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Macroeconomic structural change likely increases inequality in India more than climate policy

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Abstract

The decarbonization of India's economy will have different effects across income groups. As India is in the middle of the transformation process from an agriculture-based economy towards an industry- and service-based economy, called economic structural change, the extent of income distribution across households strongly depends also on the speed of economic transformation. While a number of recent studies have analyzed the distributional effects of carbon pricing, the specific role of structural change across sectors has not been in the focus of the related literature. Our study contrasts distributional effects from climate policy with distributional effects from structural change in India and asks how far carbon pricing supports or hinders structural change and development. We develop and apply a comprehensive model framework that combines economic growth and international trade dynamics related to structural change with detailed household income and expenditure data for India. Our study shows that changes in income and inequality due to carbon pricing vary with changes in the sectoral structure of an economy. Our results indicate that carbon pricing tends to delay economic structural change by retarding the reallocation of economic activities from the agricultural sector to the manufacturing sector. Furthermore, the results emphasize that the increase in inequality due to structural change is substantially stronger than due to carbon pricing. Consequently, socially sensitive policies supporting the process of structural transformation appear to be more important for poor households than lowering climate policy ambitions.

1. Introduction

Policy makers in low- and middle-income countries, including India's Prime Minister Modi or Nigeria's former President Buhari, often argue that climate policy must not interfere with economic development and poverty eradication[9]. There seems to be an underlying intuition that climate policy will (i) hinder or delay economic structural change and (ii) be largely regressive, i.e. mostly at the costs of poor people.

[9] '[T]he consequences of the industrial age powered by fossil fuel are evident, especially on the lives of the poor […]. Developing countries should have enough room to grow.' (Prime Minister Modi of India at COP21 in Paris).'Our major objective for the gas sector is to transform Nigeria into an industrialized nation with gas playing a major role and we demonstrated this through enhanced accelerated gas revolution.' (President Muhammadu Buhari, 29 March 2021).

In this article, we focus on India and aim to identify the conditions under which this intuition can be resonated. A number of recent studies (global or on Asian and emerging economies) analyse the distributional effects of carbon pricing and climate policies on household income groups [1–6], detecting both regressive as well as progressive effects (see Ohlendorf *et al* [7] for a review). Regressive impacts are mainly detected for developed countries, while in developing countries the impact can be expected to be (more) progressive. Cross-country differences in energy use across income groups can explain these different results [2]. Studies focusing on labour market effects report regressive effects as low-skilled labour in energy-intensive sectors is strongly affected by the transition [8, 9]. Other studies, that additionally take general equilibrium and broader income effects into account [10–12], find that even in developed countries the regressive consumption expenditure effect of climate policy tends to be dominated by progressive income effects—often supported by carbon tax recycling[10].

Accounting for income effects, e.g. increasing wages for the poor, is at the heart of structural change-induced development effects. In fact, as a major result of the literature on growth, structural change and inequality, Ciarli *et al* [13] find that wage differences are the major explaining factor of increasing inequality. Here, we analyse the distributional effects (i.e. the distribution of Indian households' wage income and consumption expenditures) of climate policies at the household level, accounting for general equilibrium and structural change effects along the low-carbon transition path. While the meaning of structural change is context-sensitive, we adopt a definition from the economics literature [14] that embeds structural change in a broader concept of economic development, and specifies it as the reallocation of economic activity across broad sectors, such as agriculture, manufacturing, and services.

Arguably, India is undergoing a transformation from an agriculture-based economy towards an industry- and service-based economy. How—and how fast—this economic transformation unfolds will have distributional consequences that interact with those from climate policies. By investigating the interaction of climate policy with economic structural change and analysing their combined and separated distributional effects, this study fills a relevant research gap. In the economics literature the phenomenon of structural change is an intensively studied phenomenon and the composition of economic structure is an acknowledged measure of development [15–17]. We introduce this phenomenon in the field of climate policy modelling and distributional analyses of climate policy effects. This includes an inherent focus on future developments, which distinguishes this study from the rich literature on structural change and inequality, which is mainly empirical [18–20].

We also contribute to the discussion on growth and welfare impacts of climate policy [21–24], where it is a major dispute whether climate policies come with positive or negative costs (e.g. due to an efficiency-increasing redirection or crowding-out of investments) in addition to the predominant positive effects of avoided climate change damages. We contribute by adding the structural change development perspective and find out that climate policy tends to slow down structural change. Only two other studies have a comparable focus—Lefevre *et al* [25] and Ciarli and Sanova [26]. The former, however, does not look into distributional effects on the household level as we do. The latter provides a review of how different climate change assessment models integrate aspects of structural change, however applies a concept of structural change which is much less focussed on the sectoral composition.

Distributional effects are best measured at the micro level (i.e. households and income groups), while drivers of climate policy and structural change are best represented at the macro level (i.e. national economies). In order to run a meaningful quantitative assessment, we develop a novel modelling framework that bridges these levels by coupling several models and combining economic growth and international trade dynamics related to structural change with detailed household income and expenditure data for India[11]. Our integrated modelling approach allows us to separate the distributional effects of climate policy and structural change on household income groups. We find the distributional effects of structural change to be more regressive than those of carbon pricing. Concomitant socially sensitive policies supporting the process of structural transformation appear to be more important for poor households than lowering climate policy ambitions. Policies should be designed in a way that supporting the poor and tackling climate change become congruent policy goals.

2. Methods

2.1. Overview of the methodology

This study is based on a large numerical scenario analysis using a newly developed model-coupling framework to connect models at the macro, meso, and micro levels. At the macro level, we use input from existing socioeconomic scenarios (called shared

[10] While Vona [57] considers standalone climate policy to be regressive and discusses green policy packages to support political acceptance for a just transition path, other studies, e.g [6, 58, 59], demonstrated that poor households can benefit from redistributional transfers (e.g. carbon tax recycling).

[11] Alternative methods predominantly make use of an extension of computable general equilibrium (CGE) models by representing different household groups [60, 61].

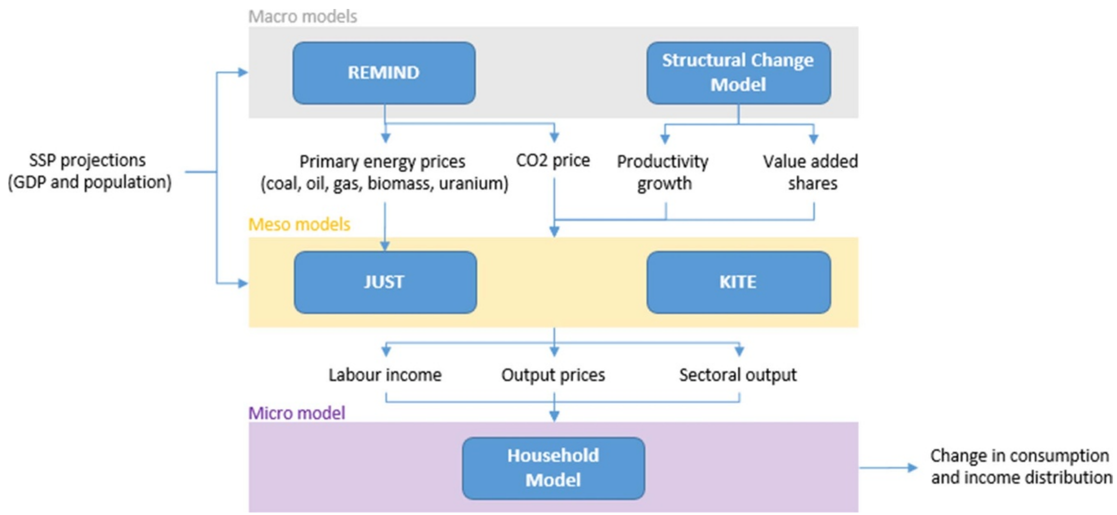

Figure 1. Data flow between models.

socioeconomic pathways—SSPs) [27, 28] and apply the regional model of investments and development (REMIND) [29]—a large-scale integrated assessment model (IAM)—and a reduced-form structural change model [30]. At the meso level, we apply two advanced trade models—the Kiel Institute trade policy evaluation (KITE) model [31] and the Justus (Liebig) University sustainable transition (JUST) model [32]. To extend the scope of climate policy and international trade modelling, we combine different model types with their specific strengths and foci. While the IAM REMIND features intertemporal dynamics and a full-fledged energy system, the advanced trade models KITE and JUST provide multiple sectors and a theory-based trade module with trade in intermediate goods. We use two trade models to test the robustness of the results. Details on all four models are provided in the appendix section A. Finally, we apply a household model that splits Indian households into five income quintiles on the micro level (see section 2.3).

2.2. Model coupling

The models and methods scrutinized in our model cascade are soft-linked via the exchange of parameter values and simulation results. Figure 1 shows the main data flows. The relevant scenario data, which are derived from REMIND and the structural change model and used as inputs for the JUST and KITE model, are: macroeconomic output (GDP), value-added shares of agriculture, manufacturing, and services, a uniform CO_2 price (imposed on all Indian production sectors and private and public consumption) and, in the case of JUST, the prices of global energy carriers (coal, crude oil, and natural gas). In the trade models, the productivities of the Indian production sectors grow over time such that the exogenously given value-added shares of agriculture, industry and services and the Indian GDP growth are represented. The output variables generated by the trade models as inputs for the household model are: sectoral labour income, sectoral output, and output prices. These variables vary based on the reaction of the trade models to the input from the macro level (see more details in the appendix, section A.4).

2.3. Household model

In the household model, we perform a micro simulation based on (a) the results obtained from the macro and meso models for India, and (b) the distribution of employment, income, and expenditures in India observed in the 2012 household consumer expenditure (NSS 68th round) survey[12]. In this analysis, we use annual household expenditures as a proxy for household income. The sum of all expenditures in a year is used to reflect the average income of each household better, smoothing out short-term income variations [33]. We assign each household to one of five income quintiles based on its income. As a reference, the median expenditure level of the poorest quintile in India is equal to 527 US dollars in 2012, while for the richest the median level is 2129 US dollars[13]. We furthermore classify each household based on the head of the household's sector of employment. Finally, we compute the households' expenditure shares by aggregating the detailed expenditure categories first to match the corresponding production sectors as defined by the global trade analysis project (GTAP) database. Then, those sectors are further aggregated to five macro-sectors (table A.1 in section F of the appendix provides a detailed

[12] Note that the 2012 household consumer expenditure survey is the most recent one available publicly. Details of the survey are documented here: (www.icssrdataservice.in/datarepository/index.php/catalog/135).

[13] Here, and in all following sections, dollar values are provided in constant 2005 market exchange rate (MER) prices.

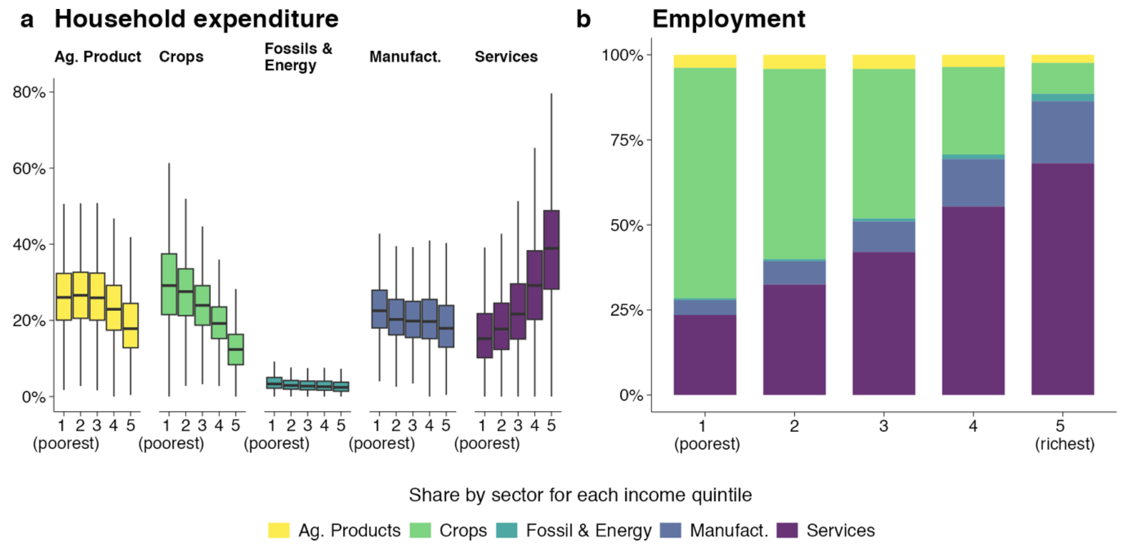

Figure 2. Expenditure shares (panel (a)) and employment shares (panel (b)) in India by income quintile and sector (boxes cover the range between the 25th and 75th percentile of the data—the inter-quartile range; whiskers extend to the furthest data point within 1.5 times the inter-quartile range; lines within the box mark the median); based on 2012 survey data, aggregated to five sectors (see mapping in appendix, table A.1).

description of the matching between consumption items, GTAP sectors and aggregated sectors used in this study).

