Energy Economics 84 (2019) 104549

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

# How global climate policy could affect competitiveness☆

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ARTICLE INFO

*Article history:*
Received 18 January 2019
Received in revised form 4 October 2019
Accepted 14 October 2019
Available online 2 November 2019

*JEL classification:*
C67
F16
F18
L50
L60
Q56

*Keywords:*
Global carbon price
Input-output analysis
Energy-intensive
Trade-exposed industries
Competitiveness
Labor market
Global supply chains

ABSTRACT

A global uniform carbon price would be economically efficient and at the same time avoid 'carbon-leakage'. Still, it will affect the competitiveness of specific industries, economic activity and employment across countries. This paper assesses short-term economic shocks following the introduction of a global carbon price that would be in line with the Paris Agreement. Based on the World Input-Output Database (WIOD), we trace the carbon content of final output through global supply chains. This allows us to estimate how prices of the final output would react to the introduction of a global carbon price. We find that impacts on industrial competitiveness are highly heterogeneous across regions and economic sectors. The competitive position of Brazil, Japan, the USA and advanced economies of the EU is likely to improve, whereas industries and labor markets in newly industrializing Asian economies as well as Eastern Europe are likely to experience substantial adverse impacts.

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## 1. Introduction

Achieving the climate targets of the Paris Agreement (UNFCCC, 2015) requires substantial reductions in global greenhouse gas (GHG) emissions. Under the current global climate governance architecture, members of the Paris Agreement pledged voluntary *unilateral* climate targets and mitigation policies as specified in their Nationally Determined Contributions (NDCs). However, the implementation of ambitious unilateral climate policies by first movers often faces resistance due to concerns about 'carbon leakage', i.e. the fear that energy-intensive, trade-exposed (EITE) industries could relocate to countries with laxer climate policies or less efficient production technologies. Countries adopting ambitious climate policies might then run the risk of incurring substantial costs to reduce their emissions while at least some of the emission reductions achieved are simply transferred elsewhere.

Economists have for a long time advocated a uniform global price on GHG emissions (Cramton et al., 2017; Edenhofer et al., 2015; High-Level Commission on Carbon Prices., 2017; Weitzman, 2014). This would be the most cost-efficient policy instrument, guaranteeing that abatement takes place for activities for which emissions can be reduced in the least-cost manner. Moreover, a global carbon price would prevent carbon leakage, as no country would benefit from an artificial comparative advantage arising from the lack of climate policy. Yet, it poses a higher cost burden on more carbon-intensive producers (Fullerton and Muehlegger, 2019). Hence, a uniform global carbon price could have important consequences for industrial competitiveness, national gross value added and employment. While the academic literature has extensively examined the effect of *unilateral* climate measures on carbon leakage and competitiveness[1], there is, to our knowledge, only very limited understanding of the implications of *global* climate policy.

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☆ Publication of this supplement was supported by ETH Zürich, the University of Münster and Economics for Energy.

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[1] See Böhringer et al., 2012; Branger and Quirion, 2014; Carbone and Rivers, 2017; Dechezleprêtre and Sato, 2017; Jakob et al., 2014; Forin et al., 2018; Kim and Kim, 2012; Saygin et al., 2011; Voigt et al., 2014.

https://doi.org/10.1016/j.eneco.2019.104549
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This paper aims to fill this gap by providing insights into the short-term competitiveness impacts induced by a global carbon price. Our analysis is based on the World Input-Output Database (WIOD) (Timmer et al., 2015), a multi-regional Input-Output (MRIO) database. We use this data to derive the 'Normalized Net Carbon Content' (NNCC) of all global supply chains, i.e. the emissions generated per USD of output from a given sector in a given country over the entire supply chain. This information can be used to determine the price increase that would result from a global carbon price in each sector and country. Thus it can help to identify sectors and countries facing the most severe risks of adverse impacts on competitiveness, value added and employment.

Vulnerable industries are those that display both a significant relative price increase and a high contribution to the national value added within the corresponding economy. These sectors can be expected to lose market share, profitability and employment. Our results indicate that a uniform global carbon price would, at least in the short term, improve the competitiveness of countries with low-carbon energy systems (e.g. Brazil or France) and efficient production technologies (particularly industrialized countries). By contrast, developing or transitioning economies with carbon-intensive energy systems, such as China, India and Russia, can be expected to experience substantial price increases in some energy-intensive industries. Overall, a globally uniform carbon pricing policy would probably make Western industries more competitive, although negative initial impacts can be expected for Eastern European and fast-growing Asian countries[2] . The most severe impacts would probably affect low-skilled workers and hence probably the poorest segments of societies.

