The effect of trade policy on climate-induced structural change

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Abstract

Climate change will cause productivity shocks that will shift international comparative advantage. But these shocks are unevenly distributed across space. While for some countries productivity will increase, for others it will decrease. Some countries are more vulnerable to climate-induced productivity shocks than others, e.g. low-income countries. These At the same time, these countries often have high barriers to trade, limiting their scope to adapt to external economic shocks.

This paper analysis how trade policy can off-set climate-induced welfare losses and how it affects climate change adaption. I focus on Germany and India, two countries in different developing stages, that are adversely affected by climate change. I use rich granular data to examine the impact of future climate change on agricultural crop productivity around the world. The productivity shocks are feed into a general equilibrium trade model to analyse world market impacts on local trade policy changes.

JEL-Codes: F13; F14; F18; Q56
Keywords: Comparative advantage; international trade; gravity; climate change

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Acknowledgement: This project benefited by funding from the German Federal Ministry of Education and Research (BMBF) under the funding line *#01LA1828D*. I am thankful for the outstanding research assistant of Jakob Kutsch.

1 Introduction

Climate change will influence structural change and economic growth around the globe, because it affects sectoral specialisation patterns. The effects of climate-induced productivity shocks will be heterogeneous across space and sectors. This will shift international comparative advantages, and hence patterns of sectoral specialization through changes in imports and exports. If trade costs (tariffs, non-tariff barriers (NTB), costs of logistics) are sufficiently low, countries can move out of the production in sectors that are negative affected by climate change. If trade costs are high, adverse productivity shocks can lead to a higher share of resources devoted to this sector to compensate production shortfalls. A relocation to the less productive sectors would rewind structural transformation and may cause significant welfare losses.

In this paper, I study how climate change affects structural transformation (the shift of sectoral production and labor allocation) and how trade policy can off-set welfare losses of that transformation for countries in different developing stages. First, I derive productivity shocks from an extremely rich granular data set on agricultural yields – before and after climate change – for 50 different crops for each of 2.3 million fields covering the surface of the earth. Second, I build a Ricardian quantitative trade model including sectoral productivities, input-output linkages, and trade across 141 countries. With that framework, I analyse different trade policy responses to off-set climate-induced welfare losses.

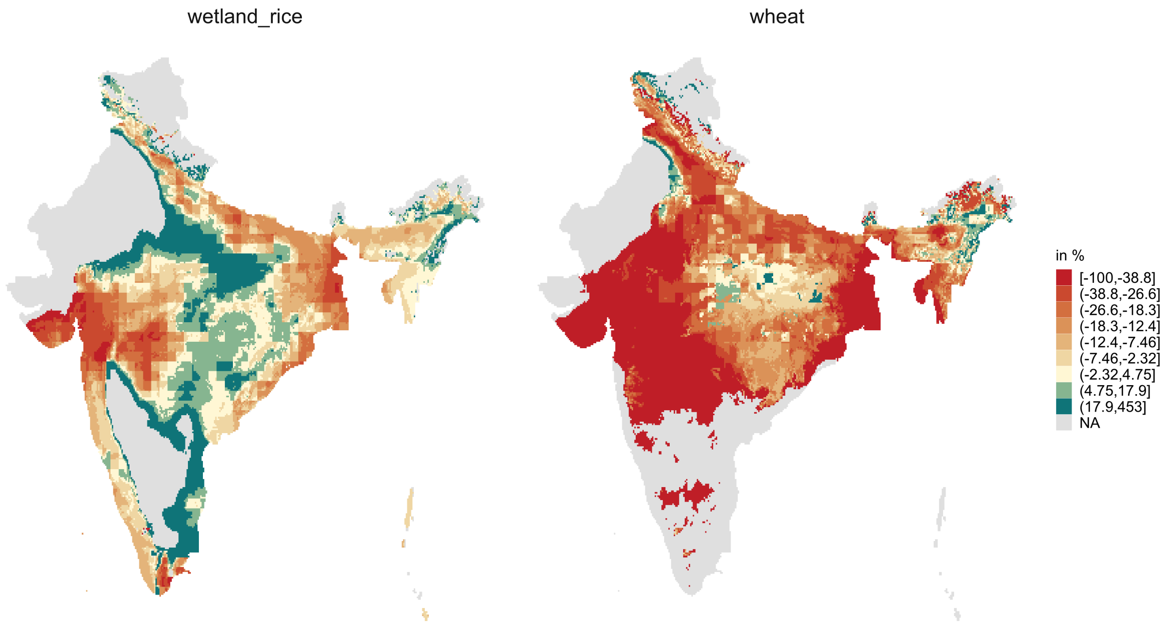
I focus on Germany and India, two countries in different developing stages, that are adversely affected by climate change. India offers a good example for an emerging economy given its size and the vast differences in economic development across the country. Germany serves as a developed focus country, because federal states differ widely in their economic structure indicating that climate change will affect structural transformation differently over space. To incorporate the rich spatial heterogeneity within both countries, I disaggregate India and Germany to the states-level in the trade model.

I contribute to several strands of the literatures. First, there is important work on climate change impact on social welfare, going from micro-level shocks to macro-level consequences. For example, the impact of weather on economic growth (Kotz et al.,

2021) through underlying channels including, for example, human health (Barreca et al., 2016; Burgess et al., 2017; Burke et al., 2018), worker productivity (Somanathan et al., 2021), and houshold consumption (Lai et al., 2022). Second, I contribute to the literature on climate change adaptation through trade. Costinot et al. (2016) use micro-level shocks and study the welfare consequences of climate change. They find out that adaptation depends on a country's ability to change its production and trade patterns. Cruz and Rossi-Hansberg (2021) develop a dynamic intergrated assesment model in which individuals can adapt to global warming via trade, migration, innovations or natality rates. They only focus on the climate damage function of temperature and find only a relative small impact of trade as an adaptation mechanism. The work of Nath (2022) is closely related to my paper. He also uses a static general equilibrium trade model in the spirit of Eaton and Kortum (2002) and analysis how sectoral reallocation between agriculture and non-agriculture production might help to adapt to climate change. All three paper investigate the effect of trade cost increases and foreclosing trade policy. In contrast, I explore how a liberalization in trade policies affect a country's ability to change its production and trade pattern under climate change.

This paper makes three main contributions. (i) I contribute to a growing literature on the climate change impact on social welfare, taking micro-level shocks and deriving macro-level consequences (ii) I analyse how trade policy may help to adapt to climate change impacts. (iii) I dis-aggregate national input-output tables for India and Germany to account for spatial heterogeneity in climate shocks and market responses.

Figure 1: Change in Indian Yields under Climate Change

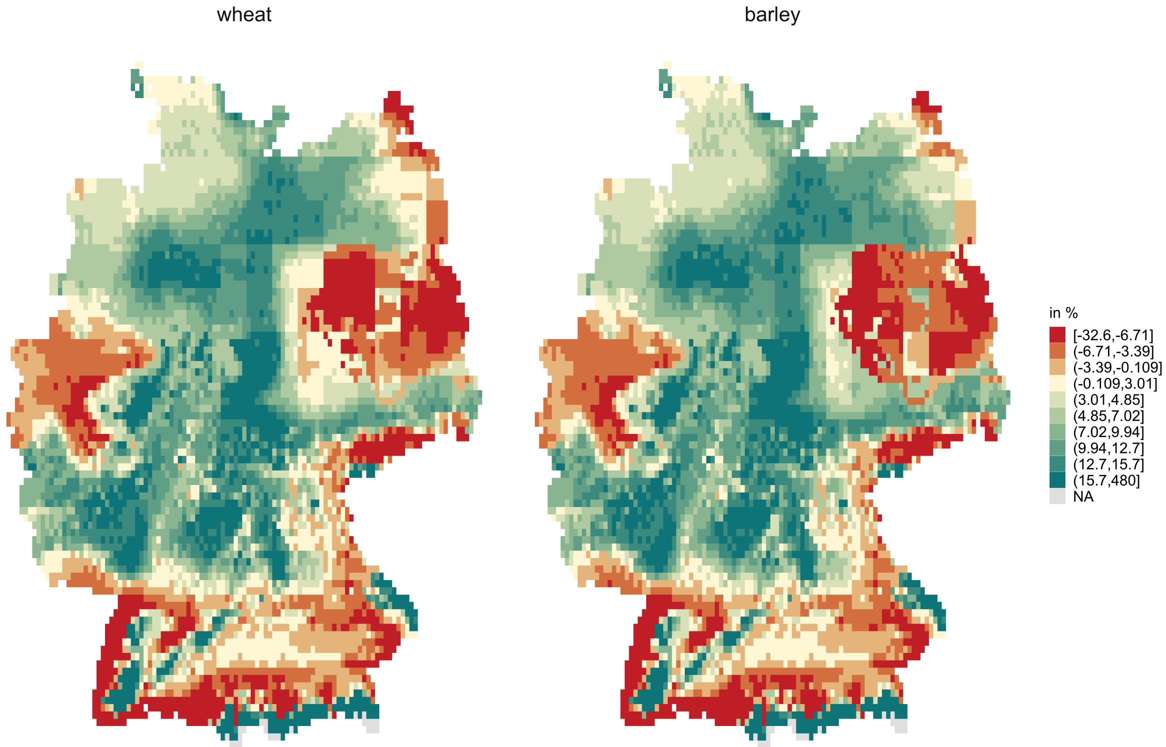


Note: Yield changes in 2071–2100 under RCP 8.5 compared to 1981–2010, HadGEM2–ES, own calculation based on GAEZ.

To analyse the impact of climate change on agriculture productivity, I take advantage of extremely rich micro-level data from the Global Agro-Ecological Zones (GAEZ) data set which was jointly developed by the UN Food and Agriculture Organization and the International Institute for Applied Systems Analysis (Fischer et al., 2021). GAEZ is based on agronomic models and high-resolution data on geographic characteristics such as soil, topography, elevation, and, crucially, climatic conditions. Using this data GAEZ predicts the obtainable yield - crop by crop - at 2.3 million high-resolution grid cells (about 9 km by 9 km at the equator) covering the surface of the earth. GAEZ is available both under contemporary growing conditions and under a climate change scenario used by the UN's Intergovernmental Panel on Climate Change (IPCC).[1]

[1]Climatic conditions are based on a time series of historical data of 1961-2010 and a selection of future climate simulations using recent IPCC AR5 Earth System Model (ESM) outputs for four Representative Concentration Pathways (RCPs). Hence, GAEZ results consistently quantify impacts on land productivity of historical climate conditions as well as of potential future climate change.

