Offshoring and Environmental Policy: Firm Selection and Distributional Effects*

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Abstract

In this paper, we analyze the impacts of a unilateral environmental policy reform on emissions and income distribution in the context of offshoring. To this end, we set up a general equilibrium model of offshoring with heterogeneous firms. Each individual firm can allocate labor to different production tasks and to the abatement of emissions. Moreover, each firm can decide whether to offshore an emissions-intensive part of the production in order to benefit from lower labor and/or emissions costs abroad. We focus on policy-induced effects on occupation choices, firm selection, emissions (on the firm-level and in aggregate) as well as on income inequality. We identify as key drivers *i)* the marginal cost savings factor of offshoring as well as *ii)* across-country wedges in *effective* emission tax rates – both based on international differentials in exogenous emission prices and endogenous labor cost. We use the model framework to analyse the introduction of a border carbon adjustment.

JEL codes: F18, F12, F15, Q58

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

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1 Introduction

Growing fragmentation of manufacturing and value chains is a major empirical trend connected to globalization. The practice of offshoring, i.e. firm-level relocations of certain production tasks to foreign countries, has been subject to controversial public debates, mainly in the context of distributional and environmental consequences.[1] In particular, in consideration of man-made global warming, the environmental impact of spatial shifts in global production patterns is a highly relevant field of analysis.[2] Besides power generation and transportation, industrial production is the most significant driver of emission generation. Federal governments, as signatories to the Paris Agreement, pledge to sharply reduce national CO_2 emissions, e.g. by raising taxation of carbon-intensive production inputs.[3]

Against this background, the aim of this paper is twofold: First, we analyse the effects of offshoring in the presence of an emission-intensive production process. We thereby aim to fill a research gap that has been identified at the intersection between trade liberalization, offshoring and emissions (cf. Cherniwchan et al., 2017). Second, we seek to analyse how globalisation – precisely, offshoring – impacts the effectiveness and various consequences of environmental and climate policy. Thus, we investigate various effects of (unilateral) environmental policy changes in the context of offshoring. For this purpose, we develop a general equilibrium model with heterogeneous firms given the option to offshore an emissions-intensive part of their production. We thereby extend the offshoring model of Egger et al. (2015) with an emissions-generating process as introduced by Copeland and Taylor (1994). Accordingly, each active firm, which produces a unique variety of an intermediate differentiated good, allocates labor to a non-routine and a routine task as well as to emissions abatement. We assume that conducting the routine task generates emissions but can be offshored at fixed costs, while subsequent importing is subject to variable transport costs. Firms self-select into offshoring if profits can be increased, while we build on occupational choice decisions of heterogeneous agents with different managerial abilities to model the initial firm entry process. Under monopolistic competition, active firms supply their varieties to a final goods sector, whose output is consumed both in the source country and host country of offshoring, which closes the model.

[1] Empirically, it can be seen that a significant share of intermediaries used for final good assembling is imported from abroad. However, there are large across-country differences, e.g. with the US importing around 12% of its intermediates from abroad, while Luxembourg imports a share of as much as around 47% (OECD, 2018)

[2] As the OECD's *Trade in embodied CO_2 ($TECO_2$) database* shows, most OECD countries are net importers of embodied CO_2, causing more consumption-based than production-based carbon emissions. On the contrary, most non OECD-countries, are net exporters of embodied CO_2, causing more production-based than consumption-based emissions. Data also reveals that both wedges have increased since 1995 (OECD, 2021, Chart 2).

[3] Across countries, there is substantial heterogeneity with respect to carbon pricing (cf. OECD, 2021).

Subject to an open economy equilibrium we conduct comparative statics analyses to investigate the nexus between offshoring and the environment. We increase the emissions tax of the source country in order to identify direct and indirect effects of unilateral environmental policy reforms in the context of offshoring. One key finding is that an increase in the source country tax makes offshoring more attractive since it increases production costs in the source country relative to the host country. This result is driven by two determinants of firms' decision to offshore. Next to iceberg trade costs being the offshorer's cost associated to its intermediate imports from abroad, the endogenous wage and exogenous emission tax differentials between source and host country determine the location decision of production. An increase in source country emission tax makes emissions in the source country more expensive compared to the host country. It also changes the $w - t$-ratio, hence the input combination of source country firms. This leads to general equilibrium effects on the wage rate which are non-monotonic and depend on the level of offshoring.[4] Additionally, since some firms will shift production abroad after an increase in the source country emission tax, host country labor demand and, subsequently the local wage rate increase which highlights further general equilibrium effects. The combination of wage and emission tax differential determining the amount of offshoring allows us to look at *Pollution-Haven* settings and beyond.[5]