This paper proceeds as follows. Section 2 introduces the data and methodology. Section 3 presents the results. Section 4 discusses policy implications and concludes.

## 2. Data and methods

Our analyses are built on an innovative way to estimate the Normalized Net Carbon Content (NNCC) of global supply chains. We build our analyses on multi-regional input output modeling based on the World Input Output Database (WIOD). In this section we will first describe the data we use. Afterwards, we will describe how we calculate the NNCC. Based on the NNCC, we estimate the implications of implementing a global carbon price on countries' economic performance and labor market. Finally, we will critically discuss the methodological approach taken in this paper. The following sub-sections describe the underlying data, the methodology to estimate the carbon content of trade and how it can be used to assess the competitiveness impacts of a global carbon price. We then discuss the limitations of our approach.

### 2.1. Data

We use the World Input-Output Database (WIOD) (Timmer et al., 2015) and the corresponding 'satellite data' on energy-related $CO_2$ emissions for each sector in each region[3] . The dataset reflects 41 regions and 35 sectors. WIOD includes the EU27 (which is the current European Union without Croatia), as well as major economies (including Australia, Canada, Japan, Mexico, South Korea and United States), and newly industrialized economies (Brazil, China, Indonesia, India, Russia, Taiwan and Turkey). These regions account for approximately 85% of world GDP (Timmer et al., 2015). The remainder is included in a residual region, referred to as the 'Rest of the World' (ROW).[4] We use the year 2009, as it constitutes the most recent release that includes emissions data. This high regional and sectoral resolution enables a detailed understanding of the carbon content of global supply chains.

### 2.2. Estimating the normalized net carbon content

We apply a modified supply-side footprint analysis to identify the carbon content of global supply chains. In the MRIO data, output from a certain sector in one region employed as an input for production in a different sector and/or country is described by the inter-industry flow matrix $Z \in \mathbb{R}^{(m*n)\times(m*n)}$, with $m$ being the number of sectors and $n$ being the number of regions. Final consumption, by sector and country, of all countries is denoted by the final demand matrix $Y \in \mathbb{R}^{(m*n)\times n}$. The elements of $Z$ are given by $Z_{r,s}^{r',s'}$, which denotes all monetary flows from region $r$, sector $s$ to region $r$', sector $s$' Correspondingly, $Y$ consists of elements $Y_{r,s}^{r'}$, which represent the aggregated monetary flow from region $r$, sector $s$ into the final demand of region $r'$.

In order to assess the carbon content of final consumption, we need to derive the Leontief inverse $L$, which specifies the inputs used to generate a unit of final output over the entire supply chain (Miller and Blair, 2009). For this reason, we divide the elements of $Z$ by the corresponding total sectoral output $O_{r,s} = \sum_{r'}\sum_{s'} Z_{rs}^{r's'} + \sum_{r'} Y_{r,s}^{r'}$. The technology matrix that reflects all necessary direct inputs to produce one unit of output in each sector is denoted by $A$. The Leontief inverse is then calculated as $L = (I - A)^{-1}$, where $I$ denotes the unity matrix. To relate monetary inputs from different sectors to $CO_2$ emissions, we use data on emission $F_r^s$ by sector $s$ in region $r$, which we divide by sectoral outputs $O$ to arrive at $CO_2$ emissions per USD.

The total $CO_2$ emissions $\hat{f}_r^s$ associated with one unit of sector $s$ in region $r$ for final consumption can then be expressed as $\hat{f}_r^s = \sum_{r'}\sum_{s'} f_{r'}^{s'} L_{r',s'}^{r,s}$. We call the emissions associated with the entire global supply chain of a unit of final output the 'Normalized Net Carbon Content' (NNCC). NNCC allows the comparison of associated carbon per unit of output, and related price increases within sectors and across countries. This approach yields a substantially higher resolution than a conventional carbon footprint analysis, where two vectors are multiplied (i.e., $(f \cdot L) \cdot Y$), hence omitting important sectoral, as well as regional, details.

### 2.3. Assessing impacts on competitiveness and employment

Our analysis assumes that a globally uniform carbon price is implemented and that the associated price increases for manufactured goods are fully passed through to consumers (Kenkel, 2005), regardless of whether the carbon price is applied at the point of extraction, production or consumption (Karstensen and Peters, 2018). This is in line with the observation that in the short term, price increases resulting from fuel taxes are mainly borne by consumers (Chouinard and Perloff, 2004; Marion and Muehlegger, 2011). We assume perfect substitutability of economic output from a given sector across countries, i.e. that all final output of a given sector is produced for the global market. The short-term impact on industrial competitiveness is then determined by the price increase and the associated demand-side reaction within each economic

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[2] For a spatial distribution, see Fig. A3 in the *Supplementary information*

[3] We do not consider emissions from land use and land use change.