We analyse the distributional effects of changes in household expenditures (consumption incidence) and income (income effect). The consumption basket in 2012 is the reference and all changes in the consumption incidence are measured based on the assumption that the consumption basket of each income quintile does not change between the base and the target year, which is 2030 in this study. To approximate income and income changes, we refer to the head of household's sector of employment. Figure 2 shows the 2012 expenditure and employment shares.

Notably, the differences in expenditure shares across income groups are significant. While poor households spend comparatively more on agricultural products, rich households spend comparatively more on services. Furthermore, according to the survey data, poor households tend to have comparatively high employment shares in the agricultural sector, whereas rich households have high employment shares in the services and manufacturing sectors. For the sake of transparency, we keep the composition of income groups constant over time and assume that each household is employed in the same sector as in the benchmark year 2012[14].

Income changes arise from labour income changes, which in this study are approximated by changes in sectoral labour income and value-added, respectively, computed by the trade models. While the two trade models assume perfect mobility of labour across all sectors within each country/region and therefore result in a uniform wage across all sectors in each country/region, computed changes in labour income resemble wage-specific changes that one would expect under imperfect mobility of labour as assumed in the household model.

To calculate the distributional effects of structural change and climate policy across income quintiles, we first calculate the new income of households as:

$$\text{HHincome}_{i,s,t+1} = \text{HHincome}_{i,s,t} * (1 + \Delta\text{wage}_{i,s}) \tag{1}$$

where $\text{HHincome}_{i,s,t}$ is the average income of a household of income quintile i employed in sector s. Index t indicates the period, covering the base year 2015 (period 1) and the target year 2030 (period 2). $\Delta\text{wage}_{i,s}$ is calculated as the relative change in labour income (value-added) in the sector of employment of household i between the periods t and $t+1$. For the base year, income is approximated by total expenditures per capita. The income effect (section 3.3) is calculated as the difference in $\text{HHincome}_{i,s,t+1}$ between two specified scenarios aggregated over all sectors s.

Based on the computed income of each household in $t+1$, we calculate the new total expenditures of each household ($\text{HHconsumption}_{i,s,t+1}$). The total expenditures are the sum of the expenditures on all goods q. Changes in the expenditures on (domestically produced and imported) goods q are a result of relative changes in the prices of these goods (Δp_q) computed by the trade models. The composition of the household's consumption bas-

[14] While ignoring some dynamic effects, the simplifying assumptions regarding the employment structure as well as the consumption basket within the household model have only a minor impact on the analysis of distributional effects in section 3.3, because that analysis focuses on comparing pairs of scenarios which all start from the same harmonized assumptions.

Table 1. Scenario classification.

	Structural change scenario			
	SSP1	SSP2	SSP5	Without structural change
Baseline (implemented policies only)	SSP1-Base	SSP2-Base	SSP5-Base	NoSC-Base
Climate policy				
2 °C	SSP1-CP2	SSP2-CP2	SSP5-CP2	NoSC-CP2
1.5 °C	SSP1-CP1.5	SSP2-CP1.5	SSP5-CP1.5	NoSC-CP1.5

ket defined by its expenditure shares ($\text{expshare}_{i,s,q}$) remains unchanged:

$$\text{HHconsumption}_{i,s,t+1} = \sum_q (1+\Delta p_q) * \left(\text{expshare}_{i,s,q} * \text{HHincome}_{i,s,t+1}\right). \quad (2)$$

We then compare the new total expenditures with the new income of the household to calculate the consumption incidence:

$$\text{incidence}_{i,s,t+1} = \left(\text{HHincome}_{i,s,t+1} - \text{HHconsumption}_{i,s,t+1}\right) / \text{HHconsumption}_{i,s,t+1}. \quad (3)$$

The consumption effect (section 3.3) is calculated as the difference of the consumption incidence between two specified scenarios aggregated over all sectors s.

2.4. Scenario design

Our scenario analysis is performed along two dimensions: (i) climate policy and (ii) structural change. Table 1 classifies the underlying scenarios. Regarding the climate policy dimension, we distinguish between a baseline, a 2 °C and a 1.5 °C climate stabilization scenario. We use the latter for a robustness test only. Within the climate policy scenarios, climate stabilization is achieved via carbon pricing. The baseline scenario represents a current policy scenario (see appendix, section A.1) and covers in a stylized way climate policies that are already implemented today [34–36]—resulting in a carbon price for India of less than one US dollar in 2030. The future carbon price in the climate policy scenarios is computed by the REMIND model. The underlying assumption is a staged accession climate policy regime (similar to the policy regime studied by Soergel *et al* [6]). In this policy regime, countries and world regions join the international climate policy coalition by implementing carbon prices at different levels depending on their differentiated responsibilities and capacities. A global uniform carbon price becomes effective in 2050. The carbon price is uniformly imposed on all fossil fuel inputs in all Indian sectors. Other greenhouse gases or process emissions, such as methane in agriculture, are not considered. Revenues from carbon pricing are recycled distributional-neutral. Each pair of baseline and climate policy scenarios assumes population and GDP growth according to the associated SSP scenario (see appendix, figure A.1). A small difference in GDP exists between the baseline and climate policy scenario due to the endogenous climate policy impact.

The dimension of structural change is covered by three SSP scenarios (see appendix B for a general characteristic of the SSPs). All applied SSPs[15]—SSP1 ('sustainability'), SSP2 ('middle of the road') and SSP5 ('fossil fuelled development')—follow a different economic growth path with different pace of changes in the economic structure. Transformation is fastest under SSP5 followed by SSP1 and SSP2 (see section 3.1). Three additional scenarios represent a development without structural change (NoSC-base, NoSC-CP2 and NoSC-CP1.5). Within this setting, we start from an SSP2 scenario in 2015 and keep the value-added shares of the different sectors constant over time.

3. Results

3.1. Structural change and climate policy

Following the economic literature, we quantify structural transformation as the change in the sector shares of total labour and value-added (defined as the sum of labour and capital income). Resulting structural transformation pathways computed by the structural change model are shown in figure 3. A general pattern applies across all chosen SSPs: the major part of future development and output growth is based on increasing activities in the service sector. Decreasing labour and value-added shares of agriculture are associated with initially increasing labour shares and nearly constant value-added shares in the manufacturing sector. While the stagnation of value-added shares in this sector can be observed in other countries as well, compared to other major emerging economies in Asia (e.g. China, South Korea, Indonesia), India exhibits

[15] The chosen SSPs are limited to those that can be computed by the REMIND model.

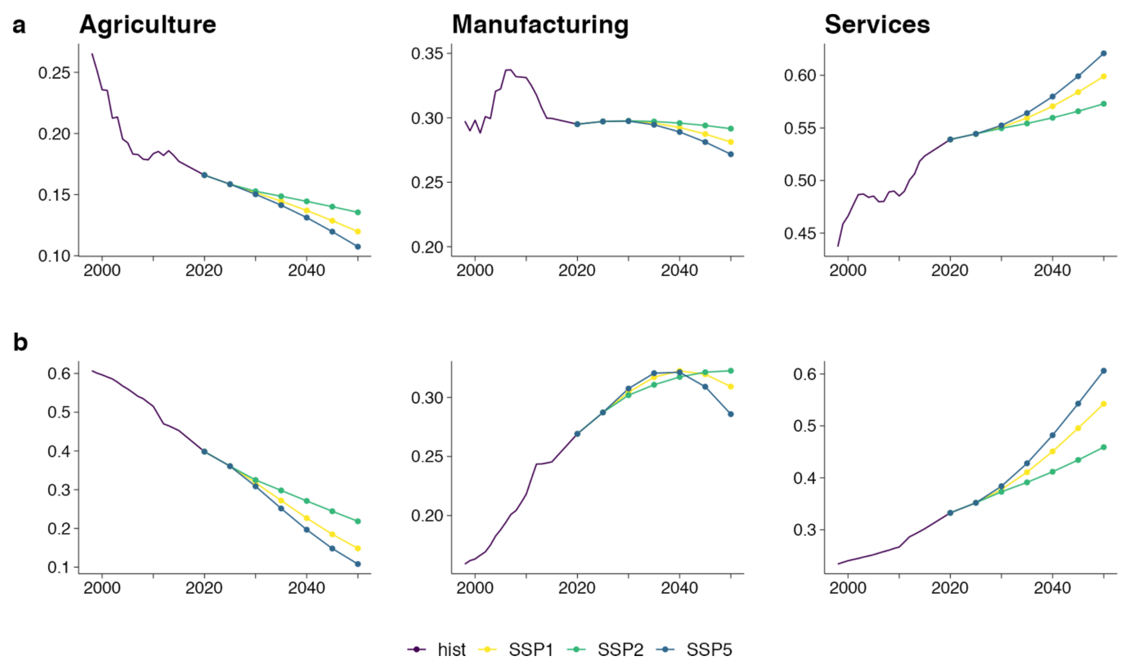

Figure 3. Structural change in India under different SSPs; panel (a) value-added shares and panel (b) labor shares of agricultural (agr), manufacturing (man) and service (ser) sectors (historical values until 2020 are from world bank's world development indicators[16]; the presented values for the manufacturing sector correspond to values of the industry sector in the world bank data base).

relatively small shares because of lower productivity and a low share in the production of high-value export goods [37]. Within our scenarios, substantial reallocation of economic activities towards manufacturing and services is projected for India under SSP1. A peak of the employment share in the manufacturing sector can be expected between 2035 and 2040. The structural transition is even faster under SSP5 where this peak is likely to appear between 2030 and 2035, while the value-added share in manufacturing starts to decline already before 2030. The transformation process will be slower under SSP2, with the peak in manufacturing value-added and labour shares not occurring before 2040 and 2050, respectively.

In this study, we apply a carbon price computed by the REMIND model to simulate climate policy in India (cf section 2.4). In order to achieve the 2 °C and 1.5 °C temperature goal, different carbon prices are needed under the different structural change scenarios. The computed CO_2 prices for India in 2030 under SSP1, SSP2, and SSP5 amount to 20, 25, and 50 US dollars per tonne of CO_2, respectively, in the 2 °C scenario, and 85, 84, and 135 US dollars per tonne of CO_2, respectively, in the 1.5 °C scenario. In Europe, by comparison, the respective CO_2 prices in 2030 are between 75 US dollars per tonne of CO_2 (SSP1-CP2) and 520 US dollars per tonne of CO_2 (SSP5-CP1.5).

3.2. Development impacts of carbon pricing

Without accounting for avoided climate change damages, carbon pricing in general has a negative impact on consumption due to increasing prices (figure 4(a)). Furthermore, the income-reducing effect of carbon pricing (figure 4(b)) is most substantial in the energy sector due the high share of fossil fuels consumed in this sector (see further explanation in the appendix, section A.4), followed by manufacturing containing carbon intensive industries. Our results are in line with the literature, e.g. Hübler and Löschl [38] find that relative income effects of carbon pricing (in 2023–2050) are slightly positive or negative in less-carbon intensive sectors, have moderate negative effect (−5% to −10%) in more carbon-intensive sectors (manufacturing and electricity) and reach substantial negative effects (−35% to –50%) in the fossil fuel sectors. Furthermore, due to differences in the CO_2 intensity, climate policy reduces production (and income) in the agricultural sector[17] on average more than in the service sector. With given demand (expenditure shares) for sectoral goods, the price of agricultural goods increases more than that of services (see figure 4). However, while income and price changes caused by carbon pricing are significant, they are much smaller than the corresponding changes along the baseline economic development path (see appendix, figures A.2 and A.3). Baseline price changes between 10% and 30% and income

[16] Accessed 6 May 2021 at https:databank.worldbank.org/source/world-development-indicators.

