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Unilateral Environmental Policy and Offshoring

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Unilateral Environmental Policy and Offshoring*

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Abstract

Expanding on a general equilibrium model of offshoring, we analyze the effects of a unilateral emissions tax increase on the environment, income, and inequality. Heterogeneous firms allocate labor across production tasks and emissions abatement, while only the most productive can benefit from lower labor and/or emissions costs abroad and offshore. We find a non-monotonic effect on global emissions, which decline if the initial difference in emissions taxes is small. For a sufficiently large difference, global emissions rise, implying emissions leakage of more than 100%. The underlying driver is a global technique effect: While the emissions intensity of incumbent non-offshoring firms declines, the cleanest firms start offshoring. Moreover, offshoring firms become dirtier, induced by a reduction in the foreign *effective* emissions tax in general equilibrium. Implementing a BCA prevents emissions leakage, reduces income inequality in the reforming country, but raises inequality across countries.

JEL-Classification: F18, F12, F15, Q58

Keywords: Offshoring; Emissions leakage; Environmental policy; BCA; Heterogeneous firms; Income inequality

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1 Introduction

The practice of offshoring is subject to controversial debates on distributional and environmental consequences. It is feared that, by shifting emissions-intensive parts of the production, firms could largely undermine stricter environmental regulation. Emissions leak. Jobs leak. Income leaks. In the context of climate change, this might be the response to stricter climate policy of an ambitious country acting in line with the Paris Agreement (UNFCCC, 2015), given the substantial and increasing heterogeneity in carbon pricing across countries (OECD, 2021a). Consistent with international price asymmetries being a key determinant of production relocation, trade in carbon-intensive production follows a specific pattern closely along a North-South division: Most OECD countries are net importers of embodied CO_2, while most non-OECD countries are net exporters (cf. OECD, 2021b; Mahlkow and Wanner, 2023). This pattern of outsourcing pollution towards the Global South intensified over time (cf. Copeland et al., 2022).[1] With firms capable to exploit international cost differences and offshore, the question arises of how effectively an open country can implement ambitious climate policy unilaterally.

To offer an answer, we develop a general equilibrium model with heterogeneous firms, which have the option to offshore an emissions-intensive part of their production. We thereby combine features of the offshoring model developed by Egger et al. (2015) with the emissions-generating process introduced by Copeland and Taylor (1994, 2003). Accordingly, each firm, which produces a unique variety of a differentiated intermediate good, allocates labor across different production tasks and emissions abatement. Firms differ in productivity as they are run by differently able managers. Only the most productive firms self-select into offshoring, while the incentives to offshore originate from differences in wages and, or emissions taxes. Controlling for productivity, offshoring firms produce less emissions-intensively if the wage differential is the determinant factor. If, by contrast, the difference in emissions taxes gives the key incentive to offshore, offshoring firms are more emissions-intensive than purely domestic (non-offshoring) firms. Against this background, we analyze a unilateral increase in the emissions tax of the source country of offshoring. We thereby focus on direct and indirect effects on emissions, income, and inequality.

A higher emissions tax reduces aggregate emissions in the reforming country, while we find a non-monotonous effect on global emissions, which follow a U-shaped pattern. At a sufficiently high level of relative stringency, by further tightening its environmental policy, the reforming

[1] Using aggregate pollution data for OECD countries, Levinson (2023) argues that outsourcing to the rest of the world cannot explain the overall deviation of economic growth and pollution in developed countries over the past decades. In contrast to Copeland et al. (2022), sector- and firm-level differences are not addressed.

country causes emissions to shift to the non-reforming country to an extent that outweighs its own emissions reduction. Emissions leakage exceeds 100%. The environmental policy reform becomes environmentally damaging in case of transboundary pollution.

The underlying channels of this finding are as follows. The unilateral increase in the source country's emissions tax changes the relative costs structure of firms and makes offshoring relatively more attractive. More firms offshore, notably, those firms that are the largest, most productive and, hence, least emissions-intensive purely domestic firms. These are the firms that can afford to avoid the emissions tax increase and do not abate. By contrast, the group of purely domestic firms, which are the ones affected by the rising emissions tax, shrinks due to the rise in offshoring firms. While, as expected, incumbent purely domestic firms adjust their production process to reduce emissions, offshoring firms react differently. Due to a rise in labor demand in the host country of offshoring, resulting in a higher wage rate, the host country's *effective* emissions tax (the tax-wage-ratio, relevant for emissions abatement) declines in general equilibrium. Generating emissions becomes relatively less costly in the non-reforming country because of the rise of the emissions tax in the reforming country. Accordingly, incumbent offshoring firms use more emissions-intensively produced inputs. This turns out to be crucial in understanding the unilateral environmental policy's effect on global emissions. It also shows an important role of the level of openness of the reforming country. The larger the initial share of offshoring firms, the more firms are affected by a declining *effective* emissions tax rather than the intended stricter environmental regulation. Jointly, these effects accumulate in an emissions tax induced change in the average emissions intensity through within- and across-firm effects. We, thus, find a prominent role for the technique effect in explaining the possibility of an unintended rise in global emissions.[2]

Our result, thereby, complements Babiker (2005). In his model of oligopolistic market structure, the production shift to non-reforming regions creates a pro-competitive effect leading to more than 100% leakage in case of homogeneous goods and increasing returns to scale in the production. Accordingly, it is the more than proportionate increase in the production of energy-intensive goods in non-reforming regions that can induce leakage of more than 100% in response

[2] The technique effect is regarded as the most important channel through which trade impacts aggregate emissions (cf. Copeland et al., 2022; Antweiler et al., 2001) and in the cleanup of manufacturing (cf. Najjar and Cherniwchan, 2021; Shapiro and Walker, 2018; Levinson, 2009). Similarly, Larch and Wanner (2024) find a prominent role for the technique effect in a quantitative modelling exercise, analyzing unilateral withdrawals from the Paris Agreement. We add to this by highlighting the technique effect as the key underlying channel of a unilateral environmental policy reform in with offshoring. Contrasting previous work, we attribute an emissions-increasing driver to the technique effect, if the relative environmental policy stringency is sufficiently large.

to a unilateral environmental policy reform.[3] We derive our finding in a profoundly different model framework: In the context of monopolistic competition absent strategic interactions across heterogeneous firms, each firm produces a unique variety of a differentiated good with constant returns to scale technology. Against the backdrop of a largely unchanged scale of production, we highlight a combination of general equilibrium effects and differentiated firm responses that drives a decisive technique effect.

Our findings highlight a dilemma of unilateral environmental policy through increasingly diverging levels of environmental stringency in a globalized world and, thus, show the need for integrating environmental with trade policy. Countries are adopting several approaches to encounter the problem of carbon leakage, with *border carbon adjustments* (BCA) being among the most widely discussed instruments. By imposing a BCA, a government closes a potential carbon price wedge between the production at home and the production in countries with lower environmental stringency.[4] In order to assess the effectiveness and economic costs of a BCA, we extend our model. We show that – in the presence of a BCA – a unilateral environmental policy reform would no longer give additional incentives to offshore. This closes the underlying channel of emissions leakage and global emissions necessarily decline. Both purely domestic and offshoring firms reduce their emissions intensity, while the latter produce cleaner due to a higher *effective* emissions tax.

Implementing a BCA, where tax revenue is collected by the source country, has implications on global income and its distribution. We show that, in the absence of a BCA, a unilateral environmental policy reform reduces income in the reforming country amid an income gain in the non-reforming country. Caused by the relocation of production, this leads to the convergence of both income levels and wage rates across countries. The between-country inequality declines. Implementing a BCA, by contrast, increases international inequality. The host country does not benefit from attracting production, but is coerced to impose stricter environmental policy, without gaining in tax revenues. In the reforming source country, a BCA can prevent an increase in income inequality, which declines in case of additional BCA-related per capita transfer.

Our paper addresses a research gap at the intersection of offshoring and the environment with a focus on unilateral environmental policy (cf. Cherniwchan et al., 2017). We thereby

[3] In a setting of two regions with emissions pricing on extraction, production, and consumption, Weisbach et al. (2023) analytically derive an interplay of optimal climate policies. Accounting for production relocation, they numerically illustrate scenarios of more than 100% leakage.

[4] To tackle carbon leakage and establish a 'level playing field', the EU, for instance, recently introduced the *carbon border adjustment mechanism* (EU CBAM) to complement its emissions trading scheme. For more details, see https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.

contribute to different strands of the literature.

We add to a vibrant literature that integrates emissions generation into general equilibrium trade models with heterogeneous firms as developed in the seminal work of Melitz (2003). Initiated by Kreickemeier and Richter (2014), the focus is on trade in final goods and the role of firms able to self-select into exporting (cf. Forslid et al., 2018; Shapiro and Walker, 2018; Cherniwchan and Najjar, 2022).[5] In such a framework, Egger et al. (2021b) examine the role of environmental policy comparable to our analysis. In the absence of offshoring, all domestic firms, exporting and non-exporting alike, are directly affected by the unilaterally increased emissions tax. Through international trade, the environmental policy reform spills over to the non-reforming country in general equilibrium. Due to reduced demand from the distorting tax rise, production and, hence, emissions in the non-reforming country decline. Emissions leakage is negative. This is in sharp contrast to our finding of positive emissions leakage in the context of offshoring, possibly exceeding 100%. The mode of globalization matters.[6]

Accordingly, for a comprehensive understanding of unilateral environmental policy, it is necessary to consider the perspective of trade in intermediate goods. By capturing international spillover effects on labor markets through the relocation of emissions-intensive production, our offshoring model offers a nuanced explanation for patterns of emission leakage connected to unilateral environmental policy. We thereby build on a growing literature on offshoring considering firm heterogeneity (see e.g. Antràs and Helpman, 2004, Antràs et al., 2006, Egger et al., 2021a, or Egger et al., 2024).[7] Our paper contributes to the literature by analyzing a unilateral rise in environmental stringency in the context of offshoring.[8] Among very few theoretical contributions related to this nexus, Schenker et al. (2018) is to be highlighted. Expanding on a multi-stage production process in general equilibrium, they link unilaterally increasing environmental stringency to the relocation of production and emissions. Featuring the sector-level,

[5] LaPlue (2019) embeds firm heterogeneity into a trade model of comparative advantages to account for within and across sector responses to policy changes. Complementing the theoretical literature, empirical work provides evidence for an exporter's environmental premium (e.g. Cole et al., 2013; Holladay, 2016; Richter and Schiersch, 2017; Forslid et al., 2018; Banerjee et al., 2021; Rodrigue et al., 2022). Kwon et al. (2023) finds that both exporting and importing firms have lower emissions intensities. Linking emissions to the use of fossil fuels, Sogalla (2023) analyzes the impact of firm heterogeneity in general equilibrium in the context of unilateral environmental policy via adjustments within and across firms.

[6] This is in the tradition of a literature, which emphasises differences in labor market outcome. For instance, Hummels et al. (2014) provide evidence on the different wage effects of exporting and offshoring. Egger et al. (2024) rationalize job polarisation by offshoring-specific reallocation of labor to low and high productive firms.

[7] Expanding on a broad offshoring survey, Bernard et al. (2023) highlight firm-level differences in relocation incentives. For the role of productivity dispersion in intermediate goods trade, see Bernard et al. (2003).

[8] Several papers assess the impact of environmental policy using comparable models with heterogeneous firms in closed economy setups. See, for instance, Konishi and Tarui (2015), Tombe and Winter (2015), Andersen (2016), Anouliès (2017), Andersen (2018), and Najjar and Cherniwchan (2021).

they do not account for adjustments within and between firms.

There is a growing empirical literature on the intersection of offshoring and emissions at the firm-level. Using data for Swedish, French, and Danish firms, respectively, Akerman et al. (2021); Dussaux et al. (2023); Leisner et al. (2023) provide firm-level evidence for the effect of offshoring on emission intensity and domestic CO_2 emissions. In Akerman et al. (2021), the productivity-enhancing effect of importing intermediate goods dominates the role of offshoring dirty stages of production in reducing emissions intensities. By contrast, Dussaux et al. (2023) and Leisner et al. (2023) reveal substantial declines in firm-level emission intensities induced by offshoring. This has been reported earlier by Cherniwchan (2017) for US manufacturing firms responding to the introduction of NAFTA.[9] Cole et al. (2021) link outsourcing of Japanese firms to pollution offshoring: While the carbon content of Japanese intermediate imports increased over time, firms that newly initiated overseas outsourcing experienced a decrease in their emissions intensity. Michel (2013) finds evidence that offshoring accounts for a significant part in emissions reductions from Belgian manufacturing. Using German firm-level data, Nguyen (2023) finds evidence for lower emissions intensities of offshoring firms sourcing inputs in less stringent countries.[10]

Empirical work on the effects of environmental policies in the context of offshoring is still relatively scarce.[11] Ben-David et al. (2021) document the general pattern that multinational firms headquartered in countries with stricter policies emit relatively less than firms with headquarters in less strictly regulated countries. The analysis thereby generalizes the finding of country-specific studies such as Cole et al. (2014) for the case of Japanese manufacturing firms. Saussay and Zugravu-Soilita (2023) uses data on cross-border mergers & acquisitions and observes an impact of relative environmental policy stringency. Antonietti et al. (2017) observe a higher probability of outsourcing production to suppliers in the South, if environmental regulation in the North becomes stricter. Hanna (2010) finds that US Clean Air Act adjustments increased outgoing foreign direct investments, but not particularly in North-South constellations. Recently, Tanaka et al. (2022) causally identify pollution offshoring for the case of used lead-acid batteries recycling at the US-Mexican border as a result of stricter US environmental regulations.

Lastly, our work connects to a large body of quantitative literature that examines the effec-

[9] In a recent study, Choi et al. (2023) causally identify the reduction in US-China trade policy uncertainty as a crucial mechanism for the clean-up of US manufacturing plants through offshoring. The finding is mainly driven by plants in counties with stricter environmental regulation and with higher pollution intensity.

[10] Using similar data, Rottner (2023), however, does not find evidence for an increase in production replacing (domestically or internationally) sourced intermediates in response to a decline in electricity prices.

[11] In an extensive literature review, Cole et al. (2017) reaffirm the role of environmental regulation as determinant of FDI. They find ground supporting the link between production relocation and emissions leakage.

tiveness of BCA. Based on CGE models, Elliott et al. (2010), Fischer and Fox (2012), Böhringer et al. (2012a,b) and Schenker et al. (2018) observe strong BCA-induced leakage reductions.[12] In a structural gravity model, Larch and Wanner (2017) associate carbon tariffs with significant leakage reductions, albeit at significant welfare costs. Expanding on a multi-sector quantitative trade model with heterogeneous firms, Sogalla (2023) outlines how the implementation of the EU CBAM would reduce leakage but decrease fuel prices in sectors left uncovered. Farrokhi and Lashkaripour (2021) compare the introduction of BCA to a climate club. While the latter proposal can substantially reduce emissions, at most 1% of the emission reduction under global cooperation can be achieved through BCA.[13] Reaffirming a BCA's ability to cut leakage, Ambec et al. (2024) point out distortions of international competition evoked by the border adjustment. In a setting of heterogeneous firms capable to offshore, policy changes in our model evoke distinct reactions at the micro-level. In our model, when combined with a BCA, unilaterally raising environmental stringency does not lead to leakage.[14]

The remainder of this paper is structured as follows. Section 2 introduces the model framework, while Section 3 derives the offshoring equilibrium. Section 4 analyzes a unilateral environmental policy reform focusing on the effects on firm selection into offshoring and the factor allocation, on aggregate emissions and emissions leakage, and on income inequality. Section 5 extends our model framework to explore the impacts of a BCA. Section 6 concludes.

2 The model setup

We consider an economy that consists of a final goods sector and an intermediate goods sector as in Egger et al. (2015). The production of the final good relies on the processing of different varieties of the intermediate product as sole input. It does not generate emissions. The production of intermediates is based on the performance of two tasks. While a non-routine task is emissions-free and needs to be performed at the headquarter, a routine task, which is emissions-intensive, can be offshored. Hence, an individual firm, which is constituted by a manager and workers allocated to the execution of tasks and emissions abatement, either exclusively produces

[12] By contrast, Babiker and Rutherford (2005) and Böhringer et al. (2022) only arrive at minor leakage reductions.

[13] In a similar framework, Artuc and Sommer (2024) account for input-output linkages and allow outsourcing of tasks. The introduction of a region-specific BCA shuts down outsourcing to member countries. This leads, however, to production shifts to non-member countries, thereby reducing the policy effectiveness, albeit overall increased abatement efforts.

[14] Modelling a three-stage game with oligopolistic competition, Hecht and Peters (2019) demonstrate how a BCA effectively complements and supports unilateral environmental action.

domestically or offshores part of the production to a second country.[15]

Each of the two countries is populated by an exogenous mass of individuals, N in the source country of offshoring, and N^* in the host country of offshoring, respectively.[16] Individuals in the source country are heterogeneous in their managerial ability and can choose an occupation (cf. Lucas, 1978). If deciding to run a firm, an individual's managerial ability materializes in the productivity of the firm. Heterogeneity in abilities translates into heterogeneity of firms. In the host country of offshoring, by contrast, individuals can only perform the routine task as workers; neither final nor intermediate goods production takes place.

In both countries, income is solely used to consume the source country's final good, which is freely tradable. We assume balanced trade between the two asymmetric countries. Accordingly, final goods are shipped in one direction in exchange for the output of offshored routine tasks being shipped in the other direction.

2.1 The final goods sector

Following Ethier (1982) and Matusz (1996), we define final goods output as a CES-aggregate of differentiated intermediate goods $y(v)$:

$$Y = \left[\int_{v \in V} y(v)^{\frac{\sigma-1}{\sigma}} dv \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

with V denoting the set of available varieties of the intermediate good and $\sigma > 1$ being the elasticity of substitution between varieties. Final output Y is used as the numéraire and its price is normalised to unity. Profit maximisation under assumed perfect competition leads to the demand for each intermediate variety v as

$$y(v) = Yp(v)^{-\sigma}. \tag{2}$$

Demand positively depends on aggregate income of the two countries, equal to Y, and negatively on a variety's own price.

[15] We follow Grossman and Rossi-Hansberg (2008, p. 1981) who consider offshoring as international displacement of tasks "either within or beyond the boundaries" of the firm. Hence, offshoring includes the geographical relocation of production within the same company (in-house) and to external suppliers (foreign outsourcing).

[16] We indicate expressions for the host country of offshoring with an asterisk.

2.2 The intermediate goods sector

Firms in the intermediate goods sector operate under monopolistic competition, each producing a unique variety v of the differentiated intermediate good. The productivity of a firm is determined by its manager's managerial ability φ, which is Pareto distributed with lower bound of one and shape parameter $k > \sigma$.[17] The cumulative density function is then given by $G(\varphi) = 1 - \varphi^{-k}$. Each manager decides on worker employment and allocation, on offshoring activity, and on the production volume of her variety v.

We specify the production technology as

$$y(v) = \varphi(v) \left[\frac{x^n(v)}{\eta}\right]^{\eta} \left[\frac{x^r(v)}{1-\eta}\right]^{1-\eta} \qquad \text{with} \quad \eta \in (0.5, 1), \tag{3}$$

where $x^n(v)$ and $x^r(v)$ denote the used output of a non-routine task and the used output of a routine task, respectively.[18] Both $x^n(v)$ and $x^r(v)$ thus describe the demand for the two needed inputs into the production process of variety v.

The supply of these two inputs looks as follows. While the non-routine task is conducted domestically, the routine task can be conducted domestically or offshored. The routine task generates emissions. As in Acemoglu and Autor (2011) and Egger et al. (2015), labor can be allocated across tasks.[19] In addition, in our framework labor can also be used to reduce emissions as in Copeland and Taylor (2003). Independent of the production location, with the details deferred to Appendix A.1, we use the following technology to describe the execution of tasks:

$$x^n = l^n \qquad \text{and} \qquad x^r = \beta\,(e)^{\alpha}\,(l^r)^{1-\alpha} \qquad \text{with} \quad \alpha \in (0,1), \quad \beta > 0, \tag{4}$$

where l^n and l^r denote labor allocated to the non-routine and routine task, respectively, and with e being the generated emissions.[20]

[17] The assumption of a sufficiently large k ensures positive and finite means of relevant model variables, such as average firm production.

[18] The lower limit of $\eta > 0.5$ is in line with Egger et al. (2015) and backed by empirical findings (cf. Baldwin and Dingel, 2021). As we will show below, this assumption implies that the wage rate in the source country is at least as high as the wage rate in the host country, as long as N^* is not much smaller than N.

[19] By modelling production as the combination of routine and non-routine task, we use the respective taxonomy established by Becker et al. (2013). Task differentiation has gained increasing relevance in the context of offshoring frameworks. Carluccio et al. (2019) present empirical evidence for offshoring-induced changes in skill composition (and thus task assignment) of domestic labor employment.

[20] As an intermediate goods firm potentially sources the output of the two tasks from outside, we omit v on the supply side. However, in the following, we attribute employed labor and generated emissions during task executions to firm v. This extends to embedded labor and embedded emissions from the imported output of the routine task used by offshoring firms.

Accordingly, and as common in the literature (e.g. Copeland and Taylor, 1994; Shapiro and Walker, 2018; Egger et al., 2021b), we treat emissions as an input factor in the production process that is imperfectly substitutable with labor. This formulation entails a declining marginal effectiveness of emissions abatement. Parameter α can be interpreted as the costs share of emissions in the production of the routine task. Jointly, Eqs. (3) and (4) can be written as a nested Cobb-Douglas production function with labor and emissions being the inputs.