[4] See the *Supplementary information* for a sectoral overview.

sector[5]. Our analysis considers that changes in the demand of final goods will have repercussions for all sectors forming part of their global supply chain. If a global carbon price $p$ is implemented and passed on to the consumer, final goods from sector $s$ in region $r$ will see a price increase of $\Delta p_s^r = p \cdot \hat{f}_r^s$ per USD. For our analysis, we assume a global carbon price of USD 50 per $tCO_2$, which would be roughly in line with the 2 °C target (High-Level Commission on Carbon Prices., 2017).

We assume that all final output is exported to the global market, from which it may be consumed either in the region where it was produced, as domestic consumption, or in a different region. We employ a price elasticity of export values of $\delta = -2.84$ from Solleder (2013)[6] to assess changes in final output resulting from these price changes by sector and country. We use this parameter to project changes in final output as a function of price changes relative to the global average. That is, we assume that sectors in regions that are subject to a price increase that is higher (lower) than the global average, experience a loss (gain) in market share. Using the above elasticity to modify each entry of the final consumption matrix $Y$ gives us the matrix $Y^*$. The elements of this matrix are calculated as $y^{*r'}_{r,s} = y^{r'}_{r,s} \cdot (1 + \Delta p_s^r - \Delta \bar{p}_s)^{\delta}$, with $\Delta \bar{p}_s$ being the global mean price change for sector $s$. $Y^*$ can then be used to calculate all sectoral outputs with a global carbon price, $O^* = LY^*$.

The matrix $Z$ can also be used to determine payments for production factors, such as wages and returns to stakeholders, as the difference between outputs from one sector and this sector's inputs from other economic sectors. The inputs of sector $s$ of country $r$ are calculated as $I_{r,s} = \sum_{r'} \sum_{s'} Z^{r,s}_{r',s'}$. Hence the corresponding value added (VAD) can be calculated as $VAD_{r,s} = O_{r,s} - I_{r,s}$. The VAD per unit of output is then given by $vad_{r,s} = VAD_{r,s}/O_{r,s}$.

Multiplying the newly derived elements of $O^*$ with the corresponding elements $vad$ allows us to project changes in regional and sectoral value added.

Finally, WIOD also accounts for sectoral labor use $LU$ (in hours for three different levels of qualification, low-, medium-, and highly-skilled). We calculate the sectoral *labor intensity* $LI^q_{r,s}$ in sector $s$, region $r$ of qualification $q$ per unit of output as $LI^q_{r,s} = LU^q_{r,s}/O_{r,s}$. On this basis we can project how changes in final output relate to changes in labor demand for each sector $s$ and region $LU^{q*}_{r,s} = LI^q_{r,s} \cdot O^*_{r,s}$. The sum of all sectoral changes in each region gives a rough indication of impacts on regional labor markets.

### 2.4. *Discussion of the methodology*

Although the analysis allows the identification of the initial impacts of a global carbon price at a relatively high level of sectoral detail, it faces a number of limitations.

First, sectoral resolution is restricted by the availability of underlying data. Although there are datasets with higher regional resolution (Aguiar et al., 2016; Lenzen et al., 2013), we decided to use WIOD, as it accounts for the largest and most advanced countries with high quality national accounting. This is an asset (Steen-Olsen et al., 2015).

Second, using monetary input-output (IO) data implicitly assumes homogeneity of products across regions. This assumption can be questioned (for further details see e.g. Alexeeva-Talebi et al. (2012); Steen-Olsen et al. (2015) and Ward et al. (2017)). Considering differences in products across sectors and regions would add additional detail to our approach. In the same vein, using more heterogenic elasticities across sectors could help refine results. However, given that products in a certain sector are similar across countries, it seems unlikely that this extension would overturn the main insights of our analysis.