Figure 2: Change in German Yields under Climate Change

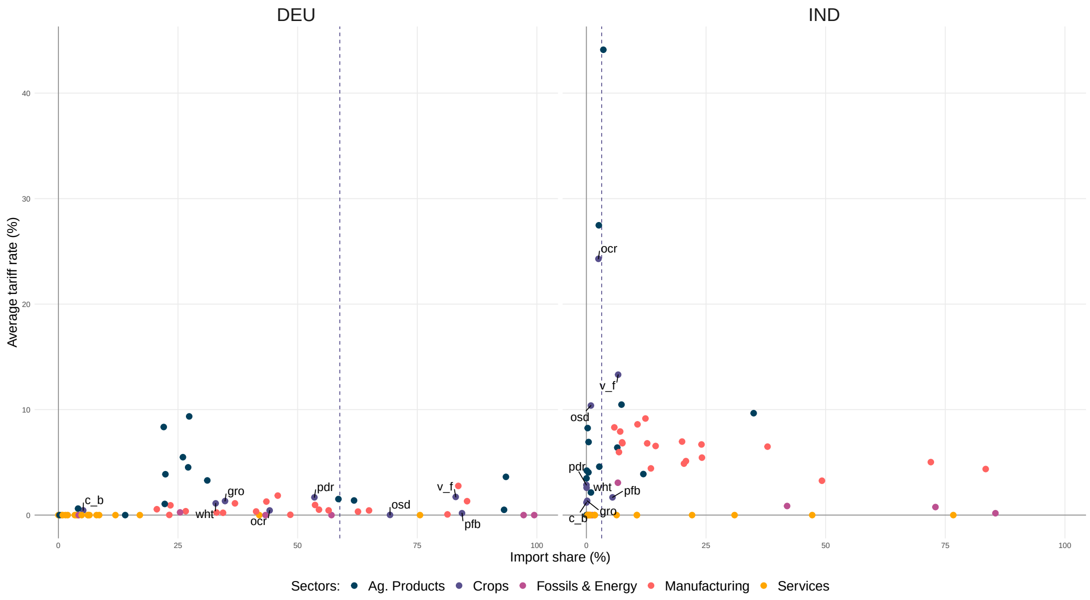


Note: Yield changes in 2071–2100 under RCP 8.5 compared to 1981–2010, HadGEM2–ES, own calculation based on GAEZ.

Using GAEZ, Figure 1 shows yield changes under future climate change for rice and wheat in India, the two crops with the highest current production value. Rice yield changes show a lot of spatial heterogeneity, but the majority of grid cells (55.5 %) will experience yield declines. In contrast, wheat yields will decrease in almost every grid cell (92.5 %), while one third of cells will experience a yield decline of 50 % and more. Climate change impacts in Germany are less severe. Figure 2 shows yield changes for wheat and barley, the two crops with the highest current production value. Wheat yields will increase in 69.4 % of cells, and the average yield increase per cell (10.9 %) is higher than the average decline (5.8 %). Because barley has similar weather and soil requirements as wheat the numbers are similar. Yields will increase in 70.1 % of cells.

A potential adaptation strategy to mitigate negative climate change impacts is international trade. Trade can help countries diversify their economies and reduce their

Figure 3: Tariffs and Import Shares in Germany and India



Note: Average unweighted tariff rates over all importers for 65 sectors in Germany (left pane) and India (right pane). Dashed line: average import share (weighted by home production) for crop sectors. Crop sectors are labeled. For the sector concordance see Table 5. Own calculations based on GTAP 10.

reliance on sectors that are vulnerable to climate change. Trade can also reduce the risks associated with climate change by allowing a country to access a wider range of goods and services from different regions under heterogeneous climate change effects. For example, if wheat yields in India will decrease substantially under climate change (see Figure 1), the country could import the quantity that is necessary to meet its domestic demand from countries that might experience a positive productivity shock (e.g. Germany, Figure 2). If workers can move out of wheat production into other sectors whose products can also be sold internationally, labour market impacts can even be positive.[2]

The adaptation potential of trade depends on the amount of barriers to trade, such as tariffs or non-tariff barriers, e.g. time-consuming administrative procedures, technical requirements, and differences in regulations. If trade barriers are low countries can adapt to production shocks by importing and exporting different goods and quantities.Figure 3 shows the average tariffs and import shares in India and Germany. India's average tariff for crop sectors is 7.2 %, while it is only 0.9 % in Germany. The average import share for

[2]This depends on the overall change in comparative advantage among the trading partners. The sign of the labour market impacts is not clear from a reduced-form perspective.

crop sectors is 3.2 % in India and 58.8 % in Germany (dashed lines in Figure 3). India imports only a small fraction of its demand and pays relatively high tariffs on its imports. The data indicates that it is more difficult for India to substitute national production through imports, making the country more exposed to local productivity shocks in this sectors. But average numbers can be misleading when it comes to counterfactual analysis. For example, India's average tariffs on crops might be high, but tariffs on imports from large producers with low trade costs might be low. Then, import substitution might be feasible and less costly. But this also depends on how demand and supply will develop under climate change outside of India. I build a general equilibrium trade model to account for those circumstances worldwide.

The remainder of the paper is structured as follows: In Section 2 I set up a genereal equilibrium model of international trade that allows me to compute a counterfactual world with climate change impacts and trade policy responses. I describe the data and estimation procedure in Section 3, before computing the counterfactual scenarios in section 4. Section 5 concludes.

2 Model

The analysis is carried out with the help of the "Kiel Institute Trade Policy Evaluation" model ("KITE model") which is based on the trade model proposed by Caliendo and Parro (2015), who provide a multi-sector version of the Eaton and Kortum (2002) gravity model with input-output linkages. The model is extensively used in academic publications (e.g., Chowdhry et al., 2022; Felbermayr et al., 2023). For this analysis, I decompose total factor productivity and use the latest version of the Global Trade Analysis Project (Aguiar et al., 2019) as the primary model database.

2.1 Preferences

There are N countries, indexed o and d, and J sectors, indexed j and k. In each sector, there is a continuum of goods $\omega^j \in [0, 1]$. Households in n obtain utility from consumption C according to a two-tier Cobb-Douglas utility function:

$$u(C_d) = \prod_{j=1}^{J} C_d^{j\ \alpha_d^j} \quad \text{with} \quad \sum_{j=1}^{J} \alpha_d^j = 1.$$

where α_d^j is the constant consumption share on industries j's goods. While the aggregation of utility from different varieties *within* one sector is the same for all countries, expenditures shares *across* sectors vary between countries, allowing for differently agricultural-intensive consumption patterns.

2.2 Production

Sectors j use two production factors: labour and intermediate inputs. Labour is fully mobile across sectors $L_n = \sum_j^J L_d^j$, but not across countries. It can be seen as an aggregate factor[3].

All goods are produced using composite intermediate input bundles m from the own and other sectors. In all sectors, countries differ in their productivity for different goods from the continua and in the intermediate input cost shares γ. Total factor productivity is composed of two terms, a country-sector specific "fundamental productivity" A, and a variety-specific productivity z. The production technologies are Cobb-Douglas and hence given by:

$$q_d^j(\omega^j) = A_d^j z_d(\omega^j) \left[l_d^j(\omega^j)\right]^{\beta_d^j} \left[\prod_{k=1}^{J} m_d^{k,j}(\omega^j)^{\gamma_d^{k,j}}\right]^{1-\beta_d^j}$$

with $l_d^j + \sum_{k \in J} \gamma_d^{k,j} = 1$. l_d is the labour input and β_d the labour input share. With constant returns to scale and perfectly competitive markets, unit cost are given by

$$c_d^j = \frac{\Upsilon_d^j w_d^{\beta_d^j}}{A_d^j z_d^j(\omega^j)} \left[\prod_{k=1}^{J} (P_d^k)^{\gamma_d^{k,j}}\right]^{1-\beta_d^j}$$

where $\Upsilon_d^j = (\beta_d^j)^{-\beta_d^j} (\eta_d^j)^{-\eta_d^j} \prod_{k \in \mathcal{J}} (\gamma_d^{k,j})^{-\gamma_d^{k,j}}$, w denotes the wage, and P the price of

[3]The factor is a composite of many factors, as for example labour, capital, land, and natural resources, which are all non-tradeable in our framework.

a composite intermediate bundle. Hence, the cost of the input bundle depends on wages and the prices of *all* composite intermediate goods in the economy. Producers of composite intermediate goods supply Q_d^j at minimum costs by purchasing intermediate goods ω^j from the lowest cost supplier across countries, so that

$$Q_d^j = \left[\int d_d^j(\omega^j)^{1-1/\sigma^j} d\omega^j \right]^{\sigma^j/(\sigma^j-1)} .$$

$\sigma^j > 0$ is the elasticity of substitution across intermediate goods within sector j, and $d_d^j(\omega^j)$ the demand for intermediate goods ω^j from the lowest cost supplier such that

$$d_d^j(\omega^j) = \left(\frac{p_d^j(\omega^j)}{P_d^j} \right)^{-\sigma^j} Q_d^j$$

where P_d^j is the unit price of the composite intermediate good

$$P_d^j = \left[\int p_d^j(\omega^j)^{1-\sigma^j} d\omega^j \right]^{1/(1-\sigma^j)}$$

and $p_d^j(\omega^j)$ denotes the lowest price of intermediate good ω^j in n across all possible origin locations, i.e.

$$p_d^j = \min_o \{p_{od}^j\} . \tag{1}$$

Composite intermediate goods are used in the production of intermediate goods ω^j and as the final good in consumption as C_d^j, so that the market clearing condition is written as

$$Q_d^j = C_d^j + \sum_{k=1}^{J} \int m_d^{j,k}(\omega^j) d\omega^j \tag{2}$$

2.3 International trade

Trade in goods is costly, such that the offered price of ω^j from i in n is given by

$$p_{od}^j = \phi_{od}^j \cdot \frac{c_o^j}{z_o^j(\omega^j)} \tag{3}$$

where ϕ^j_{od} denote generic bilateral sector-specific trade frictions.[4] These can take a variety of forms — e.g. tariffs, non-tariff barriers, export taxes. In that case we can specify

$$\phi^j_{od} = \tau^j_{od} \cdot \kappa^j_{od} \cdot \zeta^j_{od},$$

where τ^j_{od} represent sector-specific ad-valorem tariffs, $\kappa^j_{od} \geq 1$ iceberg trade costs, and ζ^j_{od} export taxes or subsidies. Tariff revenue $(\tau^j_{od} - 1)$ and export tax revenue (or subsidy cost) $(\zeta^j_{od} - 1)$ is collected (or spent) by the importing country and exporting country, respectively, and transferred lump-sum to its households.

