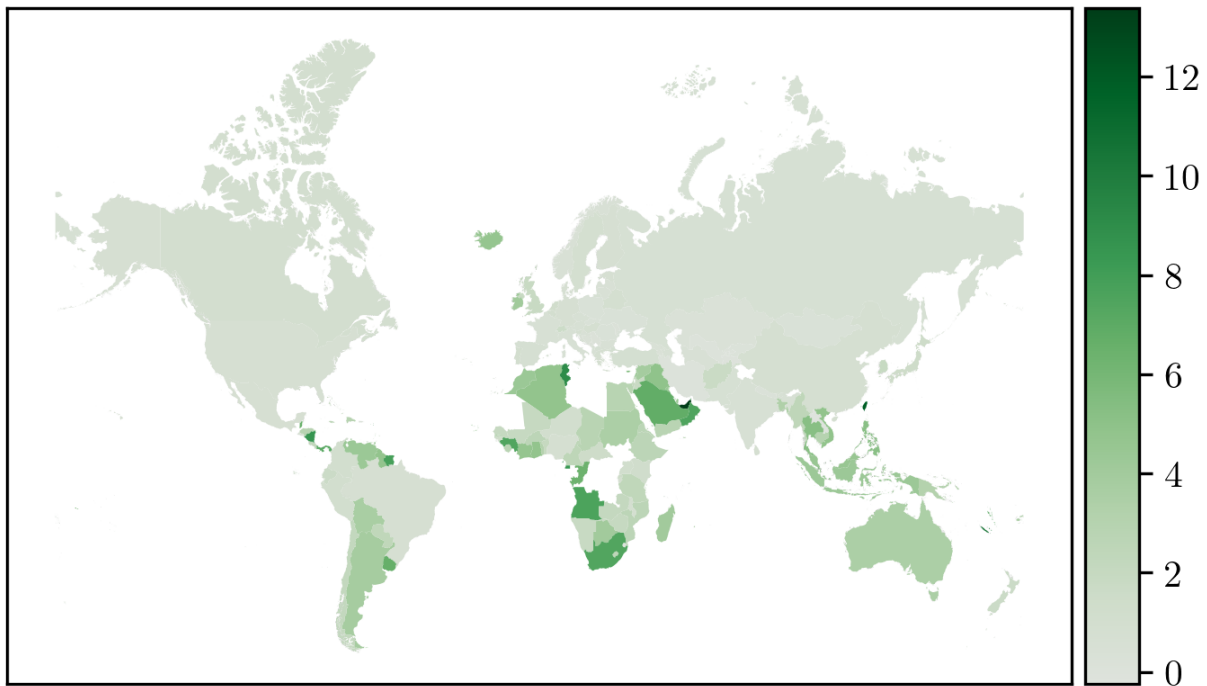
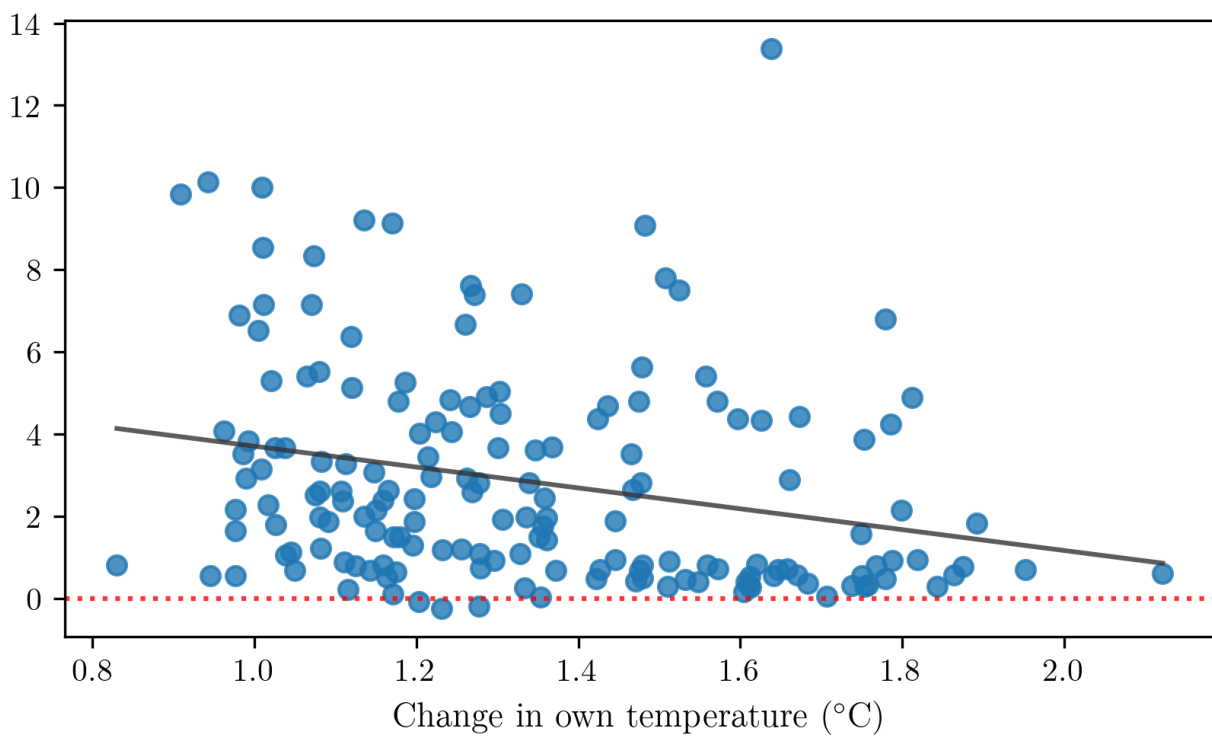
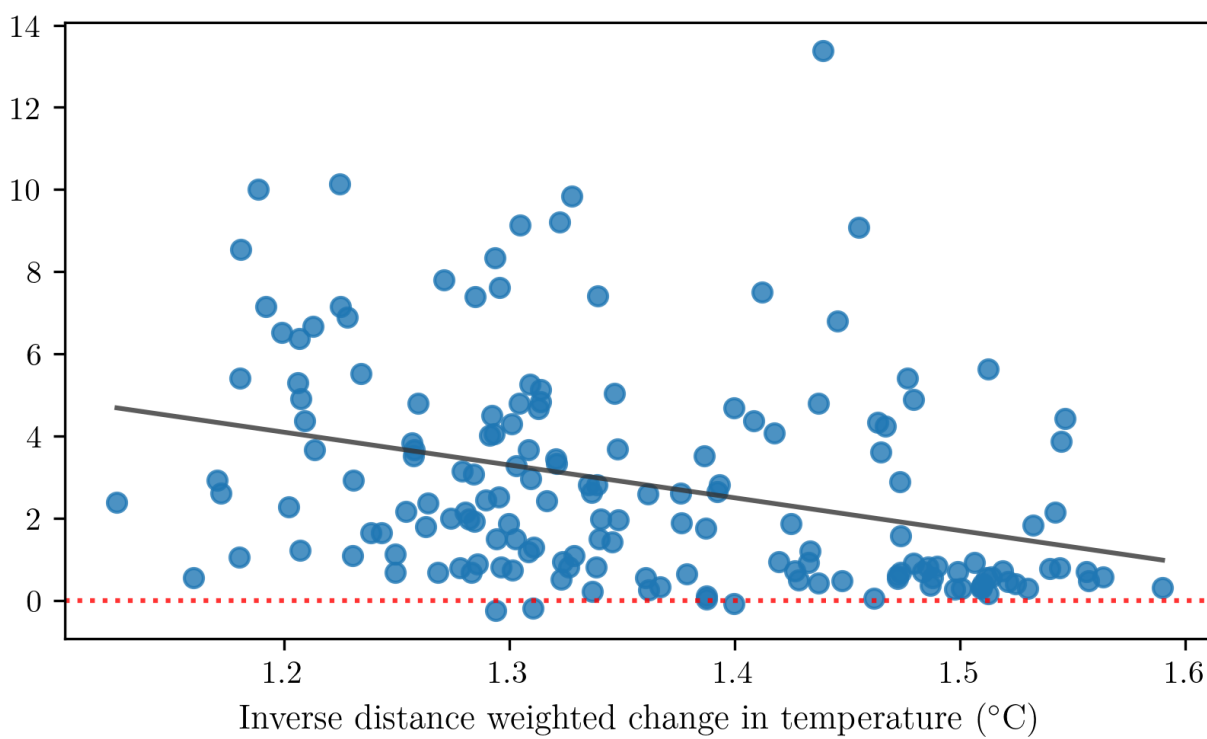


Figure 24: Welfare change (percent) in 1910s climate counterfactual across change in own temperature between the 1910s and 2010s