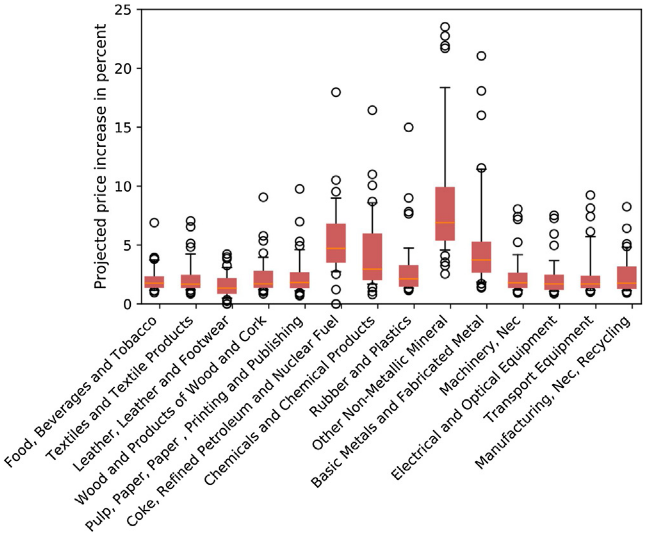

**Fig. 1.** Short-term price increases across countries from a global USD 50 carbon price by economic sector. Boxes represent 25th to 75th percentiles, black center lines refer to medians, whiskers in each direction correspond to the 10th percentile (lower bound) and the 90th percentile (upper bound). An outlier for Coke, Refined Petroleum and Nuclear fuels has been excluded from the plot[12]. The boxplots indicate the heterogeneity in carbon content of global supply chains of final demand goods ending in the respective regional sector.

Third, this paper aims to identify the short-term implications of price shocks. This type of analysis is highly relevant in assessing the political economic implications of different policies (Fullerton and Muehlegger, 2019), but does not appropriately capture dynamic adjustment effects in the long run. Long-term effects, such as changes in global supply chains, substitution of carbon-intensive inputs, or inducing technological change, could be assessed with computable general equilibrium (CGE) models (see e.g. Carbone and Rivers (2017) and Mattoo et al. (2009)). However, CGE models are unable to appropriately capture short-term effects and the (potentially costly) adaptation processes from one state of equilibrium to another (Fullerton and Muehlegger, 2019). Our approach, by contrast, considers global supply chains and international connections at a higher level of detail than a CGE[7], thus providing important complementary information.

## 3. Results

This section first assesses short-term price increases that would occur, by economic sector and region, in response to the introduction of a global carbon price. We then use this information to assess

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[5] Given this assumption, we use a price elasticity of export values to simulate the short-term impact of price changes in final demand. Our analysis assumes that all commodities produced in a given sector are subject to the same elasticity (however, the composition of commodities produced in each sector does need not be identical across countries).

[6] The elasticity refers to changes in trade value caused by an export tax. The $\delta$-value is close to the numbers observed by Head and Mayer (2014), who, in a meta-analysis, find a median price elasticity for trade gravity equations of -3.19.

[12] This outlier is Estonia with a *53%* projected price increase. It is likely to be caused by the comparatively large importance of Estonian shale oil production (IEA, 2009), see Table A1 in the SI for further detail.

[7] Typically nested production functions, which are used for CGE modelling have a structural deepness $\leq 5$ (Aguiar et al., 2016; Gerlagh and Kuik, 2014; Koesler and Pothen, 2013; Koesler and Schymura, 2015). Frequently, the embedded carbon content, which we are interested in, depends on one fossil fuel nest. Hence, a CGE based analysis does not reflect the level of detail that is considered in our analysis.