Ricardian comparative advantage is induced à la Eaton and Kortum (2002) through a country-specific idiosyncratic productivity draw z^j from a Fréchet distribution.[5]

The price of the composite good is then given as

$$P^j_d = A^j \left[\sum_{o=1}^{d} \lambda^j_o (c^j_o \phi^j_{od})^{-\theta^j} \right]^{-1/\theta^j} \tag{4}$$

which, for the non-tradable sector or embargoed sector towards *all* non-domestic sources collapses to

$$P^j_d = A^j (\lambda^j_d)^{-1/\theta^j} c^j_d \tag{5}$$

where $A^j = \Gamma(\xi^j)^{1/(1-\sigma^j)}$ with $\Gamma(\xi^j)$ being a Gamma function evaluated at $\xi^j = 1 + (1 - \sigma^j)/\theta^j$. Total expenditures on goods from sector j in country d are given by $X^j_d = P^j_d Q^j_d$. The expenditure on those goods originating from country o is called X^j_{od}, such that the share of j from o in d is $\pi^j_{od} = X^j_{od}/X^j_d$. In other words, it is the share of an exporter country in the total expenditure, by sector, of an importer country. This share

[4] The "phiness" of trade à la **?**.

[5] The productivity distribution is characterized by a location parameter λ^j_o that varies by country and sector inducing *absolute* advantage, and a shape parameter θ^j that varies by sector determining *comparative* advantage. θ^j describes the elasticity of trade to trade costs

can also be expressed as

$$\pi_{od}^j = \frac{\lambda_o^j (c_o^j \phi_{od}^j)^{-\theta^j}}{\sum_{h=1}^d \lambda_h^j (c_h^j \phi_{hd}^j)^{-\theta^j}} \tag{6}$$

2.4 General Equilibrium

Total expenditures on goods from sector j are the sum of the firms' and households' expenditures on the composite intermediate good, either as input to production or for final consumption

$$X_d^j = \sum_{k=1}^J (1-\beta_d^k)\gamma_d^{j,k} \sum_{o=1}^d X_o^k \frac{\pi_{do}^k}{\tau_{do}^k \zeta_{do}^k} + \alpha_d^j I_d \tag{7}$$

with $I_d = w_d L_d + R_d + D_d$, i.e., labor income, government revenue (tariff and export taxes minus export subsidies) and the aggregate trade balance. Sectoral trade balance is simply the difference between imports and exports

$$D_d^j = \sum_{o=1}^d X_{od}^j - X_{do}^j \tag{8}$$

and the aggregate trade balance $D_d = \sum_{j=1}^J D_d^j$, and $\sum_{d=1}^d D_d = 0$, with D_d being exogenously and D_d^j being endogenously determined. The trade balance can then be expressed as

$$\sum_{j=1}^J \sum_{o=1}^d X_d^j \frac{\pi_{od}^j}{\tau_{od}^j \zeta_{od}^j} - D_d = \sum_{j=1}^J \sum_{o=1}^d X_o^j \frac{\pi_{do}^j}{\tau_{do}^j \zeta_{do}^j}. \tag{9}$$

The goods market clearing (7) and trade balance (9) conditions close the model.

2.5 Solving for Counterfactual Equilibria

As suggested by Dekle et al. (2007), a counterfactual general equilibrium for alternative trade costs in the form of $\hat{\phi}_{od}^j = \phi_{od}^{j\prime}/\phi_{od}^j$ — i.e. where any variable $\hat{x}$ denotes the relative change from a previous value x to a new one x' — can be solved for in changes such that

$$
\begin{aligned}
&\textit{Input costs} && \hat{c}_d^j = \left[\frac{\hat{w}_d}{\hat{A}_d^j}\right]^{\beta_d^j} \left(\prod_{k=1}^{J} [\hat{P}_d^k]^{\gamma_d^{k,j}}\right)^{1-\beta_d^j} && (10)\\
&\textit{Prices} && \hat{P}_d^j = \left(\sum_{o=1}^{d} \pi_{od}^j [\hat{\phi}_{od}^j \hat{c}_o^j]^{-1/\theta^j}\right)^{-\theta^j} && (11)\\
&\textit{Trade shares} && \pi_{od}^{j\prime} = \pi_{od}^j \left(\frac{\hat{c}_o^j}{\hat{P}_d^j}\hat{\phi}_{od}^j\right)^{-1/\theta^j} && (12)\\
&\textit{Expenditures} && X_d^{j\prime} = \sum_{k=1}^{J}(1-\beta_d^k)\gamma_d^{j,k}\left(\sum_{o=1}^{d}\frac{\pi_{do}^{k\prime}}{\tau_{do}^{k\prime}\zeta_{do}^{k\prime}}X_o^{k\prime}\right) + \alpha_d^j I_d' \quad \text{with} && (13)\\
&\textit{Income, value added} && I_d' = \hat{w}_d w_d L_d &&\\
&\textit{Tariff revenue} && \quad + \sum_{k=1}^{J}\sum_{o=1}^{d}(\tau_{od}^{k\prime}-1)\left(\frac{\pi_{od}^{k\prime}}{\tau_{od}^{k\prime}}\right)X_d^{k\prime} &&\\
&\textit{Export tax revenue} && \quad + \sum_{k=1}^{J}\sum_{o=1}^{d}(\zeta_{do}^{k\prime}-1)\left(\frac{\pi_{do}^{k\prime}}{\tau_{do}^{k\prime}\zeta_{do}^{k\prime}}\right)X_o^{k\prime} &&\\
&\textit{Trade balance} && \quad - D_d' &&\\
&\textit{Trade balance} && D_d = \sum_{j=1}^{J}\sum_{o=1}^{d}\frac{\pi_{od}^{j\prime}}{\tau_{od}^{j\prime}\zeta_{od}^{j\prime}}X_d^{j\prime} - \sum_{j=1}^{J}\sum_{o=1}^{d}\frac{\pi_{do}^{j\prime}}{\tau_{do}^{j\prime}\zeta_{do}^{j\prime}}X_o^{j\prime}. && (14)
\end{aligned}
$$

As a measure of welfare changes I use changes in real consumption, obtained as

$$\hat{W}_d = \frac{\hat{I}_d}{\prod_{j=1}^{J}(\hat{P}_d^j)^{\alpha_d^j}}. \tag{15}$$

The model provides static level effects on real consumption and trade. As dynamic effects of trade integration are not taken into account, it provides a lower bound for the potential effects of climate adaptation through trade.

3 Data

The core data for this study are taken from the Global Trade Analysis Project (GTAP) database (Aguiar et al., 2019). The data provide a snapshot of the global economy in 2014, including domestic inter-industry flows and bilateral trade flows. The full database covers 141 regions, of which 121 are individual countries, and 65 sectors. The GTAP data are based on official trade flows. The backbone of the data are national input-output (I-O) tables.

The main difficulty in constructing consistent I-O tables is in gathering accurate and comprehensive data on the production, consumption, and trade of goods and services within an economy. Once the data has been collected, it must be carefully analyzed and organized into a consistent and coherent format, which requires a significant amount of analysts' judgment. Another difficulty is that the collected data may not always be directly comparable. This requires the use of linear programming techniques to adjust the data and make it consistent.

GTAP combines multiple I-O tables in a consistent manner. The complex process requires a high level of expertise and attention to detail, otherwise small inconsistencies and measurement errors of individual I-O tables would add up significantly.

From GTAP I derive all model parameters[6], such as production factor shares of labour β and intermediate input costs γ.

3.1 Regional Disaggregation

Countries face heterogeneous climate change impacts across space (see Figure 1 and 2). For the trade model, I disaggreate India and Germany onto the state level to account for impact heterogeneity. Because regional input-output tables are not available for both countries in 2014, I rely on proxy data to distribute national values onto the states for the initial condition of the model (Wenz et al., 2015). I assume homogeneous consumers and producers across states $s \in S_d \equiv [1, ..., S_d]$ in country d. Therefore, consumption share α, intermediate share γ, and factor share β are the same across $s \in S_d$. Also trade fraction among states are the same as in the parent country, such as tariffs τ and export subsidies ζ. Intranational trade across states $s \in S_d$, as well as intra-state trade is supposed to be friction less.

I use regional value added on a state level as proxy data to disaggregate natual value added ($V_d = w_d L_d$), international trade shares for s, and intranational trade across

[6]Despite the trade elasticities θ^j, which we take from Fontagné et al. (2018), who use a gravity framework to estimate trade elasticites for all GTAP sectors despite services. Service flows don't face tariffs. Therefore, I rely on an estimate for the aggregate service sector provided by Egger et al. (2012)

$s \in S_d$. The simplified assumption for regional export shares π_{sd} is that the region with proportional higher sectoral value added also produces more international exports in relation to the other regions,

$$\pi^j_{sd} = \pi^j_{od} t^j_s \quad \text{with} \quad \sum_{s=1}^{S_d} t^j_s = 1, \tag{16}$$

and the state-sector value added share $t^j_s = V^j_s * {V^j_d}^{-1}$. I assume the same international import shares π_{os} across states $s \in S_d$ as for the parent country d.

Intranational trade across states s_1 and s_2 is also proportional distributed by state's s_1 value added share in d,

$$\pi^j_{s_1,s_2} = \pi^j_{dd} t^j_{s_1} \quad \text{with} \quad \sum_{s_1=1}^{S_d} t^j_{s_1} = 1, \tag{17}$$

and $t^j_{s_1} = V^j_{s_1} * {V^j_d}^{-1}$.

Data on sectoral value added per state V^j_s in 2014 are taken from Reserve Bank of India (2022) for Indian states, and from DESTATIS (2022) for German states.

3.2 Climate Impacts on Crop Yields

I focus on agricultural crop sectors to model the impact of climate change because the link between climate conditions and agricultural productivities is studied intensively. I use the micro-level GAEZ data set (Fischer et al., 2021), which provides yields for 72 crops under temporary climate conditions and under future climate change. GAEZ is based on detailed data from a range of sources, including satellite imagery, ground observations, and computer models. The spatial resolution is about 9 km by 9 km at the equator[7], 2.3 million grid cells on the earth's surface. Primarily, GAEZ is used by farmers and government agencies to asses the production *potential* for different crops in any given location on earth.

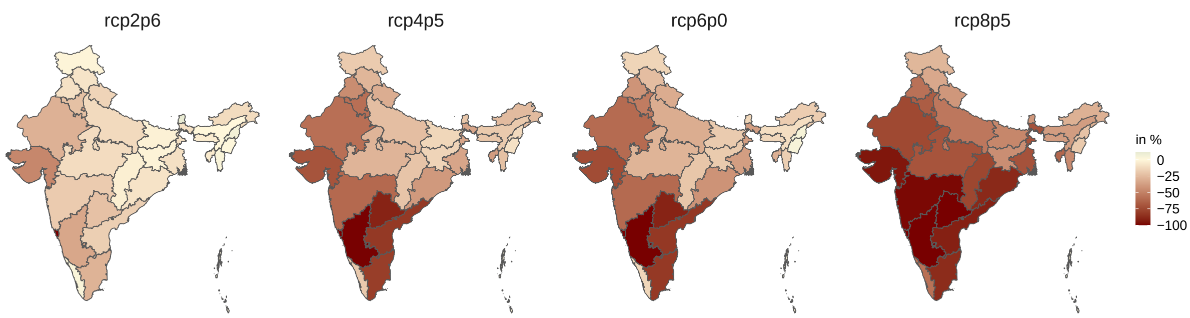
GAEZ productivity estimates are available for each cell, regardless of whether a crop is actually growing there. GAEZ uses state-of-the-art agronomic models, combining a

[7]Owing to the curvature of the earth, grid cells at different latitudes cover different areas.