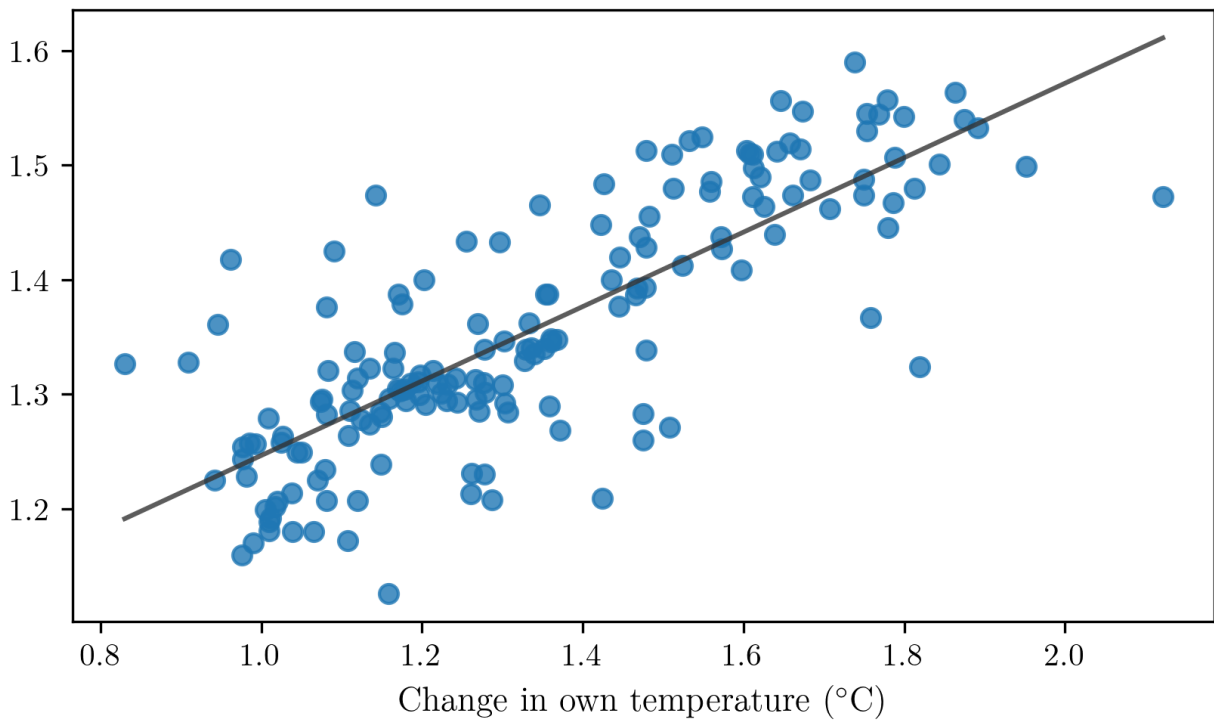
Note: Change in own temperature is the change in country i 's own temperature between the 1910s and 2010s. The solid line shows a linear fit.

Figure 25: Welfare change (percent) in 1910s climate counterfactual across inverse distance weighted change in other countries' temperature between the 1910s and 2010s



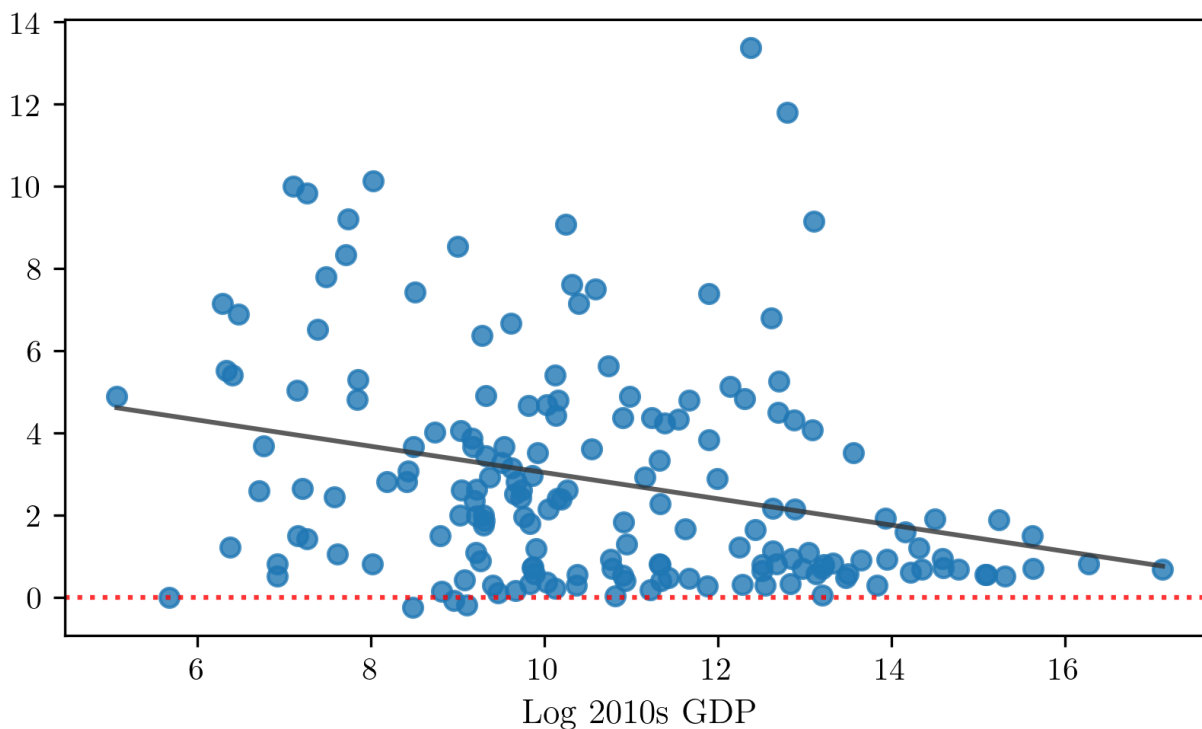
Note: The inverse distance weighted change for country i is the average change in all other countries' temperatures, weighted by the inverse of their distance to i . The solid line shows a linear fit.

Figure 26: Inverse distance weighted change in other countries' temperature between the 1910s and 2010s across change in own temperature between the 1910s and 2010s



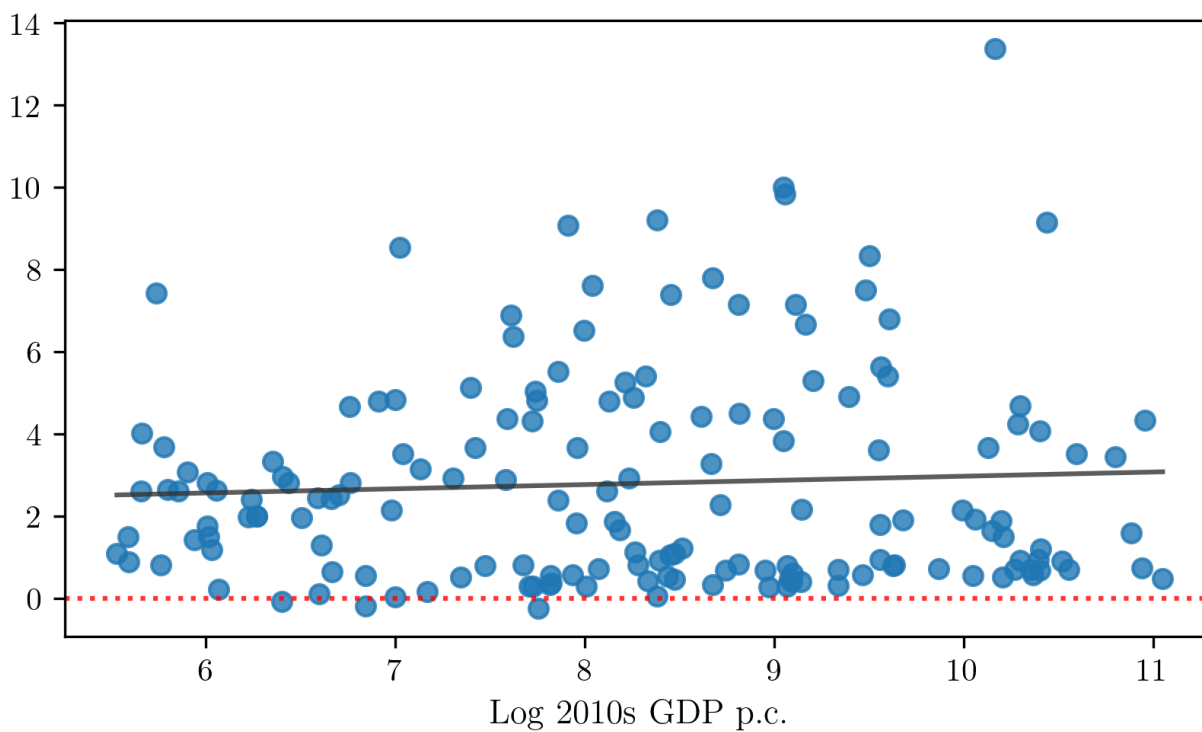
Note: The inverse distance weighted change for country i is the average change in all other countries' temperatures, weighted by the inverse of their distance to i . The solid line shows a linear fit.