[17] In the analysed trade models, CO_2 emissions from burning fossil fuels in agriculture are included while greenhouse gas emissions from livestock farming and fertilization are not included.

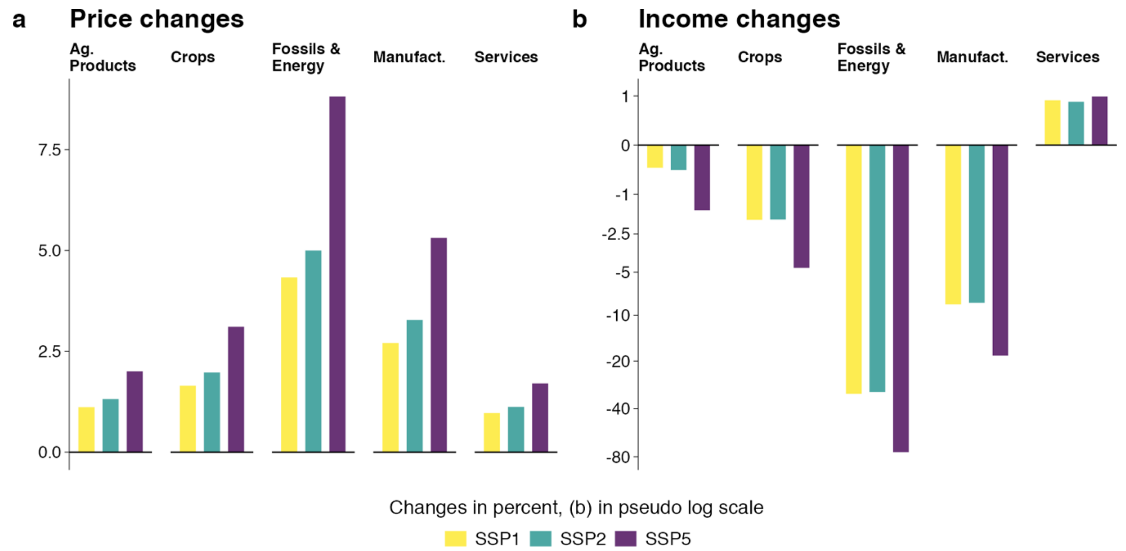

Figure 4. Sectoral output price changes (panel (a)) and sectoral income changes (panel (b)) in India induced by carbon pricing compatible with 2 °C climate policy under different assumptions of structural change (SSP1, SSP2, SSP5). The figures show the difference in the percentage changes over in time (between 2015 and 2030) between climate policy scenarios (SSP1-CP2, SSP2-CP2, SSP5-CP2) and the corresponding baseline scenarios (SSP1-Base, SSP2-Base, SSP5-Base). Sectoral output from the KITE model is aggregated to five sectors with agricultural products and crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

changes between 150% and 250% can be observed on average across aggregated sectors with moderate variation across SSPs. Even energy prices are subject to a much larger intertemporal effect (10%–50%) than carbon pricing effect (3%–15%). To some extent, this relationship is due to the comparatively small CO_2 price. Climate policy impacts grow if India faces a higher carbon price—as for example in the 1.5 °C scenario (see section 4 and figure A.5 in the appendix).

Nevertheless, the impact of carbon pricing on income and consumption opportunities differs significantly under different assumptions on structural change. As shown in figure 4[18], adverse impacts turn out to be always highest across all sectors under the fast structural change scenario SSP5 and much lower under SSP1 and SSP2. Price changes between 1% and 4% under SSP1 compare with changes between 2% and 8% under SSP5. The same pattern also applies to the distributional effects (see appendix, figure A.11). Households of each income group face higher impacts from carbon pricing under SSP5. The most substantial regressive effect is associated with this scenario as well. Based on KITE model output, poor Indian households suffer from an income loss of 7%, while rich Indian households face income losses of less than 4% under SSP5.

The observed variation in the impact of carbon pricing on the level and distribution of gains and losses partly results from the properties of the different structural change scenarios (e.g. differences in sectoral labour and output shares, income and price changes induced by the implied sectoral productivities). The carbon price itself depends significantly on properties that are only indirectly related to structural change. While energy and carbon intensities are primarily based on GDP per capita levels, which also drive the sectoral composition of the economies, the SSP scenarios also feature properties that decouple GDP from energy use. This applies in particular to SSP1 which is assumed to follow an environmentally sustainable and less energy intensive pathway already in the baseline. This explains why the impact of carbon pricing is comparable or even slightly smaller under the fast structural change scenario SSP1 than under SSP2.

In order to separate the impacts of carbon pricing and structural change, we set up another comparison experiment. We, first, run a reference scenario without structural change and without climate policy (NoSC-Base—see methods section). Additionally, we run a counterfactual scenario with climate policy included (NoSC-CP2) and another counterfactual scenario that just includes structural change according to SSP2 but no climate policy (SSP2-Base). This set-up allows us to address a question which is crucial from a development perspective: does climate policies accelerate or hinder structural change? This study finds mixed results. While structural change manifests in decreasing value-added shares of the agricultural sector and increasing value-added shares of the service sector, carbon pricing induces increasing shares in both sectors (see figure 5 and additional

[18] Here and in the following, we present results from one trade model (KITE) only. Corresponding results based on the JUST model are presented in the Appendix and discussed in the Discussion section.

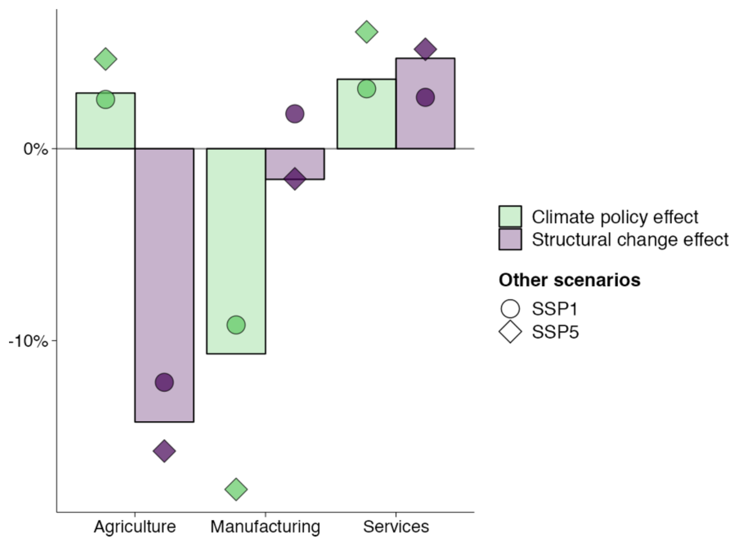

Figure 5. Changes in Indian sectoral value-added shares (in 2030) caused by structural change (purple bar) and 2 °C climate policy (green bar) under SSP2 (variation under SSP1 and SSP5 is labelled by circles and squares, respectively). The former represents the difference between scenarios with and without structural change (no climate policy); the latter represents the difference between scenarios with and without climate policy (no structural change). Changes are measured in % of sectoral shares of baseline scenario NoSC-Base (no policy, no structural change); based on KITE model results.

explanation in the appendix, section A.4). The decline in value-added in the manufacturing sector due to climate policy is substantial and can be interpreted as a risk for development. While India has undergone a transformation process that—in contrast to that of China—is characterized by a smaller share of the manufacturing sector, it is not a fully developed country for which declining manufacturing shares are already part of the usual transformation process. Due to its high share in the production of investment goods, the manufacturing sector is crucial for India's development. Climate policy tends to slow down economic structural change. While this holds on a macroeconomic level with three sectors, results are more diverse on the level of heterogeneous subsectors (for further details, see appendix, section A.4, figures A.9 and A.10). Some manufacturing subsectors (e.g. manufacture of computers, pharmaceutics and wood products) expand their value-added shares due to climate policy.

3.3. Distributional effects

As figure 6 shows, both climate policy and structural change have negative average consumption and income effects across income groups. The consumption incidence[19], which measures basically the change in purchasing power of a given income, is for the lowest income group 2.1% lower with climate policy than without climate policy, and 3.4% lower with structural change than without structural change. This difference is larger for the income effect: 2.7% and 17% lower, respectively. There is an even larger difference between the distributional effects of climate policy and structural change. While both tend to have regressive effects (i.e. poor households are more adversely affected than rich households), the spread between household groups is very different. Climate policy causes more evenly distributed losses of consumption and income, whereas structural change places a severe burden on the poor. The income of poor households is 17% lower with structural change than without it, whereas rich households even gain by the order of 5%.

Why does structural change make the poor worse off in relative terms? The explanation given is based on the household characteristics (see section 2.3) and applies in a similar way also to the middle income groups of quintiles 2 and 3. Poor households are mainly employed in the agricultural sector (see figure 2). Structural change shifts more activity, and thus income, to the service sector (and some manufacturing subsectors, see figures A.9 and A.10 in the appendix) and reduces the increase of income in the agricultural sector (see figure 5). Consequently, poor households become worse off if they are not able to switch to other sectors. While allowing for labour mobility in the distributional analysis could dampen the estimated income effects, the assumption of labour immobility appears to be reasonable because the examined time horizon covers only 15 years. Current workers, who work throughout the period, tend to find it difficult to move to another sector, while it is easier for the next generation to

[19] See equation (3) in section 2.3 for a definition of consumption incidence.

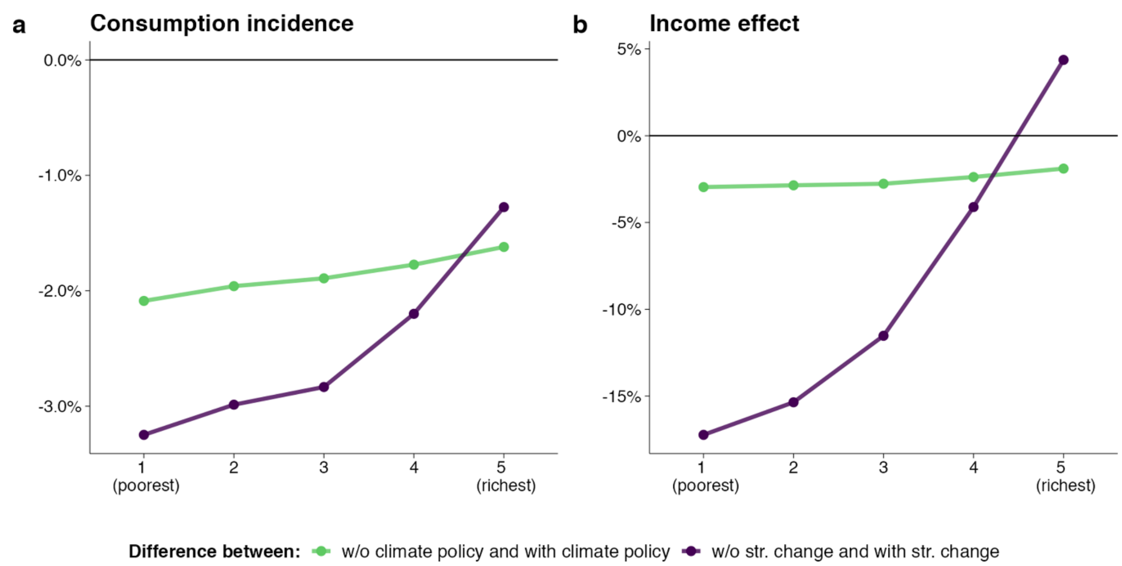

Figure 6. Consumption incidence and changes in income across Indian household income groups due to 2 °C climate policy and structural change in 2030. The green lines represent the differences in consumption incidence (panel (a)) and income (panel (b)) in a scenario with climate policy (SSP2-CP2) and a scenario without climate policy (SSP2-Base). The purple lines represent the respective differences between scenarios with (SSP2-Base) and without structural change (NoSC-Base). Negative values indicate that consumption incidence/income values are lower in scenarios with climate policy and structural change, respectively; based on KITE model results.

choose a different sector by acquiring the respective skills in early years already. Furthermore, price differences between the scenario with structural change and the scenario without structural change disproportionately favour rich households. In contrast to poor households, which spend relatively more on agricultural products (food), rich households spend more on services (see figure 2). Therefore, they benefit more from a more substantial drop in prices for services compared to a less substantial reduction of prices for crops (see appendix, figure A.6).