In the context of final goods trade, various heterogeneous firm frameworks depict mechanisms through which environmental stringency decreases emissions per unit of output: Shapiro and Walker (2018) find that increased "implicit" pollution prices in US manufacturing sharply reduced emission intensity at the product level. LaPlue (2019) outlines how enhanced environmental regulation induces within-firm clean-ups by incentivizing abatement investments. Egger et al. (2021) show how the unilateral increase of environmental taxation enhances productivity in the reforming country but internationally lowers wage rates as well as emission levels. In contrast, firms in our offshoring model react to environmental policy changes in a different way: Confronted with increased domestic emission tax rates, the marginal non-offshoring firm has to increase revenues. It adjusts by allotting more of their labor force to abatement efforts while offshoring firms may decide to relocate parts of their production to less regulated destinations. Thus, as we find, increased environmental stringency does not necessarily reduce aggregate in-

[4] As shown in Section 2, depending on the wage-tax-ratio across countries, the firm's decision to offshore may raise or lower its (embedded) emission intensity. Importantly, offshoring in our setting can decrease emission intensity even in a *Pollution-Haven* scenario.

[5] We discuss a carbon border adjustment mechanism later in the paper and our model also allows for *Anti-Pollution-Haven* scenarios of offshoring in which the (low wage) host country surpasses the (high wage) source country with respect to environmental stringency. In light of empirical evidence this is not the case we focus on.

come in our setting. As the outside option of offshoring becomes more attractive, additional firms are motivated to offshore, raising emission levels in the host country. With respect to aggregate emissions, this leakage effect shows to be strictly dominant in every Pollution-Haven setting.[6] With regards to inequality measures, we can outline some counter-intuitive mechanisms induced by a unilateral emission tax increase in the source country: As it raises the level of offshoring, an emission tax increase in the source country lifts wage levels in the host country, resulting into reduced income inequality between workers of both countries. Simultaneously, due to the increase in the share of offshoring firms, inequality between workers and managers within the source country intensifies. Hence, as we can depict through firm heterogeneity and occupational choice, an environmental policy reform in the source country may be likely to come specially at the expense of its own workers. In an extension to our model, we outline how the source country government can reduce emission leakage and worker income outflow by implementing a CBAM: Under the carbon border adjustment, an emission tax increase no longer raises the level of offshoring, avoiding undesired environmental and distributional effects. However, as the CBAM makes offshoring less attractive, growth of aggregate income and welfare may be attenuated.

Our model framework draws from several features of the trade literature. Our asymmetric two country setting captures the idea of the North-South literature (in the tradition of Feenstra and Hanson, 1997). We borrow from famous work by Grossman and Rossi-Hansberg (2008) and Acemoglu and Autor (2011) since we model production as the combination of routine and non-routine task using the respective taxonomy established by Becker et al. (2013). Furthermore, we add to the still quite scarce literature on offshoring considering firm heterogeneity (e.g. Antras and Helpman, 2004, Antràs et al., 2006, Egger et al., 2019).

Our work is related to several contributions in the field of trade, offshoring and the environment. Developing a model of exporting, emissions and heterogeneous firms, Kreickemeier and Richter (2014) show that trade liberalization – through the reallocation of resources towards more productive firms – decreases emission intensity per unit of output. On the firm-level, Forslid et al. (2018) identify an additional trade-induced effect on emissions: By allowing for firm-specific endogenous abatement investments, they can show that exporting firms, being more productive, adopt a "cleaner" production technology than (less productive) non-exporting firms, providing an additional channel reducing emissions per unit of output.

Turning to trade in intermediates, literature mainly highlights two channels through which

[6] With respect to factor allocation, we identify the well-known counteracting *international relocation* and *productivity* effects at the firm-level (Egger et al., 2015), latter being dominant at low levels and former at high levels of offshoring leading to a non-monotonic aggregate effect on factor allocation.

offshoring firms reduce emissions domestically (cf. Akerman et al., 2021): Firstly, by importing intermediates, firms may be able to relocate particularly dirty stages of their production chain abroad. Secondly, the import of intermediates may improve the firm's technology, raising its productivity and lowering its emissions per unit of output. The first mechanism is possibly motivated by strict environmental standards and regulations in the source country.

This so-called *Pollution Haven Hypothesis* (PHH) does meet significant empirical support: Investigating environmental determinants of outsourcing, Cole et al. (2014) identify an "environmental outsourcing effect", finding that the likelihood of outsourcing increases in firm size and environmental abatement expenditures. Cherniwchan (2017) also provides plant-level evidence for a relocation of emission-intensive steps of production across borders towards weakly regulated destinations. However, the role of environmental stringency as key determinant of the offshoring decision is subject to debate: Antonietti et al. (2017) find that the rigidness of governmental emission regulations does not play a decisive role for the firm-level decision to offshore. When differentiating between northern (highly regulated) and southern (weakly regulated) offshoring destinations, they can uphold a moderately positive effect of domestic environmental rigidity.Looking at potential causes of Japanese firm-level pollution offshoring, Cole et al. (2021) do not see any significant role of cross-country heterogeneity in factor endowments or environmental regulation, but highlight differences in energy costs[7] as decisive factor for the firm-level decision to outsource emission-intensive tasks. Importantly, they also identify firm size as crucial in determining the impact of environmental policy changes on plant-level emissions. Najjar and Cherniwchan (2021) find that most of the plant emission reduction in Canada was driven by firm exit (*selection effect*) on the extensive margin as well as by a decline in firm output (*relocation effect*). On the contrary, the role of firm-level emission intensity reductions (*process effect*) is found to be insignificant w.r.t. the overall clean-up.