Figure 27: Welfare change (percent) in 1910s climate counterfactual across 2010s GDP



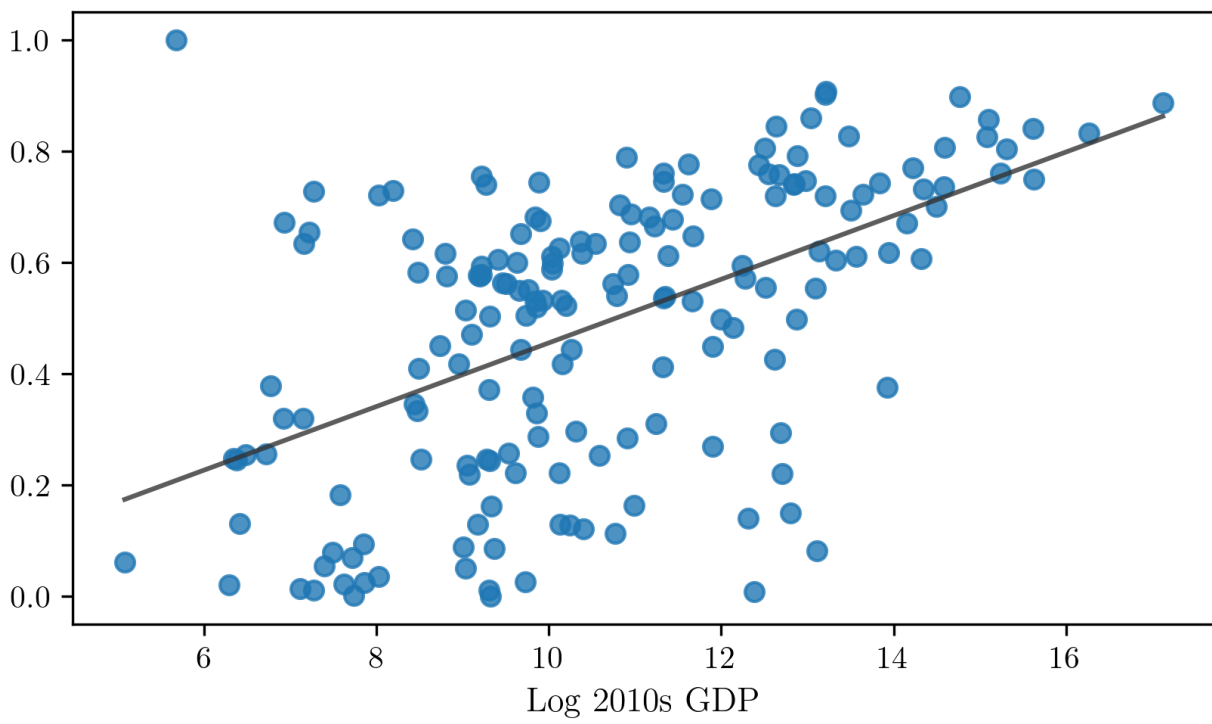
Note: The solid line shows a linear fit.

Figure 28: Welfare change (percent) in 1910s climate counterfactual across 2010s GDP per capita



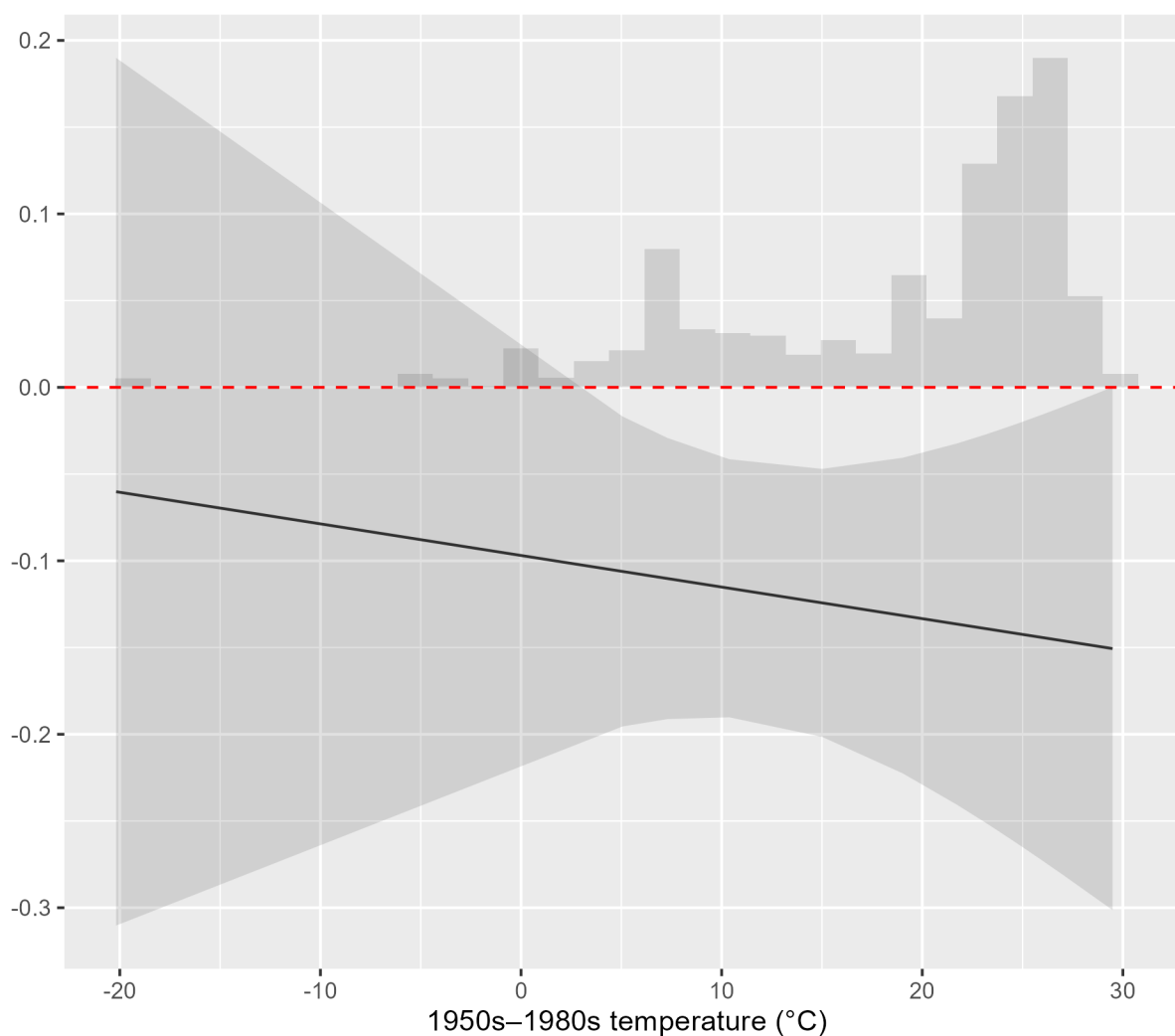
Note: The solid line shows a linear fit.