We are now equipped to specify the optimal firm behavior subject to entry and sorting into offshoring, where the selection mechanisms are detailed in Section 3. Taking factor prices exogenously, each firm determines input demand in order to minimize costs subject to technology constraints. A purely domestic firm thereby faces the economy-wide wage rate w and the emissions tax $t > 0$. An offshoring firm, in turn, employs domestic workers at wage w for the non-routine task only, and imports the offshored input at price p^{r*}. The routine task is executed abroad with the same technology but using foreign labor and generating emissions abroad. Under (assumed) perfect competition, the host country offers its product at marginal costs, i.e. at $p^{r*} = (t^*)^{\alpha}(w^*)^{1-\alpha}$, with $t^* \in (0; t]$.[21] We assume iceberg transport costs $\tau \geq 1$ for international shipments. Hence, in order to use $x^{or}(v)$ units in the production process, an offshoring firm needs to purchase $\tau x^{or}(v)$ units.[22]

As formally shown in Appendix A.2, we derive marginal costs of a purely domestic firm and an offshoring firm, respectively, as

$$c^d(v) = \frac{\left(t^{\alpha} w^{1-\alpha}\right)^{1-\eta} w^{\eta}}{\varphi(v)} \qquad \text{and} \qquad c^o(v) = \frac{\left(\tau p^{r*}\right)^{1-\eta} w^{\eta}}{\varphi(v)}. \tag{5}$$

Only if there is an incentive to offshore from marginal costs savings, a particular firm would want to do so. Accordingly, we express the ratio between the marginal costs of a particular firm in case of solely producing domestically and in case of offshoring as

$$\kappa \equiv \frac{c^d(v)}{c^o(v)} = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{w}{w^*}\right)^{1-\alpha}\right]^{1-\eta}, \tag{6}$$

where the last expression follows from replacing p^{r*}.[23] Only for $\kappa > 1$, an offshoring equilibrium materializes and κ represents the *marginal cost savings factor of offshoring*. Note that κ incor-

[21] We, hence, restrict the model to the empirically plausible case that the emissions tax of the host country of offshoring does not exceed the emissions tax of the source country.

[22] In the given model setup, iceberg transport costs are equivalent to an assumption of lower (Hicks-neutral) productivity of the routine task's production in the host country than in the source country of offshoring. More inputs need to the employed per utilized unit of output of the routine tasks.

[23] This is a generalisation of Eq. (4) in Egger et al. (2015), which it collapses to if $\alpha \to 0$.

porates two potential incentives to offshore: *i.)* an across-country environmental tax differential and *ii.)* an across-country wage gap. Hence, the decision to offshore can either be driven by a less stringent environmental policy in the host country, by lower wages in the host country, or by both. Transport costs τ, by contrast, reduce the incentive to offshore. Importantly, emissions taxes t and t^* and transport costs τ are exogenous model parameters, while wages w and w^* are endogenous and, hence, adjust to policy changes. We elaborate on this feature in Section 4, when analyzing a unilateral environmental policy reform.

Equipped with these insights, and noting that firms in the intermediate goods sector charge a constant markup $\sigma/(\sigma-1) > 1$ over marginal costs,[24] we can express the role of a firm's offshoring status for her price, output and operating profits:

$$\frac{p^o(v)}{p^d(v)} = \kappa^{-1}, \qquad \frac{y^o(v)}{y^d(v)} = \kappa^{\sigma} \qquad \text{and} \qquad \frac{\pi^o(v)}{\pi^d(v)} = \kappa^{\sigma-1}. \tag{7}$$

Accordingly, by offshoring a firm can offer its variety at a lower price and still earn higher operating profits due to larger volumes sold.

Within each status (purely domestic or offshoring), the more productive a firm, the higher her operating profits from more volumes sold at a lower price:

$$\frac{p(\varphi_1)}{p(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{-1}, \qquad \frac{y(\varphi_1)}{y(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma} \qquad \text{and} \qquad \frac{\pi(\varphi_1)}{\pi(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}. \tag{8}$$

Importantly, the ratio of operating profits of two firms (as well as the ratios of other firm performance measures) solely depends on the ratio of the productivity levels of the two firms. Hence, we suppress firm index v and use productivity level φ to distinguish the different firms.

Additionally, we can investigate the difference in emissions across firms. A purely domestic firm generates emissions in the source country, whereas an offshoring firm, by contrast, does not generate emissions directly. Indirectly, however, it causes emissions in the host country by importing the output of the routine task. In the following, we take these *embedded* emissions of offshoring firms into account to allow for a fair comparison of environmental footprints across firms.[25]

Complementing Eq. (7) and with formal derivations deferred to Appendix A.3, we can state the role of a firm's offshoring status on emissions and emissions intensity, defined as the ratio of

[24] This follows from the constant price elasticity of demand in Eq. (2) and monopolistic competition.
[25] This particularly matters for global pollutants, like CO_2, where the location of emissions generation is irrelevant to its environmental impact.

(direct or embedded) emissions and output, i.e. $i(\varphi) \equiv e(\varphi)/y(\varphi)$.[26] Accordingly,

$$\frac{e^o(\varphi)}{e^d(\varphi)} = \frac{t}{t^*}\kappa^{\sigma-1} \qquad \text{and} \qquad \frac{i^o(\varphi)}{i^d(\varphi)} = \frac{t}{t^*}\kappa^{-1}. \tag{9}$$

Hence, the decision to offshore is associated with higher emissions,[27] whereas the difference in emissions intensity is ambiguous. Suppose that the emissions taxes were equal across the two countries. To ensure an incentive for offshoring, i.e. for $\kappa > 1$ to hold in light of transport costs τ, there must be a sufficiently large difference in the wage rates between the two countries. Given $w > w^*$ and $t = t^*$, it directly follows that the tax-wage ratio, i.e. the *effective* emissions tax, is necessarily higher in the host country. Accordingly, the routine task is produced less emissions-intensively if offshored, leading to lower firm's emissions intensity in the case of offshoring. Importantly, this reasoning also holds for sufficiently small differences in the emissions taxes with $t > t^*$, while $\kappa > 1$.[28] If, by contrast, the difference in emissions taxes is sufficiently large, and constitutes the main incentive to offshore to begin with, the emissions intensity of an offshoring firm is higher.

The ambiguity in the ratio of emissions intensities stands in contrast to models with emitting heterogeneous firms that select into exporting: controlling for productivity, exporters are either found to produce equally emission-intensively as purely domestic competitors, since they adjust to the same domestic tax-wage-ratio (cf. Egger et al., 2021b), or are characterised by lower emissions intensities due to higher abatement investments (cf. Forslid et al., 2018). Here, whether the decision to offshore leads to a higher or lower emissions intensity controlling for productivity, crucially depends on the determinants of offshoring.

Finally, for a given status (purely domestic or offshoring), a more productive firm produces less emissions-intensively, while, due to its larger scale, it nevertheless generates more emissions:

$$\frac{e(\varphi_1)}{e(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1} \qquad \text{and} \qquad \frac{i(\varphi_1)}{i(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{-1}. \tag{10}$$

Let us summarize our findings in the following lemma:

Lemma 1. *Controlling for productivity, a firm's emissions intensity is smaller in case of offshoring, if the source country's emissions tax is equal to the emissions tax in the host country or*

[26] In Appendix A.4, we additionally derive different labor employment ratios between purely domestic and offshoring firms.

[27] This directly follows from $t \geq t^*$ (by assumption) and $\kappa > 1$ as precondition for an offshoring equilibrium. It is driven by the higher output of an offshoring firm.

[28] It is straightforward to derive the following condition for $i^o(\varphi) < i^d(\varphi)$ from Eqs. (6) and (9): $1 \leq t/t^* < (w/w^*)^{(1-\alpha)(1-\eta)/[1-\alpha(1-\eta)]}(1/\tau)^{(1-\eta)/[1-\alpha(1-\eta)]}$.

only slightly larger, depending i.a. on relative wage rates. A firm's emissions intensity is larger in case of offshoring otherwise. Controlling for the offshoring status, a more productive firm produces less emissions-intensively but generates more emissions.

3 The offshoring equilibrium

In the source country, an individual can either become a manager, worker or offshoring consultant. We assume that each individual chooses her occupation solely based on her achievable income. If an individual decides to become a worker or offshoring consultant, her managerial ability remains unexploited. Accordingly, all non-managers are homogeneous and paid the same economy-wide wage rate w. By contrast, as a manager, and (assumed) firm owner, an individual's managerial ability translates into firm productivity, and hence determines the profit income of the individual. In addition to wage payments (workers and offshoring consultants) or profit income (managers), each individual receives a uniform per capita transfer $b \equiv tE/N$ from redistributed tax revenues from aggregate domestic emissions E.[29]

Denoting the threshold ability to become a manager by φ^d, all individuals with ability at least as high ($\varphi \geq \varphi^d$) decide to run a firm, while all individuals with lower managerial ability ($\varphi < \varphi^d$) become workers or offshoring consultants. In line with the empirical evidence of self-selection of the most productive firms into offshoring (cf. Paul and Yasar, 2009; Hummels et al., 2014; Cole et al., 2014), the least productive firm, i.e. the firm run by the marginal manager, does not offshore. This leads to the following condition of the individual who is just indifferent between becoming a manager and choosing a wage-remunerated occupation:

$$\pi^d(\varphi^d) + b = w + b, \tag{11}$$

where, intuitively, the per capita transfer b does not distort the decision and cancels out.

There is a second choice to be made by all managers, whether to produce purely domestically or to move part of the production process offshore. Offshoring promises higher operating profits from lower variable production costs, see Eq. (7), but requires to hire one offshoring consultant as fixed input requirement. Accordingly, only the most productive firms can afford to offshore.

[29] It is regularly proposed to redistribute emissions tax revenues on the basis of a uniform per capita transfer. See for instance, the well-known US carbon dividends plan `https://clcouncil.org/our-plan`. In 2022, Austria launched a similar scheme called "Klimabonus", which pays the same absolute transfer to all people living in the same region but more to those living in less connected regions.

The marginal offshoring firm with productivity φ^o is determined by

$$\pi^o(\varphi^o) - \pi^d(\varphi^o) = w, \tag{12}$$

where the additional operating profits of offshoring, on the left-hand side of Eq. (12), must cover the costs of hiring an offshoring consultant, on the right-hand side.

Jointly, the two cutoff productivity levels, φ^d and φ^o, determine the share of offshoring firms

$$\chi \equiv \frac{1 - G(\varphi^o)}{1 - G(\varphi^d)} = \left(\frac{\varphi^d}{\varphi^o}\right)^k. \tag{13}$$

We are able to express all aggregate variables as functions of χ as sole endogenous variable and will emphasize the impact of a unilateral environmental policy reform via χ in the next section.

To solve for an offshoring equilibrium (i.e. with at least some firms offshoring), we derive two links between the share of offshoring firms χ and the marginal cost savings factor κ.[30] We then set out the conditions for an interior solution.[31]

A first link between κ and χ, the *offshoring indifference condition* $A(\chi)$, originates from the two indifference conditions laid out in Eqs. (11) and (12):

$$\kappa = A(\chi) \equiv \left(1 + \chi^{\frac{\sigma-1}{k}}\right)^{\frac{1}{\sigma-1}}. \tag{14}$$

This condition captures a positive relation between κ and χ: A higher marginal cost savings factor induces relatively more firms to offshore.

We derive a second link, the *labor market constraint* $B(\tau, t, t^*, \chi)$, between κ and χ via the labor market equilibrium in both countries. Given the (exogenous) population sizes and the eligible occupations, we define the following resource constraints for the source country and the host country, respectively:

$$N = L + (1 + \chi)M \qquad \text{and} \qquad N^* = L^*, \tag{15}$$

where L and L^* denote the mass of workers, M the mass of managers, while χM subsumes all offshoring consultants. From these conditions, we can derive the relative wage w/w^* as a

[30] See Appendix A.5 for the derivation.

[31] In Appendix A.6, we derive the necessary conditions for τ and t/t^* in order to guarantee $\chi \in (0, 1)$. In particular, we need to exclude cases with $\chi > 1$, as these would violate equilibrium condition Eq. (11) based on the assumption of the marginal firm being a purely domestic firm.

declining function of χ. Inserted in our definition of κ in Eq. (6), we finally get the second link:

$$\kappa = B(\tau, t, t^*, \chi) \equiv \left[\frac{1}{\tau} \left(\frac{t}{t^*} \right)^{\alpha} \left(\frac{\gamma^l(\chi)}{\gamma^{l*}(\chi)} \frac{N^*}{\lambda(\chi) N} \right)^{1-\alpha} \right]^{1-\eta}, \tag{16}$$

where $\gamma^l(\chi)$ and $\gamma^{l*}(\chi)$ denote the share of factor income that accrues to workers in the source country and in the host country, respectively, while $\lambda(\chi)$ is defined as the share of workers in the source country's population, i.e. $\lambda(\chi) \equiv L/N$. The labor market constraint in Eq. (16) shows a negative relation between κ and χ. An increase in the share of offshoring firms χ leads, *ceteris paribus*, to a rise in labor demand in the host country, amid a decline of labor demand in the source country. This, in turn, causes a relative rise in the host country's wage rate, which reduces the attractiveness to offshore and is expressed by a declining κ.

Jointly, these two links, Eqs. (14) and (16), determine κ and χ. For an interior equilibrium of offshoring with $\chi \in (0, 1)$ to hold, the environmental tax differential must not be too large and the level of iceberg trade cost neither too small nor too large. Figure 1 illustrates an interior offshoring equilibrium, where the solid line represents the upward-sloping $A(\chi)$-function and the dashed line the downward-sloping $B(\tau, t, t^*, \chi)$-function. The intersection of these two curves determines the equilibrium solutions of κ and χ. The dashed-dotted line will be presented in the next section.

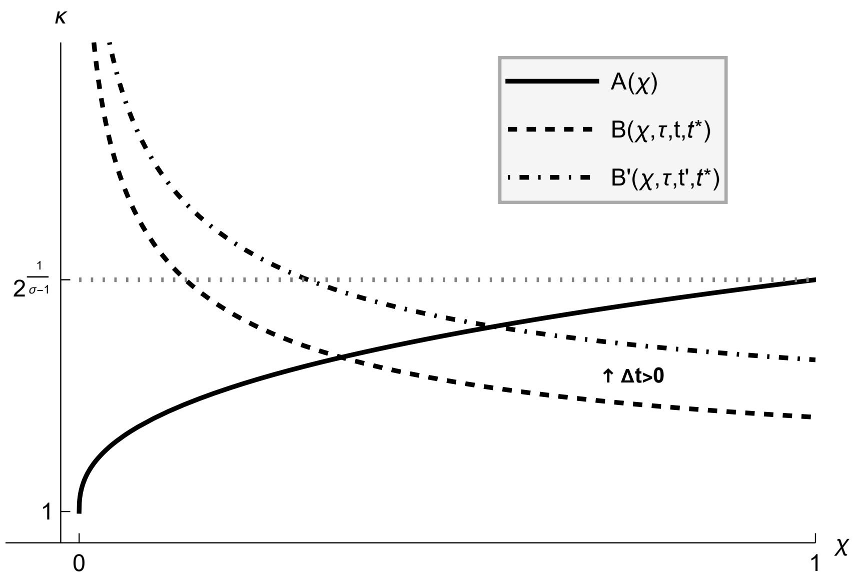


Figure 1: Determining the offshoring equilibrium

4 Unilateral environmental policy reform

This section analyzes the effects of a unilateral environmental policy reform in an offshoring equilibrium. To this end, we focus on an increase in the source country's emissions tax, while in the host country, the emissions tax remains unchanged, i.e. $dt > dt^* = 0$.

Key to our solution strategy is the understanding of how χ changes in response to a rise in t. With this knowledge, we show how occupational choice decisions and the aggregate factor allocation change (Section 4.1). This gives valuable insights into how the economy is affected and is essential to understand the change in aggregate emissions in the reforming country (Section 4.2) and emissions leakage to the non-reforming country (Section 4.3). Finally, we analyze the distributional effects of the unilateral environmental policy reform (Section 4.4).

4.1 Effect on the share of offshoring firms and the factor allocation

We apply the implicit function theorem to derive the change in χ in response to a rise in t, with the formal details shown in Appendix A.7. We find that a rise in the source country's emissions tax monotonously increases the share of offshoring firms, $d\chi/dt > 0$. This is intuitive, as it is the rise in production costs in the source country that makes offshoring the emissions-intensive routine task more attractive for a larger share of firms. The marginal cost savings factor κ increases. Figure 1 highlights this new offshoring equilibrium, with the upward shift from $B(\chi, \tau, t, t^*)$ to $B'(\chi, \tau, t', t^*)$, the dashed-dotted line, resulting in an increase in both χ and κ.[32]

It is not only the share of offshoring firms that increases, but also the mass of offshoring firms, $d(\chi M)/dt > 0$.[33] Accordingly, at the extensive margin, more firms avoid to pay the domestic emissions tax by offshoring part of their production process. These firms are the most productive purely domestic firms that react to the rise in the source country's production costs by offshoring.[34]

The implication of this result is remarkable: deduced from Lemma 1, it is the purely domestic firms with the lowest emissions intensities, i.e. the cleanest firms, that start to offshore in response to a rise in the emissions tax rate. This runs against the common perception of the dirtiest firms

[32] Formally, this can be seen by a direct effect of t on $B(\chi, \tau, t, t^*)$ in Eq. (16), whereas $A(\chi)$ in Eq. (14) remains unaffected.

[33] In Appendix A.8, we derive the changes in the factor allocation and firm selection.

[34] Note that from the expression of the mass of offshoring firms, $\chi M = [1 - G(\varphi^o)]N = (\varphi^o)^{-k} N$, it directly follows that $d(\chi M)/dt > 0 \Leftrightarrow d\varphi^o/dt < 0$. Hence, the cutoff productivity of the marginal offshoring firm declines.

to offshore.[35] In our model with heterogeneous firms, this is a direct consequence of the fixed costs of offshoring: A firm needs to be sufficiently productive to start offshoring, while the emissions tax rise makes offshoring relatively more attractive.

We summarize these results as follows:

Proposition 1. *A unilateral increase in the source country's emissions tax leads to a rise in the share and mass of offshoring firms. The most productive and, hence, least emissions-intensive purely domestic firms start offshoring.*

While purely domestic firms leave at the upper end of the firm distribution (to become offshorers), the effect at the lower end is ambiguous. We can define, however, two threshold levels of χ to get the following statements:[36] First, for $\chi > \tilde{\chi}$, an increase in the source country's emissions tax reduces the mass of active firms, $dM/dt < 0$.[37] This also implies a decline in the mass of purely domestic firms, $d(1-\chi)M/dt < 0$, as we have firm exits on both ends of the firm distribution (into inactiveness and offshoring). Second, for $\tilde{\chi}^d < \chi < \tilde{\chi}$, the mass of active firms increases, $dM/dt > 0$, despite a decline in purely domestic firms, $d(1-\chi)M/dt < 0$. Low-productive firms become newly active, but in fewer quantities than relatively high-productive firms start offshoring. Finally, for $\chi < \tilde{\chi}^d$ the mass of purely domestic firms and the mass of all active firms increases. Both the second and third case (that share the feature of a sufficiently low initial share of offshoring) imply that low-productive, highly emissions-intensive firms are newly established. This result is fundamentally different from Melitz-type models of trade in final goods. In these models, a stricter unilateral environmental policy unambiguously leads to the exit of the least productive, and thus dirtiest, firms. Exporters, which are relatively less affected due to a smaller demand reduction in the non-reforming country, soak up the freed labor of those firms (cf. Egger et al., 2021b). This is different in the context of offshoring, where newly offshoring firms replace domestic workers in the performance of the routine task by foreign labor. We show in the following, how freed domestic labour is relocated across tasks and firm types.

Independent of this ambiguity in M, an increase in t unambiguously leads to a decline in the mass of workers in the source country L. It is both the rise in production costs and

[35] We acknowledge the existence of across-sector differences in emissions intensities, with a rise in the emissions tax potentially inducing firms from particularly dirty sectors to offshore. This channel is not featured in our one (intermediate) sector model.

[36] In Appendix A.8, we provide formal details and derive the two threshold levels $\tilde{\chi}$ and $\tilde{\chi}^d$ in terms of parameters only. Similarly, Egger et al. (2015) discuss an ambiguous effect on the mass of firms of a change in trade costs.

[37] Since the mass of active firms is negatively related to the domestic cutoff productivity level, $M = [1-G(\varphi^d)]N = \left(\varphi^d\right)^{-k} N$, it directly follows $d\varphi^d/dt > 0$ in this case. The least able managers stop running a firm.

the increasingly attractive option to offshore, with offshoring firms only employing workers for non-routine tasks, that leads to lower labor demand in the source country. In addition, we make two observations from decomposing aggregate labor employment, with details provided in Appendix A.9. First, we find a tax-induced shift (in relative and absolute terms) of workers from the routine to the non-routine task.[38] Second, we find a tax-induced shift of workers from purely domestic firms to offshoring firms, despite the latter only executing the non-routine task in the source country. In detail, we derive the following responses to a rise in t:

$$\frac{dL^d}{dt} < \frac{dL^r}{dt} < \frac{dL}{dt} < 0 < \frac{dL^n}{dt} < \frac{dL^o}{dt}. \tag{17}$$

We can summarize these findings as follows:

Proposition 2. *A unilateral increase in the source country's emissions tax leads to a decline in the mass of workers amid more individuals conducting the non-routine task and working at offshoring firms. The effect on the mass of managers and, hence, the mass of active firms is ambiguous. In the case of a sufficiently high initial share of offshoring, the effect is negative; it is positive otherwise.*

4.2 Effect on aggregate emissions in the source country

Equipped with these insights, we can now turn to aggregate emissions in the source country. Based on the costs share of tax payments, we derive aggregate emissions as:

$$E = \gamma^e(\chi)\frac{\sigma-1}{\sigma}\frac{Y}{t} \qquad \text{with} \qquad \gamma^e(\chi) \equiv \frac{\alpha(1-\eta)(1-\chi^{\frac{k-\sigma+1}{k}})}{1+\chi}, \tag{18}$$

where $\gamma^e(\chi)$ is the share of aggregate income net of aggregate operating profits that accrues to tax payments in the source country.[39] Since both γ^e and Y decrease in t, also aggregate source country's emissions decline in the emissions tax, $dE/dt < 0$. While this environmentally beneficial emissions tax effect should not come at a surprise, a deeper look at the underlying channels reveals the existence of multiple opposing effects.