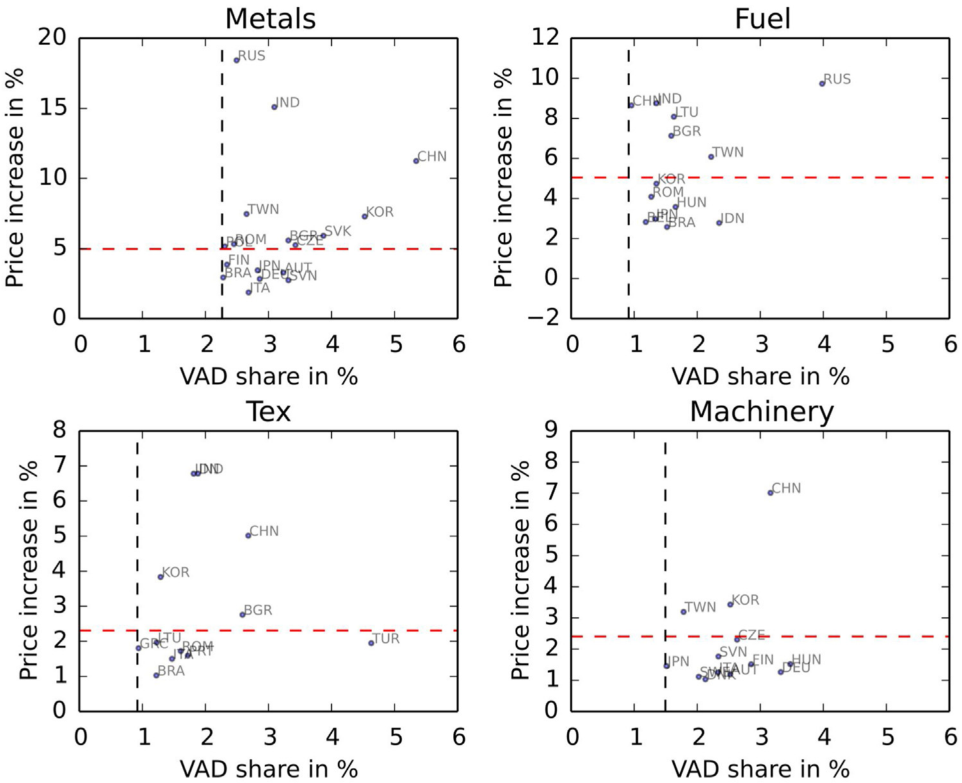

**Fig. 2.** Projected price increases due to a carbon price of USD 50 per $tCO_2$ vs. the share of a given sector in the region's total value added. The dotted lines show the average price increase across the countries considered and the average regional VAD share. Only regions with a VAD share greater than the global mean are plotted. Values for price increases and regional value added for all sectors are given in Table A1 and Table A7 in the SI, respectively.

potential impacts on economic output, value added and employment.

### 3.1. Impacts on industries

Fig. 1 assesses the short-term effect of a global carbon price of USD 50 per $tCO_2$ on the prices of final output across sectors. For any given economic sector, there is a substantial variation in terms of NNCC for final output, which can be attributed to differences in production technologies and energy systems within supply chains. This variation results in substantial differences in price changes of final output across countries for any given economic sector. In some countries, price increases for metals would be more than 20%, and more than 15% for chemicals, plastic, and (fossil and nuclear) fuels. The highest levels of heterogeneity across countries are identified for Coke, Refined Petroleum and Nuclear Fuel as well as Other Non-Metallic Minerals (refer to Table A1 in the Supplementary information for further details). The lowest (average) price increases are projected for Textiles and Textile Products, Manufacturing nec[8], Electrical and Optical Equipment, and Transport Equipment and Machinery nec. From a regional perspective, the highest price increases are projected in newly industrializing Asian economies, such as China, Indonesia and India. Other East Asian economies (such as Korea and Taiwan) as well as Eastern European states (such as Russia or Bulgaria) also display carbon-intensive supply and production chains. A carbon price would result in comparatively large increases in the prices of the final output of these regions. In contrast, economies with the least carbon-intensive supply and production chains (several EU members as well as Brazil) would see only modest price increases.

For three of the four most carbon-intensive sectors (Fuel, Other Non-Metallic-Minerals, Chemicals and Basic Metals) and the majority of the other sectors, value added is positively correlated with carbon-intensity (see Table A10 in the SI). This observation suggests that countries with more carbon-intensive production patterns would be over-proportionally affected by a global carbon price. Such a policy would place the highest burden on the most important economic sectors.

Figs. 2 and 3 relate price increases that would result from a global price of 50 USD per $tCO_2$ in a certain sector to that sector's economic importance. In Fig. 2 economic importance is measured by the percentage contribution of a particular sector to the national value-added (VAD). Fig. 3 considers VAD relative to global VAD for each particular sector (i.e. a proxy for the producing country's share of the global market)[9] . The dashed lines represent global averages. Hence regional sectors of high domestic (Fig. 2) or global (Fig. 3) relevance within the global sample are located in the right half. Regional sectors in the top-right quadrant are also projected to be subject to strong price increases.

For instance, for China's Textile sector, we project a relatively large price increase of about 5%. This sector accounts for about 3% of China's total VAD, and about 30% of global value added in the Textile sector. In comparison, for Turkey (for which Textiles account for about 5% of total national VAD) the price increase would be only about 2%, which is below the global average price increase for this sector. Hence, we would expect a global carbon price to generate an increase in Turkey's global market share in Textiles, but a decline

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[8] nec= not elsewhere classified

[9] An additional investigation of competitiveness impacts using "Revealed Comparative Advantage" is provided in the SI. We plot regional sectors that have a higher than average share in Figs. 2 and 3, only. A lower share does not exclude relevant adjustments. See tables A1, A3, A6 and A7 for further details.