Figure 29: 2010s own trade share across 2010s GDP



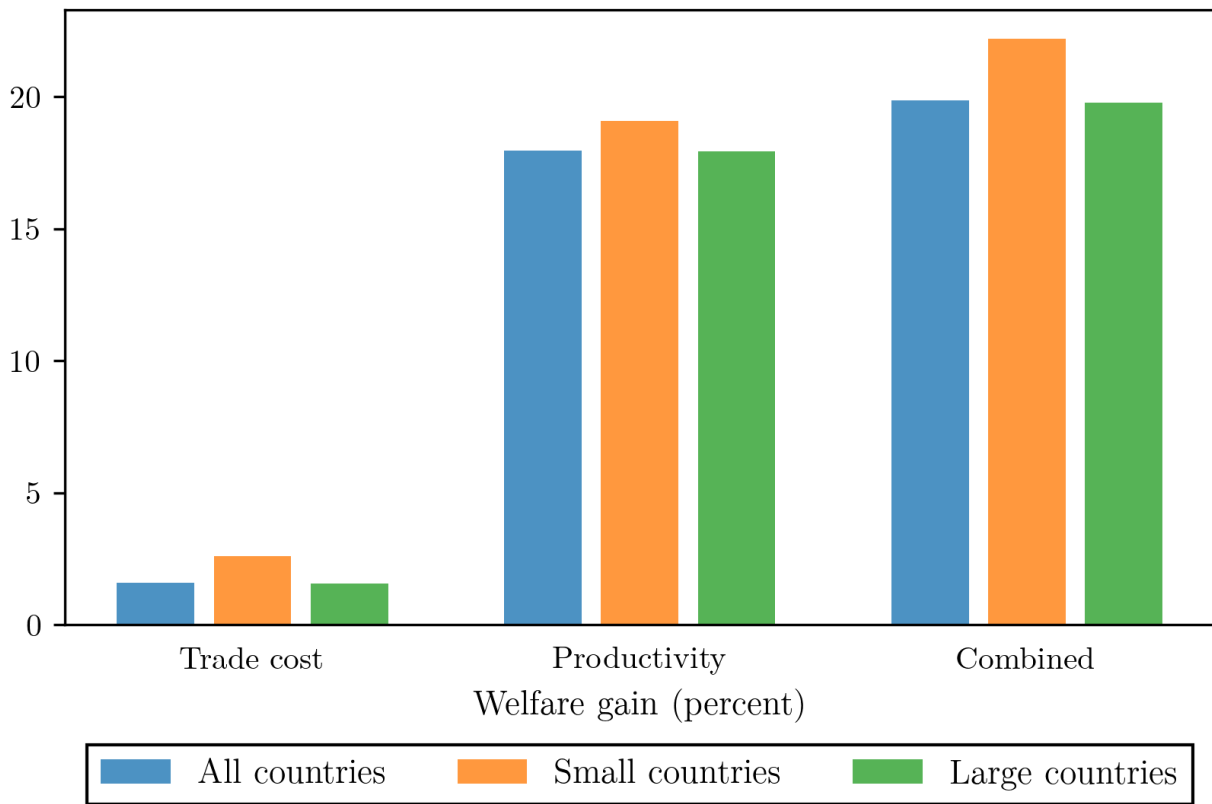
Note: The solid line shows a linear fit.

Figure 30: Marginal effect of decadal temperature changes on log GDP per capita



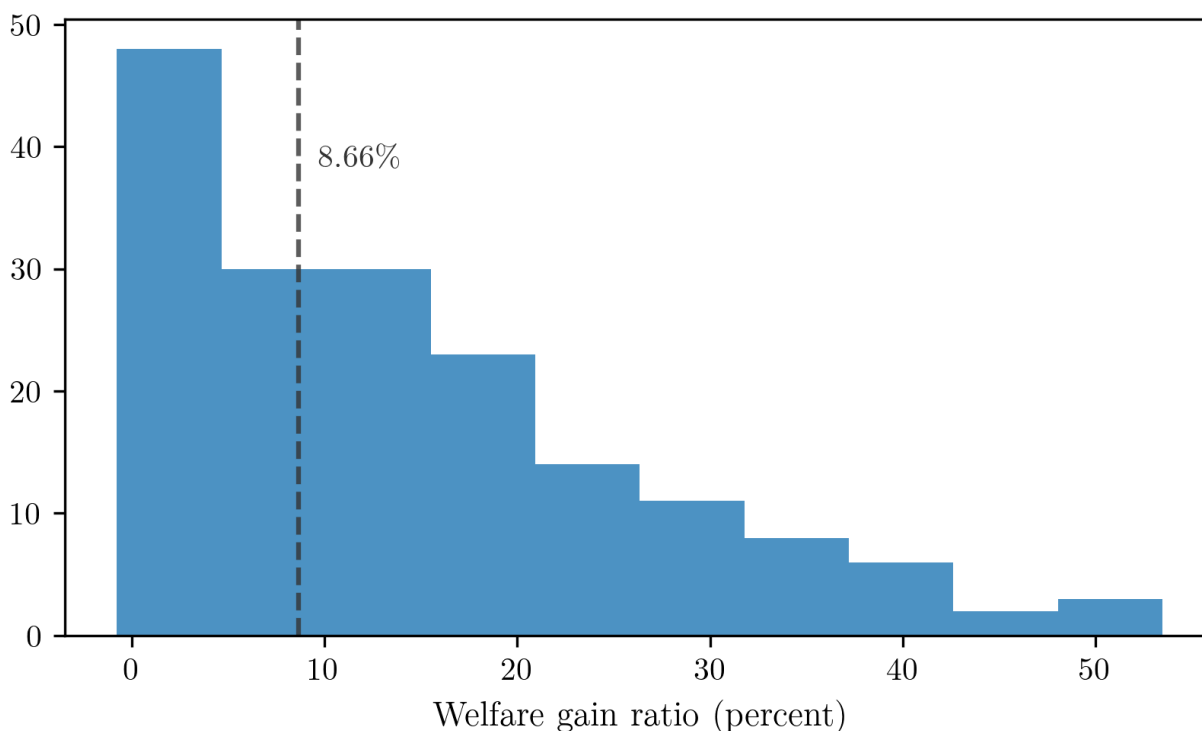
Note: Results are from a regression of log change in decadal average GDP per capita on decadal temperature changes and country fixed effects. The effect of temperature varies with countries' 1950–1980 average temperature. This graph shows the marginal effect of temperature shocks across 1950–1980 average temperature. The graph also shows a histogram of 1950–1980 average temperature. The shaded area indicates a 90 percent confidence interval.

Figure 31: Population-weighted average welfare gains (percent) across different scenarios for 1910s climate counterfactual



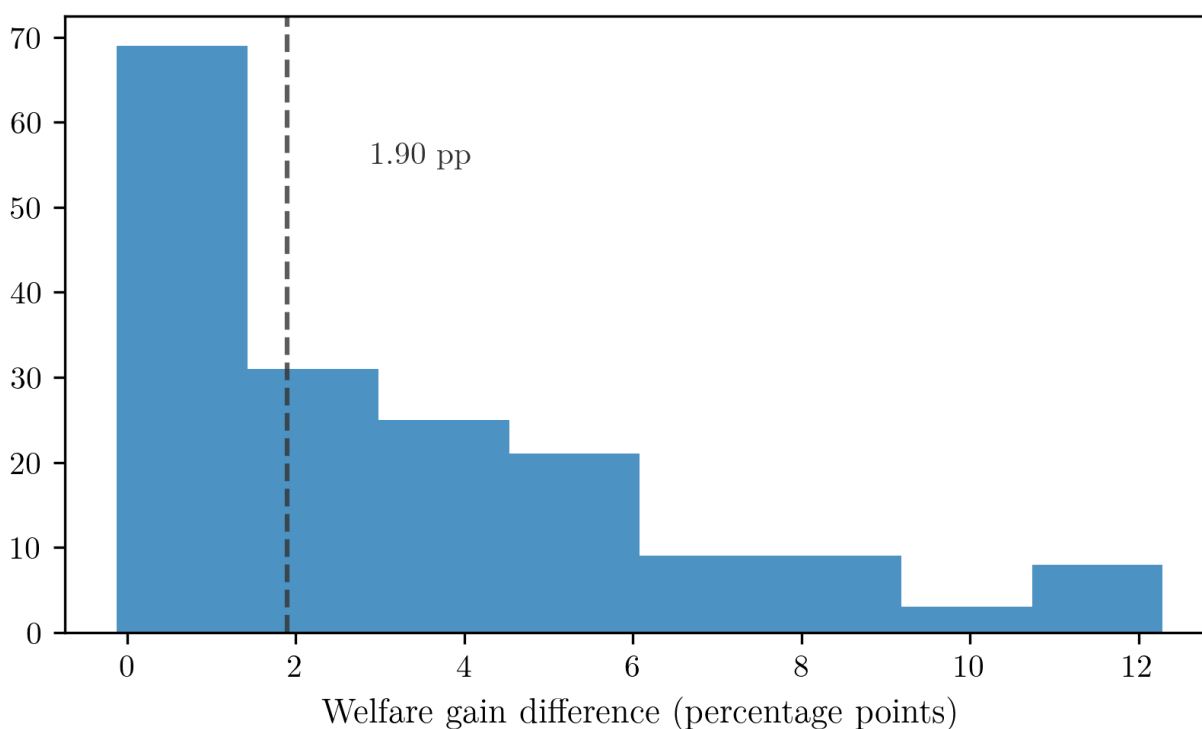
Note: The figure shows population-weighted average welfare gains under each scenario. *Trade cost* undoes the impact of climate change on trade cost. *Productivity* undoes the impact of climate change on productivity. *Combined* undoes both. *All countries* shows the average for all countries in the data. *Small economies* shows the average for countries with below median 2010s GDP. *Large economies* shows the average for countries with above median 2010s GDP.