In addition to clean-ups due to international relocation of emissions, a second channel for reductions in emission intensity levels is constituted by offshoring-induced productivity gains: Akerman et al. (2021) show that increases in imports of intermediate goods were accompanied by significant reductions in Swedish firm-level carbon intensity. As they show, this clean-up was mainly driven by productivity improvements. The positive link between offshoring and firm productivity finds further support in manufacturing firm-level data from Hungary between 1993 and 2002 (Halpern et al., 2015) as well as from Indonesia between 1991 and 2001 (Amiti and Konings, 2007).

[7] Cole et al. (2021) show that the gap between electricity and fuel prices in Japan and host countries constantly increased over the period of observation. At the same time, the gap in real wages stayed rather constant.

Looking at trade policy from an environmental perspective, challenges of carbon leakage and free-riding arise. In light of international environmental agreements, both phenomena have been thoroughly discussed in literature. Aichele and Felbermayr (2015) find clear carbon leakage evidence following the Kyoto protocol's ratification: Although carbon exports of signatory states declined post ratification, this effect was found to be overcompensated by higher carbon imports from non-signatory states as well as greater carbon intensity to those imports. Investigating the EU Emission Trading Scheme (ETS) with respect to carbon leakage, Dechezleprêtre et al. (2021) find no evidence for significant emission relocation, suggesting that only strong carbon tax differentials could sufficiently incentivize firms to shift their emission-intensive production abroad. Furthermore, leakage of carbon may also occur with respect to energy: Investigating spillover effects of unilateral carbon pricing, McAusland and Najjar (2015) highlight the role of the *energy market leakage effect* as part of carbon leakage: Due to increased carbon prices in the home country, the associated reduction in home energy demand may cause a decline in the world market price of energy, making the extraction and use of energy as well as emission-intensive production more attractive abroad.

Addressing "international externalities" (Markusen, 1975) around emission leakage, there are mainly two policy mechanisms largely discussed in recent literature.[8] Firstly, a *Carbon Border Adjustment Mechanism* (CBAM) aims at eliminating effective cross-national carbon taxation wedges by collecting the respective tax gap while importing (Kuik and Hofkes, 2010). Carbon Border adjustments are an important element of current trade policy, such as the European Green Deal[9]. The effectiveness of a CBAM mechanism is assessed in various aspects: Elliott et al. (2010) show that designing a comprehensive carbon adjustment mechanism may be able to largely offset emission increases in developing countries caused by changes in unilateral taxation. Fischer and Fox (2012) find that the implementation of a complete CBAM mechanisms proves to be significantly more effective than imposing either only carbon import tariffs or export rebates. Additionally, they propose an output-based rebate (OBR)[10] as second best mechanism, performing nearly equally effective w.r.t. leakage reduction, even though being far less harmful in terms of trade and welfare losses. Modelling a three-stage game including carbon price

[8] In section 4, it is shown that the environmental trade policy instrument of unilateral carbon taxation strongly suffers from carbon leakage in the presence of the offshoring possibility.

[9] In 2021, the European Commission adopted plans of a CBAM mechanism. The policy measure will come into effect by 2026 (European Commission, 2021). By pricing carbon imports, the EU seeks to secure its contribution to reduce global emissions as well as prevent 'carbon leakage' and relocation of "carbon-intensive production".

[10] Whereas a CBAM aims to reduce consumption of carbon-intensive imports, the OBR provides financial support to domestic emission- and export-intensive manufacturing firms, aiming to incentivize them to reduce emissions in their production process. (cf. Fischer and Fox, 2012)

competition, also Hecht and Peters (2019) point out that carbon adjustments may reduce leakage significantly, both Cournot and Bertrand competition. However, not only the dimension of leakage reduction is relevant for the assessment of a CBAM mechanism: Böhringer et al. (2018) find border tariffs to be highly cost-ineffective, failing to incentivize emission intensity reductions on the firm-level and unduly burdening developing countries. Larch and Wanner (2017) arrive at similar conclusions, even arguing that the CBAM-induced leakage reduction might be largely offset when accounting for energy market leakage. Böhringer et al. (2017) propose firm-targeted carbon tariffs as possible alternative, motivating the single firm to clean up its production process and minimizing overall welfare losses due to successful firm-level adjustments. Additionally, they strongly suggest to include "indirect emissions", i.e. non-fossil fuel embodied in emissions, such as electricity, in carbon pricing.