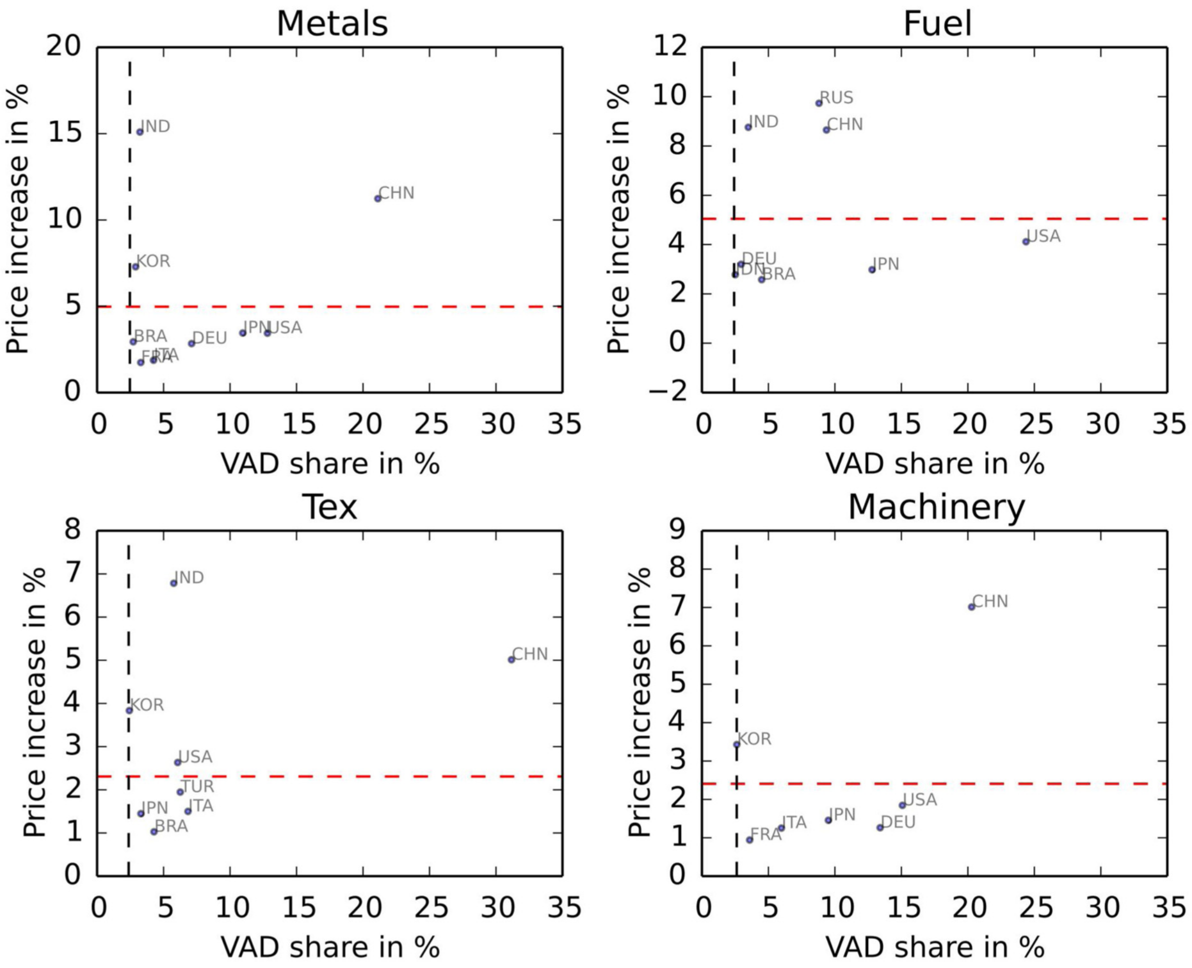

**Fig. 3.** Projected price increases due to a carbon price of USD 50 per $tCO_2$ vs. the share of a region in the global value added for a given sector. The dotted lines show the average price increase across countries and the average VAD share. Only regions with a VAD share larger than the world mean are plotted. Values for price increases and sectoral shares in global value added are given in Table A1 and Table A6 in the SI, respectively.

in China's share. Likewise, for Metals, China would experience a price increase of more than 10%, whereas prices in most European countries as well as Japan and Brazil would increase by less than the global average.