Figure 32: Additional welfare gains from combined trade cost and productivity change vs. productivity change alone for 1910s climate counterfactual — welfare gain ratio



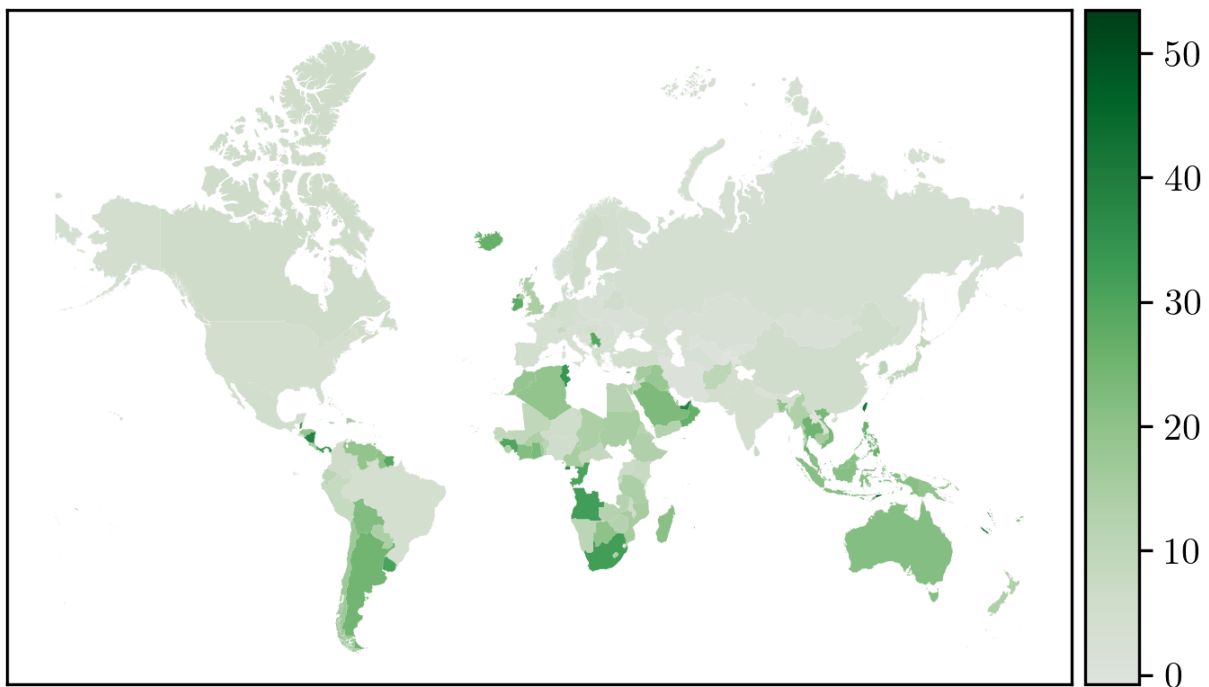
Note: This graph shows a histogram of the welfare gain ratio between the trade cost and productivity and the productivity only counterfactual. The welfare gain ratio is the welfare change from undoing climate change impacts on both productivity and trade networks divided by the welfare change from only undoing the impact on productivity. A welfare gain ratio of 10 percent, for example, means that welfare gains from undoing both effects are 10 percent larger than those from only undoing productivity effects. The dashed line indicates the population-weighted average of the welfare gain ratio.

Figure 33: Additional welfare gains from combined trade cost and productivity change vs. productivity change alone for 1910s climate counterfactual — welfare gain difference



Note: This graph shows a histogram of the welfare gain difference between the trade cost and productivity and the productivity only counterfactual. The welfare gain difference is the welfare change from undoing climate change impacts on both productivity and trade networks minus the welfare change from only undoing its impact on productivity. A welfare gain difference of 10 percentage points, for example, means that welfare gains from undoing both effects are 10 percentage points larger than those from only undoing productivity effects. The dashed line indicates the population-weighted average of the welfare gain difference.

Figure 34: Additional welfare gains from combined trade cost and productivity change vs. productivity change alone for 1910s climate counterfactual across countries



Note: This map shows the global distribution of the welfare gain ratio between the trade cost and productivity and the productivity only counterfactual. The welfare gain ratio is the welfare change from undoing climate change impacts on both productivity and trade networks divided by the welfare change from only undoing the impact on productivity. A welfare gain ratio of 10 percent, for example, means that welfare gains from undoing both effects are 10 percent larger than those from only undoing productivity effects. The dashed line indicates the population-weighted average of the welfare gain ratio.

Appendix A Additional tables

Table 4: Population-weighted summary statistics for welfare change (percent) across decades

Statistic	1880s	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
Mean	1.777	1.656	1.626	1.604	1.391	1.275	1.138	1.151	1.164	1.120	0.878	0.529	0.221
p_5	0.583	0.530	0.511	0.510	0.398	0.372	0.316	0.288	0.374	0.387	0.291	0.144	0.047
p_{10}	0.664	0.532	0.511	0.554	0.463	0.441	0.399	0.394	0.426	0.409	0.306	0.197	0.056
p_{25}	0.664	0.543	0.559	0.558	0.471	0.467	0.399	0.394	0.426	0.418	0.333	0.238	0.069
p_{50}	0.882	0.824	0.827	0.811	0.683	0.680	0.525	0.603	0.586	0.556	0.461	0.241	0.085
p_{75}	2.453	2.134	2.103	1.992	1.792	1.699	1.434	1.584	1.629	1.522	1.167	0.630	0.213
p_{90}	4.503	4.458	4.149	4.309	3.743	3.289	3.107	2.898	2.924	2.580	2.118	1.264	0.601
p_{95}	5.527	5.399	5.211	4.890	4.595	3.982	3.663	3.530	3.569	3.490	2.633	1.583	0.867

Note: The table summarizes the estimated percent change in welfare under climate change counterfactuals for each decade. *Mean* reports the average welfare change for each decade, while p_x reports the x^{th} percentile of welfare changes for each decade. The mean and percentiles use 2010s population as weights.

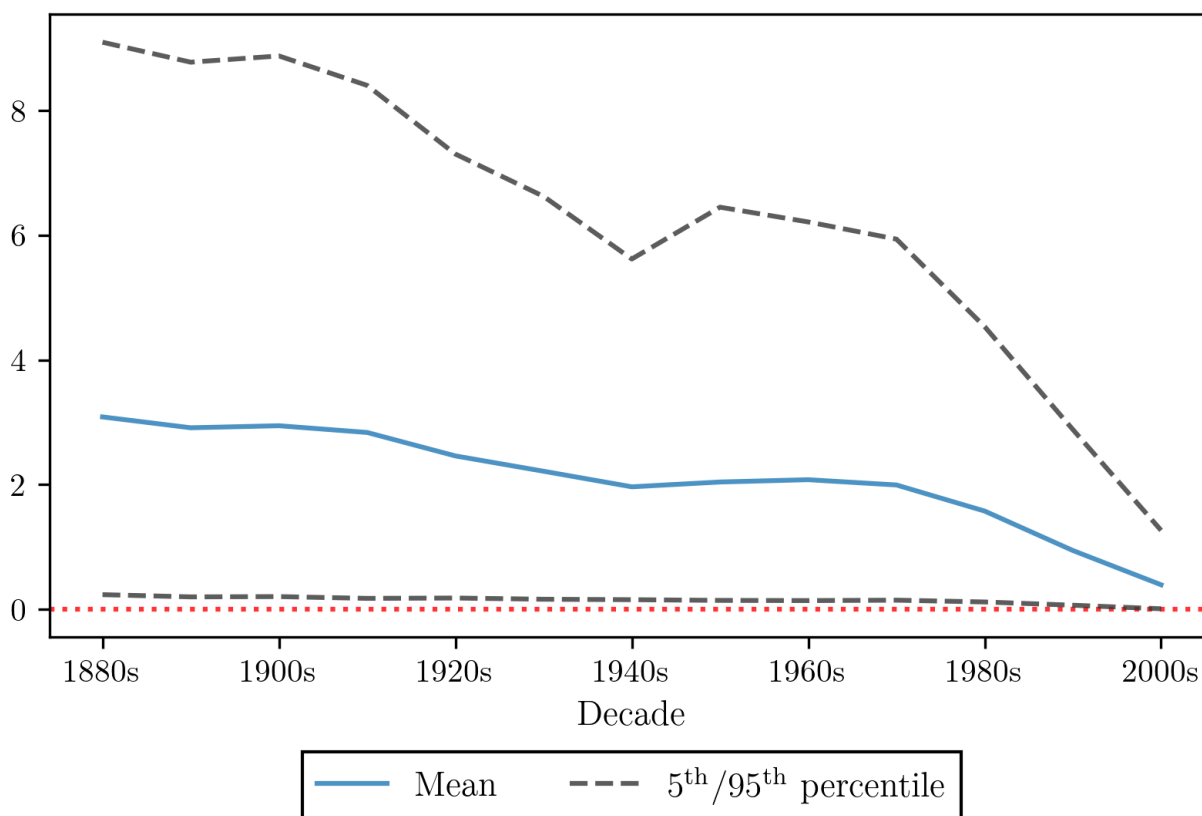
Table 5: Summary statistics for welfare change (percent) across decades

Statistic	1880s	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
Mean	3.086	2.912	2.944	2.836	2.460	2.215	1.965	2.042	2.079	1.994	1.576	0.943	0.394
p_5	0.236	0.200	0.205	0.176	0.181	0.162	0.155	0.144	0.140	0.147	0.118	0.066	0.009
p_{10}	0.407	0.374	0.365	0.328	0.327	0.227	0.307	0.276	0.257	0.260	0.243	0.136	0.034
p_{25}	0.859	0.751	0.772	0.718	0.635	0.512	0.526	0.536	0.554	0.557	0.441	0.237	0.084
p_{50}	2.292	2.134	2.089	1.992	1.659	1.605	1.396	1.566	1.530	1.483	1.016	0.597	0.218
p_{75}	4.801	4.325	4.252	4.322	3.612	3.305	2.877	2.957	2.946	2.988	2.381	1.419	0.597
p_{90}	7.334	7.096	7.201	6.854	5.827	5.430	4.638	4.929	4.923	4.631	3.729	2.240	1.005
p_{95}	9.094	8.774	8.874	8.402	7.302	6.622	5.618	6.449	6.212	5.937	4.533	2.883	1.267

Note: The table summarizes the estimated percent change in welfare under climate change counterfactuals for each decade. *Mean* reports the average welfare change for each decade, while p_x reports the x^{th} percentile of welfare changes for each decade.