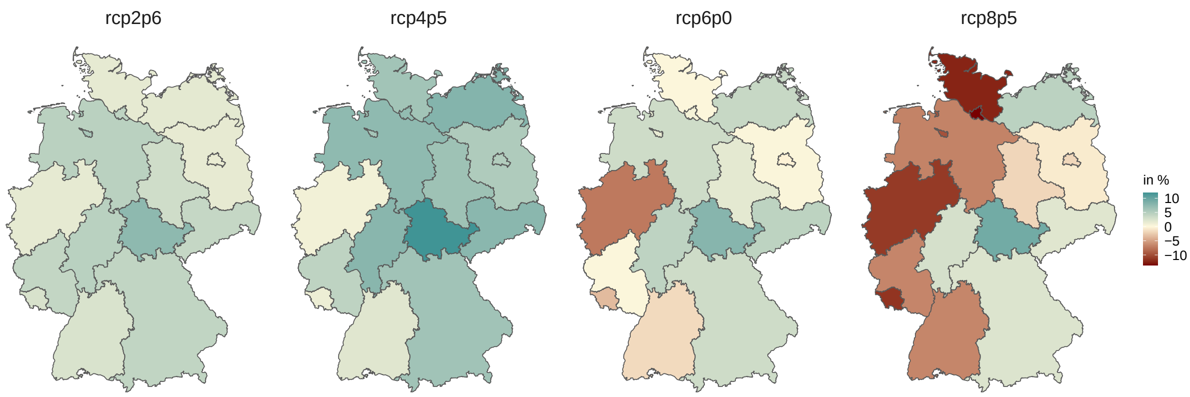
vector of (i) attributes describing the growing characteristics in each cell, (ii) multiple parameters that govern how a given set of growing characteristics map into the yield of a specific crop, (iii) assumptions about farming techniques and inputs, such as irrigation, fertilizers, machinery, and labor, that might influence crop yields at each cell.

GAEZ provides pre–climate change estimates of average agricultural productivity A_g^c over a period from 1981 to 2010 for crop c and grid-cell $g \in \mathcal{G}_d \equiv [1, ..., \mathcal{G}_d]$ in country d. For the pre-climate change estimates GAEZ uses an average of model runs on past daily weather realizations. This average takes into account the idiosyncratic variability of weather patterns from year to year in a coherent manner. I use this *historical* values as a "baseline" to calculate yield changes under future climate conditions.

Figure 4: Productivity Changes for Wheat Production by RCP



(a) India



(b) Germany

Note: Mean productivity change of two ESMs (*HadGEM2–ES* and *GFDL–ESM2M*) and between rain-fed and irrigated crops for the GTAP sector *wheat* by RCP.

Future climatic conditions are based on simulations from recent IPCC AR5 earth system model (ESM) outputs for four representative concentration pathways (RCPs). I use two ESMs, *HadGEM2-ES* (Collins et al., 2011) and *GFDL-ESM2M* (Dunne et al., 2013), to account for model uncertainty, and four RCPs to account for future greenhouse gas concentration uncertainty. RCPs are based on a range of assumptions about future social, economic, and technological developments, and provide a common framework for evaluating the potential impacts of different emission pathways on the climate. There are four RCPs, each representing a different level of future greenhouse gas concentrations.[8] The only difference to the "baseline" estimates, instead of past weather realizations GAEZ uses predicted future daily stream of weather from 2071 to 2100 to estimate future crop yields $A_g^{\prime c}$.

The change in productivity of agricultural sector j is then calculated the following

$$\hat{A}_d^j = \frac{\sum_{c\in\mathcal{J}_c}\sum_{g\in\mathcal{G}_d} s_g A_g^{\prime c}}{\sum_{c\in\mathcal{J}_c}\sum_{g\in\mathcal{G}_d} s_g A_g^{c}}, \tag{18}$$

where $c \in \mathcal{J}_c \equiv [1, ..., \mathcal{J}_c]$.[9] This approach assumes a certain within-sector substitutability that isn't modeled directly. If two crops within $\mathcal{J}_c$ face opposite climate impacts in the same absolute amount this would be leveled out in the aggregate, $\hat{A}_d^j$ would be one.[10] Alternatively, I could calculate $\hat{A}_g^j$ for each grid cell and average the changes over all cells $g \in \mathcal{G}_d$ in each country d. But this would add additional degrees of freedom because I have to decide how to treat infinite changes, if $A_g^c = 0$ and $A_g^{\prime c} > 0$.

I assume that only current fields can be used for crop production. The share of current cropland per cell is s_g and is derived from the GAEZ data set, see Figure 8. The approach permits within-field crop substitution, but prohibits substitution at the extensive margin. Cropland expansion is a likely adaptation strategy to decreasing yields , but land use change (LUC) comes with externalities, such as biodiversity losses (Zabel et al 2019) and

[8]RCP 2.6: This scenario represents a rapid and deep reduction in greenhouse gas emissions, resulting in atmospheric concentrations of around 430 parts per million (ppm) of CO2-equivalent by the year 2100. RCP 4.5: This scenario represents a moderate reduction in greenhouse gas emissions, resulting in atmospheric concentrations of around 640 ppm CO2-equivalent by 2100. RCP 6.0: This scenario represents a stabilization of greenhouse gas concentrations at around 710 ppm CO2-equivalent by 2100. RCP 8.5: This scenario represents a continuation of high levels of greenhouse gas emissions, resulting in atmospheric concentrations of around 970 ppm CO2-equivalent by 2100.

[9]For a sector-crop concordance see Table 6.

[10]Even though this consideration is highly unlikely given the narrow sector-crop matching.

greenhouse gas emissions (Houghton et al 2012). To model LUC properly, feedback loops with market prices and emissions are required. It would also benefit from a dynamic framework with future population and economic growth projections. Both is beyond the scope of my work.

Figure 4 shows the values of $\hat{A}_d^j$ for j = wheat[11] in all Indian and German states. When you compare India to Germany the across-country heterogeneity of climate impacts is striking. India's productivity in all RCPs declines drastically, which is not the case in Germany. The figure also shows that within-country heterogeneity of climate impacts is substantial. In RCP 8.5 productivity decreases in India range from 19.3 % in Manipur to 100 % in Goa, Karnataka, and Telangana.[12] In Germany, productivity changes range from an increase of 9.1 % in Thuringia to a decrease of 12.4 % in Schleswig-Holstein and 13.6 % in Hamburg under RCP 8.5. This illustrates that a more aggregated approach, where only countries enter the trade model, misses important spatial variation, that may cover up issues of climate-induced across-state structural change. Instead, with the proposed disaggregated approach it is further possible to study internal migration or within-country wealth distribution.

4 Results

I consider three different trade policy scenarios to deal with climate-induced productivity changes: (1) business as usual with current trade policies; (2) autarky; and (3) a decrease in trade barriers. Scenario 3 is devided into two sub-scenarios: (a) elimination of all tariffs and (b) a decrease of non-tariff barriers by 5 % for trade with the rest of world. Scenario 2 and 3 refer only to trade policy changes of India and Germany. In this way, I can analyse the effect of trade policy on economies in different development

[11]GTAP sector "wht", see Table 6 for the concordance of GAEZ crops c to GTAP sector j.

[12]In the densely populated union territory Puducherry, and on Andaman and Nicobar Islands the initial productivity $\sum_{c\in\mathcal{J}_c}\sum_{g\in\mathcal{G}_d} A_g^c$ for $\mathcal{J}_c$ = wheat is zero. Even small productivity increases under climate change lead to $\hat{A}_d^j$ approaching infinite. In such a case, I assume that countries and states where the initial productivity is zero are not able to grow the crop in the future and I set $\hat{A}_d^j$ to 1. This procedure is necessary because the model can not handle infinite values. Alternatively, I can depart from the "exact hat-algebra" approach of Dekle et al. (2007) and solve the model in levels as demonstrated by Gouel and Laborde (2021). This would require additional data on national prices, factor endowments, supply and demand quantities, to my knowledge that is not provided by a single database in a coherent manner.

stages and opposite climate-induced productivity changes.

Each scenario is computed for each of the four RCPs, to account for uncertainty about future climate change. Productivity shocks for each RCP are the average of two ESMs, and for irrigated and rain-fed yields.

Scenario 1: Business as usual. Table 1 presents the results of future climate change for India and Germany under a current trade policy regime. The results are heavily influenced by future concentration pathways. Under RCP 2.6, both India and Germany gain in welfare. At a first glance India's gain might be surprising, because their crop production decreases by 23.32 % (Column 5). But India can compensate this shortfall by imports. Imports in crop sectors grow by 1008 % and total imports by 14 % (Column 7). Through imports India benefits from productivity increases elsewhere. Under a very stringent concentration pathway productivities increase in many parts of the world, as for example Germany (see Figure 4), which decrease world crop prices. Cheaper crop imports release agriculture work forces, who already suffer from climate-induced productivity declines. In response, workers enter manufacturing and service sectors, whose production grow by 5.46 and 2.34 %. That structural change makes India more competitive internationally, resulting in an increase in exports by 7.91 % (Column 9).

Table 1: Scenario 1 "buisness as usual", changes in percent

	Δ Welfare		Δ Total production		Δ Crop production		Δ Total imports		Δ Total exports	
	IND	DEU	IND	DEU	IND	DEU	IND	DEU	IND	DEU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
RCP 2.6	1.64	0.97	1.55	3.09	-23.32	641.89	14.00	1.67	7.91	2.98
RCP 4.5	-0.61	1.01	-0.22	4.11	-12.05	888.54	1.05	1.43	1.07	3.83
RCP 6.0	-0.96	1.05	-0.67	4.46	-14.24	962.05	0.59	1.51	0.40	4.19
RCP 8.5	-2.03	1.14	-1.28	5.41	-28.81	1183.97	1.90	1.69	2.09	5.15

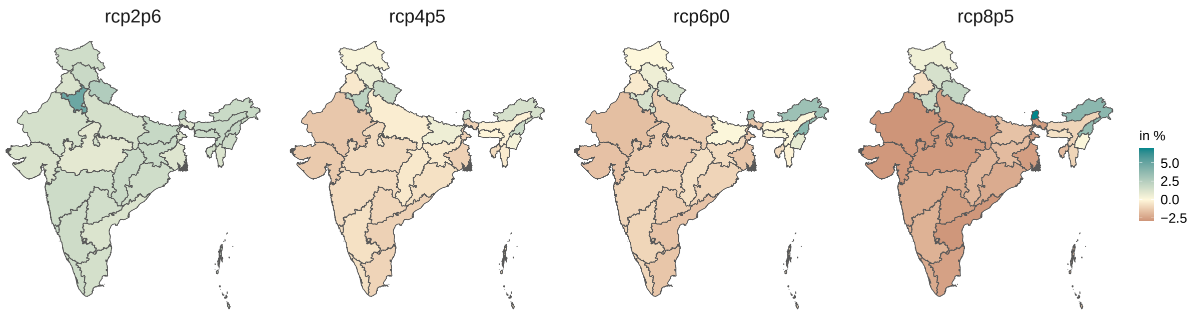
Note: Changes in production refer to changes in *real* production values. Changes in im- and exports refer to changes in *real* im- and export values.