4. Discussion

Given that India is projected to have the largest population in the world, a global effort to tackle climate change depends crucially on India's ability to decarbonize its economy [39]. However, the changes in energy prices and employment opportunities implied by decarbonization policies may be socially contentious [40, 41] and reduce the willingness of political decision-makers in India to implement ambitious climate policies in line with the Paris climate targets. While this study finds results that support this position, by taking structural change effects along the low-carbon transition path into account the overall conclusion points in the opposite direction.

As a first major result, we find that carbon pricing implies the risk of delaying the structural transformation process, mainly by increasing the cost of production and therefore changing the relative competitiveness of Indian manufacturing sectors over time compared to non-manufacturing Indian sectors as well as to manufacturing sectors in other countries. The development effect indicated by the decrease in manufacturing production goes beyond the second-order impact found by Lefevre *et al* [25] in a global study, in which, due to a longer time horizon (until 2050), economies have more time to adapt. Changes in output and value-added shares can be expected to be large on a disaggregated manufacturing sector level (see figures A.9 and A.10 in the appendix), in particular in the fossil energy sector. The change in sectoral composition is somewhat smaller, but still significant at the aggregate level (see figure 5). Carbon pricing results in a decline in the manufacturing sector share due to the sector's high share of energy and emission intensive production, and because India is able to import manufactured goods to meet its demand from countries with a more competitive and greener production[20]. Output shares of the agricultural and service sectors consequently increase. This result also holds under the more ambitious 1.5 °C climate policy (see figure A.8 in the appendix). While climate policy strongly supports structural transformation within the energy sector [42] through the intrasectoral reallocation of labour, it partially undermines the reallocation of economic activities away from agriculture driven by structural change.

Our results show that carbon pricing implies a larger agricultural sector at the expense of activities in

[20] We explicitly allow for import substitution in our framework.

the manufacturing sector. While this can be beneficial for the large share of poor households employed in agriculture (where labour mobility is low) in the short term, it may also delay industrialization and the transition to an advanced technology-based economy with the creation of better-paid jobs in the manufacturing and service sectors. Recent studies provide new evidence supporting the role of the manufacturing sector as a growth engine [43, 44].

Given the interacting distributional effects of carbon pricing and structural change, disentangling and comparing them provides new insights. A second major result of our scenario analysis emphasizes the dominance of the distributional effects of structural change. The structural transformation that India is facing—with or without climate policy—may substantially reduce wages in sectors where mostly poor people work. Thus, structural change is likely to increase inequality more than climate policy. This result is even supported by the more ambitious 1.5 °C climate policy scenario (see appendix, figure A.12) although the absolute level of the climate policy impact increases under this scenario, resulting in a larger negative price effect and a similar average income effect compared to that of structural change. Climate policy has a rather neutral distributional effect—with regard to the income effect, slightly regressive in the results from the KITE model and slightly progressive in the JUST model results (see appendix, figure A.11). This is in line with those previous studies that see comparatively small distributional effects for India (e.g. Steckel *et al* [4]). While at a somewhat lower per capita income level, this result is also consistent with Dobrand *et al* [2] who find distributional effects to shift from progressive towards regressive for per capita income levels that are typical for emerging economies. On the other hand, Budolfson *et al* [45] find this crossing point at around 20 000 US dollars, which is significantly above India's near-term GDP per capita level.

As a third result, we find indication that the near-term impact of carbon pricing in India differs depending on the assumptions on the development of the structure of India's economy. As shown and discussed in section 3.2, changes in income and inequality due to carbon pricing are largest under scenarios with fast structural change (SSP5). While this result has not been highlighted in the literature so far, its robustness is contained because the carbon pricing effect under different structural change scenarios is compared based on different carbon prices. Moreover, features (e.g. baseline share of renewable energies), not specifically associated with economic structural change, are attached to the applied scenarios. Thus the SSP1 scenario, which is presumed to have faster (or at least comparable) structural transformation than the SSP2 scenario, shows lower income and price changes du to carbon pricing. In other words, among scenarios with similar pace of structural change, in scenarios that are 'greener', carbon pricing increases inequality to a smaller extent. The robustness of the basic finding is again supported by results from the 1.5 °C climate policy scenario (see appendix, figures A.5 and A.12). The gap between the impacts on the poorest and the richest households is always largest in the fast structural change scenario SSP5.

The application of two trade models helps to further evaluate the robustness of our results. Findings discussed in section 3 based on results from the KITE model are predominantly supported by results from the JUST model. This applies to the sensitivity of distributional effects of carbon pricing on the structural change assumptions (see figures A.4 and A.11 in the appendix) despite income changes in the opposite direction in some sectors. It also partly applies to the impact of carbon pricing on structural change (appendix, figure A.7), where a slight increase (decrease) of economic activity in the agricultural (service) sector indicates a slowdown of structural change. Yet, the strong decline of the aggregate manufacturing sector is not observable in the JUST model.

5. Conclusions

By taking structural change effects along the low-carbon transition path into account, we put adverse effects of climate policies into perspective. Considering the difference between the results from the two examined trade models (e.g. positive versus negative income effects), overall, climate policy has a small impact on the increase or decrease of inequality across household income groups while structural change has more pronounced effects. Poor households suffer larger income and consumption losses than rich households. Less stringency in climate policy to lower the impact on poorer households is relevant, but less effective than supporting the process of structural transformation. In fact, climate policy dampens some of the effect of structural change for poorer households—as indicated by increasing labor shares in the agricultural sector (figures 5, A.7 and A.8). Consequently, supporting the poor and tackling climate change are not mutually exclusive but congruent policy goals. A number of studies have demonstrated how transfers and the recycling of revenues from carbon pricing can help the poor [6, 11, 12, 45]. Other studies indicate that climate change damages tend to hit the poor hardest [46] and climate policy is able to avoid this. Our results point to an additional mechanism supporting the poor. A policy portfolio that stimulates (rural) economic development and structural transformation, enabling high value-added jobs in the manufacturing and service sectors, seems to be most effective. Such a policy portfolio may include employment programmes [47], education, digitalization and trade openness; and it should support labour mobility because distributional effects of long-term structural adjustments will be more severe if mobility is constrained.

While investigating a new research strand, this study can be perceived as a first attempt to quantify distributional effects from the interaction of climate policy and economic structural change. The robustness of the results is subject to certain assumptions and limitations, including: (i) the impact of land use competition on food prices is not taken into account, (ii) climate change damages are not taken into account, (iii) the complex impact channels of structural change affecting inequality are only partially represented [48]. Future research is needed to deal with these aspects, as well as with the sensitivity of the distributional effects with respect to the specification of the scenario elements (e.g. the climate policy target, structural change projections, or the time horizon).

Data availability statement

All code (expect for the KITE and JUST source code) is available from the authors upon reasonable request.

The GTAP data can be purchased at www.gtap.agecon.purdue.edu/.

The data that support the findings of this study are openly available at the following URL/DOI: https://zenodo.org/records/10229177 [49].

Acknowledgments

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Appendix A. Models

A.1. Integrated assessment model

REMIND is an IAM that provides a holistic view of the global energy–economy–emissions system and explores self-consistent transformation pathways [29]. It investigates a broad range of possible futures and their relation to technical and socioeconomic developments, as well as policy choices. REMIND is a multi-regional model incorporating the economy of each region with a detailed representation of the energy sector. In each region, a representative household maximizes utility according to per capita consumption. Each region generates macroeconomic output (GDP) based on a nested constant elasticity of substitution production function using the production factors of labour, capital, and final energy as inputs. Using non-linear optimization, REMIND solves for an intertemporal Pareto optimum in capital and energy investments in the model regions for the time horizon 2005–2100, fully accounting for interregional trade in a composite good and different energy carriers. REMIND thereby enables analyses of technology options and policy proposals for climate change mitigation, with the distinct capability of representing the scale-up of new technologies and the integration of renewable energies in power markets. The spatial resolution of REMIND is flexible. The applied version distinguishes 12 world regions with India modelled as a single region.

REMIND is calibrated to a wide range of data to ensure the consistency of the scenarios with historical developments and realistic future projections. To align with SSP GDP, population, and final energy trajectories, REMIND calibrates its production function, thereby fixing labour productivities. Historical data for the year 2005 is used to calibrate most of the free variables (e.g. primary energy mixes, secondary energy mixes, standing energy conversion capacities, trade in all traded goods). Technology parameters are projected into the future, in general assuming a convergence of technology costs across regions in the very long term. The default baseline scenario in REMIND represents in a stylized way climate policies that are currently implemented. In this baseline scenario, a low carbon price trajectory is modelled [29] based on nationally determined contributions (NDCs) until 2020. The policy implementation, however, is assumed to miss the NDC targets by 2030. Instead, carbon prices are assumed to grow and converge across regions more slowly, leading to emission trajectories in line with bottom-up studies on the effect of currently implemented policies [35].

A.2. Structural change scenario model

The structural change scenarios are constructed on the basis of a regression model which combines country-level data from different sources. Based on given initial shares of labour, value-added, and energy for 2015, and using estimated regression coefficients, projections are computed with an updated set of SSP-specific GDP and population scenarios [50] as independent variables. A detailed description of the regression approach can be found in Leimbach *et al* [30]. The structural change scenarios represent projections of sectoral shares that are independent of units and can therefore, in contrast to absolute level values, directly be adopted by other models. The shares of the agriculture, manufacturing, and service sectors in economy-wide employment, value-added, and final energy use are projected until 2050. The development of these key variables of economic activity is provided for each SSP scenario.

A.3. New quantitative trade (NQT) models

The scenario simulation results produced by the two macro models are fed into two advanced numerical trade models based on the theoretical Ricardian trade model introduced by Eaton and Kortum [51]. In the Eaton and Kortum model, international trade is driven by Ricardian specialization in lowest-cost varieties of each good without assuming regional preferences for goods. The implementations use a computable general equilibrium framework that is commonly described as a NQT model. They are similar to the model originally developed by Caliendo and Parro [52]. They represent a multi-sector version of the Eaton and Kortum model, where countries/regions produce and sell domestically as well as internationally according to their relative comparative advantage. Both models incorporate domestic and international input–output linkages, such that trade includes final and intermediate goods and services. Trade policy analyses can be conducted by tightening or easing trade barriers in the form of tariffs or non-tariff barriers. Output prices are combined to a domestic price index in a consumption bundle. Likewise, the prices of the imported goods are combined to an import bundle similar to the standard Armington approach. These two bundles are then combined to a compound price index that the final consumer of each country perceives. Similarly, the producer of each sector and country perceives a compound price index of intermediate goods that are domestically produced and imported.

The first established advanced global trade model is called JUST. The static version of the model, focusing on German climate and energy policy, has been introduced by Pothen and Hübler [53]. This model uses global trade analysis project[21] (GTAP) data version 9 with the benchmark year 2011. The recursive dynamic version presented by Pothen and Hübler [32] adds scenarios of economic growth, energy use, and CO_2 emissions until 2050. Hübler and Pothen's [54] version of the model expresses relative changes between two scenarios and focuses on the sand sector. The new model under scrutiny builds on these previous model versions, but focuses on the Indian economy and uses new SSP scenarios.

The JUST model encompasses 19 countries and aggregated world regions, including India, China, Brazil, the United States, Canada, the former Soviet Union, and the biggest European economies. Each country/region has one representative consumer and a representative producer in each sector. The model covers 17 production sectors and goods (see table A.1). For each time period, the model solution presents a global general equilibrium with market clearance, zero profits, and balanced (private and public) budgets. This equilibrium consists of the market-clearing prices of goods and factors and the corresponding quantities.