It is common in the literature to decompose aggregate emissions in order to isolate the partial effects of a policy reform (cf. Grossman and Krueger, 1995; Antweiler et al., 2001; Levinson,

[38] For reasons of tractability, our model does not distinguish between skills to perform the different tasks; hence, the outcome of all workers being paid the economy-wide wage rate. Beyond the model, the finding of a shift of the labor force towards non-routine headquarter tasks is consistent with empirical findings of heterogeneous effects of offshoring on different types of workers (cf. Hummels et al., 2014).

[39] In Appendix A.10 we present formal details and derive the change of E in response to the increase in t.

2009; Shapiro and Walker, 2018). Accordingly, we can express aggregate emissions in the source country as:

$$E = (1-\chi)M\bar{y}^d\bar{\imath}^d, \tag{19}$$

where the bars indicate averages, which, importantly, are determined jointly by the firm decisions on labor allocation, abatement and production volumes, and by the composition of the heterogeneous firms. According to Eq. (19), a change in aggregate emissions can be attributed to a change in the scale of production, $Q \equiv (1-\chi)M\bar{y}^d$, i.e. overall output given by the product of the mass of domestic firms and their average production volume, and in the average technique of production, $\bar{\imath}^d$, i.e. the (output-weighted) average emissions intensity of purely domestic firms.[40] Let us take a closer look at the two effects.

First, we find a negative scale effect on aggregate emissions in the source country. The production of purely domestic firms shrinks. This is due to a decline in average output, which dominates an opposing effect on the mass of domestic firms (in case of a low initial level of χ), or is magnified by a declining mass of domestic firms (in case of a high initial level of χ), see Proposition 2. Average output decreases in the emissions tax due to four factors: First, the tax increase leads to a shift of labor from productive use to emissions abatement. Second, increased costs lead to reduced demand and thus production. Third, the most productive firms select into offshoring and, hence, do not contribute to average output of purely domestic firms anymore. Finally and relatedly, labor is reallocated towards offshoring firms, see Proposition 2.

Second, we find opposing channels driving the technique effect. Formally, we can express the average emissions intensity as:

$$\bar{\imath}^d = \alpha\left(\frac{t}{w}\right)^{\alpha-1} \cdot (1-\eta)\left(\frac{t}{w}\right)^{-\alpha\eta} \cdot \frac{1}{\bar{\varphi}^d}, \tag{20}$$

where the first term relates to the (average) emissions intensity of the routine task, the second term to the importance of the routine task in the (average) input bundle and the third term to the (output-weighted) average productivity. Accordingly, the first and second effect are within-firm channels,[41] while the third effect is an across-firms-within-sector channel originating from

[40] In Appendix A.11 we present formal derivations of the individual terms and derive the partial effects of t on E via these channels. Alternative to Eq. (19), we can expresses aggregate emissions by the product of the mass of purely domestic firms and their average emissions: $E = (1-\chi)M\bar{e}^d$, where the latter is given by $\bar{e}^d = \bar{y}^d\bar{\imath}^d = [k(\sigma-1)]/(k-\sigma+1)\alpha(1-\eta)\left[1-\chi^{(k-\sigma+1)/k}\right]/(1-\chi)w/t$. Since both the tax' direct effect and its indirect effect via χ reduce average firm emissions, we can safely state that purely domestic firms generate fewer emissions, on average. While the tax-impact on the mass of domestic firms is ambiguous (see Proposition 2), in case of a positive sign, this effect is dominated by the decline in average emissions.

[41] Najjar and Cherniwchan (2021) refer to these within-firms channels of the technique effect as *process effect*.

firm selection and reallocation of factor inputs.

Both within-firm channels solely depend on the *effective* tax rate, t/w. Consistent with a decline in labor demand, see Proposition 2, we find the source country's wage to fall. This magnifies the increase in the emissions tax and induces the emission intensity of all incumbent purely domestic firms to decline. However, there are tax-induced changes in the distribution of purely domestic firms. While the most productive, and cleanest, firms select into offshoring, see Proposition 1, there might be entry at the lower end of the firm distribution, see Proposition 2. Accordingly, the emissions intensity reducing within-firm effects are likely opposed by the decline in average productivity of purely domestic firms,[42] which increases the average emissions intensity, *ceteris paribus.*[43]

We summarize our findings as follows:

Proposition 3. *A unilateral increase in the source country's emissions tax leads to a decline in aggregate domestic emissions. This effect originates from a tax-induced reduction in the scale of production, while the effect on average emissions intensity is ambiguous. Within-firm effects lead to a decline in the average emissions intensity, whereas the change in the composition of firms tends to lower average productivity and, hence, increase average emissions intensity, ceteris paribus.*

4.3 Emissions leakage and the effect on global emissions

To assess the total environmental consequences of the source country's unilateral environmental policy reform, we have to understand the effect on aggregate emissions in the host country. Making use of income shares and in analogy to the derivation of E in Eq. (18), we compute

$$E^* = \gamma^{e*}(\chi)\frac{\sigma-1}{\sigma}\frac{Y}{t^*} \qquad \text{with} \quad \gamma^{e*}(\chi) \equiv \frac{\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{1+\chi}, \tag{21}$$

where $\gamma^{e*}(\chi)$, being positively related to χ, is the share of aggregate income net of aggregate operating profits that is linked to the host country's emissions tax payments.[44]

We find an increase in E^* in response to the rise in t, despite the overall decline in Y. Hence, emissions leak via the possibility of firms to offshore. The emission-intensive production is shifted from the source to the host country in reaction to the unilateral emissions tax increase. While

[42] Average productivity $\bar{\varphi}^d$ unambiguously decreases at low levels of χ, while there are opposing effects at higher levels of χ. Simulations suggest that the negative effect dominates, such that $d\bar{\varphi}^d/dt < 0$ holds.

[43] Accordingly, at very low levels of χ, both $\bar{i}^d$ and $(1-\chi)M$ may rise in t. Yet, E declines due to a reduced $\bar{y}^d$.

[44] We defer the derivation of E^* and its components to Appendix A.12.

plausible and in itself not a new finding, this effect of (positive) carbon leakage is fundamentally different in comparable models of trade in final goods with heterogeneous firms (cf. Egger et al., 2021b). These models feature negative emissions leakage originating from a reduced market size of the reforming country, which translates into reduced production and, hence, lower emissions in the non-reforming country. Here, by contrast, due to the possibility to avoid the emissions tax increase through offshoring, emissions are leaked to the non-reforming country. The mode of globalisation matters.

The rise in aggregate emissions in the host country is driven by the increase in the mass of offshoring firms, see Proposition 1, amid a decline in average emissions of offshoring firms.[45] Newly offshoring firms are less productive and thus smaller than incumbent offshorers, leading to a decline in the average output of offshoring firms $d\bar{y}^o/dt < 0$. The decline in average output and average emissions is equivalent to the tax effect on purely domestic firms. By contrast, a closer inspection of the effect on average emissions intensity shows crucial differences between purely domestic and offshoring firms. To this end, we derive

$$\bar{i}^o = \tau \cdot \alpha(1-\eta)\left(\frac{w^*}{t^*}\right)^{1-\alpha} \cdot \left[\frac{w}{\tau\left(w^*\right)^{1-\alpha}\left(t^*\right)^{\alpha}}\right]^{\eta} \cdot \frac{1}{\bar{\varphi}^o}, \qquad (22)$$

which is only indirectly affected by the source country's environmental policy reform. Amid an increase in offshoring, labor demand in the host country rises, leading to an increase in the host country wage. Accordingly, the *effective emissions tax* in the host country, t^*/w^*, decreases. Generating emissions abroad gets relatively cheaper; emissions per unit of the routine task's output consequently increase (differently to domestic firms). Yet, there is an opposing channel working via the reduced differences in wages. Offshoring firms rely to a larger extent on the emissions-free non-routine task (similarly to domestic firms). Finally, offshoring firms become less productive on average. Accounting for these effects in general equilibrium, in Appendix A.12, we show that the average emissions intensity of offshoring firms unambiguously increases in t. Offshorers become dirtier, on average.

Depending on the initial difference in the emissions taxes across countries, this increase might well take place at an equilibrium where the average emissions intensity of offshoring firms is lower than that of purely domestic firms, i.e. at $\bar{i}^o < \bar{i}^d$. This finding extends Lemma 1 making use of the fact that $\bar{\varphi}^o > \bar{\varphi}^d$ from self-selection of the most productive firms into offshoring. We can summarize this result as:

[45] Similar to Eq. (19), we can decompose aggregate emissions in the host country as $E^* = \chi M\bar{e}^o = \chi M\bar{y}^o\bar{i}^o$.

Lemma 2. *The average emissions intensity of offshoring firms increases in the source country's emissions tax. This can occur at a level lower than the average emission intensity of purely domestic firms.*

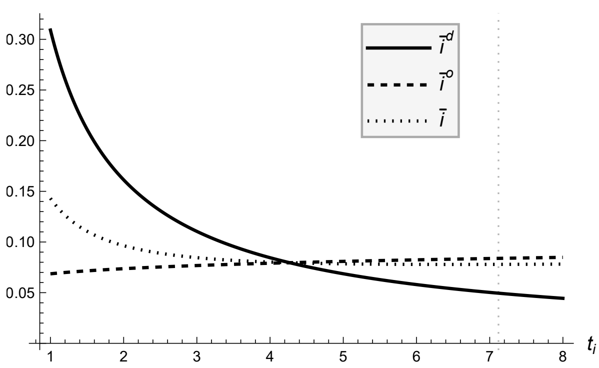
With opposing tax-induced changes in aggregate emissions in the source country and the host country, it is *ex ante* unclear how the unilateral environmental policy reform affects global aggregate emissions, $E^W \equiv E + E^*$. Remarkably, we find that emissions leakage can exceed 100% and, hence, outweigh the decline in domestic emissions. Let us first establish this finding and determine, second, the underlying driving forces. Making use of Eqs. (18) and (21), we derive global emissions as

$$E^W = \left(1 + \frac{E^*}{E}\right) E \qquad \text{with} \quad \frac{E^*}{E} = \frac{\chi + \chi^{\frac{k-\sigma+1}{k}}}{1 - \chi^{\frac{k-\sigma+1}{k}}} \frac{t}{t^*}, \tag{23}$$

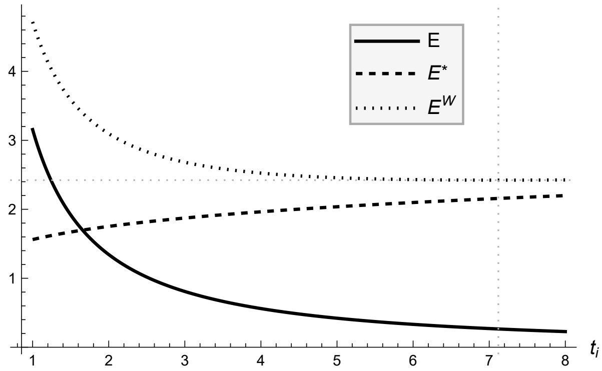
where, quite intuitively, the ratio of host country's to sources country's emissions, E^*/E, positively depends on the share of offshoring and on the ratio of source to host countries' emissions taxes. Hence, aggregate emissions shift to the host country in response to an increase in the source country's emissions tax, $d(E^*/E)/dt > 0$. This effect opposes the tax-induced decline in domestic emissions, $dE/dt < 0$, while the relative strength of both drivers determines the impact on global emissions.

From Eq. (23) it follows that the shift of emissions to the host country crucially depends on the initial level of χ. At low levels of χ, the environmental policy reform causes production inputs to be relocated towards (very few) relatively low emission-intensive offshoring firms. In this scenario, this type of across-firm relocation lowers global aggregate emissions levels. On the contrary, at high levels of χ, resources are shifted towards many relatively high emissions-intensive offshoring firms. In this case, across-firm relocation can raise aggregate emissions. As χ is endogenous and increasing in t, there is a threshold level of t that induces a sufficiently high level of offshoring such that global emissions actually rise. This threshold level positively depends on transport costs τ, which structurally reduce χ (cf. Egger et al., 2015).

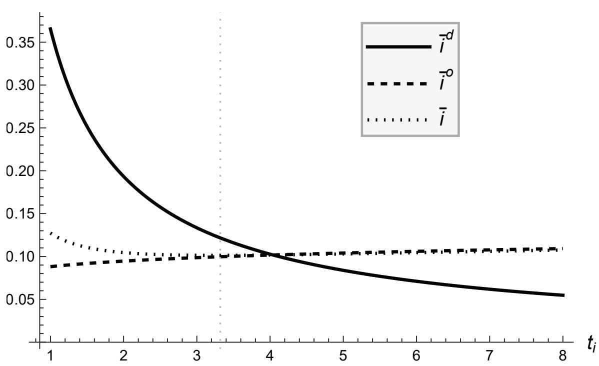
Figure 2 presents numerical simulations to illustrate this argument. The upper part of the figure shows a case with relatively low levels of χ (scenario "low χ"), whereas the lower part shows a scenario with relatively high levels of χ (scenario "high χ"). Parameter assumptions are identical across scenarios, except for the value of τ, with higher transport costs in scenario "low χ". On the left side of the figure, i.e. in Figures 2a and 2c, we show how average emissions intensity levels (of purely domestic, offshoring, and all active firms) relate to t. On the right side of the figure, i.e. in Figures 2b and 2d, we depict the level of aggregate emissions (in the source, host, and both countries) for a given t.



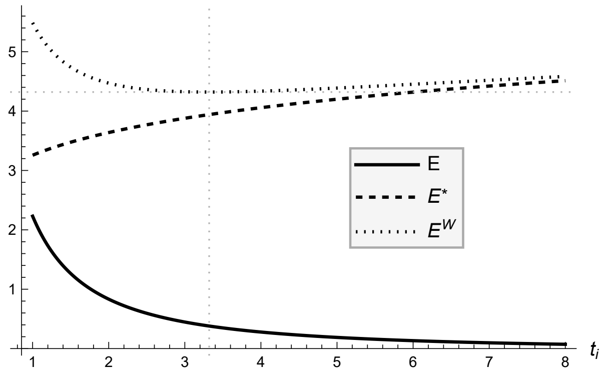
(a) Average emissions intensities - scenario "low χ"



(b) Aggregate emissions - scenario "low χ"



(c) Average emissions intensities - scenario "high χ"



(d) Aggregate emissions - scenario "high χ"

Figure 2: Scenario comparison: Average emissions intensities and aggregate emissions.

Note: The assumed parameter values are $\tau = 2.5$ (for scenario "low χ", upper panel), $\tau = 1.2$ (for scenario "high χ", lower panel) and $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$ (for both scenarios). Variable $\bar{i}$ denotes average emissions intensity of all active firms and is calculated as weighted average. The dotted vertical lines show, for each scenario respectively, the emissions tax level that leads to lowest aggregate global emissions.

It is common to both scenarios that M, $\bar{e}^d$ and $\bar{e}^o$ decline in t, throughout.[46] Yet, at some level of the source country's emissions tax, a further increase leads to rising global emissions in both scenarios, implying a leakage rate of more than 100%. While the minimum level of aggregate emissions is reached at $t \approx 7.1$ in scenario "low χ" (see Figure 2b), the minimum is reached already at $t \approx 3.3$ in scenario "high χ" (see Figure 2d). In line with Lemma 2, at this level of t in scenario "high χ", the average emissions intensity of offshoring firms is below that of purely domestic firms.[47]

It is worth exploring the underlying forces. In analogy to Eq. (19), we can express aggregate

[46] Following our discussion above, the tax-induced decline in M implies that χ is always higher than $\tilde{\chi}$. In turn, the decline in average emissions of both domestic and offshoring firms does not depend on the initial equilibrium.

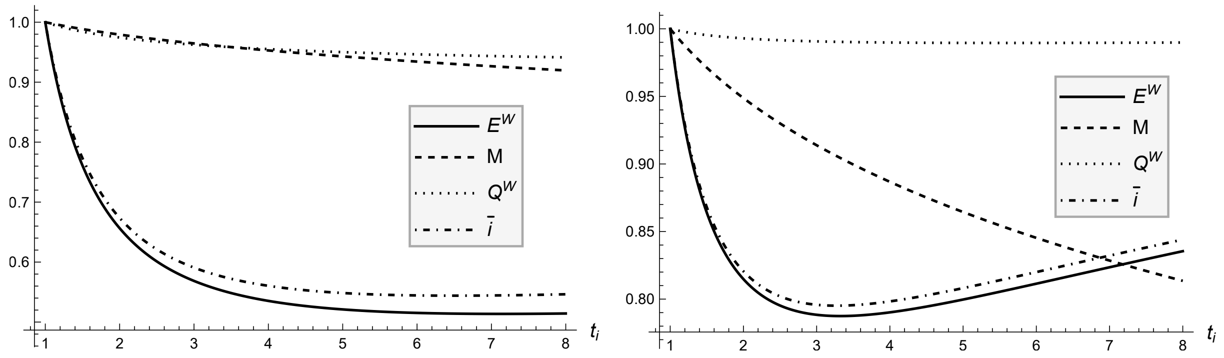
[47] In the Online Appendix S.1, we provide a sensitivity analysis and compare the emissions tax rates that lead to minimum global emissions for different parameter assumptions on η, α, and k. For all constellations, it holds that this emissions tax rate is lower for a more open reforming source country (a lower τ).

emissions as the product of three channels, i.e. the mass of firms, average output $\bar{y}$, and (output-weighted) average emission intensity $\bar{i}$ across all active firms. Accordingly,

$$E^W = M\left[(1-\chi)\bar{y}^d + \chi\bar{y}^o\right]\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right] = M\bar{y}\bar{i}, \tag{24}$$

where global emissions are expressed by the global scale $Q^W \equiv M\bar{y}$ and technique $\bar{i}$ of the intermediate good sector.[48]

Figure 3 illustrates this decomposition along an increase in t for scenario "low χ" in Figure 3a and scenario "high χ" in Figure 3b. All variables are normalized to unity at the initial level of $t = t^* = 1$.



(a) Scenario "low χ"

(b) Scenario "high χ"

Figure 3: Scenario comparison: Decomposition of global emissions.

Note: The assumed parameter values are $\tau = 2.5$ (for scenario "low χ", left panel), $\tau = 1.2$ (for scenario "high χ", right panel) and $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$ (for both scenarios). All illustrated variables are normalized to unity at the level of $t = t^* = 1$.

Remarkably, in both scenarios the change in aggregate emissions tracks the technique effect very closely, while, by contrast, the scale effect only plays a negligible role. It is, hence, the change in the average emissions intensity that crucially determines the overall environmental impact of the unilateral environmental policy reform. This technique effect relies on a complex mix of across-firm and within-firm effects, with differences between incumbent domestic firms, incumbent offshoring firms and firms that change their status.

Accordingly, tax-induced changes in the composition of producers and their production technology determines whether the global production becomes cleaner or dirtier. Throughout, we observe the concentration on fewer but larger active firms.[49] With a rise in the emissions tax

[48] With our definition of $\bar{i}$, we link emissions to the (physical) output of all intermediates Q^W. There is a vital difference to the aggregate production of the final good Y, whose production exhibits external returns to scale.
[49] Since Q^W is the product of M and $\bar{y}$, the latter must increase at a similar rate as the former declines to keep the scale largely unchanged.

ratio, a larger share of those firms produces in the host country and is, hence, reliant on the host country's factor prices. Accordingly, the unilateral increase in the emissions tax induces only the (declining) group of the relatively small active firms to become cleaner, while the decline in the host country's effective emissions tax induces the (increasing) group of the relatively large active firms to become dirtier. For a given level of openness, a rise in t leads to a decline in global emissions as long as the initial difference in emissions taxes is small. For a sufficiently large difference in emissions taxes, however, the unilateral environmental policy reform becomes environmentally damaging.[50]

Our finding of a potential increase in global emissions in response to unilateral environmental policy, thereby complements the work of Babiker (2005). In a model of oligopolistic competition, Babiker (2005) finds leakage rates of up to 130%. This is due to a rise in overall production from increasing returns to scale. Our result of a potential leakage rate exceeding 100%, by contrast, relies on a tax induced rise of the global average emissions intensity. A scale effect is not the driver of this outcome.[51] We summarize our findings as follows:

Proposition 4. *A unilateral increase in the source country's emissions tax leads to an increase in aggregate emissions in the host country. At a sufficiently high tax rate, emissions leakage can more than offset the reduction in the source country's aggregate emissions, leading to a rise in global aggregate emissions. The more open the reforming country, the lower the threshold tax rate where increases lead to emissions leakage exceeding 100%.*

4.4 Effect on aggregate income and income inequality

Our model allows us to analyze the distributional effects of the unilateral environmental policy reform from different perspectives. First, we compare the impact on aggregate income of the two countries. Second, we develop a measure of between-country inequality. Finally, we analyze the policy impact on the within-country income inequality in the reforming source country.

Aggregate income of the source country consists of operating profits (joint income of managers and offshoring consultants), worker income and emissions tax revenues, $I = \bar{\pi}M + wL + tE$.

[50] In the Online Appendix, we develop two alternative decomposition approaches. First, in S.2, we abstract from the firm perspective and focus on the worldwide production of the emissions-intensive routine task. This confirms the decisive role of the global average emissions-intensity, jointly determined by the world composition of routine task production and the individual country's average emissions intensities. Second, in S.3, we focus on the underlying firm-level drivers behind the change in average firm emissions. This shows the decline in emissions of purely domestic firms from both scale and technique, a partial effect on global emissions, which is eventually dominated by the tax-induced shift towards dirtier offshoring firms.

[51] On the contrary, for both scenarios illustrated in Figure 3, we find a (small) decline in the global scale around the respective minimum of aggregate global emissions. This opposes the net increase in global emissions.