Even though Germany's real production value in crop sectors grows by 642 % under RCP 2.6 (Column 6), German welfare only increases by 0.97 % (Column 2), which is below India's increase of 1.64 %. The strong increase in crop production originates from the relative small share of crop sectors in total production. In the baseline, crop production accounts for 0.45 % of Germany's total production. Exports in crops increase by 1124 % and total exports grow by 2.98 % (Column 10).

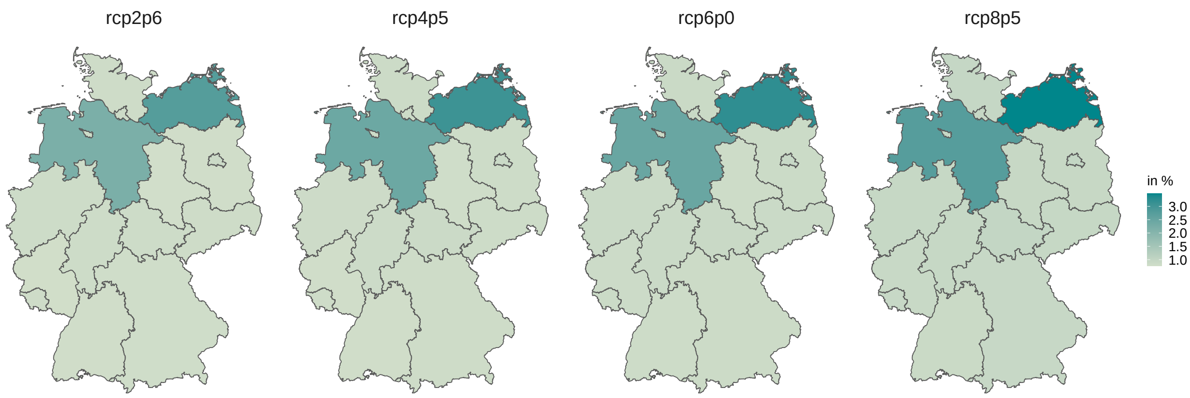
For higher future greenhouse gas concentrations, the development of India and Germany departs. Germany's welfare increases slightly with higher concentrations. At RCP 8.5 welfare grows up to 1.14 % (Column 2).[13] India's welfare decreases by up to 2.03 % under RCP 8.5 (Column 1). The range of future climate change spans 3.67 percentage points in India. Crop production in India declines by 28.82 % (Column 5) and domestic productivity decline can not fully be compensated by imports. Crop imports only grow by 228.25 % in RCP 8.5, because global substitutability is limited due to more productivity declines. Subsequently, global crop supply decreases which makes it more expensive for India to substitute their own productivity shock by imports.

[13] The welfare measure (Eq. 15) doesn't account for climate damages beyond crop yields. If the social cost of carbon is factored in welfare effects might be completely different, even with an opposite sign.

Figure 5: Welfare Change in Scenario 1



(a) India



(b) Germany

Figure 5 shows the spatial distribution of welfare effects of Scenario 1. In Germany, welfare changes are relative homogeneous. Under RCP 2.6 changes range from 0.77 % in Saxony-Anhalt to 0.84 % in Hesse, with two exceptions: Lower Saxony (2.2 %) and Mecklenburg-Vorpommern (2.77 %). The latter are rural states with an already strong agriculture industry in the baseline. Both states particularly benefit from crop productivity increases. In India, all states profit from low greenhouse gas concentrations but with more heterogeneity. Under RCP 2.6 welfare changes range from 0.92 % in Madhya Pradesh to 4.84 % in Haryana. Already under an intermediate concentration of RCP 4.5 24 out of 33 states lose welfare. States that gain welfare are further north where climate change also increases some crop productivites. For example, Haryana's welfare grows by 2.22 %, mainly because productivity of *Crops nec* (GTAP sector "ocr"), e.g. tea or tobacco, and *Paddy rice* (GTAP sector "pdr") increases by 620 % and 6.6 %, while productivity of all other crops decreases. The spatial heterogeneity of welfare effects shows the importance of disaggregated climate change analysis for target-oriented adaptation policies at the sub-national level. Welfare effects for the rest of the world at RCP 4.5 and 6.0 are depicted in Figure 9 and 10.

Table 2: Scenario 2 “Autarky”, changes in percent

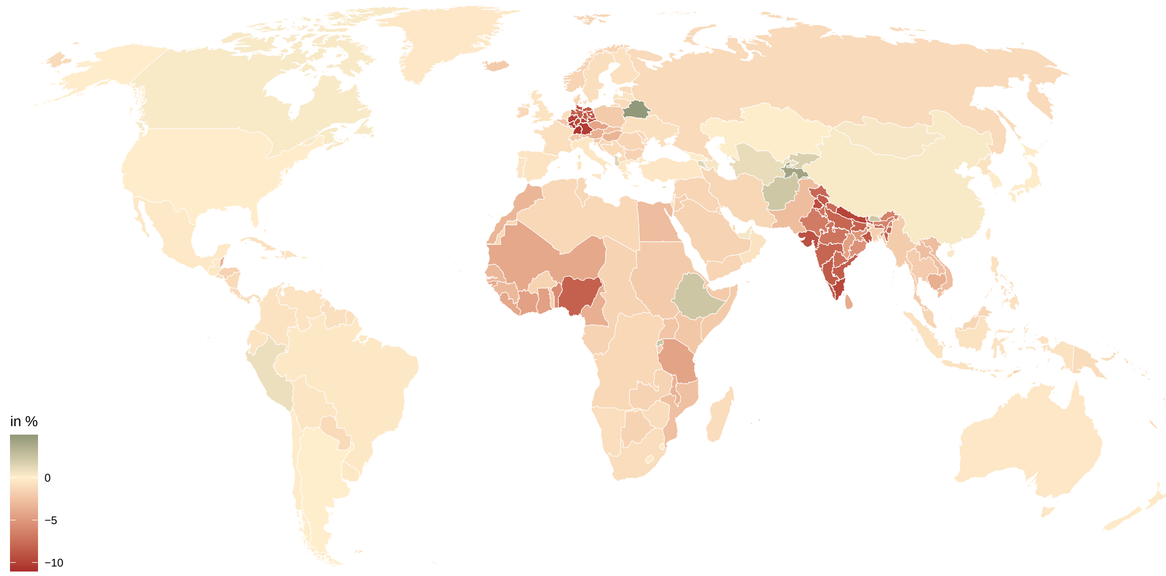
	Δ Welfare		Δ Total production		Δ Crop production		Δ Total imports		Δ Total exports	
	IND (1)	DEU (2)	IND (3)	DEU (4)	IND (5)	DEU (6)	IND (7)	DEU (8)	IND (9)	DEU (10)
RCP 2.6	-7.44	-9.98	-7.25	-11.73	-11.32	201.72	-100.00	-99.99	-99.99	-100.00
RCP 4.5	-8.06	-9.86	-7.61	-11.44	-14.89	249.27	-100.00	-99.99	-99.99	-100.00
RCP 6.0	-8.42	-9.82	-7.98	-11.34	-17.80	267.34	-100.00	-99.99	-99.99	-100.00
RCP 8.5	-9.88	-9.72	-8.97	-11.12	-26.52	304.91	-100.00	-99.99	-99.99	-100.00

Note: Changes in production refer to changes in *real* production values. Changes in im- and exports refer to changes in *real* im- and export values.

Scenario 2: Autarky Scenario 2 models a complete decoupling of India and Germany from the rest of the world. The results are reported in Table 2, which is structured in the same way as Table 1. Trade is fully suspended (Column 7 to 10). Under RCP 2.6, autarky hurts Germany more than India, because Germany is more interlinked with global value chains (see e.g. Figure 3). Germany’s welfare decrease by 9.98 %, India’s by 7.44 %. Autarky decreases India’s and Germany’s total production by 7.25 and 11.73 % (Column 3 and 4). While crop production increases by 202 % in Germany (Column 6), it decreases in India by 11.32 % (Column 5).

With higher greenhouse gas concentrations, India’s welfare decreases further to minus 9.88 % under RCP 8.5 (Column 1). As productivity shocks get more severe under higher RCPs for most crop sectors (see Table 7), India’s crop production decreases by 26.52 % (Column 5). In Germany the development is different. With higher RCPs most crop productivities even increase further (Table 7). As a consequence, welfare losses under RCP 8.5 are slightly below the losses under RCP 2.6 (Column 2).

Figure 6: Welfare Change in Scenario 2 under RCP 4.5



Figrure 6 shows global welfare change in Scenario 2 under RCP 4.5. Although only India and Germany cut off from trade global spill-over effects are severe. Compared to Figure 9 in the Appendix more countries experience a welfare decline. Not surprisingly, India and Germany face the highest welfare declines globally. Through autarky India is more exposed to climate-induced productivity shocks. Even though Germany's welfare losses decline with higher RCP, the initial losses from moving to autarky can not be compensated.

Scenario 3: Trade liberalization An approach to deal with external production shocks is trade liberalization. In this scenario I analyse whether a *tariff liberalization* (Scenario 3a) or a *NTB liberalization* (Scenario 3b) can compensate for climate-induced welfare changes.

Table 3: Scenario 3a “tariff liberalization”, changes in percent

	Δ Welfare		Δ Total production		Δ Crop production		Δ Total imports		Δ Total exports	
	IND	DEU	IND	DEU	IND	DEU	IND	DEU	IND	DEU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
RCP 2.6	1.70	0.47	2.51	3.30	-30.92	643.02	36.39	3.76	29.31	5.08
RCP 4.5	-0.42	0.52	0.65	4.33	-19.97	892.00	19.94	3.50	21.48	5.91
RCP 6.0	-0.75	0.56	0.27	4.69	-22.72	967.60	19.77	3.58	21.28	6.28
RCP 8.5	-1.84	0.66	-0.16	5.65	-37.81	1193.67	21.38	3.76	24.31	7.24

Note: Changes in production refer to changes in *real* production values. Changes in im- and exports refer to changes in *real* im- and export values.