The second advanced trade model is called KITE. It is a new, updated and further elaborated model that provides a novel tool for simulating various types of trade and climate policy effects [32]. The KITE model extends the framework of Caliendo and Parro [52] by incorporating carbon emissions and climate policies [55] and allowing for subnational input–output linkages across Indian states. KITE uses version 10 of the GTAP database with the benchmark year 2014 [56]. The model provides a very rich geographical and sectoral resolution. It features 65 production sectors (see table A.1) as well as 141 countries and aggregated world regions. India is further disaggregated into 33 states, which reveals the spatial heterogeneity of distributional effects. Each state exhibits different production, trade, and comparative advantage patterns.

A.4. Comparison of trade model features and results

On the model implementation side, the KITE model is programmed in terms of relative changes between a counterfactual and a baseline scenario, while JUST is written and solved in absolute terms for each scenario. While the KITE model uses a Cobb-Douglas production function that combines inputs at one level (see Felbermayr *et al* [31]), the JUST model uses more complex nest structures with different elasticities of substitution (see Pothen and Hübler [32]). The nest structures combine labour, capital and intermediate goods inputs (from abroad and the domestic economy) with energy as well as fossil fuel inputs

[21] https://www.gtap.agecon.purdue.edu/.

and electricity within the energy aggregate. While the production factor labour is internationally immobile in both models, it is mobile across sectors within each model region. In JUST, additionally, the production factor capital is internationally immobile but mobile across sectors within each model region, and natural resource endowments are region- and sector-specific. Both models represent the full global input-output matrix including trade in intermediate goods. Furthermore, both models include existing taxes and subsidies. Therefore, they represent a second-best world, where the effects of CO_2 pricing can be complex due to the interaction with existing taxes and subsidies. Different to the JUST model, the KITE model distinguishes between Indian states, i.e. provinces within India[22]. On the data side, KITE uses GTAP 10, while JUST uses GTAP 9. Additionally, in JUST, the key parameter values governing international trade are estimated in a structural estimation. While international energy carrier prices are governed by the REMIND data in JUST and increase over time (figure A.2), they have more flexibility in KITE resulting in stronger adjustments of energy prices and quantities and hence more flexibility in terms of reactions to climate policy and structural change.

The output variables generated by the trade models as inputs for the household model are: sectoral labour income, sectoral output, and output prices. These output variables vary based on the reaction of the trade models to the input from the macro level mainly in two ways. First, an exogenously increased sectoral productivity, ceteris paribus, results in an extended sectoral output quantity and a lower output price because the output-to-input-ratio has been improved. The increased total factor productivity implies a higher labour productivity and hence a higher wage rate, which together with increased input and output eventually results in higher labour income. Second, carbon pricing raises the prices of fossil fuel inputs and hence the sectoral production costs, where the costs increase in the CO_2 intensity of production. Since output prices equal marginal production costs, they rise accordingly. Ceteris paribus, the corresponding output and total input decline to a larger extent in more CO_2-intensive sectors, such that the demand for energy including fossil fuels and labour declines. At the same time, based on the models' elasticities of substitution, fossil fuels are substituted by other inputs, such as labour. Because the total factor endowments with labour, capital and land are fixed, these factors are reallocated towards less CO_2-intensive sectors. As a result, climate policy reduces labour income to a larger extent in more CO_2-intensive sectors and creates positive or less negative income effects in less CO_2-intensive sectors. Strategic terms-of-trade effects on international markets can add positive or negative income effects.

With increasing carbon prices, in the KITE model, decarbonization is mainly achieved by drastically phasing out fossil fuels, especially coal, and significantly reducing industrial production in the manufacturing sector (figure 4). As a result, the value-added shares of the agriculture and service sector significantly expand (figure 5). In the JUST model, carbon emission reductions are mainly achieved by expanding agricultural production given the low carbon intensity and low marginal abatement costs in agriculture (figure A.7). This expansion is in accordance with the need to improve the nutrition of the large (and increasing) Indian population. In JUST, however, the transport sector (TRNS) shrinks due to climate policy (figure A.9). In both models, the manufacturing sector is an aggregate of heterogeneous subsectors with different CO_2 intensities and hence various effects of climate policy and structural change (figures A.9 and A.10). While the overall share of the manufacturing sector stays almost constant in JUST (figure A.7), decarbonization is achieved via intrasectoral restructuring within the manufacturing sector (figure A.9) and strategic benefits on international markets. In both models, coal production is by far to the largest extent reduced among all sectors (figures A.9 and A.10); the phase-out of fossil fuels in JUST, however, is overall less significant than in KITE.

[22] Regional production, international trade and intranational trade shares of Indian states are disaggregated by sectoral value added data from the Reserve Bank of India [62].

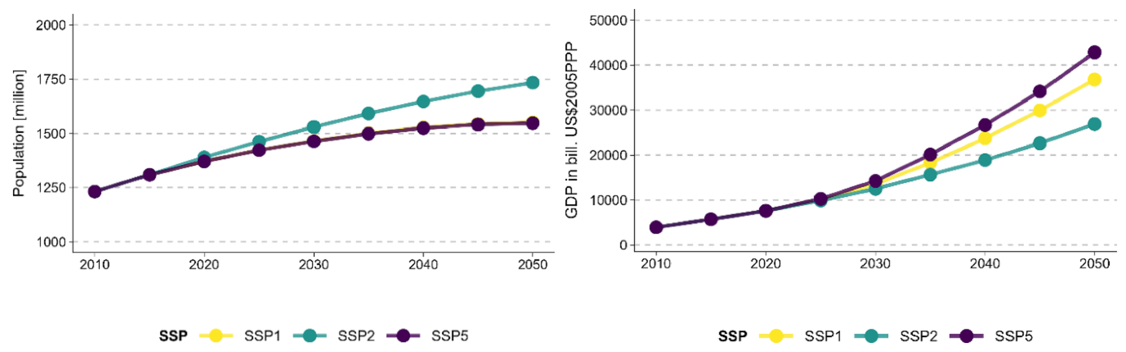

Figure A1. Projections of population (left panel) and GDP (right panel) in India within different SSPs (population values are the same for SSP1 and SSP5).

Appendix B. SSP scenario characteristics

- SSP1 ('sustainability'): medium/high GDP per capita growth based on fast technological progress; less energy intensive; high share of renewable energies already in the baseline scenario; comparatively high energy prices in the short term, and lower energy prices (apart from oil) in the long term; fast structural change towards manufacturing and services.
- SSP2 ('middle of the road'): continuation of long-term trends (e.g. population growth, technological progress, energy, and land use); medium GDP per capita growth; comparatively high energy intensity (similar to SSP5); medium energy prices; moderate structural change towards manufacturing and services.
- SSP5 ('fossil fuelled development'): high GDP growth based on fast technological progress; energy intensive; abundant fossil resources; energy prices are low in the short term but high in the long term as energy demand is substantial; fast structural change towards services.

Appendix C. Income and price changes across SSPs

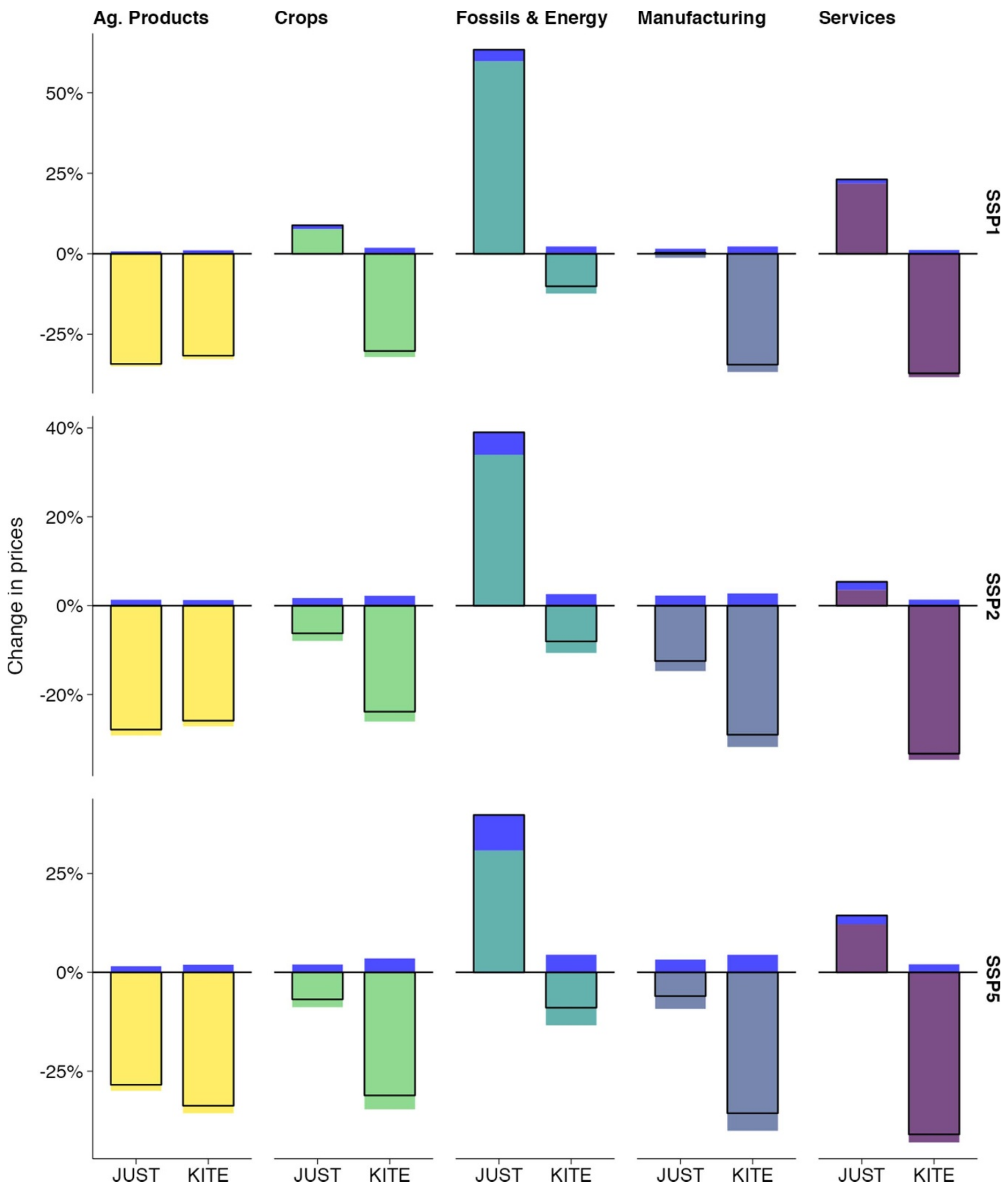

Figure A2. Sectoral output price changes in India computed by the models KITE and JUST. Each bar shows the relative difference between 2015 and 2030. The differential impact of climate policy is represented by the embedded dark blue bar. Sectoral output from KITE and JUST is aggregated to five sectors with agricultural products and crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