By contrast, aggregate income of the host country only originates from the latter two sources, $I^* = w^* N^* + t^* E^*$. Jointly, the two add up to world aggregate income, which equals aggregate output of the final good at a price normalized to one, i.e. $I + I^* = Y$. Making use of the implied income share of the assumed CES and Cobb-Douglas production functions in Eqs. (1) and (3),[52] we can rewrite aggregate income of the two countries as

$$I = \left[\frac{1}{\sigma} + \frac{\sigma - 1}{\sigma}\left(\gamma^l + \gamma^e\right)\right] Y \qquad \text{and} \qquad I^* = \left[\frac{\sigma - 1}{\sigma}\left(\gamma^{l*} + \gamma^{e*}\right)\right] Y. \tag{25}$$

With formal derivations deferred to Appendix A.13, we get the following inequality chain in the income effects induced by the unilateral environmental policy reform:

$$\frac{dI}{dt} < \frac{dY}{dt} < 0 < \frac{dI^*}{dt}. \tag{26}$$

While world aggregate income Y declines due to the tax distortion of the economy,[53] this decline is not evenly spread across the two countries. Since more firms relocate parts of their production process abroad, a higher share of income accrues to the host country of offshoring. Indeed, I^* rises not only relative to total income, but in absolute terms. This rise is due to enhanced production raising w^* (for a given N^*) and E^* (for a given t^*). It necessarily follows that aggregate income in the source country is reduced by more than world aggregate income. This convergence in aggregate income across countries translates into the convergence of average individual income.

Comparing the group of wage-earners only, thereby accounting for the uniform per capita transfer of emissions tax revenues, we define between-country inequality as $\Xi \equiv (w + b)/(w^* + b^*)$.[54] As we show in Appendix A.14, between-country inequality negatively depends on the level of offshoring and hence on t, i.e. $d\Xi/dt < 0$. A unilateral increase in the emissions tax harms the domestic workers relative to the non-reforming country's workers due to the shift of production and the following decrease in local labor demand. As a consequence, wage rates converge.

[52] Given monopolistic competition and constant markup-pricing, operating profits of each firm equals the share $1/\sigma$ of total revenues, while the share $(\sigma - 1)/\sigma$ is spent on worker remuneration and emissions tax payments. This aggregates to the final goods revenues, where γ^l and γ^e (and the respective variables for the host country γ^{l*} and γ^{e*}) describe the distribution of aggregate production factor income.

[53] We find that the possibility of offshoring in the open economy attenuates the decline in aggregate economic activity. While newly offshoring firms increase their production making use of cheaper foreign production inputs (an indirect effect of t on Y via χ), the dominant effect is a reform-induced decline in the intermediate production of purely domestic firms following the cost increase (a direct effect of t on Y). Hence, the net negative effect on Y.

[54] While $w + b$ equals the minimum income level in the source country by virtue of the occupational choice condition Eq. (11), $w^* + b^*$ equals the average income level in the host country of offshoring.

In the source country, heterogeneity in managerial ability and individual occupational choices translate into income inequality: individuals are either paid the economy-wide wage rate or earn firm-profits; all receive the transfer b. We define the source country's inter-group inequality as a relative measure of average secondary managerial income (i.e. post-transfer managerial income net of labor income for the offshoring consultant) and post-transfer income of workers and offshoring consultants: $\Theta \equiv (\bar{\pi} - \chi w + b)/(w + b)$. We find a tax-induced increase in inter-group inequality, i.e. $d\Theta/dt > 0$ (see Appendix A.15). This result is driven by two factors. First, by a decline in the uniform transfer b, which workers benefit more than proportionally from relative to managers with higher incomes. Second, by an increase in the ratio of profits to wage income. Managers loose relatively less, capturing the tax avoidance possibility of offshoring firms on the one side and the downward pressure on source country's wage due to production relocation on the other side.[55]

We can summarize our findings as follows:

Proposition 5. *A unilateral increase in the source country's emissions tax leads to a convergence in aggregate income level and wages between the source and host country. Within the reforming source country, inter-group inequality increases.*

5 Extension: Environmental policy reform with BCA

We now extent the model to investigate the impact of a border carbon adjustment mechanism. By imposing a BCA, a country tracks whether imported goods are exposed to equally high emissions prices. If not, the difference is charged at the border; emissions prices are adjusted.

We can transfer this idea into our model by redefining the host country's emissions tax. Suppose the initial difference in emissions taxes is $\hat{t} \equiv t - t^* \geq 0$. Then, in the presence of a BCA, the induced emissions tax in the host country becomes $\tilde{t}^* \equiv t^* + \hat{t} = t$, while, importantly, tax revenues of $\hat{t}E^*$ are collected by the source country.[56]

The following analysis encompasses two distinct policy interventions. First, in Section 5.1, we investigate the implementation of a BCA in an initial offshoring equilibrium with strictly

[55] A similar conclusion can be drawn from investigating the impact of the unilateral emissions tax increase on the source country's Lorenz curve. In Appendix A.15, we derive and plot the Lorenz curve and find an increase in inequality after the environmental policy reform.

[56] In our model, the host country only serves to execute the emissions-intensive routine task, with the entire output being exported. In the following, a BCA is, hence, based on complete carbon pricing of foreign emissions, while we do not account for resource shuffling of foreign products across markets. Moreover, we implicitly assume complete information about the carbon content of trade. Tracking this information has been reported to become a major issue for the EU CBAM. Campolmi et al. (2023) propose a combination of import tariffs and export subsidies as a less complex and more effective alternative to prevent leakage.

tighter environmental regulation in the source country than in the host country, i.e. $t > t^*$.[57] Second, in Section 5.2, we analyse a unilateral emission tax increase of the source country in the presence of a BCA. This analysis is structurally similar to Section 4 and, hence, allows us to highlight the role of BCA in implementing an ambitious environmental policy reform.

5.1 Implementation of BCA

After the implementation of the BCA, purely domestic and offshoring firms face the same emissions tax levels, i.e. $\tilde{t}^* = t$. They adjust to the new costs in choosing their input mix optimally. This translates into an altered *marginal costs savings factor of offshoring* in Eq. (6), which reduces to $\kappa_{BCA} = \left[(1/\tau)\,(w/w^*)^{1-\alpha}\right]^{1-\eta}$. Intuitively, the introduction of the BCA puts an end to the emission tax advantage of offshoring. The incentive for offshoring solely originates from across-country differences in labor costs.

This has two implications. First, controlling for productivity, a firm's emissions intensity is unambiguously smaller if it chooses to become an offshoring firm, see Lemma (1).[58] Second, the least productive offshoring firms re-shore. The new equilibrium with BCA is characterized by a smaller offshoring cost advantage κ and a smaller share of offshoring firms χ. Specifically, the direct reducing BCA-effect on κ via the *labor market constraint* $B(\tau, t, t^*, \chi)$ in Eq. (16) is partly offset by a rise in the relative wage rates w/w^* in the new equilibrium, to also satisfies the *offshoring indifference condition* $A(\chi)$ in Eq. (14). Figure 4 illustrates this new equilibrium from a downward shift of B in response to the implementation of a BCA (the dotted line), compared to the impact of a unilateral environmental policy reform as outlined in Section 4 (the dashed-dotted line).

Aggregate emissions in the host country decline, while there is an increase in aggregate emissions in the source country of offshoring.[59] This is intuitive as the BCA reduces the costs disadvantage for domestic production from $t > t^*$. Production and emissions shift to the source country. Emissions leakage (from the stricter source country's environmental policy) to the host country declines. Overall, the implementation of a BCA lowers global emissions. It does so the more successful, the larger the divergence in initial emissions taxes. This stands in contrast to a unilateral emissions tax rise, which can result into higher global emissions. In this sense, implementing a BCA can be a better suitable climate policy than a unilateral emissions tax rise.

[57] We assume that the post-BCA implementation equilibrium is still characterised by offshoring.

[58] Firms face the same emissions tax rates. Yet, given the differences in wage rates, this translates into different *effective* emissions tax rates: the host country's emissions tax is effectively higher due to the lower wage level.

[59] See Appendix A.16 for this and further derivations related to this subsection.

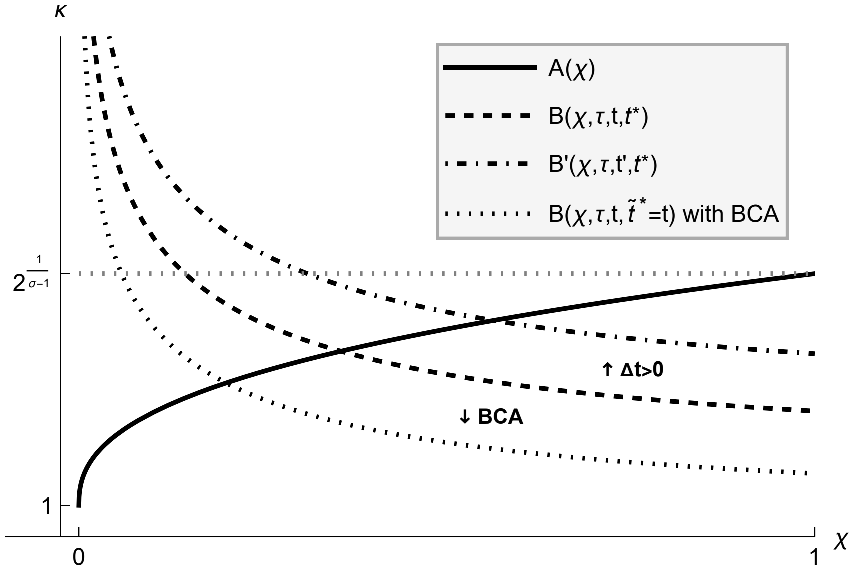


Figure 4: The impact of BCA on the offshoring equilibrium

Alongside the decrease in aggregate global emissions, global income falls. The impact on the income distribution, thereby, depends on the outflow of BCA emissions tax revenues from the host to the source country. We find that the implementation of a BCA increases international inequality: The wage rates between the source country and the host country further diverge (see above); between-country inequality Ξ increases, and the ratio of aggregate income across the two countries, I/I^*, rises. By contrast, we find a decline in the source country's inter-group inequality Θ. It reduces due to the lower profit opportunities of highly able managers (incorporated in the lower χ) and from the additional BCA-related per capita transfer, which particularly benefits the low income group of wage earners.

We can summarize our findings as follows:

Proposition 6. *The introduction of the BCA reduces the host country's cost advantage from less strict environmental policy. In equilibrium, fewer firms offshore. Aggregate emissions rise in the source country but decline in the host country and globally. Income inequality increases across countries but declines within the reforming source country.*

5.2 Unilateral environmental policy reform with BCA

We now explore the effects of a unilateral emissions tax increase in the presence of the BCA. In this context, the unilateral increase in t translates into an identical rise in the relevant emissions tax $\tilde{t}^*$ in the host country.[60] Hence, by construction, the unilateral environmental policy reform does not lead to differences in the emissions prices that firms face. This is the crucial difference to the analysis of Section 4, affecting our previous findings:

Because of the BCA, the tax increase does neither affect the share of offshoring firms nor the relative wage rates across countries, as it does not give rise to an additional incentive to offshore.[61] As a direct consequence, the factor allocation in the source country does not change with the unilateral environmental policy reform. Individuals do not respond by changing their occupational choice. It also implies that the composition of firms and, hence, the average productivity of purely domestic and offshoring firms remain the same. Accordingly, Proposition 2 does not hold under BCA.

Aggregate emissions in the source country decline. This is as postulated in Proposition 3 but associated with different underlying channels. In particular, the reduction is due to within-firm adjustments with labor being reallocated from production to abatement and not related to firms shifting production abroad. There is no opposing average productivity effect at work. Purely domestic firms become unambiguously cleaner, on average.

In the absence of an offshore-induced surge in the host country's labor demand, the wage rate w^* falls. This general equilibrium effect magnifies the BCA-induced emission tax increase in the host country, leading to within-firm adjustments from emission-intensive production to abatement. Hence, the host country's aggregate emissions unambiguously fall due to a negative scale and technique effect. Consequently, emissions leakage turns negative and global aggregate emissions decrease in response to the source country's emissions tax increase.[62] This contrasts Proposition 4.

We find that global income shrinks, while the aggregate income levels of the two countries diverge, with I/I^* rising amid a decline in I^*. On the one hand, this carries forward our findings of a BCA's implementation. Here, however, without any changes in χ, the income divergence only originates from the transfer of emissions tax revenues from the host to the source country. On the other hand, we observe a crucial difference to a unilateral environmental policy reform absent a BCA. In that case, income levels converge with a rise in the host country's income level, see Eq. (26). Accordingly, our findings emphasise the BCA's potential adverse economic

[60] Specifically, for our analysis we use $dt = d\hat{t} = d\tilde{t}^* > dt^* = 0$ at an initial offshoring equilibrium with $t = \tilde{t}^* \geq t^*$. The following analysis is structurally different to analysing a joint emissions tax increase. For distributional effects, it matters that the host country does not itself collect the entire emissions tax revenues.

[61] In Figure 4, both the *labor market constraint* B (the dotted line) and the the *offshoring indifference condition* A (the straight line) remain unaffected in the presence of a BCA. Hence, there is no change in the equilibrium outcomes of κ and χ. Accordingly, Proposition 1 does not hold under BCA.

[62] See Appendix A.17 for this and further derivations related to this subsection.

effects on the Global South.

We can summarize the results as follows.

Proposition 7. *In conjunction with a BCA, a unilateral increase in the source country's emissions tax implies an identical rise in the effective host country's emission tax. This leaves the share of offshoring firms, factor allocation and firm composition unaffected. Within-firm reallocation of labor towards abatement reduces emissions intensities of all firms and aggregate emissions in both countries. In the presence of the BCA, aggregate income in the host country declines in response to the environmental policy reform and across-country income diverges.*

6 Conclusions

This paper investigates the effects of a unilateral environmental policy reform in the presence of offshoring. The analysis builds on an asymmetric two-country general equilibrium model with heterogeneous firms. Firm heterogeneity originates from an occupational choice mechanism of individuals who differ in managerial ability. In the source country of offshoring, manager-owned firms use labor to perform non-routine and routine tasks, where only the routine task generates emissions and can be offshored. Differences in wage rates and emissions taxes both constitute an incentive to offshore. Firms self-select into offshoring, while only the most productive firms can afford to offshore parts of their production. Accordingly, offshoring firms can be cleaner than purely domestic firms for two reasons: due to their higher productivity and if wage – rather than emissions tax – differences predominantly determine offshoring.

A unilateral increase in the source country's emissions tax incentivizes more firms to offshore. Notably, the most productive, and thus least emissions-intensive, purely domestic firms start to offshore. All firms adjust their production input mix due to the direct emissions tax effect (in the source country) and general equilibrium effects via the labor markets (in both countries). A rise in the source country's *effective* emissions tax – the tax-wage ratio, which determines the level of emissions abatement – reduces emissions per output for incumbent purely domestic firms. By contrast, a lower *effective* emissions tax in the host country, due to an induced increase in the wage rate, raises the emissions intensity of offshoring firms' routine task. These within-firm effects, joint with changes in the composition of firms, affect emissions, income, and inequality in both countries.

Accordingly, the unilateral increase in the emissions tax reduces aggregate emissions in the source country, while aggregate emissions in the host country increase. We highlight a non-monotonic effect on global emissions: With world emissions falling to a minimum and rising thereafter, a unilateral emissions tax increase eventually leads to a leakage rate of more than 100%. Notably, with many firms offshoring, this turning point is reached even with smaller emissions tax differences. Thus, the consequences of an environmental policy reform crucially depend on the initial degree of trade openness of the reforming country. The finding of a net increase in global emissions sharply contrasts with canonical exporting frameworks with heterogeneous firms, which provide a rationale for negative emissions leakage (Egger et al., 2021a). Hence, the mode of globalization is crucial for the impact of unilateral environmental policy in an open economy. Our result thereby complements Babiker (2005) who finds emissions leakage of more than 100% in the presence of increasing returns to scale. By contrast, we highlight a crucial role of the tax-induced change in the (global) average emissions intensity against the backdrop of a, by and large, unchanged scale of production. Firm heterogeneity in emissions-intensity joint with location-specific firm decisions are the underlying forces.

Our findings highlight the well-known externality problem of unilateral policies in the context of globalization and point towards the need for greater North-South coordination. While regulating transboundary pollution is an inherently difficult task (cf. Barrett, 2005), BCA has been discussed as an accompanying measure to a unilateral environmental policy reform. We highlight that in the presence of BCA, a unilateral rise in the emissions tax no longer gives an additional incentive to offshore. Both purely domestic and offshoring firms are affected by an increase in the *effective* emissions taxes they face and adjust their production processes accordingly. Emissions leakage becomes negative. Remarkably, controlling for productivity, offshoring firms are induced to produce less emissions-intensively than purely domestic firms in the reforming country. This is due to the higher *effective* emissions tax in the host country of offshoring given a lower wage but same emissions tax rate. Furthermore, we show how implementing a BCA can reduce inequality in the reforming country, while it leads to the divergence of aggregate income across countries. Hence, in conjunction with BCA, stricter unilateral environmental policy can effectively reduce global emissions, at the costs of rising international inequality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

A Appendix

A.1 Emissions abatement

We follow Copeland and Taylor (2003) in specifying the emissions-generating process and the abatement technology by two assumptions. First, we assume

$$x^r = l^r \xi, \tag{A.1}$$

where $\xi \in (0;1)$ is the (endogenous) share of l^r that is employed in the production process, while the share $1-\xi$ is devoted to emissions abatement. Second, we assume that emissions are generated as

$$e = \left(\frac{\xi}{\beta}\right)^{\frac{1}{\alpha}} l^r \qquad \text{with} \quad \beta \equiv (1-\alpha)^{-(1-\alpha)}\alpha^{-\alpha}. \tag{A.2}$$

Solving Eq. (A.2) for ξ and inserting into Eq. (A.1) yields Eq. (4) in the main text.

A.2 Derivation of marginal costs

A.2.1 Purely domestic firm

For simplicity, we assume that a purely domestic firm directly employs labor to execute the two tasks and to abate emissions. The firm producing variety v then faces costs of $wl^{dn}(v) + wl^{dr}(v) + te^d(v)$. Cost minimization subject to the production technology from Eqs. (3) and (4) gives the optimal factor demands:

$$l^{dn}(v) = \frac{\eta}{\varphi(v)}\left(\frac{t}{w}\right)^{(1-\eta)\alpha} y^d(v) \tag{A.3}$$

$$l^{dr}(v) = \frac{(1-\eta)(1-\alpha)}{\varphi(v)}\left(\frac{t}{w}\right)^{(1-\eta)\alpha} y^d(v) \tag{A.4}$$

$$e^d(v) = \frac{(1-\eta)\alpha}{\varphi(v)}\left(\frac{w}{t}\right)^{1-(1-\eta)\alpha} y^d(v). \tag{A.5}$$

It follows the respective cost function:

$$C^d(v) = \frac{\left(t^\alpha w^{1-\alpha}\right)^{1-\eta} w^\eta}{\varphi(v)} y^d(v). \tag{A.6}$$

By means of Eqs. (A.2), (A.4) and (A.5), we can solve for the share ξ of routine task labor employment that is used for production:

$$\xi(v) = \beta\left[\frac{e^d(v)}{l^{dr}(v)}\right]^\alpha = \frac{1}{1-\alpha}\left(\frac{w}{t}\right)^\alpha. \tag{A.7}$$

Accordingly, the share of routine task labor allotted to production increases in w and α, while it decreases t.

A.2.2 Offshoring firm

Assuming that an offshoring firm directly employs labor to execute the non-routine task, it minimizes its costs of $wl^{on}(v) + \tau p^{r*} x^{or}(v)$ subject to the production technology from Eq. (3).

Cost-minimizing input demands are given by

$$l^{on}(v) = \frac{\eta}{\varphi(v)} \left(\frac{\tau p^{r*}}{w}\right)^{1-\eta} y^o(v) \qquad \text{and} \quad x^{or}(v) = \frac{(1-\eta)}{\varphi(v)} \left(\frac{w}{\tau p^{r*}}\right)^{\eta} y^o(v), \tag{A.8}$$

while the cost function of the offshoring firm is derived as:

$$C^o(v) = \frac{(\tau p^{r*})^{1-\eta}\, w^{\eta}}{\varphi(v)} y^o(v). \tag{A.9}$$

In order to derive p^{r*}, we turn to the host country. Given production technology in Eq. (4), minimization of the production costs of $w^* l^{r*} + t^* e^*$ yields the following cost minimizing inputs

$$l^{r*} = (1-\alpha) \left(\frac{t^*}{w^*}\right)^{\alpha} x^{r*} \qquad \text{and} \quad e^* = \alpha \left(\frac{w^*}{t^*}\right)^{1-\alpha} x^{r*} \tag{A.10}$$

and cost function:

$$C^* = (t^*)^{\alpha} (w^*)^{1-\alpha} x^{r*}. \tag{A.11}$$

Due to assumed perfect competition, the offshored routine task output's price corresponds to marginal costs, i.e. $p^{r*} = (t^*)^{\alpha}(w^*)^{1-\alpha}$, and is used to derive Eq. (6) in the main text.

A.3 Derivation of firm-level emissions and emissions intensities

The optimal emissions level of a purely domestic firm is provided by Eq. (A.5). Accounting for iceberg transport costs, an offshoring firm's (embedded) emissions level is given by τe^*. Using Eqs. (A.8) and (A.10) and the expression for p^{r*} this can be derived as:

$$e^o(\varphi) = \tau \frac{\alpha\,(1-\eta)}{\varphi} \left(\frac{w^*}{t^*}\right)^{1-\alpha} \left(\frac{w}{\tau (t^*)^{\alpha} (w^*)^{(1-\alpha)}}\right)^{\eta} y^o(\varphi). \tag{A.12}$$

While it is well-established in trade models with emitting heterogeneous firms that both a firm's productivity level and the wage-tax ratio play an important role for the emissions of an individual firm (cf. Egger et al., 2021b), it is specific to the offshoring context that also factor price differences across countries are vital.

Dividing firm-level emissions in Eqs. (A.5) and (A.12) by the respective intermediate output level $y^d(\varphi)$ and $y^o(\varphi)$ yields the following expressions for emissions intensities:

$$i^d(\varphi) = \frac{\alpha\,(1-\eta)}{\varphi} \left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \tag{A.13}$$

$$i^o(\varphi) = \tau \frac{\alpha\,(1-\eta)}{\varphi} \left(\frac{w^*}{t^*}\right)^{1-\alpha} \left(\frac{w}{\tau (t^*)^{\alpha} (w^*)^{(1-\alpha)}}\right)^{\eta}. \tag{A.14}$$

Finally, dividing $e^o(\varphi)$ by $e^d(\varphi)$ as well as $i^o(\varphi)$ by $i^d(\varphi)$ yields the ratios as shown as in Eq. (9) in the main text.