Table 3 presents the output for a tariff liberalization in India and Germany. All tariff lines in both countries are cut to zero. Without tariffs imports to India and Germany get cheaper. Therefore, domestic production shortfalls, for example induced by climate change, can be less costly substituted by imports from other part of the world, for example countries that experience opposite productivity effects. As expected, India profits from tariff liberalization. With higher RCP welfare losses are lower than under *business as usual* (Scenario 1). Under RCP 8.5 welfare declines by 1.84 % (Column 1) compared to 2.03 % in Scenario 1. Due to trade openness less crops have to be produced domestically. Crop production shrinks by 37.81 %. The crops import share rises from 3.8 % in the baseline (see Figure 3) to 23 %. Total imports increase by 21.38 % (Column 7). Compared to Scenario 1 it gets obvious that India’s relatively high tariffs on crops increase the country’s climate vulnerability.

At a first glance it might be surprising that welfare doesn’t increase as much in Germany under Scenario 3a (see Table 3) compared to Scenario 1 (see Table 1). Imports (Column 8), exports (Column 10), crop production (Column 6), and total production (Column 4) increase more than under the *business as usual* scenario. But Germany looses 28.5 bn USD tariff revenue, which reduces income I in Eq. 15. That loss can not be fully compensated by the increase in total production and trade flows.

Table 4: Scenario 3b “NTB liberalization”, changes in percent

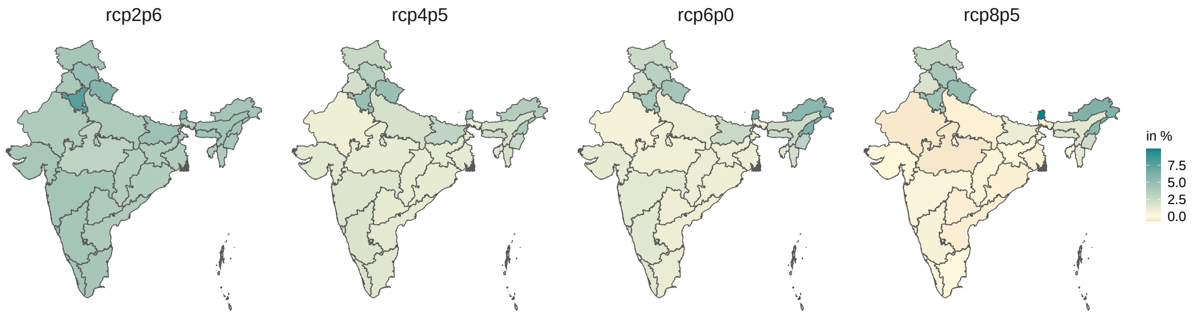
	Δ Welfare		Δ Total production		Δ Crop production		Δ Total imports		Δ Total exports	
	IND	DEU	IND	DEU	IND	DEU	IND	DEU	IND	DEU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
RCP 2.6	4.24	3.87	4.72	8.51	-24.04	669.76	47.70	35.17	38.10	35.14
RCP 4.5	1.75	3.89	2.80	9.56	-12.64	925.99	32.57	34.84	30.34	35.99
RCP 6.0	1.39	3.93	2.32	9.93	-14.39	1003.68	31.79	34.94	29.33	36.38
RCP 8.5	0.41	4.03	1.77	10.92	-30.14	1233.08	33.76	35.15	31.77	37.44

Note: Changes in production refer to changes in *real* production values. Changes in im- and exports refer to changes in *real* im- and export values.

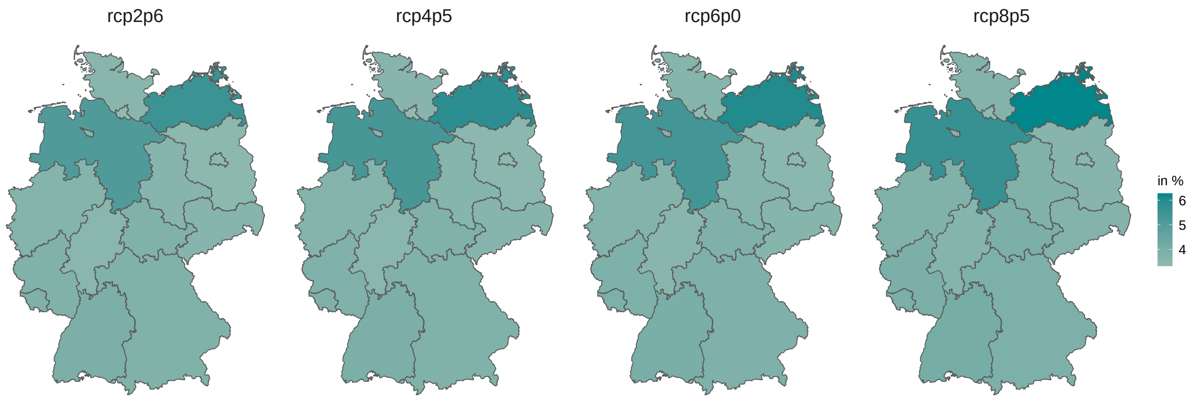
An alternative to a reduction in tariffs is a reduction in non-tariff barriers (NTBs), e.g. time-consuming administrative procedures, technical requirements, and differences in regulations. NTBs are difficult to remove. I assume a reduction of 5 % to current NTBs, both in imports and exports of India and Germany in Scenario 3b. Table 4 shows the results of this scenario.

Both countries experience welfare gains under all RCPs. Under RCP 2.6 India’s welfare increases by 4.24 % (Column 1), and Germany’s by 3.87 % (Column 2). As expected, welfare gains decline with higher RCPs in India, because crop productivities decline strongly both in India but also in many countries around the world, leading to a decline in crop supply and an increase in crop prices. But even under RCP 8.5, the decrease in NTBs is enough to compensate the climate-induced welfare costs (compare Scenario 1). Figure 7 shows that welfare effects are spatially uneven distributed. Welfare decreases in 9 out of 33 states, ranging from minus 0.72 % in Madhya Pradesh to plus 9.92 % in Sikkim. That highlights the need of intranational transfers for equal development opportunities under future climate change.

Figure 7: Welfare Change in Scenario 3b



(a) India



(b) Germany

5 Conclusion

In this paper I carry out a quantitative assessment of the trade and welfare effects of future climate change in India and Germany. I use a New Quantitative Trade Model (NQTM) (Costinot and Rodríguez-Clare, 2014) to simulate the general equilibrium effects of trade liberalization in response to climate-induced productivity changes in agriculture.

Climate change impacts are unevenly distributed around the world. While countries in the northern hemisphere experience on average small welfare gains, low- and middle-income countries tend to lose welfare substantially. India and Germany are at opposite ends of the spectrum. But the variability depends on future climate change scenarios. Under a low concentration pathway (RCP 2.6) India gains welfare, while welfare decreases with higher RCPs. Depending on future climate change, welfare spans

3.7 percentage points in India. The spatial disaggreation of India and Germany into its states in a NQTM reveals important heterogeneity in the local effects. States can differ of up to 10 % in welfare effects, with opposite sign. For climate change adaptation policies it is important to account for the spatial heterogeneity at the sub-national level.

Trade liberalization is an important adaptation policy to mitigate climate-induced welfare losses. The reduction in non-tariff barriers (NTBs) has a higher potential than a tariff elimination. Nevertheless, high tariffs on crops increase a country's climate vulnerability, as it is the case for India. Moving to autarky increases the exposure to climate change effects.

Mitigating future climate change is a rewarding endeavour. Under a low concentration pathway (RCP 2.6) almost all countries benefit from crop productivity increases, while for higher RCPs welfare costs get tremendous. The international community should therefore make every effort to cut carbon emissions.

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Appendix

A Tables

Table 5: GTAP 10 Sectorlist and Production Values

Category	Code	Sector	Production in Mil. USD	
			DEU	IND
Ag. Products	b_t	Beverages & tobacco products	49279.8	23839.3
	cmt	Bovine meat products	13532.6	7143.2
	ctl	Bovine cattle, sheep & goats, horses	5836.2	16883.2
	frs	Forestry	7263.7	38648.5
	fsh	Fishing	1051.6	18348.8
	mil	Dairy products	40357.5	30619.7
	oap	Animal products nec	15628.4	22774.2
	ofd	Food products nec	104449.8	66412.9
	omt	Meat products nec	29545.7	1182.1
	pcr	Processed rice	89.7	58834.3
	rmk	Raw milk	14033.6	68541.4
	sgr	Sugar	4198.9	17002.2
	vol	Vegetable oils & fats	8414.1	32491.3
	wol	Wool, silk-worm cocoons	560.5	6034.1
Crops	c_b	Sugar cane, sugar beet	1845.2	14819.1
	gro	Cereal grains nec	4107.8	12249.1
	ocr	Crops nec	13523.1	52620.5
	osd	Oilseeds	2492.6	30490.3
	pdr	Paddy rice	6.7	29429.6
	pfb	Plant-based fibers	60.0	16568.0
	v_f	Vegetables, fruits, nuts	6086.7	96923.7
	wht	Wheat	5576.0	33460.9
Fossils & Energy	coa	Coal	10359.4	35592.2
	ely	Electricity	93007.4	217317.0
	gas	Gas	648.1	3828.0
	gdt	Gas manufacture, distribution	2045.5	8545.1
	oil	Oil	1876.2	21766.9
	p_c	Petroleum, coal products	113025.5	247411.4
Manufacturing	bph	Basic pharmaceutical products	86032.7	28571.9

Continued on next page

Table 5: GTAP 10 Sectorlist and Production Values

Category	Code	Sector	Production in Mil. USD	
			DEU	IND
	chm	Chemical products	215934.7	103037.3
	eeq	Electrical equipment	159856.1	47467.8
	ele	Computer, electronic & optical products	201446.3	46994.6
	fmp	Metal products	177904.1	87126.8
	i_s	Ferrous metals	105984.1	102670.6
	lea	Leather products	10469.8	18289.1
	lum	Wood products	33795.4	11695.9
	mvh	Motor vehicles & parts	437195.9	72728.6
	nfm	Metals nec	70403.3	32196.5
	nmm	Mineral products nec	62120.3	55545.1
	ome	Machinery & equipment nec	317440.0	93449.0
	omf	Manufactures nec	113207.0	92708.6
	otn	Transport equipment nec	102203.7	41574.0
	oxt	Other Extraction	12725.0	11874.0
	ppp	Paper products, publishing	109491.9	23645.5
	rpp	Rubber & plastic products	118611.2	50584.6
	tex	Textiles	35811.4	106763.5
	wap	Wearing apparel	26727.7	38179.7
Services	afs	Accommodation, Food & service activities	194512.9	88665.1
	atp	Air transport	55406.0	5981.0
	cmn	Communication	434685.1	61979.6
	cns	Construction	371898.0	454873.8
	dwe	Dwellings	194204.9	103656.7
	edu	Education	219799.6	61113.8
	hht	Human health & social work activities	361169.6	105370.0
	ins	Insurance (formerly isr)	95448.1	26599.5
	obs	Business services nec	644373.4	118481.3
	ofi	Financial services nec	238009.5	105810.5
	osg	Public Administration & defense	305950.8	73960.5
	otp	Transport nec	181808.8	224151.7
	ros	Recreational & other services	213080.7	7961.3
	rsa	Real estate activities	239016.1	36257.1
	trd	Trade	541618.7	346543.7
	whs	Warehousing & support activities	102633.1	54158.9
	wtp	Water transport	6227.3	3183.1