Furthermore, especially in light of prominent challenges around international cooperation and free-riding, the proposal of a *Climate Club* (Nordhaus, 2015) adds to the most relevant sets of policy mechanisms: Forming a climate coalition, a group of governments can encourage global climate cooperation by enforcing trade penalties against non-members. Farrokhi and Lashkaripour (2021) aim to compare these two environmental trade policy mechanisms with respect to effectiveness. They associate major shortcomings with respect to the practical implementation of carbon border adjustment mechanisms.[11] In contrast, they find that strong global emission reductions could be attained by a climate coalition whose initial set of members is sufficiently large.[12] Kortum and Weisbach (2021) propose a comprehensive supply-side oriented environmental taxation scheme comprising *i)* an energy extraction tax, *ii)* an import tax on (intermediate) goods and energy as well as *iii)* an export subsidy on energy and weakly emission-intensive goods. They further highlight the importance of considering energy supply for environmental policy.

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

[11] Due to imperfect information, carbon border taxation rates cannot be determined on the basis of each firm's individual emission intensity. Instead, taxation at the border targets average emission intensity at the industry-level. This fails to incentivize the single intermediary exporting firm to scale up investments in abatement.

[12] This condition reflects the outsider's trade-off between incurring trade penalties imposed by the coalition as well as being obliged to impose carbon taxes at a higher level than unilaterally optimal.

2 The model setup

2.1 Basic model structure

At the heart of our model, 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 only input. It does not generate emissions. By contrast, the production of intermediates, based on the performance of two tasks, generates emissions. 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 tasks and emissions abatement, either exclusively produces domestically or offshores part of the production to a second country.[13]

Each of the two countries is populated by an exogenous mass of agents, N in the source and N^* in the host country of offshoring, respectively. Importantly, in our asymmetric two-country setup, only agents in the source country can choose their occupation and are heterogeneous with respect to their managerial ability, which is Pareto distributed with lower bound of one and shape parameter k: $G(\varphi) = 1 - \varphi^{-k}$. For the sake of tractability, in the host country of offshoring only routine tasks can be performed, while 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 final goods being shipped in one direction in exchange for the output of offshored routine tasks being shipped in the other direction. In the following, we indicate expressions for the host country of offshoring with an asterisk.

2.2 The final goods sector

Following Ethier (1982) and Matusz (1996), we define final goods output as a CES-aggregate of differentiated intermediate goods $y(v)$:[14]

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

[13] For our conceptual understanding, we follow Grossman and Rossi-Hansberg (2008) who consider offshoring as international displacement of tasks "either within or beyond the boundaries" of the firm (p. 1981). From this perspective, regardless of the specific organizational structure, the term "offshoring" includes geographical relocation of production both within the same company (in-house) and to external suppliers (foreign outsourcing).

[14] Egger et al. (2015) characterise this case as one of strong external increasing returns to scale.

where V denotes the set of available varieties of the intermediate good with $\sigma \in (1, k)$ being the elasticity of substitution across those. Final output Y is used as numéraire and its price is normalised to unity. Profit maximisation under assumed perfect competition leads to the demand for each intermediate variety v as

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

which positively depends on aggregate income (of both countries) and negatively on the variety's own price.

2.3 The intermediate goods sector

In contrast to the perfectly competitive final goods sector, firms in the intermediate goods sector operate under monopolistic competition, each producing a unique variety v of the differentiated intermediate good. Each firm is run by an entrepreneur of specific managerial ability φ, which directly translates into firm productivity. Each entrepreneur decides on worker employment, on offshoring activity, and on the production of her variety v.

2.3.1 Production technology and optimal firm behaviour

We specify the production technology as

$$y = \varphi \left(\frac{l^n}{\eta}\right)^{\eta} \left(\frac{x^r}{1-\eta}\right)^{1-\eta} \qquad \text{with} \quad \eta \in (0, 1), \tag{3}$$

where l^n denotes labor that is allotted to administration-related non-routine task activities (denoted by superscript n), while x^r denotes the output of a routine task (denoted by superscript r).

We assume that the routine task generates emissions. It can be conducted domestically or offshored producing a homogeneous good from the same technology independently of the production location:

$$x^r = l^r \xi, \tag{4}$$

where l^r denotes labor that is allotted to the routine task with $\xi \in (0; 1)$ being the (endogenous) share of l^r employed in the production process, while the share $1 - \xi$ is devoted to emissions abatement.

Accordingly, as in Acemoglu and Autor (2011) and Egger et al. (2015), labor is allotted to a non-routine task and a routine task,[15] while, in addition, in our framework it can also be used to reduce emissions. Following Copeland and Taylor (2003), we specify the emissions-generating process as

$$e = \left(\frac{\xi}{\beta}\right)^{\frac{1}{\alpha}} l^r \qquad \text{with} \quad \beta \equiv (1-\alpha)^{-(1-\alpha)}\alpha^{-\alpha}, \tag{5}$$

where $\alpha \in (0,1)$ will turn out to be the costs share of emissions in the production of the routine task (see below). Solving Eq. (5) for ξ and inserting into Eq. (4) yields:

$$x^r = \beta\,(e)^{\alpha}\,(l^r)^{1-\alpha}\,. \tag{6}$$

Accordingly, and as common in the literature (e.g. Copeland and Taylor, 1994; Shapiro and Walker, 2018; Egger et al., 2021), we treat emissions as an input factor in the production process, where it follows from Eq. (5) that the effectiveness of emissions abatement marginally declines. Jointly, Eqs. (3) and (6) yield a nested Cobb-Douglas production function.