A.4 Comparison of labor employment across firm types

In analogy to Eqs. (7) and (8), we compare (direct and indirect) labor employment across firms in four categories: labor employed for the non-routine task, for the routine task, labor employed in the source country, and total labor employment.

We first analyze the role of a firm's offshoring status, hence controlling for productivity. We can express the following ratios of non-routine and routine labor, respectively:[63]

$$\frac{l^{on}(\varphi)}{l^{dn}(\varphi)} = \kappa^{\sigma-1} \qquad \text{and} \qquad \frac{l^{or}(\varphi)}{l^{dr}(\varphi)} = \frac{w}{w^*}\kappa^{\sigma-1}. \tag{A.15}$$

Controlling for productivity, an offshoring firm's demand for non-routine task labor is strictly larger than that of its purely domestic counterpart. An offshoring firm's routine labor demand is strictly larger than routine labor demand of a purely domestic firm for $w/w^* > 1$. As shown below, this holds for our assumed parameter ranges. The (marginal) costs advantage of offshoring (i.e. $\kappa > 1$), translates into higher labor demand, including labor to execute the non-routine task in the source country.

It directly follows that total labor employment (domestic and foreign combined) of an offshoring firm, $l^o(\varphi) \equiv l^{on}(\varphi) + l^{or}(\varphi)$, is larger than total labor employment (only domestic) of its purely domestic counterpart, $l^d(\varphi) \equiv l^{dn}(\varphi)$. In detail, we derive the ratio of total labor employment as:

$$\frac{l^o(\varphi)}{l^d(\varphi)} = \left[\frac{\left[(1-\eta)(1-\alpha)\frac{w}{w^*} + \eta\right]}{1-\alpha(1-\eta)}\right]\kappa^{\sigma-1}, \tag{A.16}$$

where, for $w/w^* > 1$, the term in squared brackets is strictly greater than one, as is the ratio of total labor employment.

Total labor of a purely domestic firm is entirely employed in the source country of offshoring, while an offshoring firm only uses source country's labor for the non-routine task. Forming the ratio of domestic labor employment across firm types yields:

$$\frac{l^{on}(\varphi)}{l^d(\varphi)} = \left[\frac{\eta}{1-\alpha(1-\eta)}\right]\kappa^{\sigma-1}. \tag{A.17}$$

With the term in squared brackets being smaller than one, the comparison hinges on the size of $\kappa > 1$. For $\kappa > [(1-\alpha(1-\eta))/\eta]^{\frac{1}{\sigma-1}} > 1$, it holds that $l^{on}(\varphi)/l^d(\varphi) > 1$.[64] Hence, our framework allows for scenarios in which the offshorer's domestic employment is actually greater than that of its purely domestic counterpart despite sourcing the routine task abroad. Accordingly, at sufficiently high levels of marginal cost savings factor κ, the firm's decision to offshore may raise its labor employment at home.

Finally, we can compare firms of different productivity levels, controlling for their offshoring status. Forming the respective ratios yields:

$$\frac{l^n(\varphi_1)}{l^n(\varphi_2)} = \frac{l^r(\varphi_1)}{l^r(\varphi_2)} = \frac{l\,(\varphi_1)}{l\,(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}, \tag{A.18}$$

where the first expression denotes both the ratio of non-routine task labor and, for offshoring firms, the ratio of source country's labor employment, while the third expression presents both the ratio of total labor employment and, for purely domestic firms, the ratio of source country's labor employment. Accordingly, across all types of labor employment and controlling for firm type, it holds that a highly productive firm employs more labor than a firm of lower productivity.

[63] To this end, we make use of Eqs. (A.3) and (A.8) for non-routine labor and Eqs. (A.4) and (A.10) for routine labor, where for an offshoring firm, (embedded) routine labor demand is obtained by accounting for iceberg transport costs, i.e. $l^{or} \equiv \tau l^{r*}$.

[64] This threshold for κ strictly stays below the upper bound of κ as derived for an interior equilibrium below.

A.5 Derivation of the offshoring equilibrium

A.5.1 Offshoring indifference condition

In order to derive the offshoring indifference condition $A(\chi)$, we re-arrange the indifference condition of the marginal offshoring firm as provided in Eq. (12) and use the occupational choice condition of the marginal manager as provided in Eq. (11):

$$\pi^o(\varphi^o) - \pi^d(\varphi^d) = \pi^d(\varphi^o). \tag{A.19}$$

Dividing both sides of the equation by $\pi^d(\varphi^o)$ and using Eqs. (7), (8), and (13), the expression transforms to:

$$\kappa^{\sigma-1} - \chi^{\frac{\sigma-1}{k}} = 1. \tag{A.20}$$

Solving for κ yields the offshoring indifference condition as provided in Eq. (14).

A.5.2 Labor market constraint

In order to derive the labor market constraint $B(\tau, t, t^*, \chi)$, we need to replace the relative wage rates w/w^* in κ by an expression of χ and parameters, only.

In a first step, we express worker income in both countries as shares of aggregate income. To this end, we acknowledge properties of the CES final goods production function in Eq. (1) and of the nested Cobb-Douglas production technology of the intermediate good in Eqs. (3) and (4). Due to CES, aggregate income is divided into aggregate operating profits with constant share $1/\sigma$ and aggregate remuneration of production factor inputs, i.e. worker income and emissions tax payments, with constant share $(\sigma-1)/\sigma$. In the source country, due to Cobb-Douglas, a share of $(1-\alpha)(1-\eta)$ of purely domestic firms' production factor payments accrues to routine task labor, while a share η of both offshoring and purely domestic firms' production factor payments goes into non-routine task labor. In the host country, labor is employed and remunerated for the routine task, only. Against this background, we can express aggregate worker income in the two countries as:

$$wL = \frac{\sigma-1}{\sigma}\left[((1-\alpha)(1-\eta)+\eta)\int_{\varphi^d}^{\varphi^o} r^d(\varphi)dG(\varphi) + \eta\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi)\right]N \tag{A.21}$$

$$w^*L^* = \frac{\sigma-1}{\sigma}(1-\alpha)(1-\eta)\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi)N. \tag{A.22}$$

We can reformulate Eq. (A.21) by means of $dG(\varphi) = k\varphi^{-(k+1)}$, $r^d(\varphi)/r^d(\varphi^d) = \left(\varphi/\varphi^d\right)^{\sigma-1}$ and $r^o(\varphi)/r^o(\varphi^o) = (\varphi/\varphi^o)^{\sigma-1}$. This yields an expression for the domestic wage rate:

$$w = \gamma^l(\chi)\frac{\sigma-1}{\sigma}\frac{Y}{L} \qquad \text{with} \qquad \gamma^l(\chi) = \frac{1-\alpha(1-\eta)+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}}}{1+\chi} \tag{A.23}$$

being the share of production factor income allotted to the source country's workers. Analogously, we can rewrite Eq. (A.22) by making use of $[1-G(\varphi^o)]/\chi = 1-G(\varphi^d)$, $r^o(\varphi^o) = \sigma\pi^o(\varphi^o)$, $\pi^o(\varphi^o) = (1+\chi^{-(\sigma-1)/k})\pi^d(\varphi^d)$ and $Y/M = \sigma\bar{\pi}$ in order to solve for the host country's wage:

$$w^* = \gamma^{l*}(\chi)\frac{\sigma-1}{\sigma}\frac{Y}{L^*} \qquad \text{with} \qquad \gamma^{l*}(\chi) = \frac{(1-\alpha)(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{1+\chi} \tag{A.24}$$

being the share of aggregate payments to production factors that accrues to workers in the host country. It is straightforward to show that $d\gamma^l/d\chi > 0 > d\gamma^{l*}/d\chi$.[65] With a rise in the level of offshoring, relatively more income is generated in the host country. Jointly, by means of Eqs. (A.23), and (A.24), and recalling that $L^* = N^*$, we can derive the relative wage rate as

$$\frac{w}{w^*} = \frac{\gamma^l}{\gamma^{l*}} \frac{N^*}{L}, \tag{A.25}$$

where in a last step, we need to replace the endogenous variable L.

To this end, we follow Egger et al. (2015) and use Eq. (11) to solve for the equilibrium factor allocation. Operating profits of the marginal firm, on the left hand side of Eq. (11), are a constant fraction of average operating profits, a property implied by the underlying Pareto distribution of managerial abilities. Accordingly,

$$\pi^d(\varphi^d) = \frac{k-\sigma+1}{k} \frac{1}{1+\chi} \bar{\pi} = \frac{k-\sigma+1}{k} \frac{1}{1+\chi} \frac{1}{\sigma} \frac{Y}{M}, \tag{A.26}$$

where the last expression follows from the properties of the CES production function in Eq. (1) as discussed above. Jointly, from Eqs. (11), (A.21) and (A.26), we derive

$$\pi^d(\varphi^d) = w \qquad \Leftrightarrow \qquad \frac{k-\sigma+1}{k} \frac{1}{1+\chi} \frac{1}{\sigma} \frac{Y}{M} = \gamma^l \frac{\sigma-1}{\sigma} \frac{Y}{L}. \tag{A.27}$$

By means of the source country's resource constraint in Eq. (15), we can solve for the equilibrium factor allocation as follows:

$$L = \lambda N \qquad \text{and} \qquad M = \frac{1-\lambda}{1+\chi} N \qquad \text{with} \quad \lambda = \left[1 + \frac{k-\sigma+1}{\gamma^l k(\sigma-1)}\right]^{-1}, \tag{A.28}$$

where λ is the share of workers in the source country's population.

Finally, we can express the relative wage rate as function of χ and parameters. To this end, we make use of Eqs. (A.25) and (A.28) to derive

$$\frac{w}{w^*} = \frac{\gamma^l}{\gamma^{l*}} \frac{N^*}{\lambda N} = \frac{\gamma^l + \frac{k-\sigma+1}{k(\sigma-1)}}{\gamma^{l*}} \frac{N^*}{N}. \tag{A.29}$$

Since $\gamma^l > \gamma^{l*}$ and $k > \sigma$, we can state that $w > w^*$, if N^* is not substantially smaller than N and independent of χ. Eq. (A.29) also reveals that the wage ratio decreases in offshoring.

A.6 Condition for an interior offshoring equilibrium

For an interior offshoring equilibrium, the upward-sloping $A(\chi)$-function and the downward-sloping $B(\tau, t, t^*, \chi)$-function need to intersect within the interval $\chi\ (0,1)$. Accordingly, we obtain the upper bound of κ for an interior offshoring equilibrium from $\lim_{\chi\to 1} B(\tau, t, t^*, \chi) < A(\chi)$. This yields:

$$\tilde{\kappa} \equiv \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha} \left(\frac{(k-\sigma+1) + \eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)} \frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} < 2^{\frac{1}{\sigma-1}}. \tag{A.30}$$

For this condition to hold, τ must not be too small and/or t/t^* not to large, revealing a trade-off in parameter choices. Solving for τ as a function t/t^*, and vice versa, yields the respective

[65] For $\chi \to 0$ (autarky), it holds that $\gamma^l = 1 - \alpha(1-\eta)$ and $\gamma^{l*} = 0$. Approaching the case of all firms offshoring, $\chi \to 1$, it holds that $\gamma^l = \eta$ and $\gamma^{l*} = (1-\alpha)(1-\eta)$. Consequently, it holds that $\gamma^l > \eta > 0.5 > \gamma^{l*}$ given the assumed parameter ranges.

conditions for valid parameter constellations:

$$\tau > 2^{\frac{1}{(1-\sigma)(1-\eta)}} \left(\frac{t}{t^*}\right)^{\alpha} \left(\frac{(k-\sigma+1)+\eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)} \frac{N^*}{N}\right)^{1-\alpha} \tag{A.31}$$

and

$$\frac{t}{t^*} < 2^{\frac{1}{\alpha(\sigma-1)(1-\eta)}} \tau^{\frac{1}{\alpha}} \left(\frac{(1-\eta)(1-\alpha)k(\sigma-1)}{(k-\sigma+1)+\eta k(\sigma-1)} \frac{N}{N^*}\right)^{\frac{1-\alpha}{\alpha}}. \tag{A.32}$$

A.7 Effect on the share of offshoring firms

We make use of Eqs. (14) and (16), the two links between κ and χ, and define the implicit function:

$$\begin{aligned} F(\chi, \tau, t, t^*) &\equiv B(\chi, \tau, t, t^*) - A(\chi) = 0 \qquad (A.33) \\ &= \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{\gamma^l}{\gamma^{l*}}\frac{N^*}{\lambda N}\right)^{1-\alpha}\right]^{1-\eta} - \left(1+\chi^{\frac{\sigma-1}{k}}\right)^{\frac{1}{\sigma-1}} = 0. \end{aligned}$$

Applying the implicit function theorem, we get $d\chi/dt = -(\partial F/\partial t)/(\partial F/\partial \chi) > 0$ with

$$\frac{\partial F}{\partial t} = \alpha(1-\eta)\left(\frac{t}{t^*}\right)^{\alpha(1-\eta)-1} \frac{1}{t^*} \left[\frac{1}{\tau}\left(\frac{\gamma^l}{\gamma^{l*}}\frac{N^*}{\lambda N}\right)^{1-\alpha}\right]^{1-\eta} > 0 \tag{A.34}$$

and

$$\begin{aligned} \frac{\partial F}{\partial \chi} &= (1-\alpha)(1-\eta)\left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta}\left(\frac{\gamma^l}{\gamma^{l*}\lambda}\right)^{-\eta(1-\alpha)-\alpha} \qquad (A.35) \\ &\times \frac{\frac{d\gamma^l}{d\chi}\gamma^{l*} - \frac{d\gamma^{l*}}{d\chi}\left[\gamma^l + \frac{k-\sigma+1}{k(\sigma-1)}\right]}{\left(\gamma^{l*}\right)^2} - \frac{1}{k}\left(1+\chi^{\frac{\sigma-1}{k}}\right)^{\frac{2-\sigma}{\sigma-1}}\chi^{\frac{\sigma-1-k}{k}} < 0, \end{aligned}$$

where the negative sign follows from $d\gamma^l/d\chi < 0$ and $d\gamma^{l*}/d\chi > 0$.

A.8 Effects on the factor allocation

We note that t does not directly affect L and M, see the expressions in Eq. (A.28); all effects run indirectly via χ. Accounting for this, we derive the emissions tax-induced changes in the factor allocation as follows:

$$\frac{dL}{dt} < 0, \qquad \frac{d(1+\chi)M}{dt} > 0, \qquad \frac{d\chi M}{dt} > 0, \qquad \frac{dM}{dt} \lesseqgtr 0, \qquad \frac{d(1-\chi)M}{dt} \lesseqgtr 0. \tag{A.36}$$

The first expression follows from Eq. (A.28) and $d\lambda/d\chi < 0$. The second expression is a direct implication, taking Eq. (15) into account. The third expression is again directly implied by Eq. (A.28) and $d\lambda/d\chi < 0$. The fourth expression shows an ambiguous effect on M. We can (explicitly) solve for a threshold level of χ:

$$\tilde{\chi} = \left[\frac{(k-\sigma+1)(\sigma-1)(1-\eta)(1-\alpha)}{k-\sigma+1+k(\sigma-1)\eta}\right]^{\frac{k}{\sigma-1}} > 0, \tag{A.37}$$

with $dM/dt > 0$ for $\chi < \tilde{\chi}$ and $dM/dt < 0$ for $\chi > \tilde{\chi}$ (cf. Egger et al., 2015). Finally, the fifth expression is a combination of the third and fourth expression as $(1-\chi)M = M - \chi M$. To specify the sign of the tax effect, we (implicitly) solve for a second threshold level of χ:

$$\tilde{\chi}^d = \left[\frac{[(k-\sigma+1)+\chi(\sigma-1)](\sigma-1)(1-\eta)(1-\alpha)}{2[k-\sigma+1+k(\sigma-1)\eta]+k(\sigma-1)(1-\alpha)(1-\eta)}\right]^{\frac{k}{\sigma-1}} > 0, \tag{A.38}$$

where it is straightforward that $\tilde{\chi}^d < \tilde{\chi}$. Accordingly, for $\chi < \tilde{\chi}^d$ it holds that $d(1-\chi)M/dt > 0$, while $d(1-\chi)M/dt < 0$ for $\chi > \tilde{\chi}^d$.

A.9 Decomposition of aggregate source country labor employment

We can decompose source country labor with regard to task and firm type to derive the two insights discussed in the main text.

First, we decompose source country labor into labor employed for the non-routine and the routine task, i.e. $L = L^n + L^{dr}$. All workers performing the non-routine task are necessarily based in the source country, no matter the firm type that employs them: $L^n = L^{dn} + L^{on}$. Equivalent to Eqs. (A.21) and (A.22), we can derive aggregate non-routine task labor from shares in aggregate income. This gives the following expressions:

$$L^n = \frac{\eta k(\sigma-1)N}{k-\sigma+1+\gamma^l k(\sigma-1)}, \qquad L^{dn} = L^n \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1+\chi}, \qquad L^{on} = L^n \frac{\chi^{\frac{k-\sigma+1}{k}}+\chi}{1+\chi}. \tag{A.39}$$

Since $d\gamma^l/d\chi < 0$, it follows that aggregate non-routine task labor increases in t, $dL^n/dt > 0$. Moreover, we find an increase in aggregate employment of non-routine task labor of offshoring firms, while it decreases for purely domestic firms. The increasing effect dominates such that $dL^{on}/dt > -dL^{dn}/dt > 0$. Routine task, in turn, is only conducted in the source country by purely domestic firms. Since $dL^n/dt > 0$ and $dL/dt < 0$, it must hold that $dL^{dr}/dt < 0$.

Second, we decompose source country labor into labor employed by purely domestic firms and offshoring firms, i.e. $L = L^d + L^{on}$. We derived in the first decomposition of this Appendix that purely domestic firms reduce both non-routine and routine task labor. By contrast, offshoring firms increase their non-routine task labor. Hence, $dL^d/dt < 0$, while $dL^{on}/dt > 0$.

Jointly, these results can be summarised as in Eq. (17) in the main text.

A.10 Effect on source country's aggregate emissions

We follow the same strategy based on income shares as in Appendix A.5 to derive aggregate source country's emissions as given by Eq. (18) in the main text. Different to the case of labor income, the revenue share linked to emission tax income originates only from routine task production and only purely domestic firms execute this part of production in the source country:

$$tE = \frac{\sigma-1}{\sigma}\alpha(1-\eta)\int_{\varphi^d}^{\varphi^o} r^d(\varphi)dG(\varphi)N. \tag{A.40}$$

Reformulating yields Eq. (18) in the main text. It directly follows that $d\gamma^e/dt = d\gamma^e/d\chi \cdot d\chi/dt < 0$, since the numerator decreases and the denominator increases in χ. In order to understand the entire effect of t on E, it is essential to express Y as a function of χ and parameters only to derive the response to an increase in t.

To express aggregate output in closed form, we start by linking it to expressions of the marginal firm, beginning with Eq. (2).

$$y^d(\varphi^d) = Yp(\varphi^d)^{-\sigma}. \tag{A.41}$$

Furthermore, we can express the price set by marginal firm, knowing constant mark-up pricing and the marginal costs of the marginal firm from Eq. (A.6):

$$p(\varphi^d) = \left[\frac{\sigma}{\sigma-1}\frac{\left(t^\alpha w^{1-\alpha}\right)^{1-\eta} w^\eta}{\varphi^d}\right]. \tag{A.42}$$

Next, we replace source country wage rate using Eq. (A.27):

$$p(\varphi^d) = \left[\frac{\sigma}{\sigma-1}\frac{t^\alpha}{\varphi^d}\left(\frac{k-\sigma+1}{k}\frac{1}{1+\chi}\frac{1}{\sigma}\frac{Y}{M}\right)^{1-\alpha(1-\eta)}\right]. \tag{A.43}$$

We plug this solution into Eq. (A.41) and use $y^d(\varphi^d) = (\sigma-1)\varphi^d(w/t)^{\alpha(1-\eta)}$ as output of the marginal firm. Solving this for Y gives us:

$$Y = \sigma\left[M(1+\chi)\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}}. \tag{A.44}$$

Using our closed form expressions of M from Eq. (A.28) along with $\varphi^d = (N/M)^{1/k}$ we end at:

$$Y = \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}}[Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left(\frac{1}{t\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}$$
$$\times\left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}}(\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}}. \tag{A.45}$$

The total effect of t on Y is calculated as: $dY/dt = \partial Y/\partial t + \partial Y/\partial\chi \times d\chi/dt$. For the direct effect of t, we get:

$$\frac{\partial Y}{\partial t} = -\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}-1}\frac{1}{t^2}\left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}}$$
$$\times[Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left(\frac{1}{\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}$$
$$\times\left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}}(\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}} < 0. \tag{A.46}$$

For the direct effect of χ we get:

$$\frac{\partial Y}{\partial\chi} = \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}}[Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}$$
$$\times\left(\frac{1}{t\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}}(\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}}$$
$$\times\left[\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)](k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right.$$
$$\left.+\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)]k(\gamma^l-\eta)+k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]$$
$$> 0. \tag{A.47}$$

As expected, offshoring increases aggregate output due to marginal cost savings, while an emission tax increase makes production more costly, hence decreases aggregate output. Put together and extracting Y, we have for the total effect:

$$\begin{aligned}\frac{dY}{dt} &= Y \times \Bigg[-\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\frac{1}{t} \\ &+ \Bigg[\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)](k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]} \\ &+ \frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)]k(\gamma^l-\eta)+k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\Bigg] \times \frac{d\chi}{dt}\Bigg].\end{aligned} \quad \text{(A.48)}$$

To show the sign of the total effect we make use of $d\chi/dt$ with Eqs. (A.34) and (A.35) and set Eq. (A.48) equal to zero. Rearranging (while ignoring Y) gives us:

$$\begin{aligned}&\Bigg\{\Bigg[\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)](k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}}{k(1+\chi)\left(\chi+\chi^{\frac{k-\sigma+1}{k}}\right)[k-\sigma+1+\gamma^l k(\sigma-1)]} \\ &+\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)]k(\gamma^l-\eta)+k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)\left(\chi+\chi^{\frac{k-\sigma+1}{k}}\right)[k-\sigma+1+\gamma^l k(\sigma-1)]}\Bigg]\left(\chi+\chi^{\frac{k-\sigma+1}{k}}\right) \\ &-\Bigg[\frac{(1+\chi)[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)]}{(1+\chi)k[k-\sigma+1+\gamma^l k(\sigma-1)]\left(\chi^{\frac{k-\sigma+1}{k}}+\chi\right)} \\ &\times\frac{[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]}{(1+\chi)k[k-\sigma+1+\gamma^l k(\sigma-1)]\left(\chi^{\frac{k-\sigma+1}{k}}+\chi\right)}\Bigg]\Bigg\}\times B(\chi,\tau,t,t^*) \\ &\gtrless \frac{1}{k}\times A(\chi)\times\frac{1}{\chi^{\frac{k-\sigma+1}{k}}+\chi},\end{aligned} \quad \text{(A.49)}$$

with $A(\chi)$ and $B(\chi,\tau,t,t^*)$ stemming from Eq. (A.33). While the first two rows are positive, the third and fourth are negative. It is easy to see that the third and fourth row are greater than the first and second row because of $(1+\chi) > (\chi+\chi^{(k-\sigma+1)/k})$, while ignoring $k-\sigma+1+\gamma^l k(\sigma-1)$ in the second row. Focusing on this part, we compare it with the right-hand side term. Since in equilibrium both $\kappa-\chi$ conditions intersect, we can cancel out these two terms. So we end for our comparison at:

$$\frac{(k-\sigma+1+\gamma^l k(\sigma-1))\left(\chi^{\frac{k-\sigma+1}{k}}+\chi\right)}{k(1+\chi)(\chi^{\frac{k-\sigma+1}{k}}+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]} \gtrless \frac{1}{k}\frac{1}{\chi^{\frac{k-\sigma+1}{k}}+\chi}. \quad \text{(A.50)}$$

Cancelling out and rearranging leads to:

$$1 \gtrless \frac{1+\chi}{\chi+\chi^{\frac{k-\sigma+1}{k}}}. \quad \text{(A.51)}$$

The right-hand side is decreasing in χ and reaches one when χ approaches its maximum level of one. That means, for all $\chi \in (0,1)$ the left-hand side is smaller than the right-hand side, which means the negative term dominates the positive term. Hence, we have shown that $dY/dt < 0$, from which, together with $d\gamma^e/dt < 0$, directly follows that aggregate source country emissions fall in t, i.e. $dE/dt < 0$.