Overall, the most severely affected economic activities are located in developing and Eastern European countries. Although, for China, many sectors represent a relatively small VAD share in the national economy, the corresponding projected price increase could lead to significant shifts in the global economy in absolute terms. Due to its size, China is the largest global producer in numerous economic sectors. The Asian economies of our sample (with the exception of Japan) would be particularly negatively impacted by a global carbon price[10] . By contrast, US industries with a large share in global VAD tend to be cleaner than average supply chains. This indicates that the introduction of a global carbon price would boost these industries' comparative advantage and result in increasing market shares.

### *3.2. Short-term effects on employment and GDP*

To assess potential short-term effects of a global carbon price on sectoral employment and national GDP, we calculate the changes in final output that would occur as a result of price changes assuming that the industries concerned do not adjust their production methods and workers are unable to find employment elsewhere (see Section 2.3). The results of this analysis should be regarded as the upper boundary measure of the economic output and labor force under pressure, rather than an accurate projection of GDP and job losses resulting from a global carbon price. Understanding the extent of the effects on GDP and the labor force under pressure might be of considerable political importance; even though actual losses in production and employment can be expected to reduce, the prospect of losing a fraction of output and employment in a given industry is likely to be sufficient to generate political resistance among workers and shareholders.

Fig. 4 analyzes the total expected short-term effects into direct and indirect effects. Direct effects are those that would only be caused by changes in final output. Indirect effects result from the additional changes in global supply chains that affect all downstream sectors producing intermediate inputs. Values greater (lower) than one, denote potential gains (losses) in regional GDP. For instance, a value of 1.01 denotes a potential gain of 1% of regional GDP. Overall, direct effects dominate and determine the direction of the total effect for most regions. Total effects range from GDP under pressure of about 3% for China and India, to potential gains of about 1% for Ireland.

For the analysis of jobs put under pressure, we combine the above results with information from the MRIO on specific regional work hours used to produce final output. Fig. 5 shows that in India and China, overall jobs under pressure would amount to about 3%

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[10] An additional market concentration analysis is done in the *SI*.

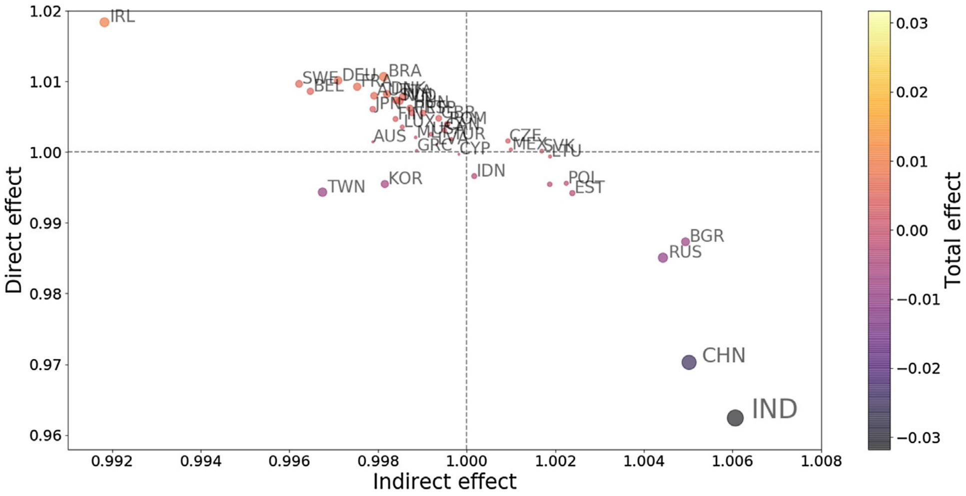

**Fig. 4.** Direct and indirect effects of a global carbon price of USD 50 per $tCO_2$ on GDP. The figure distinguishes between direct effects (referring to sectoral final demand changes by consumers) and indirect effects (referring to demand changes by downstream sectors). The size of dots refers to the total effect in percentage points, which is obtained by multiplying the two factors (direct and indirect) and converting the result to a percentage change. Table A1 in the SI provides values.