We are now equipped to specify the optimal behaviour of non-offshoring and offshoring firms.

Taking factor prices exogenously, each non-offshoring firm minimizes her costs, $wl^n(v) + wl^r(v) + te(v)$, subject to technology given in Eqs. (3)-(6), where workers employed in both the routine and non-routine tasks are paid the economy-wide wage rate w, while the generation of emissions is costly due to a tax $t > 0$ per unit of emissions. As formally shown in Appendix A.1.1, this yields constant marginal costs of a non-offshoring firm as

$$c^d(v) = \left[\left(\frac{t}{w}\right)^{\alpha}\right]^{1-\eta} \frac{w}{\varphi(v)}. \tag{7}$$

Accordingly, marginal costs increase both in the wage rate and the emissions tax, while they decrease in the firm-specific productivity level.

An offshoring firm, in turn, shifts the production of the emissions-intensive routine task to the other country and uses imported good $x^r(v)$ in the production process. It employs domestic workers for the non-routine task at wage w and buys the offshored input at price p^r. We assume iceberg transport costs τ for international shipments. Hence, in order to use $x^r(v)$ units in the production process, $\tau x^r(v)$ units need to be purchased. As formally shown in Appendix A.1.2,

[15] 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.

the technology-constraint minimization of production costs, $wl^n(v) + p^r \tau x^r(v)$, yields marginal costs of an offshoring firm as

$$c^o(v) = \left(\frac{\tau p^r}{w}\right)^{1-\eta} \frac{w}{\varphi(v)}. \tag{8}$$

The imported routine task's output is produced abroad by a host country firm with the same technology from Eq. (6) that domestic firms have access to, but using foreign labour, generating emissions abroad, and, hence, accounting for foreign factor prices w^* and $t^* \in (0; t]$.[16] Under assumed perfect competition, the host country firm offers its product at marginal costs, i.e. at $p^r = (t^*)^\alpha (w^*)^{1-\alpha}$ as formally shown in Appendix A.1.3.

Let us now express the difference in marginal costs of a firm with productivity φ in case of offshoring or solely producing domestically. Only if there is an incentive to offshore from marginal costs savings, the particular firm would do so. Accordingly, we express a marginal cost savings factor of offshoring, denoted by κ, from dividing Eq. (7) by Eq. (8):

$$\kappa \equiv \frac{c^d(v)}{c^o(v)} = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^\alpha \left(\frac{w}{w^*}\right)^{1-\alpha}\right]^{1-\eta}, \tag{9}$$

where the last expression follows from replacing p^r.[17] Only for $\kappa > 1$, an offshoring equilibrium materialises. Note that κ incorporates two incentives to offshore: *i.)* an across-country wage gap and *ii.)* an across-country environmental tax differential. Hence, the decision to offshore can either be driven by lower wages in the host country, by a less stringent environmental policy in the host country, or by both. By contrast, transport costs τ work in the opposite direction and reduce the incentive to offshore. Importantly, emissions taxes t and t^* are exogenous model parameters, while wages w and w^* are endogenous and, hence, adjusting to changes in environmental policy, for instance.

Equipped with these insights, and noting that in our setting, firms in the intermediate goods sector charge a constant markup $\sigma/(\sigma - 1) > 1$ over marginal costs,[18] we can finally express the dependence of the price, output and operating profits of a particular firm on its offshoring status:

$$\frac{p^o(v)}{p^d(v)} = \kappa^{-1}, \qquad \frac{y^o(v)}{y^d(v)} = \kappa^\sigma \qquad \text{and} \qquad \frac{\pi^o(v)}{\pi^d(v)} = \kappa^{\sigma-1}. \tag{10}$$

[16] We, hence, restrict the model to the empirically plausible case that the emissions tax of the host country of offshoring cannot exceed that of the source country.
[17] This is a generalisation of Eq. (4) in Egger et al. (2015), which it collapses to in the special case of $\alpha \to 0$.
[18] This follows from the constant price elasticity of demand in Eq. (2) and the assumed monopolistic competition.

Accordingly, in case of deciding to offshore (see Section 3 on the selection mechanism), a firm can offer its variety at a lower price and still earn higher operating profits.