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Table 5: GTAP 10 Sectorlist and Production Values

Category	Code	Sector	Production in Mil. USD	
			DEU	IND
	wtr	Water	71084.2	33343.5

Table 6: GAEZ to GTAP Concordance

GAEZ crop	Unit	GTAP sector
Sugarbeet	kg sugar/ha	c_b
Sugarcane	kg sugar/ha	
Barley	kg DW/ha	gro
Buckwheat	kg DW/ha	
Foxtail millet	kg DW/ha	
Highland maize	kg DW/ha	
Highland sorghum	kg DW/ha	
Lowland maize	kg DW/ha	
Lowland sorghum	kg DW/ha	
Maize	kg DW/ha	
Millet	kg DW/ha	
Oat	kg DW/ha	
Pearl millet	kg DW/ha	
Rye	kg DW/ha	
Silage maize	kg DW/ha	
Sorghum	kg DW/ha	
Spring barley	kg DW/ha	
Spring rye	kg DW/ha	
Temperate maize	kg DW/ha	
Temperate sorghum	kg DW/ha	
Winter barley	kg DW/ha	
Winter rye	kg DW/ha	
Cocoa	kg DW/ha	ocr
Cocoyam	kg DW/ha	
Coffee	kg DW/ha	
Coffee arabica	kg DW/ha	
Coffee robusta	kg DW/ha	
Greater yam	kg DW/ha	
Para rubber	kg DW/ha	
Tea	kg DW/ha	

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Table 6: GAEZ to GTAP Concordance

GAEZ crop	Unit	GTAP sector
Tobacco	kg DW/ha	
White yam	kg DW/ha	
Yam	kg DW/ha	
Yellow yam	kg DW/ha	
Coconut	kg DW/ha	osd
Groundnut	kg DW/ha	
Jatropha	kg DW/ha	
Rapeseed	kg DW/ha	
Soybean	kg DW/ha	
Sunflower	kg DW/ha	
Dryland rice	kg DW/ha	pdr
Wetland rice	kg DW/ha	
Alfalfa	10kg DW/ha	pfb
Biomass highland sorghum	kg DW/ha	
Biomass lowland sorghum	kg DW/ha	
Biomass sorghum	kg DW/ha	
Biomass temperate sorghum	kg DW/ha	
Flax	kg DW/ha	
Grass	10kg DW/ha	
Miscanthus	10kg DW/ha	
Napier grass	10kg DW/ha	
Pasture legumes	10kg DW/ha	
Reed canary grass	10kg DW/ha	
Switchgrass	10kg DW/ha	
Banana	kg DW/ha	v_f
Cabbage	kg DW/ha	
Carrot	kg DW/ha	
Cassava	kg DW/ha	
Chickpea	kg DW/ha	
Citrus	kg DW/ha	
Cowpea	kg DW/ha	
Dry pea	kg DW/ha	
Gram	kg DW/ha	
Onion	kg DW/ha	
Phaseolus bean	kg DW/ha	
Pigeonpea	kg DW/ha	

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Table 6: GAEZ to GTAP Concordance

GAEZ crop	Unit	GTAP sector
Sweet potato	kg DW/ha	
Tomato	kg DW/ha	
White potato	kg DW/ha	
Spring wheat	kg DW/ha	wht
Wheat	kg DW/ha	
Winter wheat	kg DW/ha	

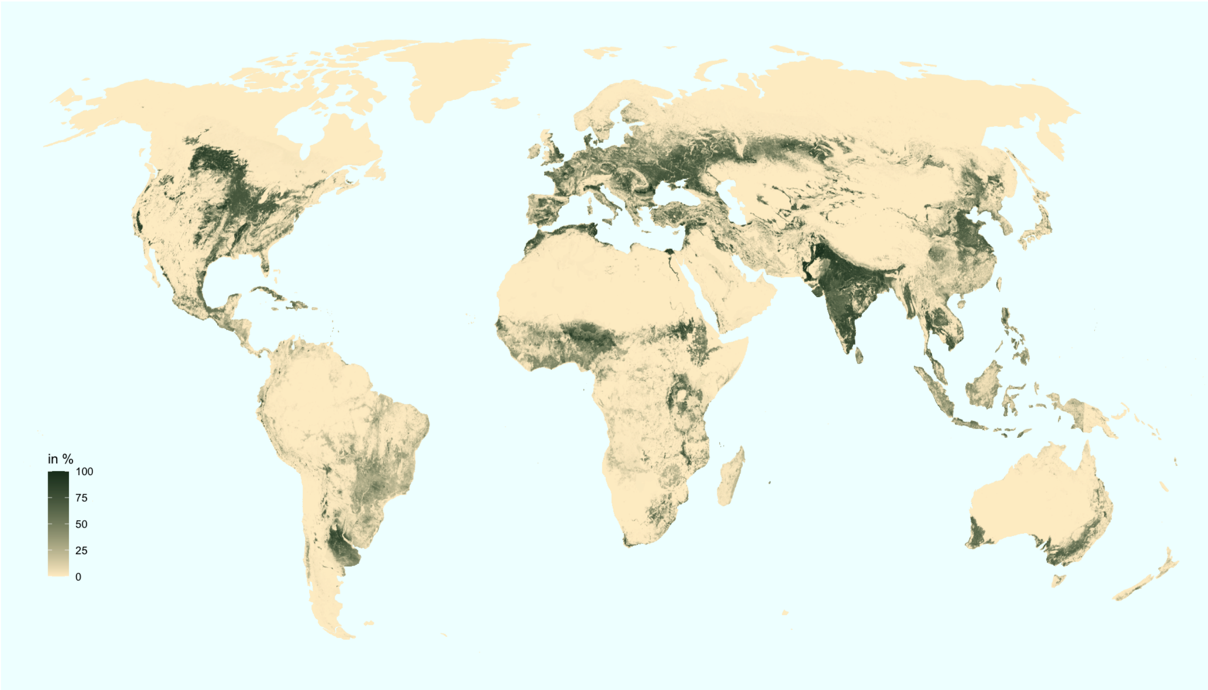
Table 7: Crop Sector Productivity Changes in India and Germany, Changes in Percent

	RCP 2.6		RCP 4.5		RCP 6.0		RCP 8.0	
	IND	DEU	IND	DEU	IND	DEU	IND	DEU
Sector	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
c_b	-6.63	3.84	-16.67	11.42	-24.45	13.95	-42.02	1.82
gro	-2.12	22.24	-13.85	30.22	-10.49	29.24	-20.62	29.43
ocr	22.73	2034.70	70.89	3257.43	60.35	3843.99	65.41	5033.53
osd	-1.00	11.14	-6.96	14.81	-6.56	18.26	-17.49	24.97
pdr	14.40	248.34	11.91	283.47	5.81	165.73	7.07	294.34
pfb	-0.40	18.31	-4.87	26.88	-6.90	28.75	-12.58	33.27
v_f	-4.37	11.58	-15.20	15.40	-15.33	17.39	-29.53	28.88
wht	-14.04	3.42	-39.37	5.83	-37.48	1.17	-58.12	-3.88

Note: Mean changes over state values. For a sector concordance see Table 5.

B Figures

Figure 8: Cropland Share, 2014



Note: Cropland share per grid cell in 2014 based on GAEZ, own calculation.