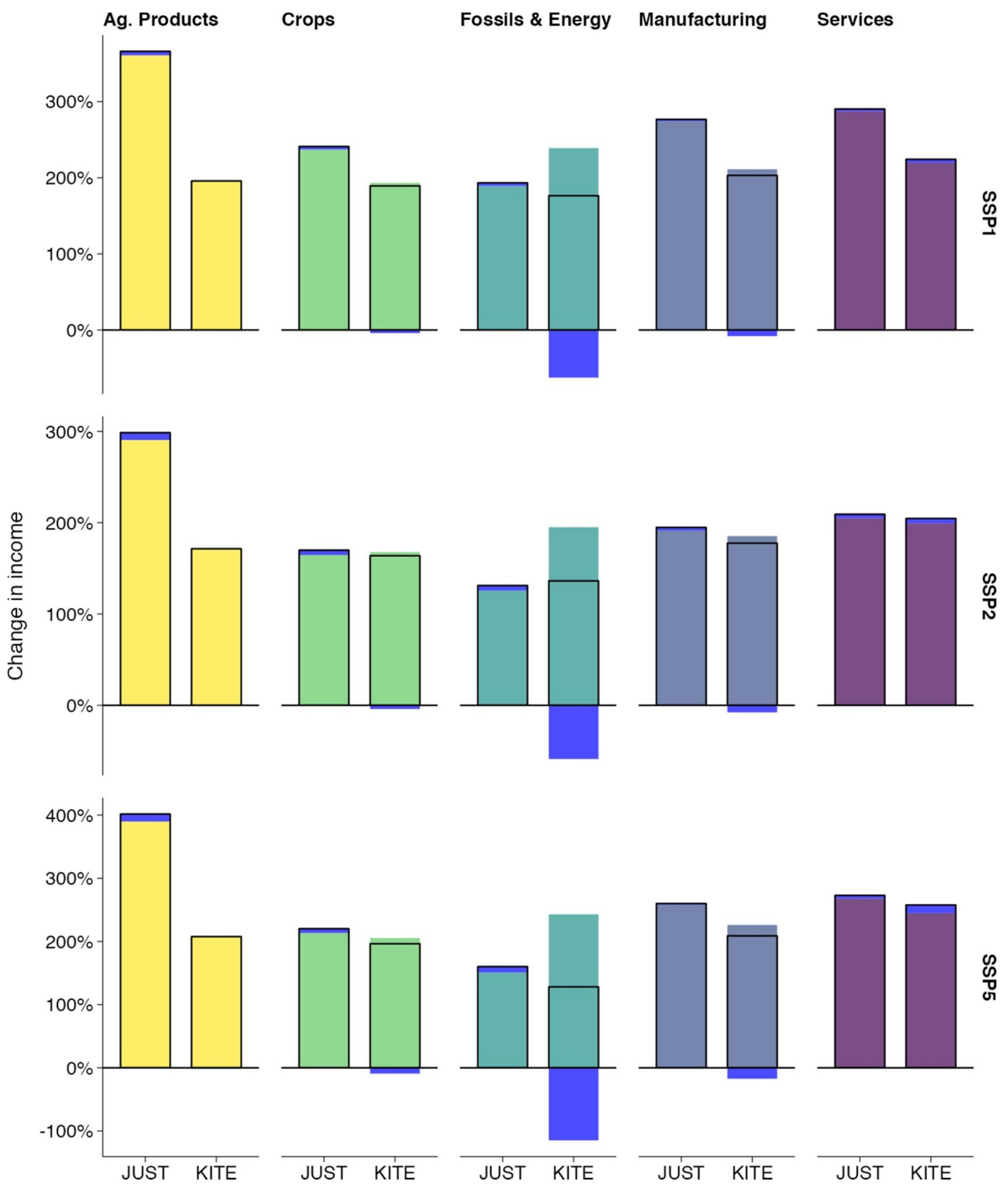

Figure A3. Sectoral income changes in India computed by the models KITE and JUST. Each bar shows the relative difference between 2015 and 2030. The differential impact of climate policy is represented by the embedded dark blue bar. Sectoral output from KITE and JUST is aggregated to five sectors with agricultural products and crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

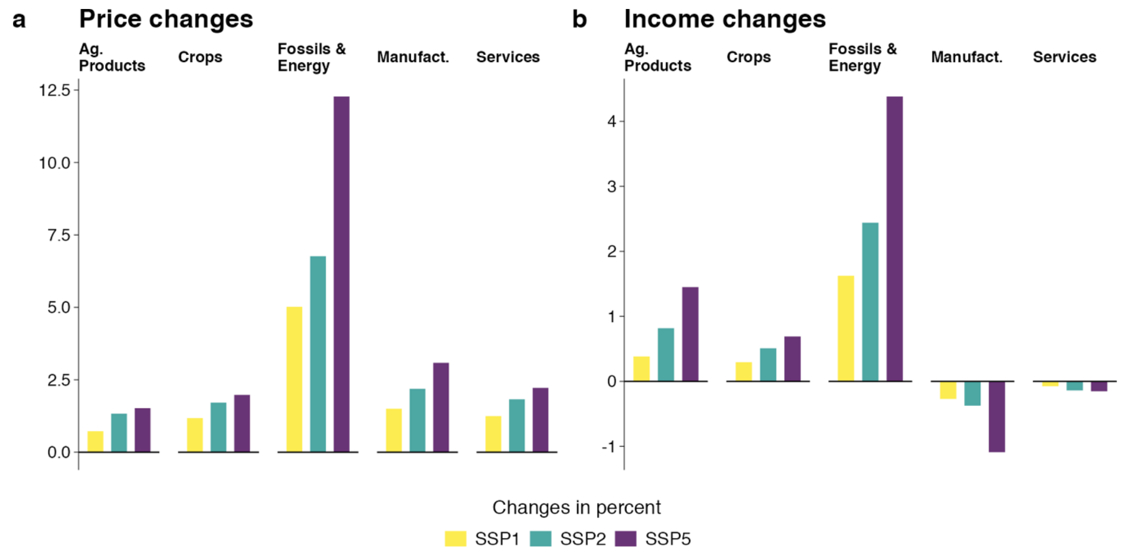

Figure A4. Sectoral output price changes (panel (a)) and sectoral income changes (panel (b)) in India induced by carbon pricing compatible with 2 °C climate policy under different assumptions of structural change (SSP1, SSP2, SSP5). The figures show the difference in the percentage changes over time (between 2015 and 2030) between climate policy scenarios (SSP1-CP2, SSP2-CP2, SSP5-CP2) and the corresponding baseline scenarios (SSP1-Base, SSP2-Base, SSP5-Base). Sectoral output from the JUST model is aggregated to five sectors with Agricultural Products and Crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

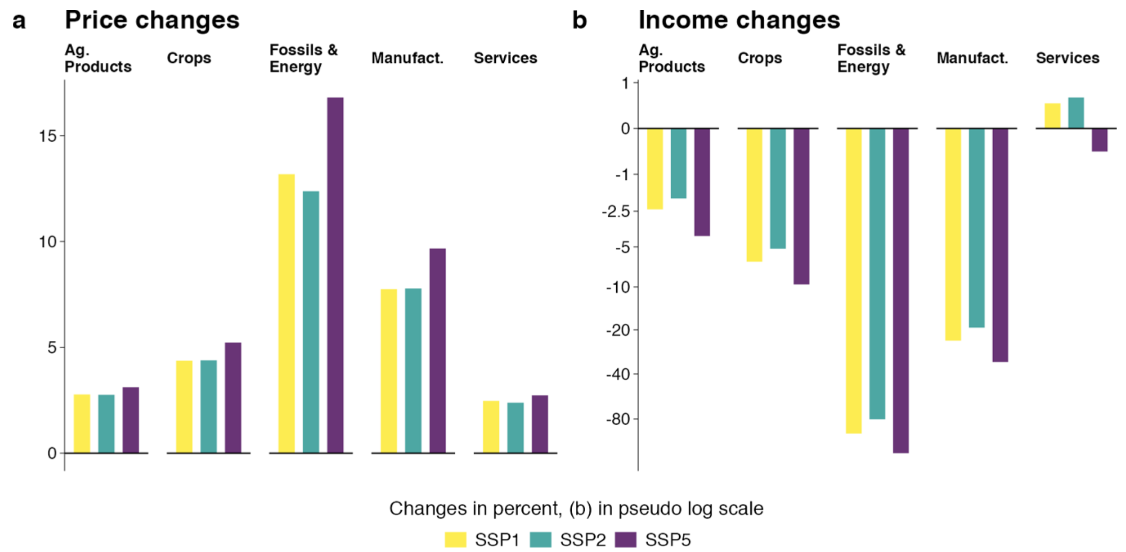

Figure A5. Sectoral output price changes (panel (a)) and sectoral income changes (panel (b)) in India induced by carbon pricing compatible with 1.5 °C climate policy under different assumptions of structural change (SSP1, SSP2, SSP5). The figures show the difference in the percentage changes over time (between 2015 and 2030) between climate policy scenarios (SSP1-CP1.5, SSP2-CP1.5, SSP5-CP1.5) and the corresponding baseline scenarios (SSP1-Base, SSP2-Base, SSP5-Base). Sectoral output from the KITE model is aggregated to five sectors with agricultural products and crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

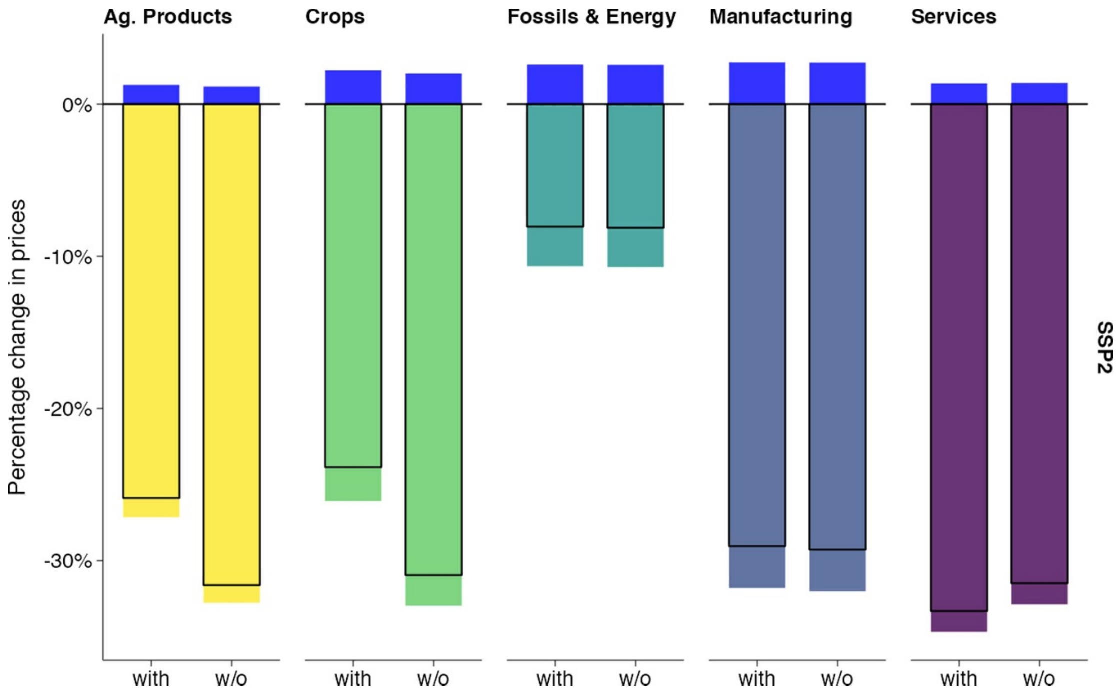

Figure A6. Sectoral output price changes in India computed by the KITE model. Each bar shows the relative difference between 2015 and 2030. Each panel pairs off price changes from SSP2 scenarios with structural change ('with') and without structural change ('w/o'). The differential impact of climate policy is represented by the embedded dark blue bar. Sectoral output from KITE is aggregated to five sectors with agricultural products and crops representing the agricultural sector, and fossil & energy and manufacturing representing the manufacturing sector.

Appendix D. Development impacts of carbon pricing

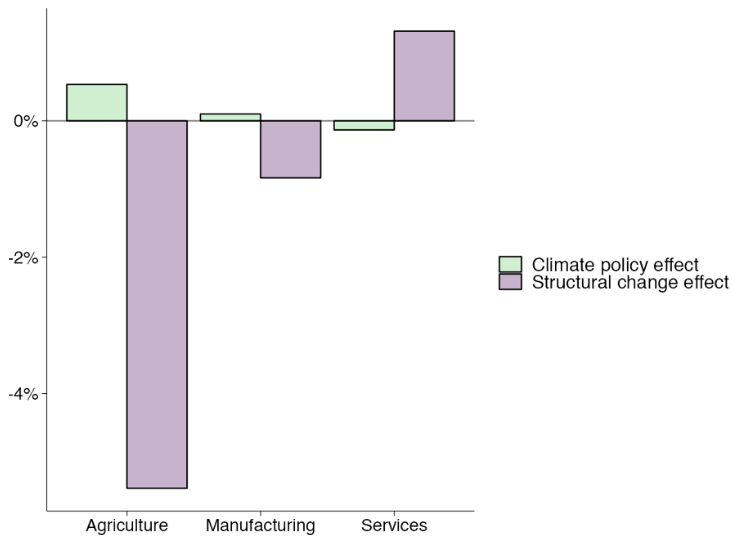

Figure A7. Changes in Indian sectoral value-added shares (in 2030) caused by structural change (purple bar) and 2 °C climate policy (green bar). The former represents the difference between scenarios with and without structural change (no climate policy); the latter represents the difference between scenarios with and without climate policy (no structural change). Changes are measured in % of sectoral shares of baseline scenario NoSC-Base (no policy, no structural change); based on JUST model results.