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

$$\frac{p(\varphi_1)}{p(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{-1}, \qquad \frac{y(\varphi_1)}{y(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma} \qquad \text{and} \qquad \frac{\pi(\varphi_1)}{\pi(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}. \tag{11}$$

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

2.3.2 Firm-level emissions

Before closing the model and determining the offshoring equilibrium in the next section, let us first investigate the difference in emissions across firms. Recall that emissions in our model are linked to the routine task only. Purely domestic firms generate emissions in the source country, while offshoring firms shift emissions to the host country by importing the output of the routine task. Formally, an offshoring firm does not generate emissions; it does not have to pay an emissions tax directly. Indirectly, however, it causes emissions in the host country and the host country's emissions tax is factored in the price of the imported input. In the following, we take into account these *embedded* emissions of offshoring firms to allow for a fair comparison of environmental footprints across firms.[19]

For each firm it holds that emissions are equal to output times emissions intensity. We can further decompose a firm's emissions intensity such as $i(\varphi) \equiv e(\varphi)/y(\varphi) = e(\varphi)/x^r(\varphi) \times x^r(\varphi)/z(\varphi) \times z(\varphi)/y(\varphi)$, where we define $z(\varphi) \equiv [l^n(\varphi)/\eta]^{\eta}[x^r(\varphi)/(1-\eta)]^{(1-\eta)}$ as the optimally chosen input bundle the firm employs. Accordingly, an individual firm's emissions intensity is determined by the generation of emissions per unit of the routine task's output, by the importance of the routine tasks' output in the overall input bundle, and by the usage of the input bundle per unit of output.

By means of the optimal factor inputs from costs minimisation as shown in Appendix A.1, we can derive the following two expressions, with the first one showing the emissions intensity

[19] This particularly matters for global pollutants, like CO_2, where the location of emissions generation is irrelevant to its environmental impact.

of a non-offshoring firm, the second one for an offshoring firm:[20]

$$i^d(\varphi) = \underbrace{\alpha \left(\frac{w}{t}\right)^{1-\alpha}}_{\frac{e^d(\varphi)}{x^{rd}(\varphi)}} \underbrace{(1-\eta)\left(\frac{w}{t}\right)^{\alpha\eta}}_{\frac{x^{rd}(\varphi)}{z^d(\varphi)}} \underbrace{\frac{1}{\varphi}}_{\frac{z^d(\varphi)}{y^d(\varphi)}} = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \frac{1}{\varphi} \tag{12}$$

$$\begin{aligned} i^o(\varphi) &= \tau \underbrace{\alpha \left(\frac{w^*}{t^*}\right)^{1-\alpha}}_{\frac{e^o(\varphi)}{x^{ro}(\varphi)}} \underbrace{(1-\eta)\left(\frac{w}{\tau(w^*)^{1-\alpha}(t^*)^{\alpha}}\right)^{\eta}}_{\frac{x^{ro}(\varphi)}{z^o(\varphi)}} \underbrace{\frac{1}{\varphi}}_{\frac{z^o(\varphi)}{y^o(\varphi)}} \\ &= \tau^{1-\eta}\alpha(1-\eta)\left(\frac{w^*}{t^*}\right)^{1-\alpha(1-\eta)}\left(\frac{w}{w^*}\right)^{\eta}\frac{1}{\varphi}. \end{aligned} \tag{13}$$

Accordingly, and taking firm selection as given at this point, the emissions intensity of a particular firm is determined by a combination of economy-wide factor prices, firm behaviour and a firm characteristic (productivity). First, each domestic firm decides on emissions abatement and, hence, on the emissions-intensity of the routine task. This decision is outsourced by offshoring firms, but incorporated in the overall intensity of embedded emissions. It depends both on the tax rate in the country of emissions generation and on the prevailing wage rate. This is intuitive as it is the wage-tax-ratio that determines the allocation of labour between emissions abatement and the production of the routine task's output. Second, each firm, non-offshoring or offshoring, determines the input mix between the emissions-free non-routine task and the emissions-intensive routine task. Again relative factor prices determine this decision, while importantly, as Eq. (13) shows, this part of the emissions intensity of an offshoring firm depends on the difference between the two countries' wage rates. Finally, the emissions intensity of each firm, no matter her status, is inversely related to her productivity. Importantly, productivity level φ is exogenous to the firm and cannot be altered.[21]

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 (cf. Egger et al., 2021), it is specific to the offshoring context that also factor price differences across countries are vital for the emissions intensity of an individual firm.

This feature also becomes visible when highlighting firm differences in emissions or emissions intensities that are due to the offshoring status, while controlling for productivity. Complement-

[20] Recall that, due to iceberg transport costs, more output of the routine task is produced in the host country than used by the offshoring firm in the source country. This is reflected by the first term τ on the RHS of (13).