A.11 Effect on decomposed aggregate domestic emissions

In a first step we analyze the scale effect. To this end, we derive average output and productivity of purely domestic firms. In a second step, to investigate the technique effect, we derive average emission intensity and emissions of purely domestic firms.

A.11.1 Derivation of the scale effect on source country emissions

We start with deriving the average output level of purely domestic firms:

$$\bar{y}^d = \int_{\varphi^d}^{\varphi^o} y^d(\varphi) \frac{g(\varphi)}{G(\varphi^o) - G(\varphi^d)} d\varphi. \tag{A.52}$$

We follow similar steps as in Appendix (A.5.2) to solve the integral and arrive at:

$$\bar{y}^d = \frac{k}{k-\sigma} \frac{(1-\chi^{\frac{k-\sigma}{k}})}{(1-\chi)} y^d(\varphi^d). \tag{A.53}$$

We now derive the inverse of the average productivity level of purely domestic firms by aggregating over all purely domestic firms' productivity level:

$$\frac{1}{\bar{\varphi}^d} = \int_{\varphi^d}^{\varphi^o} \frac{y^d(\varphi)}{\bar{y}^d} \frac{1}{\varphi} \frac{g(\varphi)}{G(\varphi^o) - G(\varphi^d)} d\varphi. \tag{A.54}$$

Rearranging and solving the integral yields:

$$\frac{1}{\bar{\varphi}^d} = \frac{k}{k-\sigma+1} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi} \frac{y^d(\varphi^d)}{\bar{y}^d} \frac{1}{\varphi^d}. \tag{A.55}$$

We make use of Eq. (A.53) for $y^d(\varphi^d)/\bar{y}^d$:

$$\frac{1}{\bar{\varphi}^d} = \frac{k-\sigma}{k-\sigma+1} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}} \frac{1}{\varphi^d}. \tag{A.56}$$

We can use this solution in $y^d(\varphi^d) = (\sigma-1)\varphi^d (w/t)^{\alpha(1-\eta)}$ and plug it into average output domestic firms, Eq. (A.53):

$$\bar{y}^d = \frac{k(\sigma-1)}{k-\sigma+1} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi} \left(\frac{w}{t}\right)^{\alpha(1-\eta)} \bar{\varphi}^d. \tag{A.57}$$

We are now equipped to analyze the scale effect of a emission tax rate increase, referring to the first part of Eq. (19). Using Eq. (A.57) we get:

$$(1-\chi)M\bar{y}^d = (1-\chi)M \frac{k(\sigma-1)}{k-\sigma+1} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi} \left(\frac{w}{t}\right)^{\alpha(1-\eta)} \bar{\varphi}^d. \tag{A.58}$$

Plugging Eq. (A.23) for source country wage into Eq. (A.58), while using Eq. (A.45) for Y as well as Eq. (A.28) for L, we get the closed form solution:

$$
\begin{aligned}
(1-\chi)M\bar{y}^d &= \frac{k(\sigma-1)}{k-\sigma}(k-\sigma+1)^{\frac{k-1}{k}} k^{\frac{\alpha(1-\eta)}{(\sigma-1)(1-\alpha(1-\eta))}} \\
&\times N^{\frac{(k+1)(\sigma-1)(1-\alpha(1-\eta))+k\alpha(1-\eta)}{k(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \\
&\times \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))}{k(\sigma-1)(1-\alpha(1-\eta))}} \left(1-\chi^{\frac{k-\sigma}{k}}\right)(1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}}.
\end{aligned} \tag{A.59}
$$

For the direct effect of the tax rate we get:

$$
\begin{aligned}
\frac{\partial(1-\chi)M\bar{y}^d}{\partial t} &= -\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}-1} \frac{1}{t^2}\frac{k(\sigma-1)}{k-\sigma}(k-\sigma+1)^{\frac{k-1}{k}} k^{\frac{\alpha(1-\eta)}{(\sigma-1)(1-\alpha(1-\eta))}} \\
&\times N^{\frac{(k+1)(\sigma-1)(1-\alpha(1-\eta))+k\alpha(1-\eta)}{k(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \\
&\times \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))}{k(\sigma-1)(1-\alpha(1-\eta))}} \left(1-\chi^{\frac{k-\sigma}{k}}\right)(1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}} < 0.
\end{aligned} \tag{A.60}
$$

The tax increase makes source country production more costly and firms have to reduce output. For the effect of χ we get:

$$
\begin{aligned}
\frac{\partial(1-\chi)M\bar{y}^d}{\partial \chi} &= \left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \frac{k(\sigma-1)}{k-\sigma}(k-\sigma+1)^{\frac{k-1}{k}} k^{\frac{\alpha(1-\eta)}{(\sigma-1)(1-\alpha(1-\eta))}} N^{\frac{(k+1)(\sigma-1)(1-\alpha(1-\eta))+k\alpha(1-\eta)}{k(\sigma-1)(1-\alpha(1-\eta))}} \\
&\times \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))}{k(\sigma-1)(1-\alpha(1-\eta))}} \\
&\times \Bigg[-\frac{k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))}{k(\sigma-1)(1-\alpha(1-\eta))} \\
&\times \frac{\frac{d\gamma^l}{d\chi}k(\sigma-1)}{[k-\sigma+1+\gamma^l k(\sigma-1)]}(1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}}\left(1-\chi^{\frac{k-\sigma}{k}}\right) \\
&+\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}(1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}-1}\left(1-\chi^{\frac{k-\sigma}{k}}\right) - \frac{k-\sigma}{k}\chi^{\frac{k-\sigma}{k}-1}(1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}}\Bigg].
\end{aligned} \tag{A.61}
$$

Because of the non-monotonic effect of χ on the mass of purely domestic firms, the sign of the offshoring effect on the scale of the domestic production is ambiguous. For readability we can ignore the constants and rearrange the term as follows:

$$
\begin{aligned}
\frac{\partial(1-\chi)M\bar{y}^d}{\partial \chi} &= \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k\alpha(1-\eta)-(\sigma-1)}{k(\sigma-1)(1-\alpha(1-\eta))}+1} (1+\chi)^{\frac{\alpha(1-\eta)}{k(1-\alpha(1-\eta))}}\left(1-\chi^{\frac{k-\sigma}{k}}\right) \\
&\Bigg[\frac{[k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))][(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]} \\
&+\frac{\alpha(1-\eta)[k-\sigma+1+\gamma^l k(\sigma-1)]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]} - \frac{k-\sigma}{k}\chi^{\frac{k-\sigma}{k}-1}\Bigg].
\end{aligned} \tag{A.62}
$$

For the total effect we combine partial results and extract the level term:

$$\frac{d(1-\chi)M\bar{y}^d}{dt} = (1-\chi)M\bar{y}^d \times \Bigg[-\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\frac{1}{t}+$$
$$\Bigg[\frac{[k\alpha(1-\eta)-(\sigma-1)+k(\sigma-1)(1-\alpha(1-\eta))][(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$+\frac{\alpha(1-\eta)[k-\sigma+1+\gamma^l k(\sigma-1)]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}-\frac{k-\sigma}{k}\chi^{\frac{k-\sigma}{k}-1}\Bigg]\times\frac{d\chi}{dt}\Bigg]. \tag{A.63}$$

By comparing the positive terms in the second and third row with our calculations for dY/dt in Appendix (A.10), we see that they are smaller. Together with the negative direct effect tax effect (which is equivalent to dY/dt) we can state that $d(1-\chi)M\bar{y}^d < 0$.

A.11.2 Derivation of the technique effect on source emissions

To analyze the technique effect, we continue with deriving average emission intensity of all purely domestic firms. We do this by aggregating over all purely domestic firms' emission intensity levels:

$$\bar{i}^d = \int_{\varphi^d}^{\varphi^o} i^d(\varphi)\frac{y^d(\varphi)}{\bar{y}^d}\frac{g(\varphi)}{G(\varphi^o)-G(\varphi^d)}d\varphi. \tag{A.64}$$

Following the same steps as in Appendix (A.5.2) we solve the integral and get:

$$\bar{i}^d = i^d(\varphi^d)y^d(\varphi^d)\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}\frac{k}{k-\sigma+1}\frac{1}{\bar{y}^d}. \tag{A.65}$$

Inserting the expression for $\bar{y}^d$ from (A.53) yields:

$$\bar{i}^d = i^d(\varphi^d)\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}}\frac{k-\sigma}{k-\sigma+1}. \tag{A.66}$$

We make a stop here and first focus on the emission intensity of the marginal firm. Looking at Eq. (A.13), we follow similar steps as in Appendix (A.11.1) and plug in Eq. (A.23) for source country wage, using Eq. (A.45) for Y as well as Eq. (A.28) for L. Subsequently, we use the link between the mass of managers and the domestic cutoff productivity $\varphi^d = (N/M)^{1/k}$ and Eq. (A.28) again to get closed form solution of the emission intensity of the marginal firm:

$$i^d(\varphi^d) = \alpha(1-\eta)\frac{\sigma-1}{\sigma}\frac{1}{t}\left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right)^{\frac{1}{\sigma-1}}. \tag{A.67}$$

With $d\gamma^l/dt < 0$ it is straightforward that there is a positive indirect effect via χ opposing the negative direct effect of a tax increase. Emissions in the source country become more costly, hence labor is moved from production to abatement, lowering emission intensity. In contrast, more offshoring allows more firms to lower their marginal costs thereby increasing output, labor demand and, finally, source country wage. This effect is accompanied by the non-monotonic adjustment in source country firm composition, captured by the cutoff productivity of the marginal firm. The combination of both is positive. Comparing the term in Eq. (A.67) with the one we know from aggregate output, Eq. (A.45), we see the following: Firstly, the negative direct effect must be stronger and secondly, the positive indirect effect must be smaller. Hence, after tedious calculations we can show that $di^d(\varphi^d)/dt < 0$.

We can continue with the (average) technique effect. Combining Eqs. (A.66) and (A.67) we get:

$$\bar{i}^d = \alpha(1-\eta)\frac{\sigma-1}{\sigma}\frac{1}{t}\left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right)^{\frac{1}{\sigma-1}}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}}\frac{k-\sigma}{k-\sigma+1}. \tag{A.68}$$

We know, there is a negative direct effect from the emission tax, a positive indirect effect of offshoring via an increase in the source country wage rate and an ambiguous effect of offshoring via average productivity of purely domestic firms, known from Proposition 2.

The total effect is given by:

$$\begin{aligned}\frac{d\bar{i}^d}{dt} =& \bar{i}^d \times \left[-\frac{1}{t} + \left[\frac{(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1} + k(\gamma^l-\eta)}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\right.\right.\\ &\left.\left.+\frac{(k-\sigma)\chi^{\frac{k-\sigma}{k}-1}(1-\chi^{\frac{k-\sigma+1}{k}}) - (k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}\left(1-\chi^{\frac{k-\sigma}{k}}\right)}{k\left(1-\chi^{\frac{k-\sigma}{k}}\right)\left(1-\chi^{\frac{k-\sigma+1}{k}}\right)}\right]\times\frac{d\chi}{dt}\right].\end{aligned} \tag{A.69}$$

Following similar steps as in Appendix (A.10) we can express an upper bound threshold $\tilde{\chi}_{\bar{i}d}$ as follows:

$$\tilde{\chi}_{\bar{i}d} = \left[\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\right]^{\frac{k}{\sigma-1}} > 0. \tag{A.70}$$

If $\chi > \tilde{\chi}_{\bar{i}d}$ the emission tax increase leads to a decrease in average emission intensity of purely domestic firms, $d\bar{i}^d/dt < 0$, if $\chi < \tilde{\chi}_{\bar{i}d}$ the effect could be positive. This result is perfectly in line with Proposition 2. First, at high levels of offshoring, the productivity effect of offshoring is positive, thereby magnifying the negative within-firm effect of the emission tax increase. Second, at low levels of offshoring, the productivity effect is negative, thereby dampening the within-firm effect, and, third, at very low levels of offshoring the productivity effect might dominate the negative effect and lead to an increase of average emissions intensity in purely domestic firms.

A.12 Effect on decomposed aggregate host country emissions

Host country aggregate emissions can be derived in a similar way as source country aggregate emissions shown in Appendix (A.10). We aggregate the respective revenue shares of offshoring firms

$$t^*E^* = \frac{\sigma-1}{\sigma}\alpha(1-\eta)\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi)N, \tag{A.71}$$

and rewrite the solution to get Eq. (21) in the main text.

A.12.1 Derivation of the scale effect on host country emissions

The approach is similar to Appendix (A.11.1). We start with deriving the average output level of offshoring firms:

$$\bar{y}^o = \int_{\varphi^o}^{\infty} y^o(\varphi)\frac{g(\varphi)}{1-G(\varphi^o)}d\varphi. \tag{A.72}$$

Solving the integral and using $y^o(\varphi) = y^d(\varphi)\kappa^\sigma$ gives us:

$$\bar{y}^o = y^d(\varphi^d)\frac{k}{k-\sigma}\frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}}. \tag{A.73}$$

We now derive the inverse of the average productivity level of offshoring firms by aggregating over all offshoring firms' productivity level:

$$\frac{1}{\bar{\varphi}^o} = \int_{\varphi^o}^{\infty} \frac{y^o(\varphi)}{\bar{y}^o} \frac{1}{\varphi} \frac{g(\varphi)}{1 - G(\varphi^o)} d\varphi. \tag{A.74}$$

Again, solving the integral and using (A.73) yields:

$$\frac{1}{\bar{\varphi}^o} = \frac{k - \sigma}{k - \sigma + 1} \frac{1}{\varphi^o}. \tag{A.75}$$

As firms start to offshore as a reaction to the emission tax increase, the productivity level of the marginal offshoring firm falls and, hence, the average productivity of offshoring firms falls as well, i.e. $d\bar{\varphi}^o/dt < 0$.

We now plug Eq. (A.75) into Eq. (A.73). Before, we use $y^d(\varphi^d) = (\sigma - 1)\varphi^d (w/t)^{\alpha(1-\eta)}$ and $\varphi^d = \varphi^o \chi^{1/k}$:

$$\bar{y}^o = \frac{k(\sigma - 1)}{k - \sigma + 1} \frac{\left(1 + \chi^{\frac{\sigma-1}{k}}\right)^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma-1}{k}}} \left(\frac{w}{t}\right)^{\alpha(1-\eta)} \bar{\varphi}^o. \tag{A.76}$$

Equipped with this, we now analyze the scale effect of a source country emission tax increase on offshoring production, expressed as:

$$\chi M \bar{y}^o = \chi M \frac{k(\sigma - 1)}{k - \sigma + 1} \frac{\left(1 + \chi^{\frac{\sigma-1}{k}}\right)^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma-1}{k}}} \left(\frac{w}{t}\right)^{\alpha(1-\eta)} \bar{\varphi}^o. \tag{A.77}$$

The effect of a emission tax increase is ambiguous. From Proposition 2 we know that the mass of offshoring firms increases in t, because domestic firms start to offshore. Regarding the average output of offshoring firms, we identify several opposing effect. First, on average, offshoring firms become less productive, because lower productive firms enter the offshoring distribution. Second, production costs in the source country rise, thereby lowering demand and output for all offshoring firms. Third, the marginal cost savings of offshoring increases, allowing offshoring firms to extend their production abroad.

To show the total effect on average output, we make use of the link to average emissions. They can be derived by aggregating emissions of all offshoring firms:

$$\bar{e}^o = \int_{\varphi^o}^{\infty} e^o(\varphi) \frac{g(\varphi)}{1 - G(\varphi^o)} d\varphi. \tag{A.78}$$

Following similar steps as before to solve the integral, we end at:

$$\bar{e}^o = e^d(\varphi^d) \frac{t}{t^*} \frac{1 + \chi^{\frac{\sigma-1}{k}}}{\chi^{\frac{\sigma-1}{k}}} \frac{k}{k - \sigma + 1}. \tag{A.79}$$

Using the link $e^d(\varphi^d) = i^d(\varphi^d) y^d(\varphi^d)$ and plugging in the respective solutions for marginal firm emission intensity and output from cost minimization we get for the average offshoring firm:

$$\bar{e}^o = \frac{k(\sigma - 1)}{k - \sigma + 1} \alpha(1 - \eta) \frac{1 + \chi^{\frac{\sigma-1}{k}}}{\chi^{\frac{\sigma-1}{k}}} \frac{w}{t^*}. \tag{A.80}$$

Since $dw/dt < 0$ and the χ-term is declining in χ as well, it is clear that average offshoring firms' emissions fall in source country emission tax, $d\bar{e}^o/dt < 0$.

Given this result, together with the result regarding the technique effect, i.e. $d\bar{i}^o/dt > 0$ which we will show below, as well as $\bar{e}^o = \bar{y}^o\bar{i}^o$, we can state that average output levels of offshoring firms fall in the source country emission tax, i.e. $d\bar{y}^o/dt < 0$. That means, we have two opposing effects and the total sign of the scale effect on host country emissions remains ambiguous.

A.12.2 Derivation of the technique effect on host country emissions

To analyze the technique effect, we again aggregate emissions intensities of all offshoring firms:

$$\bar{i}^o = \int_{\varphi^o}^{\infty} i^o(\varphi)\frac{y^o(\varphi)}{\bar{y}^o}\frac{g(\varphi)}{1-G(\varphi^o)}d\varphi. \tag{A.81}$$

Similar steps as in previous aggregations reveal that average offshoring firms' emission intensity is linked to the emission intensity of the marginal offshoring firm by Pareto:

$$\bar{i}^o = i^o(\varphi^o)\frac{k-\sigma}{k-\sigma+1}. \tag{A.82}$$

We use the solution for the emission intensity of the marginal firm Eq.(A.67) and transform it to get a closed form solution for the emission intensity of the marginal offshoring firm, with $i^o(\varphi) = i^d(\varphi)t/t^*\kappa^{-1}, i^d(\varphi) = i^d(\varphi^d)(\varphi^d/\varphi)$ and $\chi^{(1/k)}/\varphi^d = 1/\varphi^o$:

$$i^o(\varphi^o) = \alpha(1-\eta)\frac{\sigma-1}{\sigma}\frac{1}{t}\left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right)^{\frac{1}{\sigma-1}}\frac{t}{t^*}\kappa^{-1}\left[\kappa^{\sigma-1}-1\right]^{\frac{1}{\sigma-1}}. \tag{A.83}$$

We can further transform this term:

$$i^o(\varphi^o)^{\sigma-1} = \left[\alpha(1-\eta)\frac{\sigma-1}{\sigma}\frac{1}{t^*}\right]^{\sigma-1}\left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right)\left[1-\frac{1}{\kappa^{\sigma-1}}\right]. \tag{A.84}$$

Since both last two terms increase in χ it is clear that the emission intensity of the marginal offshoring firm increases in the source country emission tax rate, i.e. $di^o(\varphi^o)/dt > 0$. Thus, the average emission intensity of offshoring firms increases as well, i.e. $d\bar{i}^o/dt > 0$. Here, in contrast to Proposition 3, both within-firm adjustments as well as the composition of the offshoring firms work in the same direction. Increased labor demand in the host country lowers the *effective* emission tax, thereby increasing emission intensity for the marginal offshoring firm and on average. The entrance of new offshoring firms at the lower end of the offshoring firms productivity distribution lowers the marginal offshoring firm's cutoff productivity as well as the average productivity of all offshoring firms, thereby raising average emission intensity.

Providing proof to the explanations of the technique effect, we show what happens to the host country wage. Starting point is the solution for the host country wage from Eq. (A.24). While aggregate output Y falls in t, there is an opposing effect coming from the revenue share for host country production worker, which is increasing in t, because a higher share of production is moved to the host country. To calculate the total effect of the tax rate increase on host country wage, we follow the same procedure as for the aggregate output in Appendix (A.10), as the respective solutions are useful for this analysis.