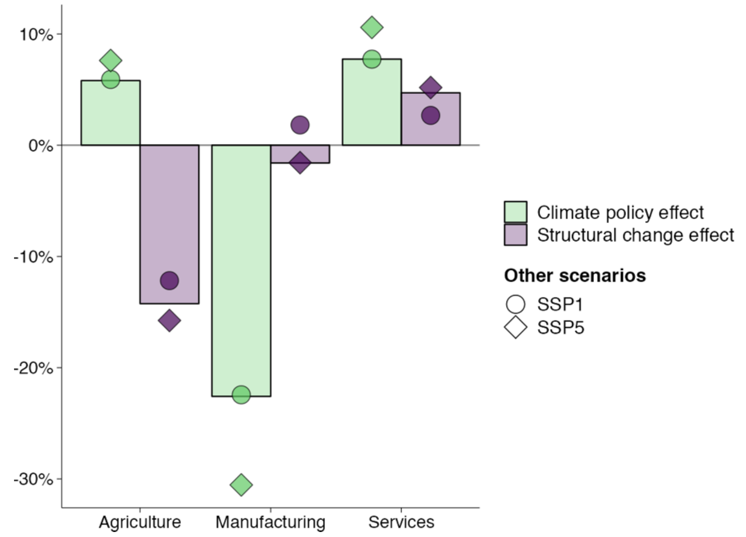

Figure A8. Changes in Indian sectoral value-added shares (in 2030) caused by structural change (purple bar) and ambitious (1.5 °C compatible) climate policy (green bar) under SSP2 (variation under SSP1 and SSP5 is labelled by circles and squares, respectively). The former represents the difference between scenarios with and without structural change (no climate policy); the latter represents the difference between scenarios with and without climate policy (no structural change). Changes are measured in % of sectoral shares of baseline scenario NoSC-Base (no policy, no structural change); based on KITE model results.

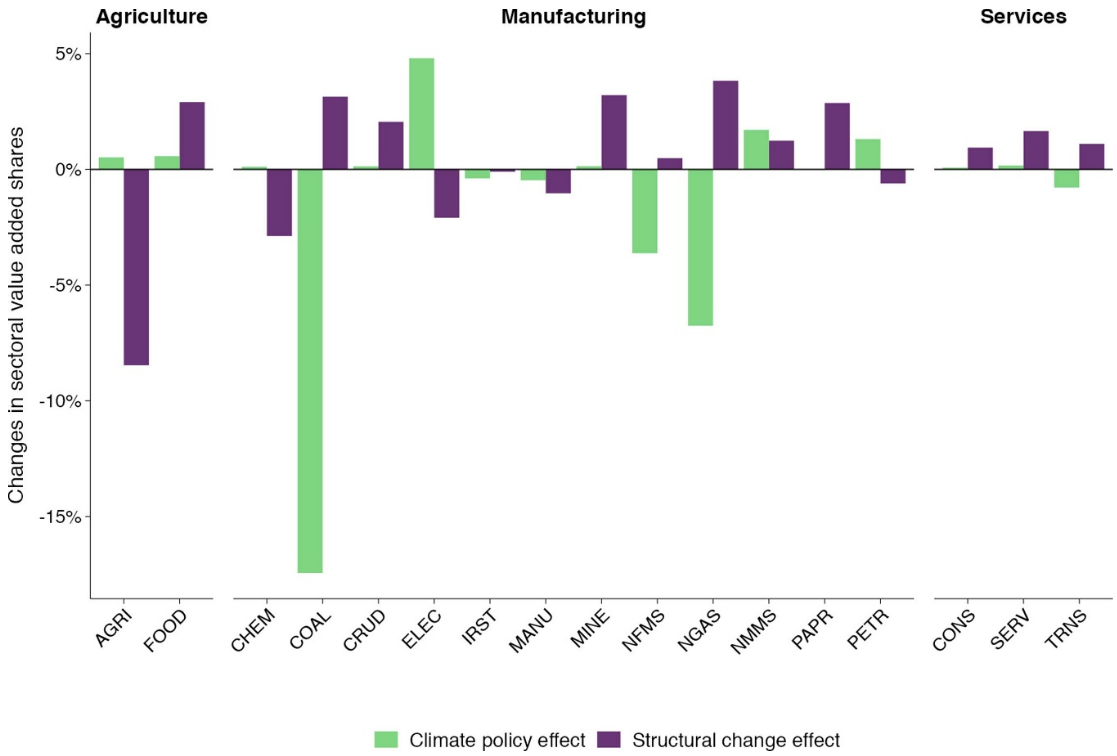

Figure A9. Changes in Indian sectoral value-added shares caused by structural change and 2 °C climate policy; measured in % of the respective sectoral value-added shares in the baseline scenario NoSC-Base (no policy, no structural change); based on JUST model results; see table A.1 for sector description.

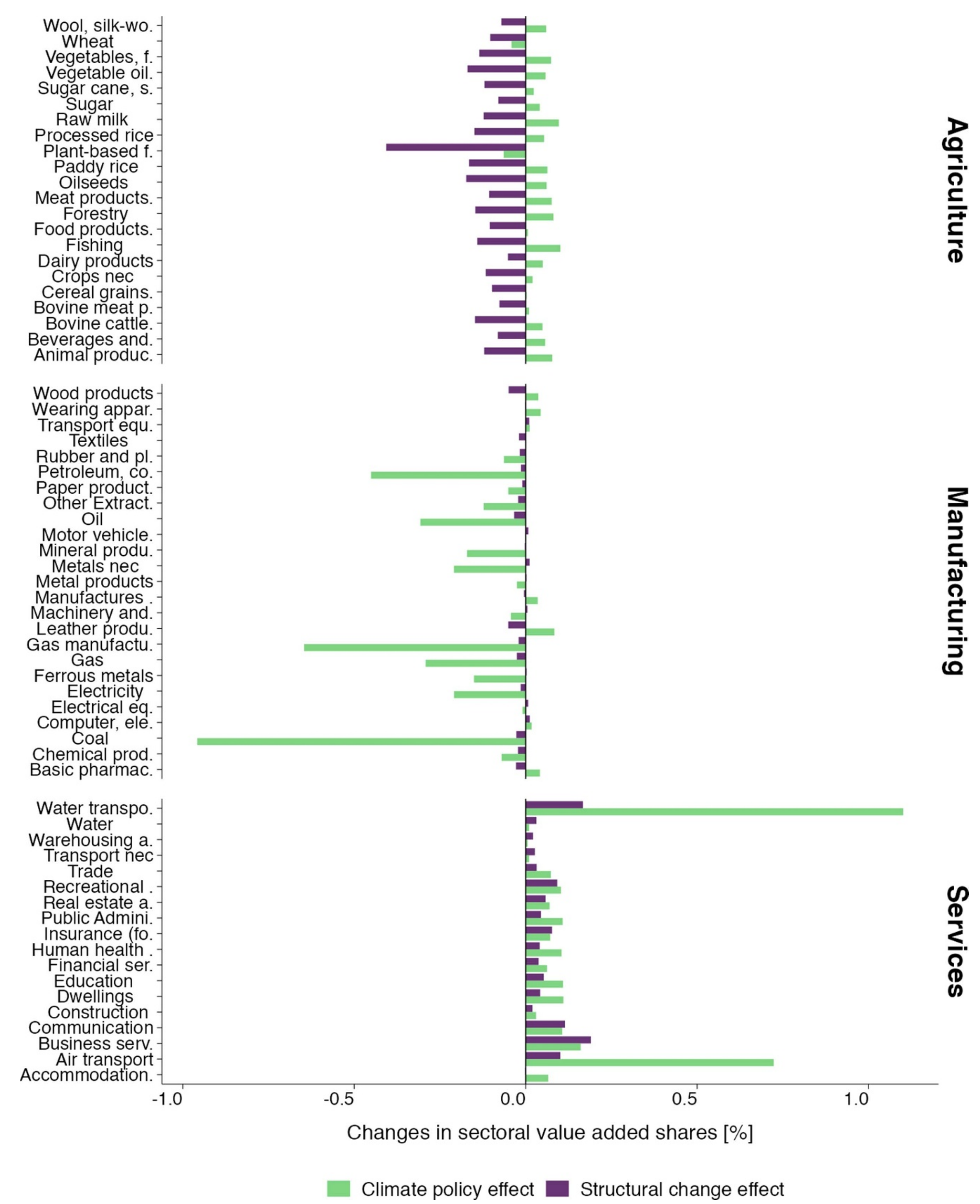

Figure A10. Changes in Indian sectoral value-added shares caused by structural change and and 2 °C climate policy; measured in % of the respective sectoral value-added shares in the baseline scenario NoSC-Base (no policy, no structural change); based on KITE model results; see table A.1 for sector description.

Appendix E. Distributional impacts of carbon pricing and structural change

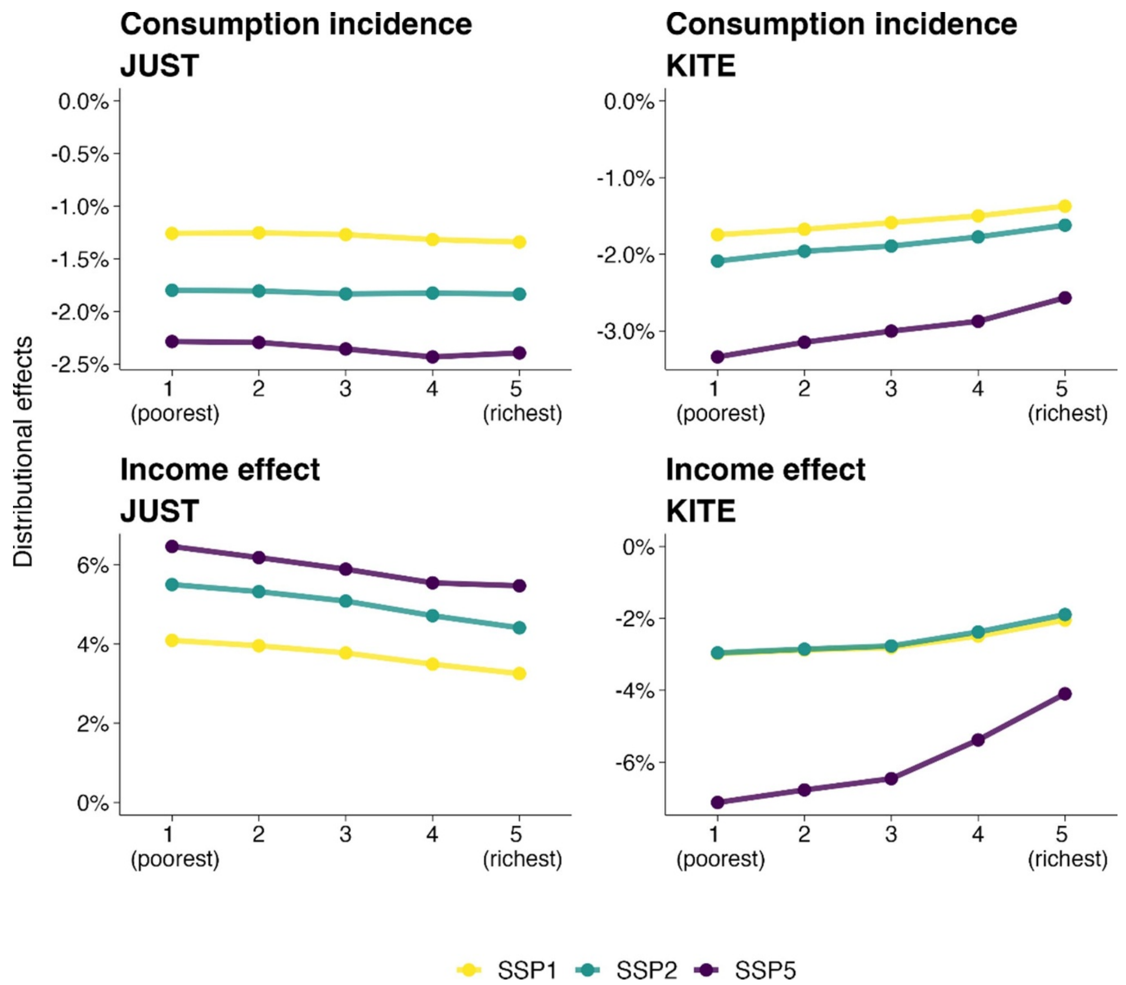

Figure A11. Consumption incidence and changes in income across Indian income groups due to 2 °C climate policy under different assumptions on structural change (SSP1, SSP2, SSP5) based on JUST and KITE model output. Negative values indicate that consumption incidence/income values are lower in scenarios with carbon pricing.