[21] This is a common assumption in the literature building on Melitz (2003). Of course, the composition of active firms, being heterogeneous in productivity, does matter for the average emissions intensity and is a crucial channel in response to (environmental) policy reforms. This will be discussed in detail in the following sections.

ing Eq. (10), we can state the following:

$$\frac{e^o(\varphi)}{e^d(\varphi)} = \frac{t}{t^*}\kappa^{\sigma-1} \qquad \text{and} \qquad \frac{i^o(\varphi)}{i^d(\varphi)} = \frac{t}{t^*}\kappa^{-1} = \tau\left(\kappa\right)^{\eta/(1-\eta)}\left(\frac{t/w}{t^*/w^*}\right)^{1-\alpha}. \tag{14}$$

Accordingly, offshoring corresponds to higher emissions of a particular firm,[22] while the difference in emissions intensity is ambiguous. This ambiguity – and, hence, the possibility of more emissions-intensive internationally active firms – stands in contrast to settings 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 wage-tax-ratio (cf. Egger et al., 2021), or exporters are characterised by lower emissions intensities due to higher abatement investments (cf. Forslid et al., 2018).

The intuition for the different finding in our offshoring framework (allowing for a higher emissions intensity of an internationally active firm) crucially builds on the international difference in factor prices. Suppose that emissions taxes were equal across the two countries, i.e. $t = t^*$. In order to still have an incentive to offshore, i.e. for $\kappa > 1$ to hold, there must be a sufficiently large difference in the wage rates. In this case, however, the *effective* emissions tax (the inverse of the wage-tax ratio) is necessarily higher in the host country. The routine task is, hence, produced less emissions-intensively if offshored; the emissions intensity of an offshoring firm is lower than of a non-offshorer, which can be seen in the first equality on $i^o(\varphi)/i^d(\varphi)$ in Eq. (14). This is despite equal emissions tax rates (by virtue of our example) and despite the increasing (net) effect of τ on the emissions intensity in Eq. (13) when offshoring. As can be deduced from the second equality on $i^o(\varphi)/i^d(\varphi)$ in Eq. (14), this reasoning also holds for sufficiently small differences in the emissions tax rates with $t > t^*$, as long as the effective emissions tax is sufficiently larger in the host country, while $\kappa > 1$. If, by contrast, the difference in emissions tax rates is sufficiently large and constitutes the incentive to offshore to begin with (including the case of wage equality), the emissions intensity is higher due to the more emissions-intensive production of the routine task's output.

To summarize, whether the decision to offshore leads to a higher or lower emissions intensity, controlling for productivity, crucially depends on the determinants of offshoring. If the (main) motive to offshore is the international difference in emissions tax rates, a firm's emissions intensity is unambiguously higher in case of offshoring. By contrast, if the offshoring decision is largely driven by across-country differences in labour costs, the emissions intensity may be

[22] This directly follows from $t \geq t^*$ and $\kappa > 1$ in an offshoring equilibrium.

lower in case of offshoring. Importantly, such a firm-level clean-up then realizes even in case of lower emissions tax rates in the host country of offshoring, a pollution haven setting.[23] It is the international difference in the effective emissions taxes, i.e. in the emissions tax relative to the wage rate, that ultimately determines the impact of offshoring on the emissions intensity of an individual firm. Let us formulate this in the following lemma:

Lemma 1. *Controlling for productivity,*

(i) a firm's emission intensity is larger in case of offshoring, if the source country's effective emissions tax (the inverse of the wage-tax ratio) exceeds that of the host country.

(ii) a firm's emission intensity may be smaller in case of offshoring, if the host country's effective emissions tax (the inverse of the wage-tax ratio) exceeds that of the source country. This holds for sufficiently small differences (or equality) in emissions tax rates.

Finally, we note from Eqs. (11)-(13) that, for a given status (offshoring or non-offshoring), a more productive firm produces less emissions-intensively, while, due to its larger scale, it nevertheless generates more emissions. The corresponding elasticities w.r.t. productivity are -1 for emissions intensity $i(\varphi)$ and $\sigma - 1$ for emissions $e(\varphi)$, respectively.

3 The offshoring equilibrium

3.1 Occupational choice and selection into offshoring

Each agent in the source country chooses her occupation, becoming either manager, worker or offshoring consultant. If deciding to run a firm, an individual's managerial ability materialises in the productivity of the firm. Heterogeneity in abilities translates into heterogeneous firms. If, by contrast, an agent decides to become a worker or offshoring consultant her managerial ability remains unexploited. Accordingly, all non-managers (workers and offshoring consultants) are homogeneous and consequently paid the same endogenous wage rate w.[24] In addition to profit income (managers) or wage payments (workers and offshoring consultants), each individual receives a uniform per capita transfer b from redistributed revenues of emissions tax revenues.

We model the occupational choice of an individual as a comparison of her expected income of the different occupations. Denoting the threshold ability to become a manager by φ^d, all

[23] Recall that our comparison builds on embedded emissions for offshoring firms. Looking at domestic emissions only, by construction, offshoring unambiguously leads to a decline in a firm's emissions intensity: going to zero in our setup.