The direct effect of t is given by:

$$\frac{\partial w^*}{\partial t} = -\frac{\sigma-1}{\sigma}Y\left(\gamma^{l*}\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\frac{1}{t}\right) < 0. \tag{A.85}$$

The effect of offshoring is given by:

$$\begin{aligned}\frac{dw^*}{d\chi} =&\frac{\sigma-1}{\sigma}Y\left[\gamma^{l*}\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right.\\&+\left[k(\sigma-1)(1-\alpha(1-\eta))^2+(k-\sigma+1)((1-\alpha(1-\eta))+\gamma^{l*})\right]\\&\left.\times\frac{\left[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{-\frac{\sigma-1}{k}}+k(\gamma^l-\eta)\right]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]>0. \qquad \text{(A.86)}\end{aligned}$$

Consequently, we can write for the total effect:

$$\begin{aligned}\frac{dw^*}{dt} =&\frac{\sigma-1}{\sigma}Y\left[-\gamma^{l*}\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\frac{1}{t}+\left[\gamma^{l*}\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right.\right.\\&+\left[k(\sigma-1)(1-\alpha(1-\eta))^2+(k-\sigma+1)((1-\alpha(1-\eta))+\gamma^{l*})\right]\\&\left.\left.\times\frac{\left[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{-\frac{\sigma-1}{k}}+k(\gamma^l-\eta)\right]}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]\times\frac{d\chi}{dt}\right]. \qquad \text{(A.87)}\end{aligned}$$

We use Eq. (A.33) for $d\chi/dt$ and, again, compare the negative direct effect with the positive offshoring effect. Tedious calculations and the simplification in equilibrium $A(\chi) = B(\chi, t, t^*, \tau)$ lead us to:

$$\begin{aligned}&-\frac{\left(1-\chi^{\frac{k-\sigma+1}{k}}\right)\gamma^{l*}\left[k-\sigma+1+\gamma^l k(\sigma-1)\right]}{k(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]\left(\chi+\chi^{\frac{k-\sigma+1}{k}}\right)}\\&+\frac{\left[k(\sigma-1)[\eta-\alpha(1-\eta)(1-\alpha(1-\eta))]+(k-\sigma+1)\frac{(1-\alpha(1-\eta))\chi+\chi^{\frac{k-\sigma+1}{k}}(1-\alpha)(1-\eta)+\eta}{1+\chi}\right]}{k(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\\&\times\left[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{-\frac{\sigma-1}{k}}+k(\gamma^l-\eta)\right]>0. \qquad \text{(A.88)}\end{aligned}$$

Comparing the parts $k-\sigma+1$ as well as $k(\sigma-1)$ separately with each other, together with our assumptions $\eta > 0,5$, $k > \sigma$ and $k > 1$, reveals that $dw^*/dt > 0$. This completes the discussion of the technique effect for offshoring firms in the main text.

A.13 Derivation of the effect on aggregate income

As shown in Eq. (25), global income Y is allocated to source and host country groups according to their revenue shares. While the revenue share of source country firms is constant, the revenue shares of source (host) country workers and emission tax income negatively (positively) depend on the level of offshoring. We know from Appendix (A.10) that global income falls in the source country's emission tax rate, $dY/dt < 0$.

Regarding aggregate income of the source country, this is magnified by the decrease of the revenue shares for worker and emission tax income, $d\gamma^e/d\chi < 0$ and $d\gamma^l/d\chi < 0$, from which follows that $dI/dt < 0$. An emission tax rate increase in the source country makes production in this country more costly, emissions as input become more expensive, hence firms move production effort to abatement which reduces output. Additionally, the most productive firms move parts of their production to the host country which increases global output, *ceteris paribus*, but decreases the revenue shares for worker and emission tax income in the source country. The effects can be summarized as follows:

$$\frac{dI}{dt} = \left[\frac{1}{\sigma} + \frac{\sigma-1}{\sigma}\left(\gamma^l + \gamma^e\right)\right]\underbrace{\frac{dY}{dt}}_{<0} + \left[\frac{1}{\sigma} + \frac{\sigma-1}{\sigma}\left(\underbrace{\frac{d\gamma^l}{dt}}_{<0} + \underbrace{\frac{d\gamma^e}{dt}}_{<0}\right)\right] Y < 0. \tag{A.89}$$

By contrast, the host country benefits from offshoring since the production shift leads to higher revenue shares spent in the host country. Firms pay higher wages and the emission tax base increases. Although the rise in the source country's emissions tax shrinks global income, we show that the host country overall gains. This is due to the dominating positive effect of the revenue shift. Accordingly,

$$\frac{dI^*}{dt} = \left[\frac{\sigma-1}{\sigma}\left(\gamma^{l*} + \gamma^{e*}\right)\right]\underbrace{\frac{dY}{dt}}_{<0} + \left[\frac{\sigma-1}{\sigma}\left(\underbrace{\frac{d\gamma^{l*}}{dt}}_{>0} + \underbrace{\frac{d\gamma^{e*}}{dt}}_{>0}\right)\right] Y > 0. \tag{A.90}$$

A.14 Derivation of the effect on between-country inequality

In our two country setting we can compare the minimum income in both countries to analyze between-country inequality. In both countries the government collects emission tax income. The same is redistributed via a lump-sum transfer to all individuals in their country. Comparing both post-transfer worker income levels gives the following inequality measure:

$$\Xi = \frac{w+b}{w^*+b^*}. \tag{A.91}$$

It is straightforward to show that $d\Xi/dt < 0$. We know from Appendix (A.5.2) that the wage ratio is falling in t. Furthermore, we observe emission leakage which shifts the emission tax base from source to host country, leading to a decrease of the source country transfer and an increase of the host country transfer. Putting all together, both, wage and transfer channel decrease between-country inequality.

A.15 Source country inequality

A.15.1 Inter-group inequality

First, we look at source country inequality by comparing the post-transfer income of worker (and consultants) and managers. The transfer is linked to budget constraint of the government, stemming from collecting emission tax rate income.

$$\Theta = \frac{\bar{\pi} - \chi w + b}{w+b} \tag{A.92}$$

It is straightforward that inter-group inequality falls in the transfer. Workers benefit more, relatively, from an increasing transfer which captures the redistribution idea. On the other hand, the transfer decreases in the source country emission tax rate. Using our solutions for average profits and wage rate (Eqs. (A.26) and (A.27)), together with setting the transfer zero reveal that managers benefit relatively more from offshoring than workers. Together with the government budget constraint $b = tE/N$ we can rewrite this measure leaving the share of offshoring firms as the only endogenous variable:

$$\Theta = \frac{[k+\chi(\sigma-1)][k-\sigma+1+\gamma^l k(\sigma-1)]+\gamma^e k(\sigma-1)(k-\sigma+1)}{(k-\sigma+1)[k-\sigma+1+\gamma^e k(\sigma-1)+\gamma^l k(\sigma-1)]}. \tag{A.93}$$

Putting all previous thoughts together it is clear that inter-group inequality must rise in source country emission tax rate. Both, the decrease in the transfer and the increase in the wedge between manager and worker non-transfer related income increase the inter-group inequality, hence $d\Theta/dt > 0$.

A.15.2 Economy-wide inequality

To understand economy-wide inequality we look at the Lorenz curve. Since workers and consultants earn the same wage rate, three income groups have to be considered, hence our curve has three parts:

$$Q(\mu;\chi) \equiv \begin{cases} Q_1(\mu;\chi) & \text{if} \quad \mu \in [0, h_1(\chi)) \\ Q_2(\mu;\chi) & \text{if} \quad \mu \in [h_1(\chi), h_2(\chi)) \\ Q_3(\mu;\chi) & \text{if} \quad \mu \in [h_2(\chi), 1]. \end{cases} \tag{A.94}$$

The first part of the curve includes workers and consultants only, $\mu \in [0, h_1(\chi))$, where their share of the population is given by:

$$h_1(\chi) = \lambda + \chi\frac{M}{N}. \tag{A.95}$$

Their income share consists of wage income plus the lump-sum transfer and is given by:

$$\frac{I_1}{I} = \frac{wL + w\chi M + bL + b\chi M}{wL + \bar{\pi}M + bN}, \tag{A.96}$$

leading to the first segment of the curve:

$$Q_1 = \frac{\gamma^e k(\sigma-1)+\gamma^l k(\sigma-1)+(k-\sigma+1)}{\gamma^l k(\sigma-1)+k+\gamma^e k(\sigma-1)}\mu. \tag{A.97}$$

To get the second part, we add income of purely domestic firms to $Q_1(h_1)$. Individuals earning less than or equal $\pi(\bar{\varphi}), \bar{\varphi} \in [\varphi^d, \varphi^o)$ receive:

$$\frac{I_2}{I} = \frac{\Pi(\bar{\varphi}) + bM(\bar{\varphi})}{wL + \bar{\pi}M + bN}. \tag{A.98}$$

The second segment of the curve is given by:

$$Q_2(\mu,\chi) = 1 - \frac{\chi(\sigma-1) + k\left[[1-\mu]\frac{(1+\chi)[(k-\sigma+1)+\gamma^l k(\sigma-1)]}{(k-\sigma+1)}\right]^{\frac{k-\sigma+1}{k}} + (1-\mu)(1+\chi)\gamma^e k(\sigma-1)}{[\gamma^l k(\sigma-1)+k+\gamma^e k(\sigma-1)](1+\chi)}. \tag{A.99}$$

The respective share of all individuals except owners of offshoring firms is equal to:

$$h_2(\chi) = \lambda + \frac{M}{N}. \tag{A.100}$$

To get the third part we add income of all offshoring firms to the previous parts. Firms with a productivity level up to $\bar{\varphi} \in [\varphi^o, \infty)$ earn the following share of total income:

$$\frac{I_3}{I} = \frac{\Pi(\bar{\varphi}) - w(M(\bar{\varphi}) - M(\varphi^o)) + b(M(\bar{\varphi}) - M(\varphi^o))}{wL + \bar{\pi}M + bN}. \tag{A.101}$$

Finally, we can derive the third part of the curve as:

$$\begin{aligned} Q_3(\mu, \chi) =& 1 - \frac{k\left(1 + \chi^{\frac{\sigma+1}{k}}\right)\left[\left((1-\mu)^{\frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}{(k-\sigma+1)}}\right)^{\frac{k-\sigma+1}{k}}\right]}{[\gamma^l k(\sigma+1) + k + \gamma^e k(\sigma-1)](1+\chi)} \\ &+ \frac{(1-\mu)(1+\chi)[k-\sigma+1+k(\sigma-1)(\gamma^l - \gamma^e)]}{[\gamma^l k(\sigma+1) + k + \gamma^e k(\sigma-1)](1+\chi)}. \end{aligned} \tag{A.102}$$

Figure 5 depicts the source country's Lorenz curves for each share μ of the population. The curves are based on the derived income segments Q_1, Q_2 and Q_3 for workers, managers of purely domestic firms and managers of offshoring firms, respectively. The dashed and straight lines illustrate different Lorenz curves resulting from a source country emission tax rate t and t', respectively, with $t < t'$. It can be easily seen that inequality in the source country is larger at a higher level of the emissions tax rate (Lorenz dominance).

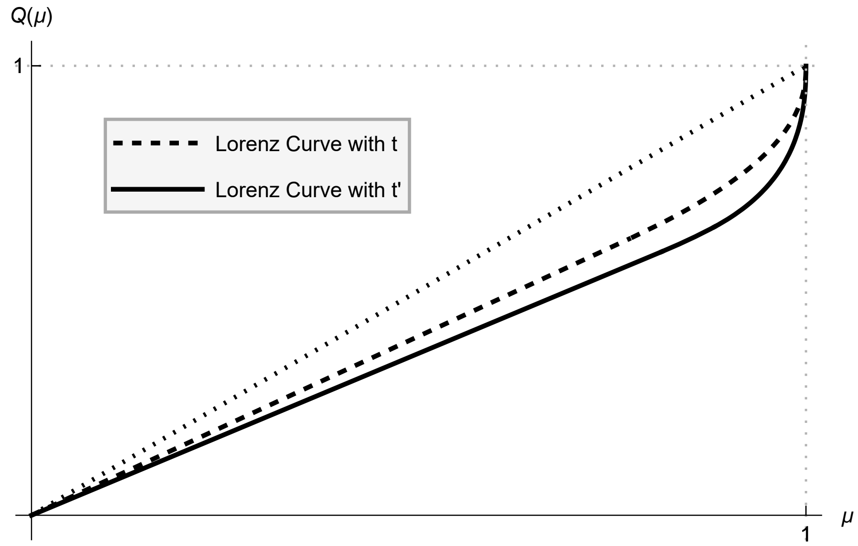


Figure 5: Source country's Lorenz curves for different emissions tax rates with $t < t'$.

A.16 Effects of BCA implementation

A.16.1 Effect on aggregate emissions

We use Eqs. (18) and (21), the definition of global emissions as $E^W = E + E^*$, and insert the expressions for γ^e and γ^{e*}. Accounting for $\tilde{t}^* = t$, this yields:

$$E^W_{BCA} = \alpha(1-\eta) \cdot \frac{1}{t} \cdot \frac{\sigma - 1}{\sigma} Y_{BCA}. \tag{A.103}$$

By forming a ratio of E^W and E^W_{BCA}, we proof that:

$$\frac{E^W}{E^W_{BCA}} = \frac{1 + \frac{t}{t^*}\chi + \left(\frac{t}{t^*} - 1\right)\chi^{\frac{k-\sigma+1}{k}}}{1+\chi} \cdot \frac{Y}{Y_{BCA}} > 1. \tag{A.104}$$

Both the ratio of income shares (first term) and the ratio of global income (second term) are strictly larger than one, given our assumption of $t^* < t$. The latter is affected by the BCA's implementation solely through the reduction in the share of offshoring firms, with $dY/d\chi > 0$ shown in Eq. (A.47).

It directly follows from Eq. (21) that aggregate emissions in the host country decline. All channels work in the same direction: First, γ^{e*} reduces due to the BCA-induced decline in χ. Second, the relevant emissions tax rises from t^* to $\tilde{t}^* = t$. Third, the decline in global income implies a decrease in the global level of production. By contrast, the impact on aggregate emissions in the source country appears ambiguous. The implementation of the BCA induces γ^e to rise and Y to fall. However, making use of our solutions for the effects on E^W and E^* gives a clear-cut answer: Due to the opposing effect via γ^e, E^W decreases less strongly than E^*. Consequently, as E and E^* sum up to E^W, E must increase.

A.16.2 Effect on between-country inequality

With the implementation of the BCA, our between-country inequality measure from Eq. (A.91) adjusts to:

$$\Xi_{BCA} = \frac{w + \frac{tE + \hat{t}E^*}{N}}{w^* + \frac{t^*E^*}{N^*}}. \tag{A.105}$$

$\Xi_{BCA} > \Xi$ must clearly hold for two reasons: Firstly, without any BCA transfer from the host to the source country, Ξ must rise due to BCA-induced $d\chi < 0$. Secondly, this effect is reinforced by the positive BCA transfer $\hat{t}E^*$.

A.16.3 Effect on source country's inter-group inequality

Making use of our measure of inter-group inequality in the source country in Eq. (A.92), we can easily see that $\Theta_{BCA} < \Theta$, with

$$\Theta_{BCA} = \frac{\bar{\pi} - \chi w + \frac{tE + \hat{t}E^*}{N}}{w + \frac{tE + \hat{t}E^*}{N}}. \tag{A.106}$$

First, abstracting from the BCA transfer, the BCA-induced decline χ translates into a decline in Θ, see Eq. (A.93). Second, the BCA's implementation increases the source country's per-capita transfer from additional revenues $\hat{t}E^*$. This particularly comes to the benefit of the low-income group of workers and, hence, reduces Θ.

A.17 Policy reform with BCA

A.17.1 Effect on Emissions

In the presence of a BCA, aggregate emissions in the source country and in the host country, respectively, are denoted by:

$$E_{BCA} = \left[\frac{\gamma^e}{t}\right] \frac{\sigma - 1}{\sigma} Y_{BCA} \quad \text{and} \quad E^*_{BCA} = \left[\frac{\gamma^{e*}}{\tilde{t}^*}\right] \frac{\sigma - 1}{\sigma} Y_{BCA}. \tag{A.107}$$

As the environmental policy reform does not impact the level of offshoring, income shares γ^e and γ^{e*} remain constant. In absence of this channel, the policy reform $dt = d\tilde{t}^* > 0$ lowers E_{BCA} and E^*_{BCA} directly (denominator in squared brackets) as well as indirectly via Y_{BCA}.[66] For the direct negative effect of t on Y, see Eq. (A.46). Hence, global emissions unambiguously decline.

A.17.2 Effect on income

The BCA transfer divides the host country's emissions tax revenues $\gamma^{e*}(\sigma-1)/\sigma Y$, with the share $\hat{t}/\tilde{t}^*$ accruing to the source country and $1-\hat{t}/\tilde{t}^* = t^*/\tilde{t}$ to the host country. Accordingly, updating Eq. (25), aggregate income levels of the two countries are given by:

$$I^* = \frac{\sigma-1}{\sigma}\left[\gamma^{l*} + \left(1-\frac{\hat{t}}{\tilde{t}^*}\right)\gamma^{e*}\right]Y \qquad \text{and} \qquad I = \left[\frac{1}{\sigma} + \frac{\sigma-1}{\sigma}\left(\gamma^l + \gamma^e + \frac{\hat{t}}{\tilde{t}^*}\gamma^{e*}\right)\right]Y, \tag{A.108}$$

which leads to the following income ratio:

$$\frac{I}{I^*} = \frac{\left[\frac{1}{\sigma} + \frac{\sigma-1}{\sigma}\left(\gamma^l + \gamma^e + \frac{\hat{t}}{\tilde{t}^*}\gamma^{e*}\right)\right]}{\frac{\sigma-1}{\sigma}\left[\gamma^{l*} + \left(1-\frac{\hat{t}}{\tilde{t}^*}\right)\gamma^{e*}\right]}. \tag{A.109}$$

Using these expressions, we can make the following statements on the impact of a environmental policy reform with BCA. First, host country aggregate income, I^*, declines. This follows from the decline in aggregate output Y, while the revenue shares γ^{l*} and γ^{e*} remain constant. Furthermore, the share of aggregate emissions tax income remaining in the host country falls, as the respective ratio $t^*/\tilde{t}^*$ declines. Second, the income ratio, I/I^*, increases. This follows from the constant revenue shares γ^l, γ^e, γ^{l*}, and γ^{e*} joint with the increasing share of foreign emissions tax revenues $\hat{t}/\tilde{t}^*$ accruing to the source country. Third, the effect on source country aggregate income, I, is ambiguous and depends on the additionally collected BCA transfer.

A.17.3 Effect on BCA transfer

Total emission tax payments related to host country emissions is divided into one part collected by the source, $\hat{t}E^*$ (BCA transfer) and one part remaining in the host country, t^*E^*. The first part is given by

$$\hat{t}E^* = \frac{\hat{t}}{\tilde{t}^*}\gamma^{e*}\frac{\sigma-1}{\sigma}Y. \tag{A.110}$$

The total effect of an increase in the source country's emissions tax, given $dt = d\tilde{t}^* > 0$, can be expressed as

$$\frac{d\hat{t}E^*}{dt} = \frac{d\frac{\hat{t}}{\tilde{t}^*}}{dt}\gamma^{e*}\frac{\sigma-1}{\sigma}Y + \frac{\hat{t}}{\tilde{t}^*}\gamma^{e*}\frac{\sigma-1}{\sigma}\frac{dY}{dt}. \tag{A.111}$$

Since $d\chi/dt = 0$, dY/dt reduces to the direct tax effect $\partial Y/\partial t$, illustrated in first row of Eq. (A.48). Inserting into our expression gives

$$\frac{d\hat{t}E^*}{dt} = \frac{t^*}{\tilde{t}^{*2}}\gamma^{e*}\frac{\sigma-1}{\sigma}Y - \frac{\hat{t}}{\tilde{t}^*}\gamma^{e*}\frac{\sigma-1}{\sigma}\frac{1}{t}\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}Y. \tag{A.112}$$

[66] If $\gamma^e < \gamma^{e*}$, the policy reform decreases host country aggregate emissions more strongly than source country emissions in absolute terms. This requires χ to be sufficiently large.

Since $\tilde{t}^* = t$, we arrive at $d\hat{t}E^*/dt \gtrless 0 \Leftrightarrow t^*/\hat{t} \gtrless \alpha(1-\eta)/\left[1-\alpha(1-\eta)\right]$. Thus, the effect of an emission tax increase on the BCA transfer is ambiguous. Firstly, it depends on the initial tax differential between the two countries. Secondly, it is determined by the cost shares of emissions and non-routine labor. The transfer increases in t if $t^* > \hat{t}$, implying a rather small initial tax differential. The implications are straightforward: For source country income, I, a rising BCA transfer may offset a fall in global output. Furthermore, an increase in the BCA transfer would reduce the source country's inter-group income inequality, Θ, since workers benefit more than proportionally from an increase in the per-capita transfer. In the absence of a change in the BCA transfer, by contrast, Θ would remain unaffected.

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Online Appendix for

Unilateral Environmental Policy and Offshoring

by Simon J. Bolz, Fabrice Naumann, and Philipp M. Richter

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S.1 Sensitivity analysis

In Table S.1, we compare, for different parameter specifications, the emissions tax rates t that lead to minimum global emissions E^W. Relative to our "base" parameter assumptions, an increase in the cost share of the non-routine task (a higher η) and a decrease in the cost share of emissions (a lower α) lead to higher emissions tax rates that minimize global emissions. A more dispersed managerial ability distribution (a higher k) increases the threshold emissions tax in scenario "low χ", while it is lower in scenario "high χ". In a more open economy (scenario "high χ" relative to scenario "low χ"), for each parameter constellation, the minimum level of E^W is reached at a lower emissions tax rate.

Table S.1: Threshold emissions tax levels, i.e. $argmin(E^W)$, for different parameter choices.