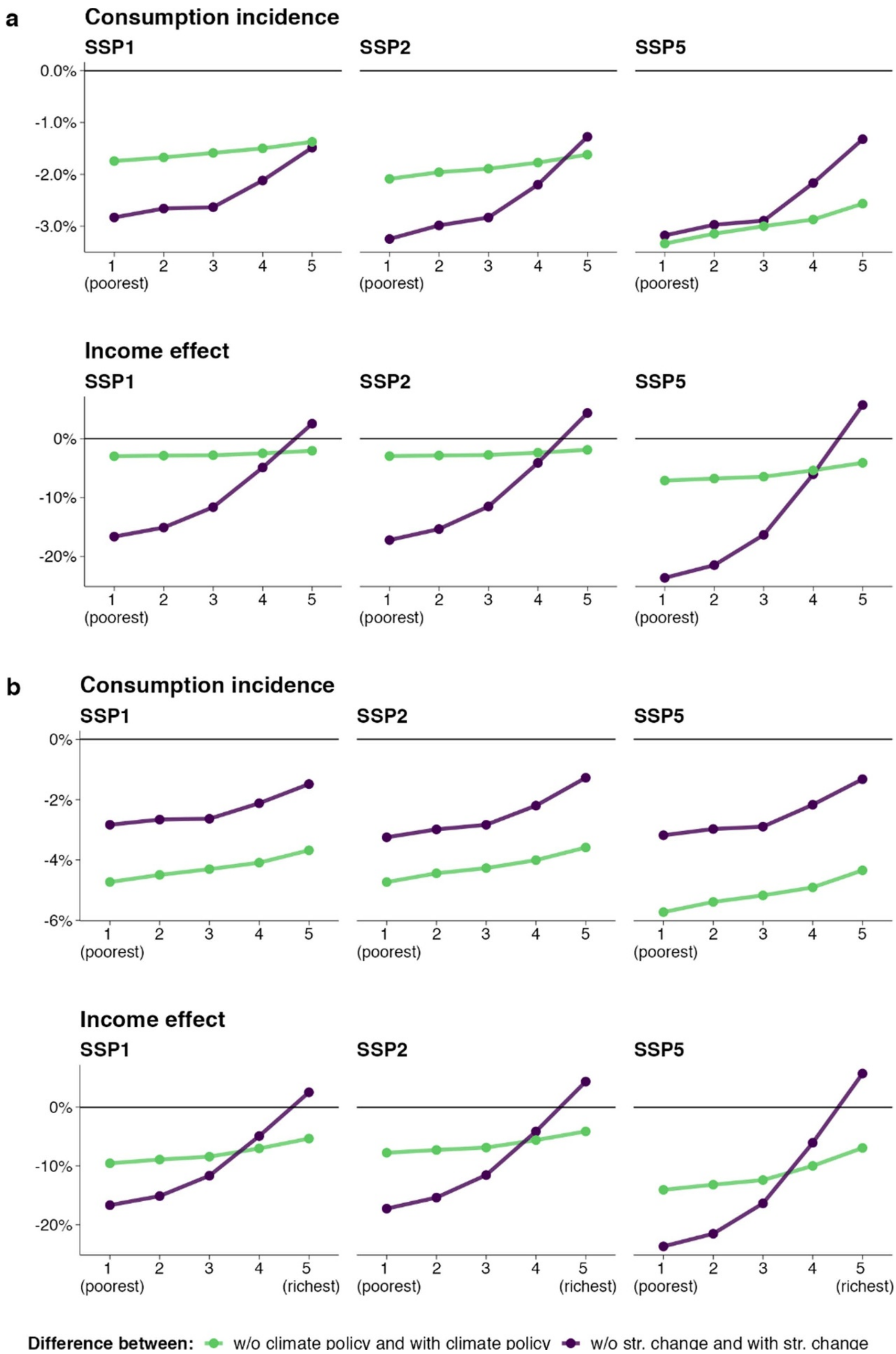

Figure A12. Consumption incidence and changes in income across Indian income groups due to climate policy (panel (a): 2 °C scenario, panel (b): 1.5 °C scenario) and structural change based on KITE model output. The green lines represent the differences in consumption incidence and income in a scenario with climate policy (SSP1-CP2, SSP2-CP2, SSP5-CP2, SSP1-CP1.5, SSP2-CP1.5, SSP5-CP1.5) and a scenario without climate policy (SSP1-Base, SSP2-Base, SSP5-Base). The purple lines represent the respective differences between scenarios with (SSP1-Base, SSP2-Base, SSP5-Base) and without structural change (NoSC-Base). Negative values indicate that consumption incidence/income values are lower in scenarios with climate policy and structural change, respectively.

Appendix F. Sector mapping

Both advanced trade models use GTAP data. While the default setting in KITE is the sectoral resolution given by GTAP (column 1 in table A.1), the JUST model uses the sectoral aggregation as shown in column 3 of table A.1. To provide consistent and comparable sectoral results, KITE und JUST results are aggregated to five sectors (column 4). These sectors are finally mapped onto the three sectors (agriculture, manufacturing and services) used at the macro level of this study.

Table A1. Sector mapping related to the JUST and KITE trade models.

GTAP (KITE)	Explanation	JUST sectors	KITE + JUST aggregation	Macro aggregation
pdr	Rice: seed	AGRI	Crops	Agriculture
wht	Wheat: seed	AGRI	Crops	Agriculture
gro	Other grains: maize (corn)	AGRI	Crops	Agriculture
v_f	Veg & fruit: vegetables	AGRI	Crops	Agriculture
osd	Oil seeds: oil seeds and oleaginous fruit	AGRI	Crops	Agriculture
c_b	Cane & beet: sugar crops	AGRI	Crops	Agriculture
pfb	Fibre crops	AGRI	Crops	Agriculture
ocr	Other crops: stimulant; spice and aromatic crops; forage products; plants and parts of plants used primarily in perfumery	AGRI	Crops	Agriculture
ctl	Cattle: bovine animals	AGRI	Ag. Products	Agriculture
oap	Other animal products: swine; poultry; other live animals; eggs of hens or other birds in shell	AGRI	Ag. Products	Agriculture
rmk	Raw milk	AGRI	Ag. Products	Agriculture
wol	Wool: wool	AGRI	Ag. Products	Agriculture
frs	Forestry: forestry	AGRI	Ag. Products	Agriculture
fsh	Fishing: hunting	AGRI	Ag. Products	Agriculture
coa	Coal: mining and agglomeration of hard coal	COAL	Fossil & Energy	Manufacturing
oil	Oil: extraction of crude petroleum	CRUD	Fossil & energy	Manufacturing
gas	Gas: extraction of natural gas	NGAS	Fossil & energy	Manufacturing
oxt	Other mining extraction (formerly omn): mining of metal ores; other mining and quarrying	MINE	Fossil & energy	Manufacturing
cmt	Cattle Meat: fresh or chilled; meat of buffalo	FOOD	Ag. Products	Agriculture
omt	Other meat: meat of pigs	FOOD	Ag. Products	Agriculture
vol	Vegetable oils: margarine and similar preparations; cotton linters; oil-cake and other residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits	FOOD	Ag. Products	Agriculture
mil	Milk: dairy products	FOOD	Ag. Products	Agriculture
pcr	Processed rice: semi- or wholly milled	FOOD	Ag. Products	Agriculture
sgr	Sugar and molasses	FOOD	Ag. Products	Agriculture
ofd	Other food: prepared and preserved fish	FOOD	Ag. Products	Agriculture
b_t	Beverages and tobacco products	FOOD	Ag. Products	Agriculture
tex	Manufacture of textiles	MANU	Manufacturing	Manufacturing
wap	Manufacture of wearing apparel	MANU	Manufacturing	Manufacturing
lea	Manufacture of leather and related products	MANU	Manufacturing	Manufacturing

(Continued.)

Table A1. (Continued.)

GTAP (KITE)	Explanation	JUST sectors	KITE + JUST aggregation	Macro aggregation
lum	Lumber: manufacture of wood and of products of wood and cork	MANU	Manufacturing	Manufacturing
ppp	Paper & Paper Products: includes printing and reproduction of recorded media	PAPR	Manufacturing	Manufacturing
p_c	Petroleum & Coke: manufacture of coke and refined petroleum products	PETR	Manufacturing	Manufacturing
chm	Manufacture of chemicals and chemical products	CHEM	Manufacturing	Manufacturing
bph	Manufacture of pharmaceuticals	CHEM	Manufacturing	Manufacturing
rpp	Manufacture of rubber and plastics products	CHEM	Manufacturing	Manufacturing
nmm	Manufacture of other non-metallic mineral products	NMMS	Manufacturing	Manufacturing
i_s	Iron & Steel: basic production and casting	IRST	Manufacturing	Manufacturing
nfm	Non-ferrous metals: production and casting of copper	NFMS	Manufacturing	Manufacturing
fmp	Manufacture of fabricated metal products	MANU	Manufacturing	Manufacturing
ele	Manufacture of computer	MANU	Manufacturing	Manufacturing
eeq	Manufacture of electrical equipment	MANU	Manufacturing	Manufacturing
ome	Manufacture of machinery and equipment n.e.c.	MANU	Manufacturing	Manufacturing
mvh	Manufacture of motor vehicles	MANU	Manufacturing	Manufacturing
otn	Manufacture of other transport equipment	MANU	Manufacturing	Manufacturing
omf	Other manufacturing: includes furniture	MANU	Manufacturing	Manufacturing
ely	Electricity; steam and air conditioning supply	ELEC	Fossil & Energy	Manufacturing
gdt	Gas manufacture	NGAS	Fossil & Energy	Manufacturing
wtr	Water supply; sewerage	SERV	Services	Services
cns	Construction: building houses factories offices and roads	CONS	Services	Services
trd	Wholesale and retail trade; repair of motor vehicles and motorcycles	SERV	Services	Services
afs	Accommodation	SERV	Services	Services
otp	Land transport and transport via pipelines	TRNS	Services	Services
wtp	Water transport	TRNS	Services	Services
atp	Air transport	TRNS	Services	Services
whs	Warehousing and support activities	SERV	Services	Services
cmn	Information and communication	SERV	Services	Services
ofi	Other financial intermediation: includes auxiliary activities but not insurance and pension funding	SERV	Services	Services
ins	Insurance (formerly isr): includes pension funding	SERV	Services	Services
rsa	Real estate activities	SERV	Services	Services
obs	Other business services n.e.c	SERV	Services	Services

(Continued.)

Table A1. (Continued.)

GTAP (KITE)	Explanation	JUST sectors	KITE + JUST aggregation	Macro aggregation
ros	Recreation & other services: recreational	SERV	Services	Services
osg	Other services (government): public administration and defence; compulsory social security	SERV	Services	Services
edu	Education	SERV	Services	Services
hht	Human health and social work	SERV	Services	Services
dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)	SERV	Services	Services

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