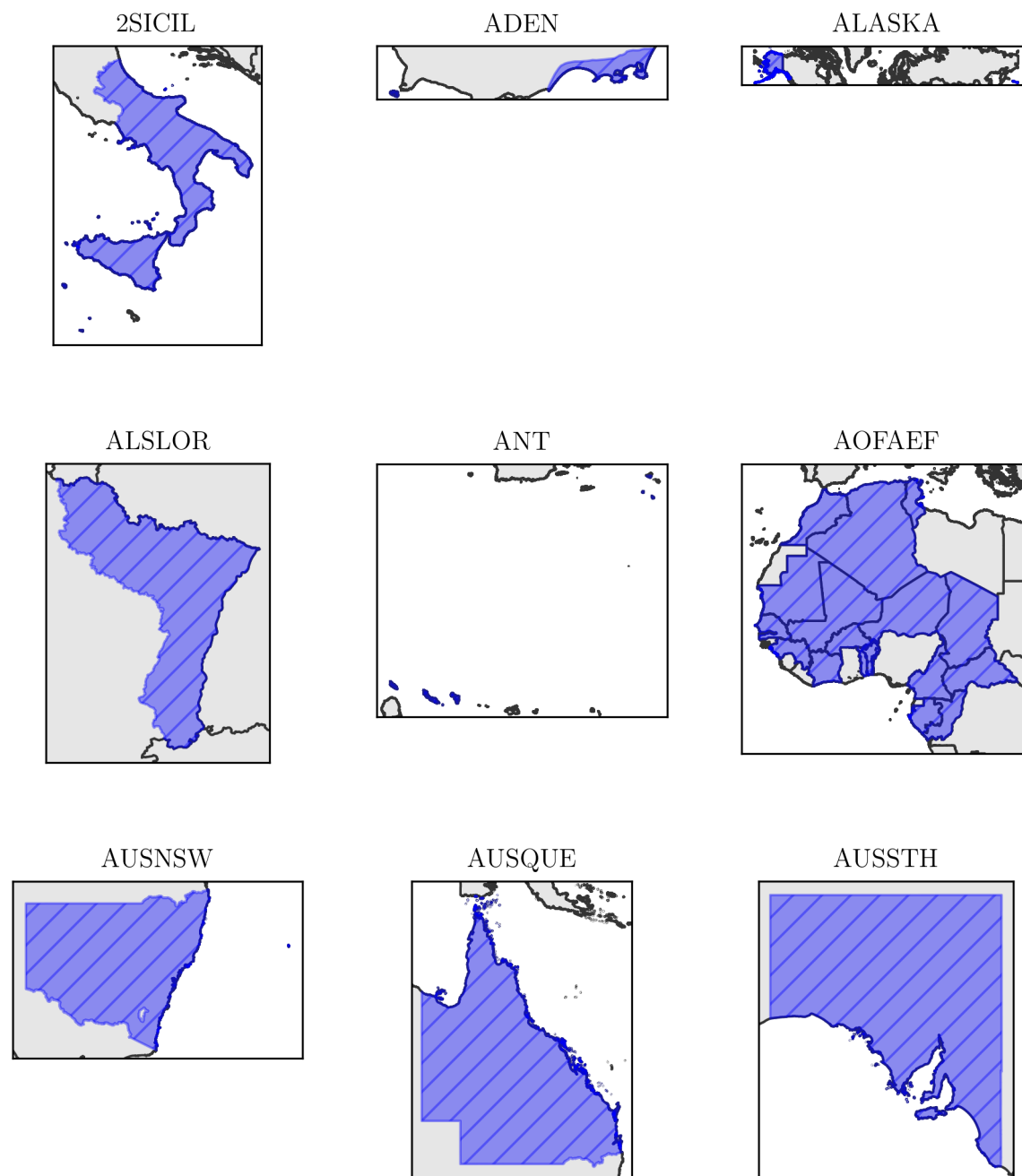
Appendix B Additional figures

Figure 35: Summary statistics for welfare change (percent) across decades

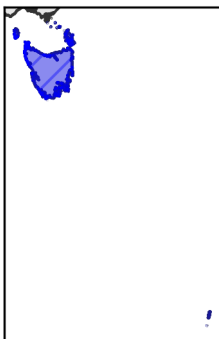


Appendix C Maps of added countries

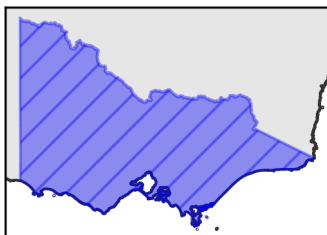
This appendix shows maps of all TRADHIST reporting units that are not currently in the GADM database. These maps were created by matching existing GADM administrative units at different levels to historical maps of each reporting unit. Map titles are CEPII's additional ISO codes for each reporting unit as found in Table 4 of the TRADHIST documentation, available at https://www.cepii.fr/PDF_PUB/wp/2016/wp2016-14.pdf.