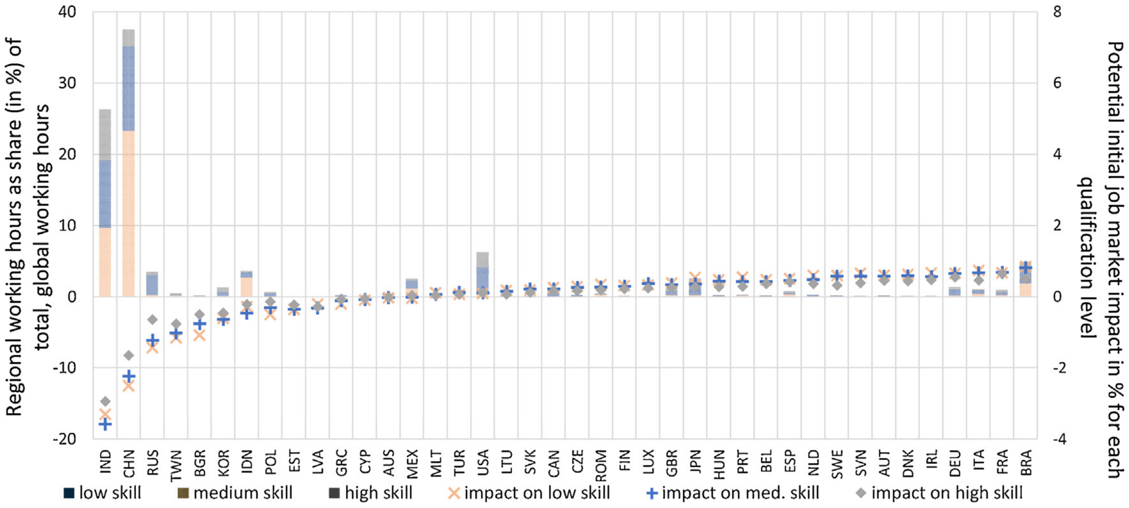

**Fig. 5.** Projected pressure on labor markets resulting from a global carbon price of 50 USD per $tCO_2$. The results consider three different levels of labor qualification, i.e. high, medium and low. The bars refer to the left y-axis. Impacts which are indicated by dots refer to the right y-axis. The results present a ceteris paribus impact and might therefore serve as an upper bound of the impact on the job market.

and 2% of the total workforce respectively[11] . Moreover, jobs are impacted in different ways depending on the qualification level. In the large majority (>75%) of all countries, low-skilled jobs are projected to see the largest relative changes. This is probably because the proportion of low qualified labor is greater than average in the sectors investigated, see Table A8 in the SI. In China, more than 2% of the low-skilled work force would be under pressure. India is an exception, as results indicate that the medium-skill work force would be most severely affected. Nevertheless, more than 3% of the low-skilled work force would also be under pressure in this country.

## 4. Discussion and conclusions

It is frequently argued that unilateral climate policy might lead to additional pressure on EITE industries and related jobs, particularly in industrialized countries. This paper demonstrates that a global uniform carbon price would, however, simply shift the problem to developing countries. These negatively impacted countries and industries might therefore be reluctant to accept binding climate measures or refuse to constructively engage in international climate negotiations.

The results presented in this paper provide an initial basis for the development of sector-specific policies to lower the vulnerability of highly relevant industries to a global carbon price, or to increase their capacity to deal with the associated price increases. This might be of special importance for poorer countries considering that manufacturing has been the "main avenue of rapid economic convergence", i.e. of high importance for developing countries (Rodrik, 2015, p. 28). For countries with carbon-intensive electricity supply, e.g. China, the impacts could be significantly reduced by de-carbonizing electricity production. Other alternatives are to promote efficient technologies that reduce the demand for carbon-intensive electricity or substitute other carbon-intensive intermediates (Kim and Kim, 2012; Saygin et al., 2011; Ward et al., 2017).

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[11] This is approximately the same proportion of the workforce that has been affected in the US as a result of China's entry into the World Trade Organization (Acemoglu et al., 2016).

Furthermore, a rational and successful climate policy might need to ensure that losers are compensated (Trebilcock, 2014; UNEP, 2017). Recycling carbon tax revenues could provide such opportunities (Goulder, 1995; Klenert et al., 2018). Learning from past experiences of (successful) structural transformations within developed economies can also help generate appropriate measures to ensure a 'just transition' (Smith, 2017) towards a decarbonized global economy.

## Statement of contribution

HW contributed the initial research idea. HW developed the analysis framework and analyzed data with inputs by MJ and JCS. HW, MJ and JCS wrote the paper.

## Acknowledgement

The authors gratefully acknowledges funding by the German Federal Ministry of Education and Research (BMBF) grant "Klimapolitische Maßnahmen und Transformationspfade zur Begrenzung der globalen Erwärmung auf 1,5 °C (PEP 1p5)", funding code 01LS1610B. The authors also want to thank Alexander Rohlf, Brigitte Knopf, Peter Ward, the participants of the 8th Atlantic Workshop on Energy and Environmental Economics, the participants of the DIE workshop on *Sustainable Production and Consumption* and anonymous referees for valuable comments and suggestions.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.eneco.2019.104549.

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