Figure 9: Welfare Change in Scenario 1 under RCP 4.5

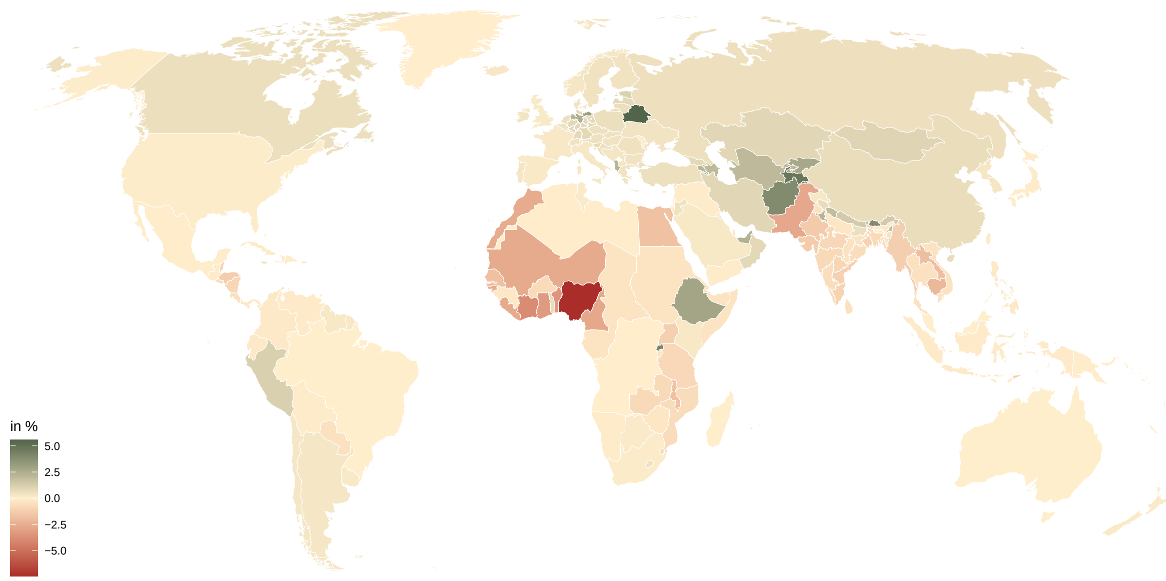


Figure 10: Welfare Change in Scenario 1 under RCP 6.0

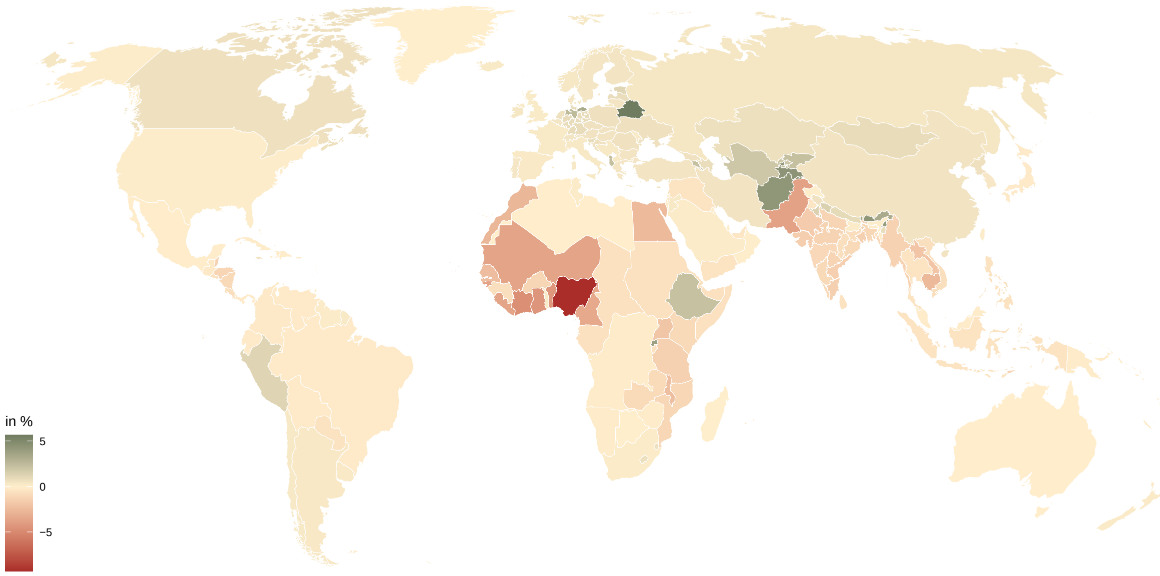


Figure 11: Welfare Change in Scenario 2 under RCP 6.0

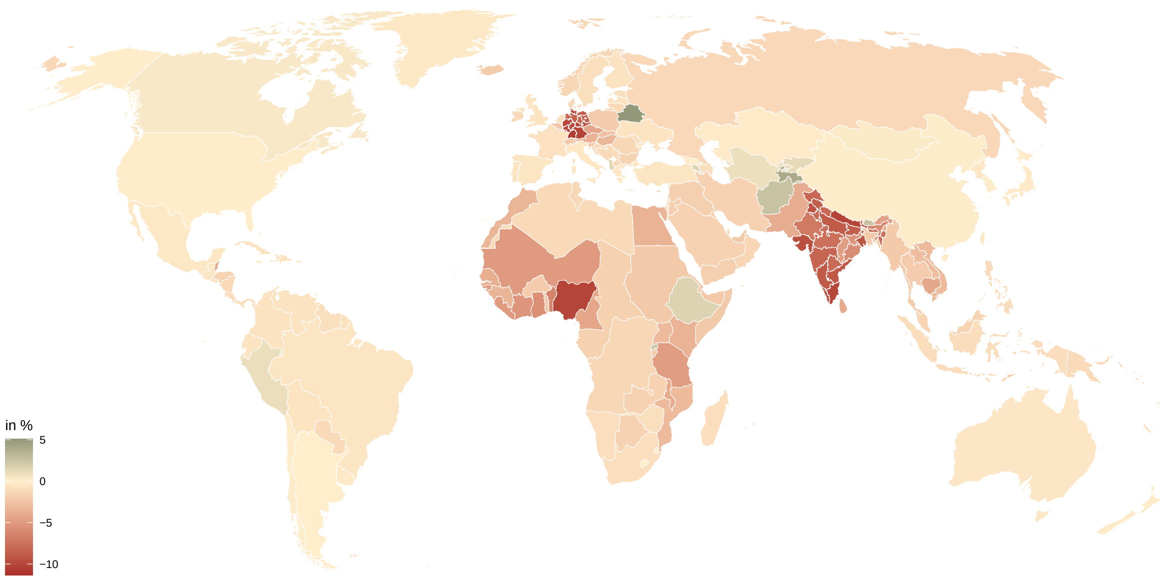


Figure 12: Welfare Change in Scenario 3a under RCP 4.5

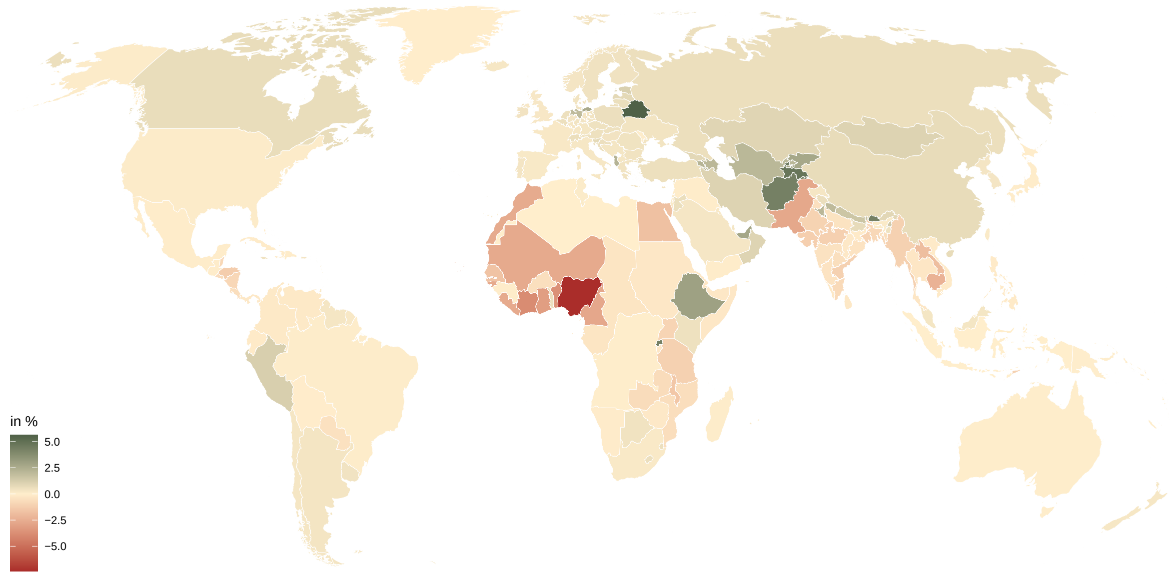


Figure 13: Welfare Change in Scenario 3a under RCP 6.0

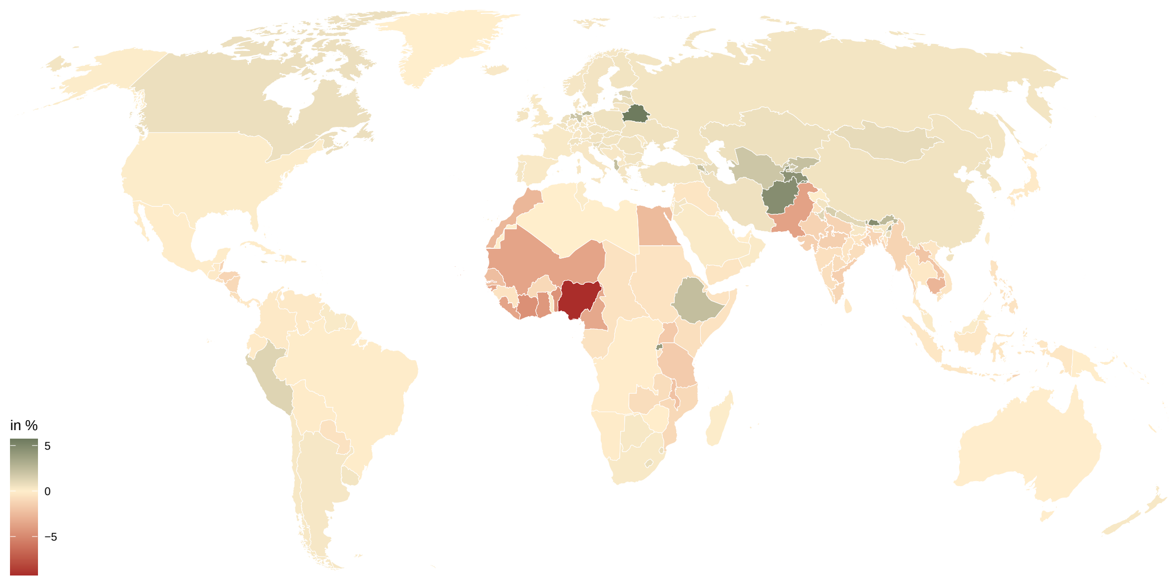


Figure 14: Welfare Change in Scenario 3b under RCP 4.5

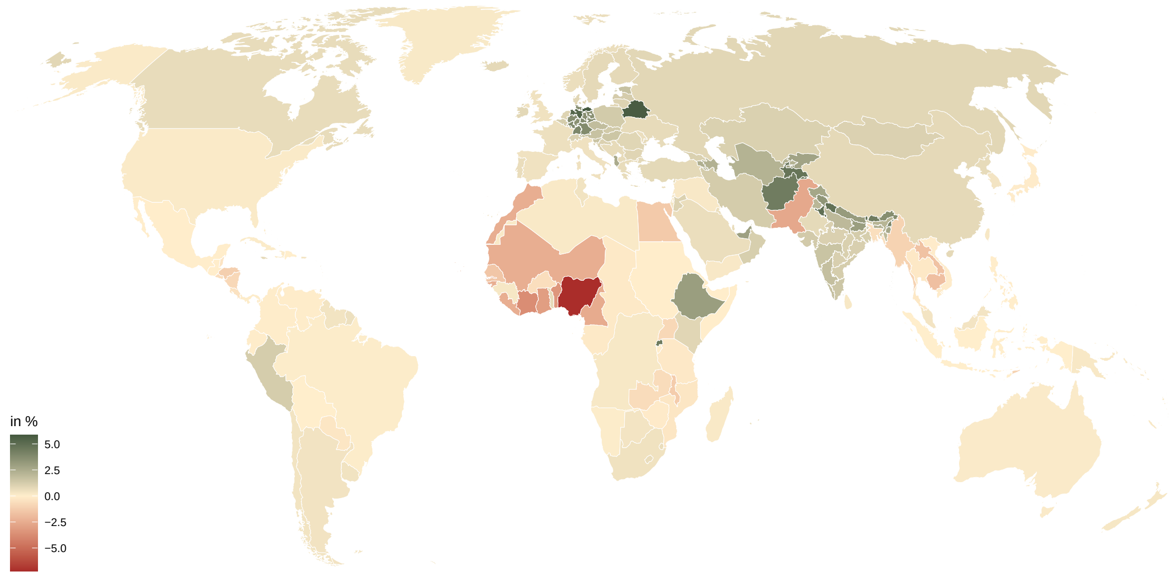


Figure 15: Welfare Change in Scenario 3b under RCP 6.0