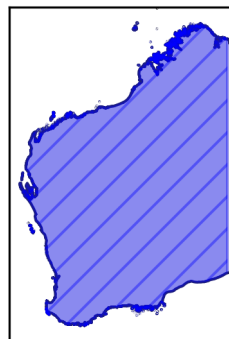
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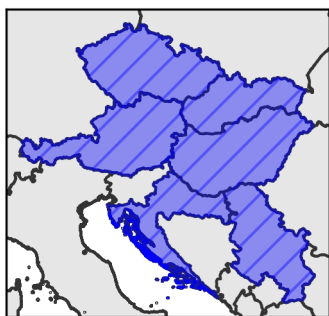
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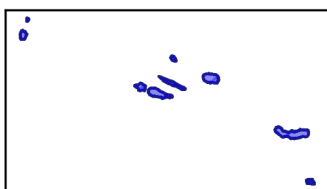
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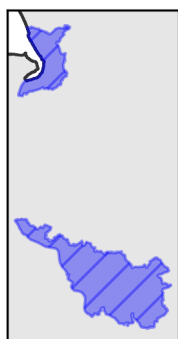
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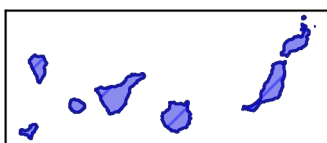
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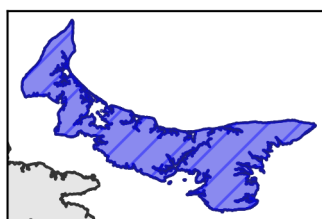
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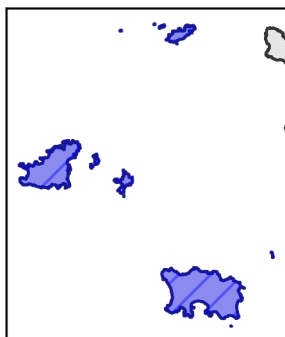
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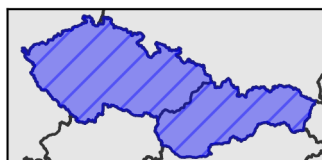
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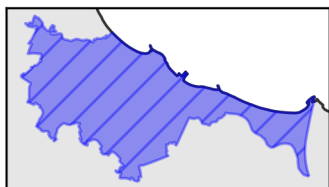
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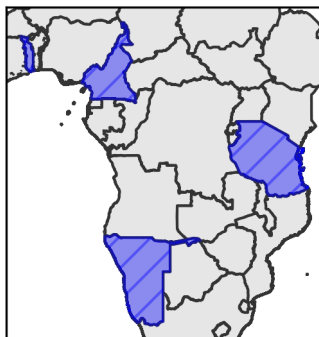
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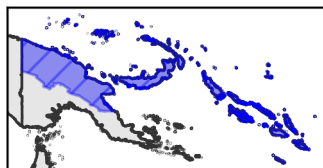
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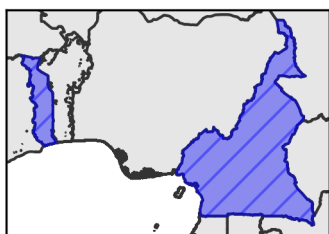
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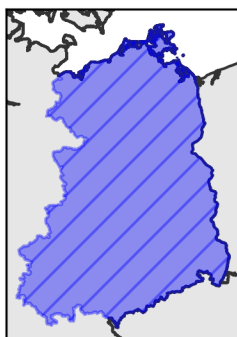
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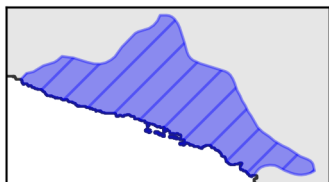
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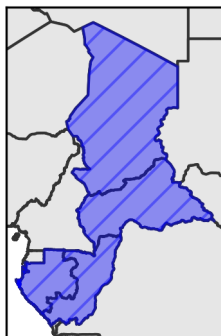
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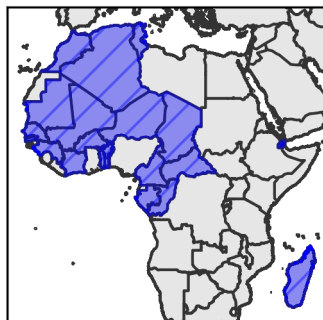
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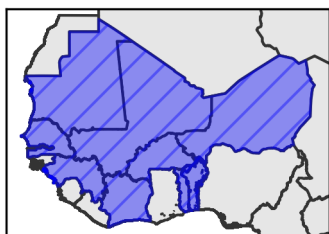
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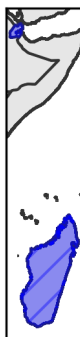
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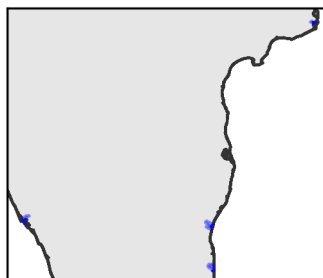
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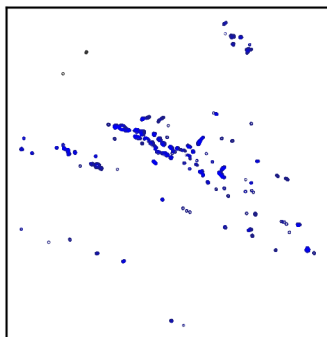
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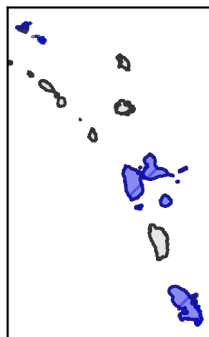
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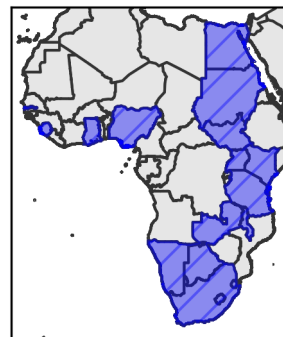
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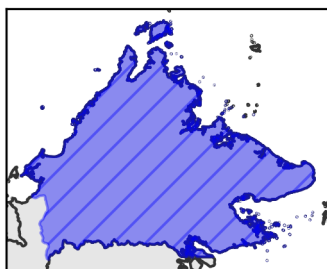
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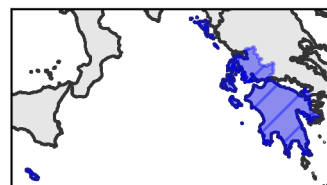
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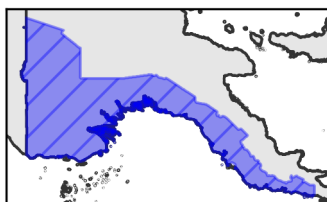
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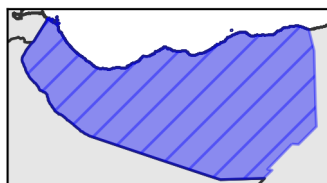
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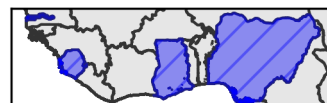
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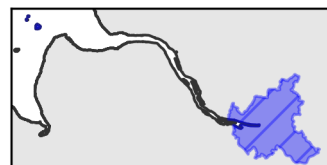
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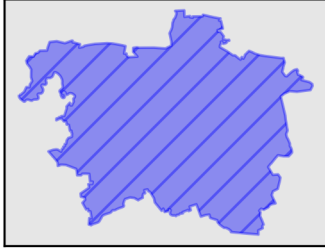
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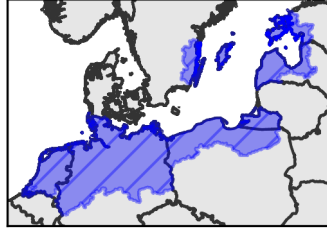
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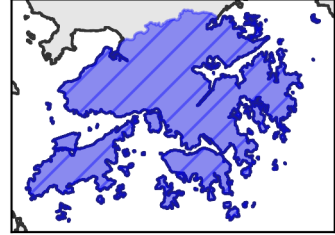
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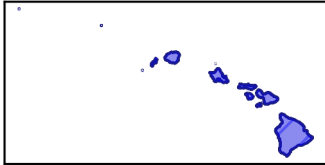
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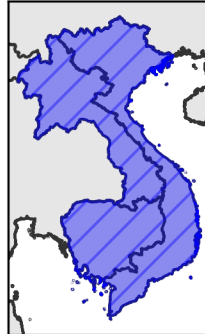
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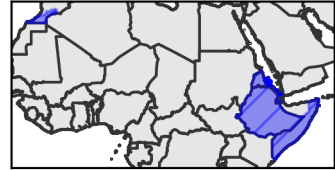
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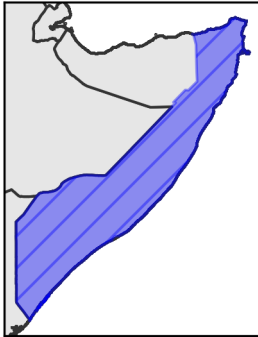
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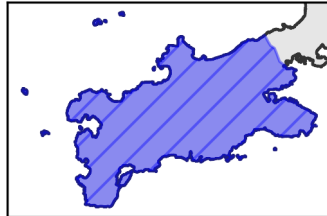
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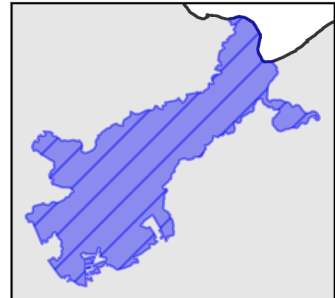