	Base	High η $\eta = 0.8$	Low α $\alpha = 0.15$	High k $k = 20$
Scenario "low χ"	7.12	12.31	14.42	7.58
Scenario "high χ"	3.32	7.55	5.72	3.02

Note: Scenario "low χ" assumes $\tau = 2.5$, while scenario "high χ" uses $\tau = 1.2$. "Base" captures the following parameter values: $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$. Further analyses capture (i) "High η": an increase in the cost share of the non-routine task to $\eta = 0.8$, (ii) "Low α": a decrease in the cost share of emissions in the routine task production to $\alpha = 0.15$, and (iii) "High k": a less dispersed managerial ability distribution resulting from a higher shape parameter $k = 20$.

S.2 Routine task decomposition of global aggregate emissions

Complementing our firm-level perspective in Section 4, we develop an alternative decomposition of global aggregate emissions by focusing on the production of the emissions-intensive routine task. Following Copeland and Taylor (2003, chapter 5.4), we express global emissions as

$$E^W = i^{rd} X^{rd} + i^{ro} X^{ro} = X^r \left[i^{rd} \frac{X^{rd}}{X^r} + i^{ro} \left(1 - \frac{X^{rd}}{X^r} \right) \right], \tag{S.1}$$

where i^{rd} and i^{ro} denote emissions intensities of the routine task in the source and host country, respectively, while $X^r \equiv X^{rd} + X^{ro}$ denotes global production of the routine task with $X^{rd} \equiv (1 -$

$\chi)M \int_{\varphi^d}^{\varphi^o} x^{rd}(\varphi)\, dG/[G(\varphi^o) - G(\varphi^d)]$ and $X^{ro} \equiv \chi M \tau \int_{\varphi^o}^{\infty} x^{ro}(\varphi)\, dG/[1 - G(\varphi^o)]$.[1] Accordingly, the term in squared brackets in Eq. (S.1) is a weighted average of the routine task's emissions intensity, where the weights correspond to the country shares in production. Building on model results from Sections 2 and 3, for the individual parts in Eq. (S.1), we derive the following expressions:

$$i^{rd} = \alpha \left(\frac{w}{t}\right)^{1-\alpha} \tag{S.2}$$

$$i^{ro} = \alpha \left(\frac{w^*}{t^*}\right)^{1-\alpha} \tag{S.3}$$

$$X^{rd} = (1-\chi)M \cdot (1-\eta) \frac{k(\sigma-1)}{k-\sigma+1} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi} \left(\frac{w}{t}\right)^{\alpha} \tag{S.4}$$

$$X^{ro} = \chi M \cdot \tau(1-\eta) \frac{k(\sigma-1)}{k-\sigma+1} \frac{\left(1+\chi^{\frac{\sigma-1}{k}}\right)^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma-1}{k}}} \left(\frac{w}{t}\right)^{\alpha(1-\eta)} \left(\frac{w^*}{t^*}\right)^{\alpha\eta} \left(\frac{w}{\tau w^*}\right)^{\eta}. \tag{S.5}$$

According to Eq. (S.1), changes in global aggregate emissions can originate from three sources: A scale effect from a change in the overall production of the routine task, a world composition effect from the change in the production shares of the two countries, and a technique effect from changes in the two countries' emissions intensities.[2]

Compared to the decomposition approach in the main text in Eq. (24), there are three notable differences: First, Eq. (S.1) takes a country-level perspective and has no explicit firm-level focus. Nevertheless, it is the underlying firm decisions that determine the average emissions intensities and production levels in each country. Second, Eq. (S.1) focuses on the routine task only, rather than on the production of the differentiated intermediate good. Accordingly, it does not account for the substitutability between the routine and non-routine tasks as one mechanism, which affects aggregate emissions. Third, Eq. (S.1) emphasises the world composition in production as separate driver, while Eq. (24) implicitly incorporates this effect in the average emissions intensity of the source country's purely domestic and offshoring firms.

Analytical results from Section 4 show that a unilateral increase in t leads to (i) a decline in i^{rd} (directly and indirectly via w), (ii) an increase in i^{ro} (only indirectly via w^*), (iii) a reduction in overall production X^r, and (iv) a shift in production from the source to the host country. The relative strengths of these effects, and thus the impact on global aggregate emissions, depend on parameter assumptions and particularly the size of the initial reforming country's emissions tax.

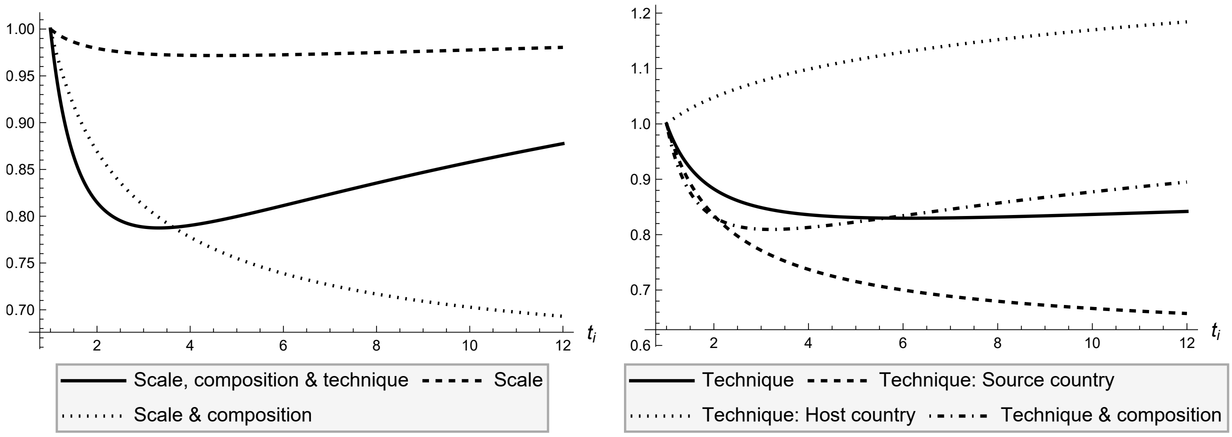
In Figure S.1, we apply the decomposition from Eq. (S.1) to a unilateral rise in t in scenario "high χ". In analogy to Levinson (2009) and Shapiro and Walker (2018) among others, on the left hand side (Figure S.1a), we show the (normalized) aggregate effect on global emissions ("Scale, composition & technique"), the isolated scale effect, and the combination of the scale and composition effects.[3] Around

[1] We account for (iceberg) transport losses in the host country's production of the routine task.

[2] Please note that the definitions of these three partial effects correspond to the employed decomposition and, hence, vary between this section in the Online Appendix and the main text.

[3] While the shown total effect is the same as in Figure 3b, the scale effect deviates from the impact on Q^W as it measures the output of the routine task only, while Q^W equals aggregate output of the differentiated intermediate good.

the minimum of global aggregate emissions, both the scale effect and the combined scale and composition effect cannot explain the policy induced rise in global emissions. Put differently, without changes in the technique of production (i^{rd} and i^{ro}), we would not see that increase. Consistent with our finding in the main text, the scale effect does not play a decisive role on aggregate emissions. By contrast, the change in the global average emissions intensity is crucial – here, a combination of composition and technique as seen in the term in squared brackets in Eq. (S.1).



(a) Decomposition of global emissions

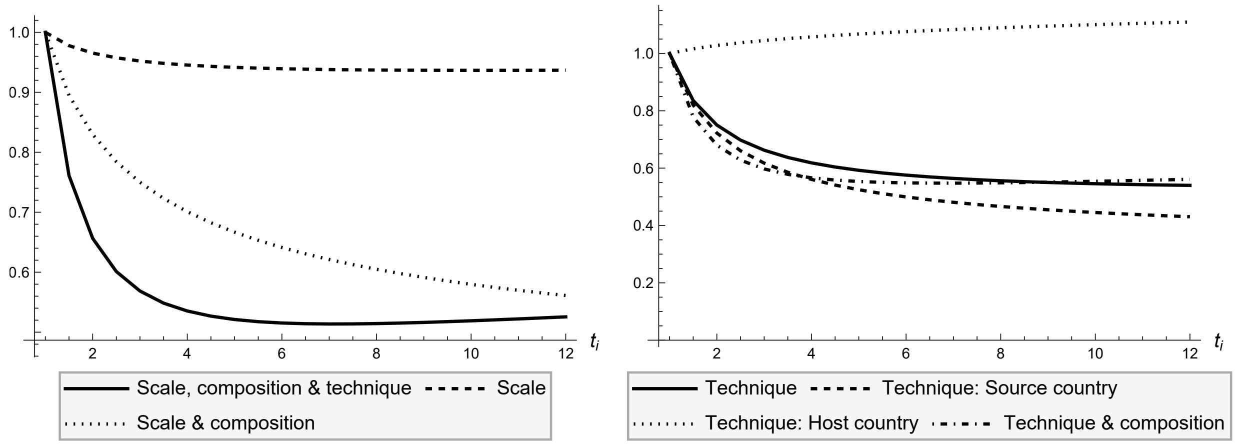
(b) The technique effect decomposed

Figure S.1: Decomposition results for Scenario "high χ".

Note: The assumed parameter values are $\tau = 1.2$, $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$. All illustrated variables are normalized to unity at the level of $t = t^* = 1$.

The right panel of Figure S.1 shows the directly computed technique effect (cf. Levinson, 2015), the combination of technique and composition effects, as well as separate country-specific technique effects, where we vary only the emissions intensity of one country at a time (Figure S.1b). In a seeming contradiction to earlier remarks on the importance of the technique effect for the rise in aggregate emissions (the residuum in Figure S.1a), the technique effect does not increase around the minimum of aggregate emissions, but only at larger levels of t. Given the initial country shares in production, the rise in the host country's emissions intensity does not outweigh the decline in the source country's emissions intensity at lower emissions tax rates. Only the combination of composition and technique – hence, the increasing importance of the more emissions-intensive production in the host country – can explain emissions leakage exceeding 100% at a relatively low emissions tax rate. This finding is, hence, consistent with the firm-level perspective presented in the main text and helps to strengthen this argument.

Figure S.2 applies the decomposition to a unilateral rise in t in scenario "low χ", where we abstain from a detailed discussion (of qualitatively similar results).



(a) Decomposition of global emissions (b) The technique effect decomposed

Figure S.2: Decomposition results for scenario "low χ".

Note: The assumed parameter values are $\tau = 2.5$, $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$. All illustrated variables are normalized to unity at the level of $t = t^* = 1$.

S.3 Alternative firm-level decomposition of global aggregate emissions

Adding to the firm-level perspective in Section 4, we develop an alternative decomposition to assess the underlying drivers of the unilateral environmental policy reform. To this end, we use global emissions as determined by $E^W = M \int_{\varphi^d}^{\infty} e(\varphi)\, dG/[1 - G(\varphi^d)]$, with $e(\varphi) = i(\varphi)y(\varphi)$. Following Forslid et al. (2018), we can decompose this expression to highlight the following six partial effects:

$$
\begin{aligned}
\frac{dE^W}{dt} = \frac{dM}{dt} &\left(\int_{\varphi^d}^{\varphi^o} e^d \, \frac{dG}{1 - G(\varphi^d)} + \int_{\varphi^o}^{\infty} e^o \, \frac{dG}{1 - G(\varphi^d)} \right) \\
&+ M \int_{\varphi^d}^{\varphi^o} \frac{di^d}{dt} y^d \, \frac{dG}{1 - G(\varphi^d)} + M \int_{\varphi^d}^{\varphi^o} i^d \frac{dy^d}{dt} \, \frac{dG}{1 - G(\varphi^d)} \\
&+ M \int_{\varphi^o}^{\infty} \frac{di^o}{dt} y^o \, \frac{dG}{1 - G(\varphi^d)} + M \int_{\varphi^o}^{\infty} i^o \frac{dy^o}{dt} \, \frac{dG}{1 - G(\varphi^d)} \\
&+ M \left\{ \frac{d\varphi^d}{dt} \left[-e^d(\varphi^d) \right] \frac{1}{1 - G(\varphi^d)} + \frac{d\varphi^o}{dt} \left[e^d(\varphi^o) - e^o(\varphi^o) \right] \frac{1}{1 - G(\varphi^d)} \right\}.
\end{aligned}
\tag{S.6}
$$

The first row contains the extensive margin effect, while all other partial effects jointly explain the change in average emissions of all active firms. The second row covers the technique and scale effect for each incumbent purely domestic firm.[4] The third row, in turn, covers these two effects for each incumbent offshoring firm. Finally, last row features the selection effect, denoting the effect of a change in the firm composition across types. Given the mass of active firms, whose change is taken into account by the extensive margin effect, this last effect shows the impact on average emissions from firms entering or exiting, and switching from or to offshoring.

[4] We characterize those firms as incumbents that do not change their status in response to a change in the emissions tax, i.e. we condition on the initial cutoff productivity levels.

Relative to the decomposition approach in the main text in Eq. (24), here, we focus on incumbent firms' changes in scale and technique, joint with a selection effect from firms switching to offshoring. The approach is, hence, more disaggregated and complements the main text's perspective on the aggregate scale and technique effect. Relative to the decomposition in Section S.2 of this Online Appendix, here, we focus on the emissions intensity at the firm-level. Conditional on its productivity level, this additionally incorporates a firm's decision on the substitution between the emissions-intensive routine and emissions-free non-routine task.

We operationalize the decomposition as follows. Our aim is to compare the difference in global emissions between two equilibria, a reference and an after-tax-equilibrium, resulting from a discrete change in the emissions tax from t to t'. In particular, we are interested in emphasizing the underlying channels behind $\triangle E^W \equiv E^{W'} - E^W$. To this end, we need to derive an expression for global aggregate emissions that allows us to separate the six effects described above.

We can denote emissions of a purely domestic firm with productivity φ as:

$$e^d(\varphi) = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \cdot (\sigma-1)\left(\frac{w}{t}\right)^{\alpha(1-\eta)} \left(\varphi^d\right)^{1-\sigma} \cdot \varphi^{\sigma-1}, \tag{S.7}$$

where we make use of Eqs. (A.5) and (A.41) and the link to the marginal firm by means of Eqs. (8) and (10). Similarly, using Eqs. (A.12) and (A.41), we can derive the following expression for the emissions of an offshoring firm with productivity φ:

$$e^o(\varphi) = \alpha(1-\eta)\kappa^{-1}\frac{t}{t^*}\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \cdot (\sigma-1)\kappa^{\sigma}\left(\frac{w}{t}\right)^{\alpha(1-\eta)} \left(\varphi^d\right)^{1-\sigma} \cdot \varphi^{\sigma-1}. \tag{S.8}$$

For an individual firm of each type, emissions are determined by economy-wide variables (factor prices and the market size, which is implicitly incorporated in φ^d in these two expressions) and the firm's productivity level in $\varphi^{\sigma-1}$.

Aggregating across all firms, we derive the following expression for global aggregate emissions:

$$\begin{aligned} E^W = M & \\ \cdot \Bigg\{ & \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \cdot (\sigma-1)\left(\frac{w}{t}\right)^{\alpha(1-\eta)} (\varphi^d)^{1-\sigma} \cdot \frac{k}{k-\sigma+1}\left[\left(\varphi^d\right)^{\sigma-1} - \chi\left(\varphi^o\right)^{\sigma-1}\right] \\ & + \alpha(1-\eta)\kappa^{-1}\frac{t}{t^*}\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \cdot (\sigma-1)\kappa^{\sigma}\left(\frac{w}{t}\right)^{\alpha(1-\eta)} \left(\varphi^d\right)^{1-\sigma} \cdot \frac{k}{k-\sigma+1}\chi\left(\varphi^o\right)^{\sigma-1}\Bigg\}, \end{aligned} \tag{S.9}$$

which we use the following shorthand notation for:

$$E^W = M \cdot \left(\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \mathcal{S}^d + \mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \mathcal{S}^o\right). \tag{S.10}$$

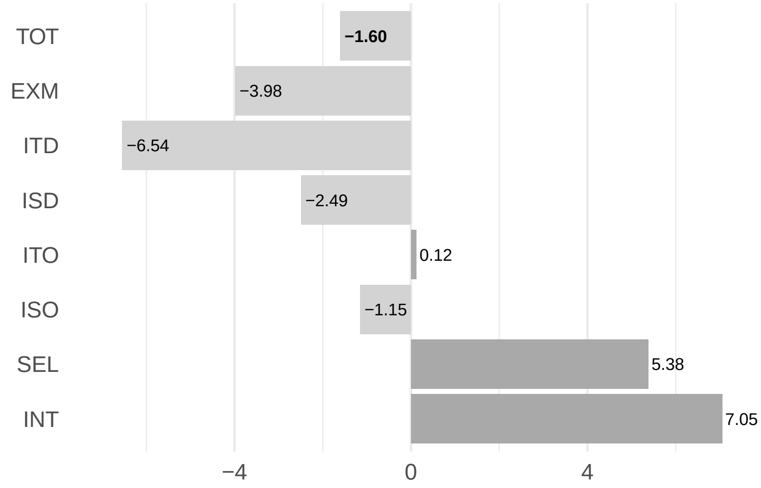
By means of this expressions, we can decompose the change in global aggregate emissions as:

$$\begin{aligned}\triangle E^W =& \triangle M \cdot \left(\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \mathcal{S}^d + \mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \mathcal{S}^o\right) \\ & + M \cdot \triangle\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \mathcal{S}^d + M \cdot \mathcal{I}_t^d \cdot \triangle\mathcal{I}_s^d \cdot \mathcal{S}^d \\ & + M \cdot \triangle\mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \mathcal{S}^o + M \cdot \mathcal{I}_t^o \cdot \triangle\mathcal{I}_s^o \cdot \mathcal{S}^o \\ & + M \cdot \left(\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \triangle\mathcal{S}^d + \mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \triangle\mathcal{S}^o\right) \\ & + \mathcal{INT},\end{aligned} \tag{S.11}$$

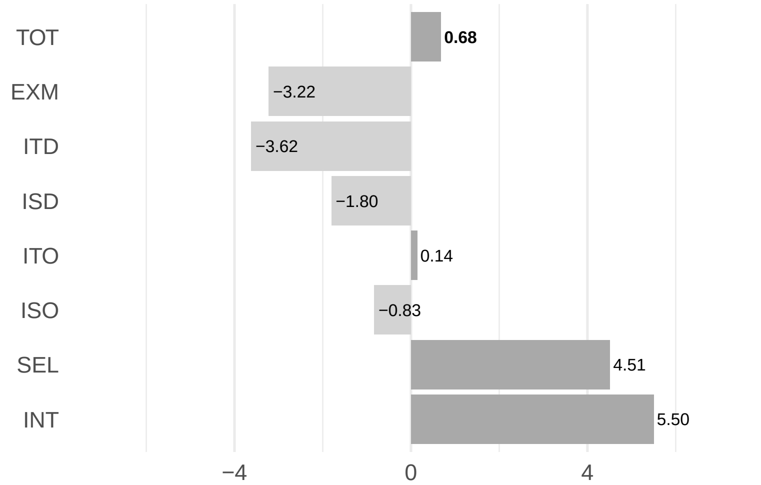
with the six partial effects as presented above, and $\mathcal{INT}$, inspired by Najjar and Cherniwchan (2021), denoting an interaction effect of combined changes:

$$\begin{aligned}\mathcal{INT} = & M \cdot (\triangle\mathcal{I}_t^d \cdot \triangle\mathcal{I}_s^d \cdot \mathcal{S}^d + \triangle\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \triangle\mathcal{S}^d + \mathcal{I}_t^d \cdot \triangle\mathcal{I}_s^d \cdot \triangle\mathcal{S}^d + \triangle\mathcal{I}_t^d \cdot \triangle\mathcal{I}_s^d \cdot \triangle\mathcal{S}^d \\ & + \triangle\mathcal{I}_t^o \cdot \triangle\mathcal{I}_s^o \cdot \mathcal{S}^o + \triangle\mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \triangle\mathcal{S}^o + \mathcal{I}_t^o \cdot \triangle\mathcal{I}_s^o \cdot \triangle\mathcal{S}^o + \triangle\mathcal{I}_t^o \cdot \triangle\mathcal{I}_s^o \cdot \triangle\mathcal{S}^o) \\ & + \triangle M \cdot \triangle\left(\mathcal{I}_t^d \cdot \mathcal{I}_s^d \cdot \mathcal{S}^d + \mathcal{I}_t^o \cdot \mathcal{I}_s^o \cdot \mathcal{S}^o\right).\end{aligned} \tag{S.12}$$

In the following, we employ this decomposition approach to scenario "high χ". Figure S.3 illustrates the six partial effects, plus the interaction effect, that jointly determine the change in global emissions around the minimum level. Specifically, we depict the difference in the outcomes of $t_{min} - 1$, t_{min}, and $t_{min} + 1$, where the minimum in global aggregate emissions is reached at $t \approx 3.3$ in this scenario (see Figure 2d), Our results identify the domestic incumbent's scale effect, the extensive margin effect, and the domestic incumbent's technique effect as the key emissions-reducing drivers. By contrast, the selection and interaction effects are the main drivers that increase emissions. This shows that firms become dirtier by switching from purely domestic production to offshoring. The offshoring incumbent's technique effect is also emissions-increasing but small: due to the shift to the non-routine task, the increase in the routine task's emissions-intensity is partly offset within firms. The emissions-reducing channels, particularly the purely domestic incumbent's technique effect, loose strength in further emissions tax rises and are dominated by the emissions-increasing drivers eventually.



(a) Unilateral Policy Reform: $t^{min} - 1$ to t^{min}



(b) Unilateral Policy Reform: t^{min} to $t^{min} + 1$

Figure S.3: Firm-level decomposition towards minimum global emissions in scenario "high χ".

Note: The assumed parameter values are $\tau = 1.2$, $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $t^* = 1$, and $N = N^* = 10$. The emissions tax that minimizes aggregate global emissions in this scenario is $t^{min} = 3.32$. Presented values are percentages changes relative to global emissions prior to the respective reform. Abbreviations: total effect (TOT); extensive margin effect (EXM); incumbent technique effect of purely domestic firms (ITD); incumbent scale effect of purely domestic firms (ISD); incumbent technique effect of offshoring firms (ITO); incumbent scale effect of offshoring firms (ISO); selection effect (SEL); interaction effect (INT).

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