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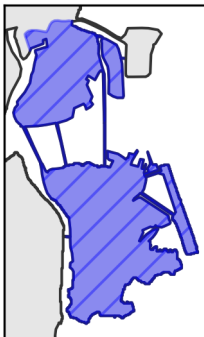
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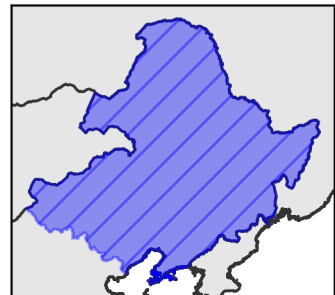
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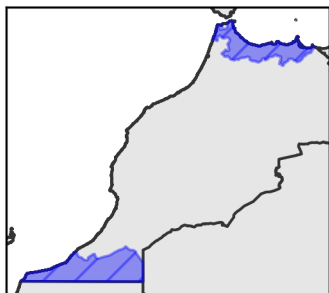
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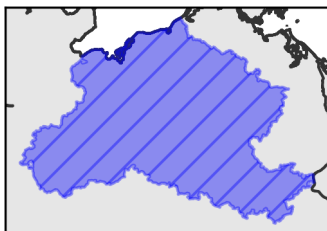
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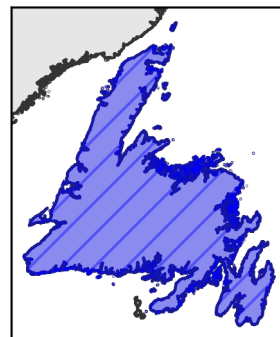
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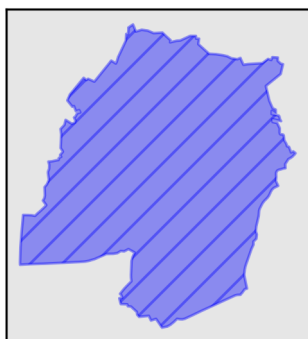
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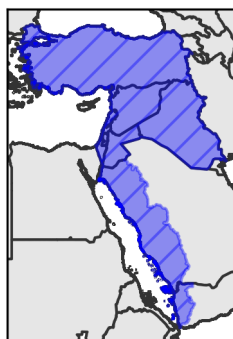
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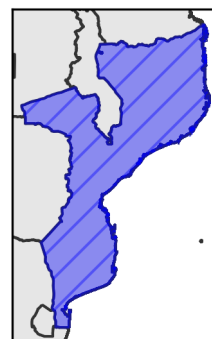
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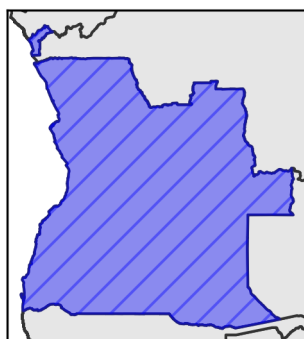
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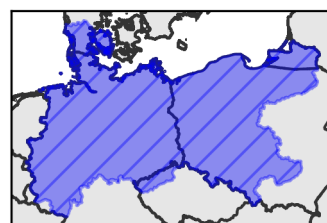
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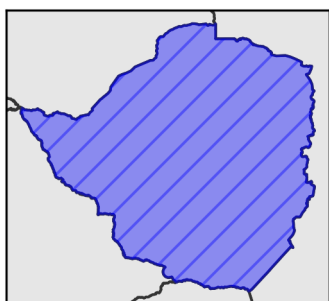
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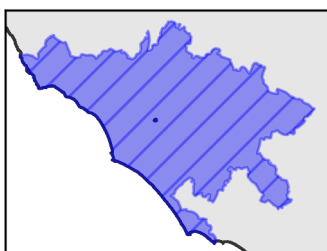
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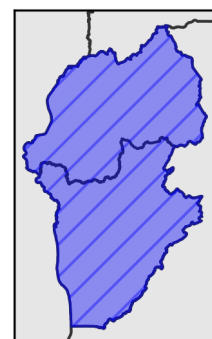
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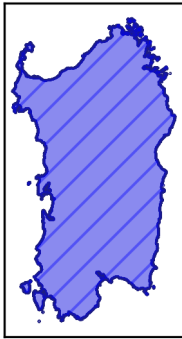
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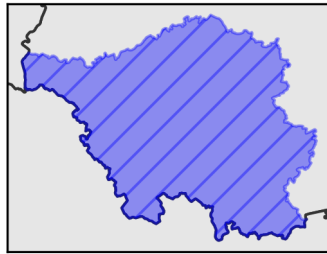
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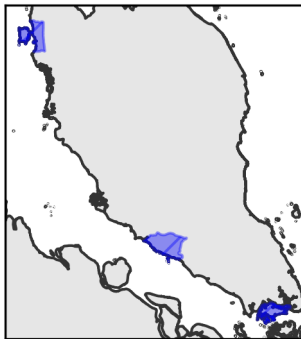
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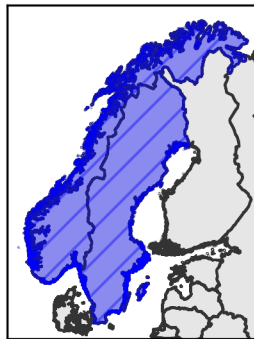
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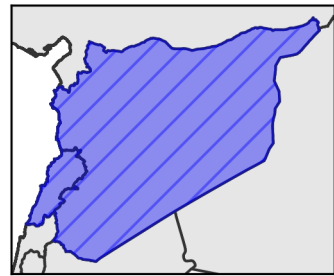
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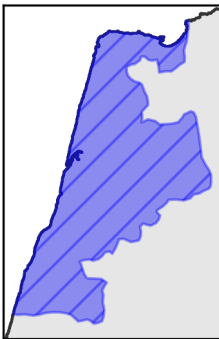
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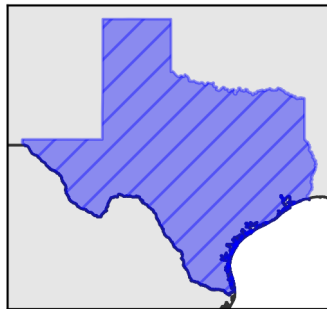
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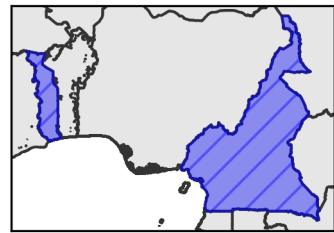
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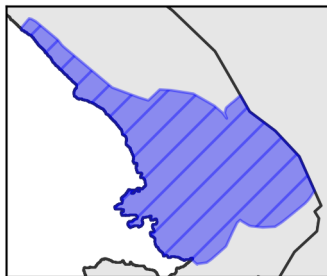
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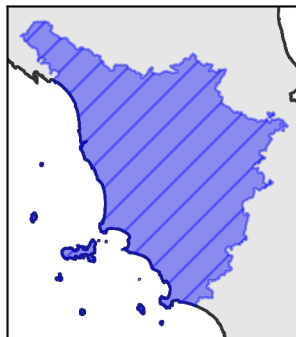
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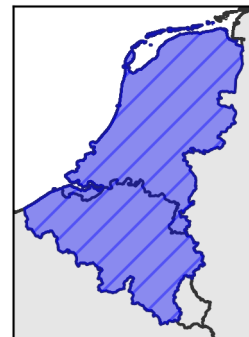
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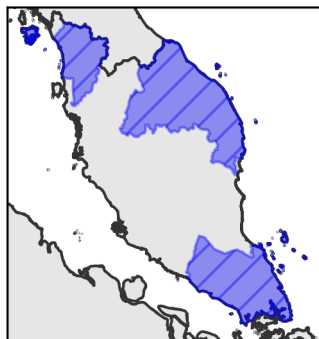
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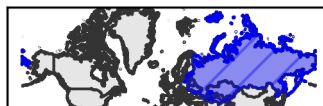
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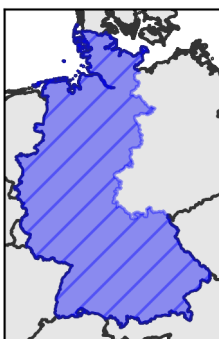
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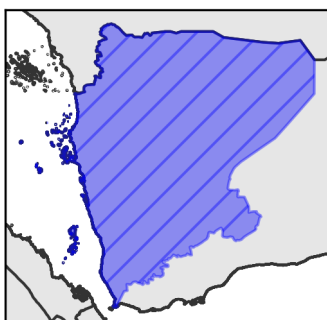
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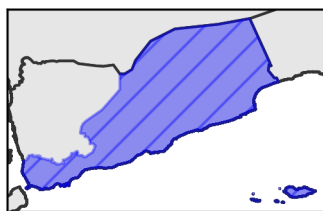
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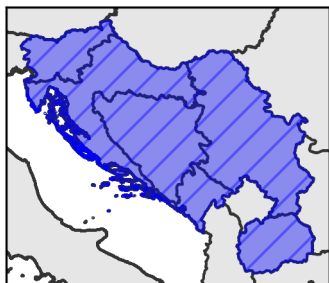
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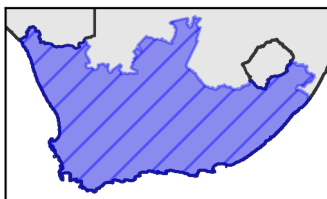
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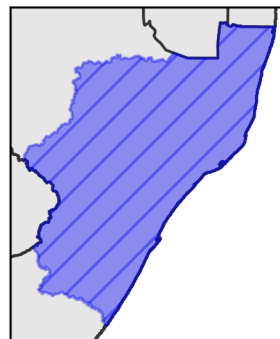
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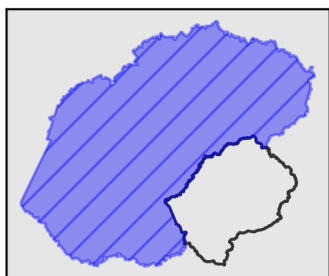
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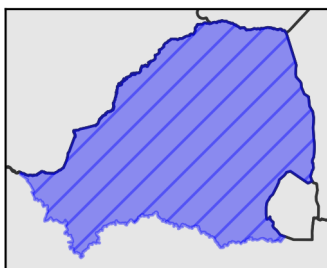
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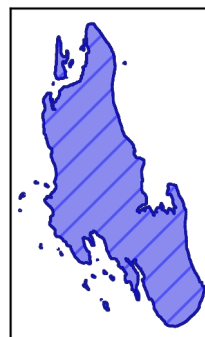
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ZAFTRA



ZANZ



ZOLL