[24] These are well-known features established by Lucas (1978).

agents 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, our least productive firm, i.e. the firm run by the marginal manager, does not offshore (cf. Paul and Yasar, 2009; Hummels et al., 2014). This leads to the following condition of the agent who is just indifferent between becoming a manager and a wage-remunerated occupation:

$$\pi^d(\varphi^d) + b = w + b, \tag{15}$$

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 entrepreneurs, i.e. 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. (10), but requires to hire one offshoring consultant as fixed costs. Accordingly, only the most productive firms can afford to offshore, with the marginal offshoring firm with productivity φ^o being determined by

$$\pi^o(\varphi^o) - \pi^d(\varphi^o) = w, \tag{16}$$

where the additional operating profits of offshoring must match the costs of hiring an offshoring consultant.

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

$$\chi \equiv \frac{1 - G(\varphi^o)}{1 - G(\varphi^d)} = \left(\frac{\varphi^d}{\varphi^o}\right)^k, \tag{17}$$

which will turn out to be the endogenous variable that is crucial for general equilibrium effects of (exogenous) policy reforms on the economy, the environment, and income inequality.

On aggregate, the assumption that all individuals become either managers, workers or offshoring consultants with no outside option, leads to the source country's resource constraint

$$N = L + (1 + \chi)M, \tag{18}$$

where L denotes the mass of workers, M the mass of managers, while χM subsumes all offshoring consultants.

Jointly using Eqs. (15)-(18), we can now solve for the domestic factor allocation depending on χ. To this end, we follow Egger et al. (2015) and first express both the operating profits of

the marginal firm and the economy-wide wage rate, i.e. the two sides of Eq. (15), in terms of aggregate variables and χ. Accordingly, as formally shown in Appendix A.2, we derive

$$\pi^d(\varphi^d) = \frac{k-\sigma+1}{k}\frac{1}{1+\chi}\frac{1}{\sigma}\frac{Y}{M} = \gamma^l\frac{\sigma-1}{\sigma}\frac{Y}{L} = w \tag{19}$$

with

$$\gamma^l = \frac{(1-\alpha(1-\eta)) + \eta\chi - (1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}}}{1+\chi} \tag{20}$$

being the share of production factor income allotted to the source country's workers. This share negatively depends on χ, which plausibly highlights the shift of income to the host country with relatively more firms offshoring.[25] Substituting for either M or L by means of the resource constraint Eq. (18), we can solve for the equilibrium factor allocation depending on χ with

$$L = \lambda N \qquad \text{and} \qquad M = \frac{1-\lambda}{1+\chi}N, \tag{21}$$

where $\lambda \equiv L/N = [1 + (k-\sigma+1)/\gamma^l k(\sigma-1)]^{-1}$ is the share of workers in the source country's population. Accordingly, L is decreasing in χ via an indirect effect through γ^l, while a positive indirect dependence of M on χ (via γ^l) is complemented by a direct negative effect, which highlights the sorting of individuals into managers or offshoring consultants.

Using the relation $M/N = [1 - G(\varphi^d)] = (\varphi^d)^{-k}$ from Pareto, we can also express the domestic cutoff productivity level φ^d and the relation between the two cutoff productivity levels φ^d and φ^o as a function of λ. This yields:

$$\varphi^d = \left(\frac{1+\chi}{1-\lambda}\right)^{1/k} \qquad \Leftrightarrow \qquad (\varphi^d)^{-k} + (\varphi^o)^{-k} = 1-\lambda, \tag{22}$$

where the equivalence directly follows from Eq. (17). As a well-known feature in the literature, under autarky ($\chi \to 0$) the domestic productivity cutoff is determined by parameters, only. In the offshoring equilibrium we cannot solve it in closed-form.

In contrast to the source country, and by construction, in the host country all individuals become workers, i.e. $L^* = N^*$. Accordingly, and in analogy to Eq. (19), we derive the host country's wage as

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

[25] It holds that $\lim_{\chi\to 0}\gamma^l = 1-\alpha(1-\eta)$ under autarky and $\lim_{\chi\to 1}\gamma^l = \eta$ approaching the case of all firms being offshorers.

being the share of aggregate payments to production factors that accrues to workers in the host country. In contrast to γ^l this share positively depends on χ, as with a rise in offshoring more income is generated in the host country.[26]

3.2 The share of offshoring firms

Our main endogenous variable χ, which incorporates both cutoff productivity levels and determines all aggregate variables, deserves some special attention. In order 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. We then set out the conditions for an interior solution.

A first link originates from the indifference conditions Eqs. (15) and (16) together with Eq. (10) on relative operating profits:

$$\kappa = A(\chi) \equiv (1 + \chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}. \tag{24}$$

This condition captures a positive relationship between κ and χ, meaning that higher marginal costs savings make offshoring more attractive and more firms offshore part of their production.

We derive a second link via the labor market equilibrium in both countries. For this purpose, we insert the expressions Eqs. (19) and (23) for the two countries' wage rates in our definition of κ in Eq. (9) to get:

$$\kappa = B(\tau, t, t^*, \chi) \equiv \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta}. \tag{25}$$

This condition shows a negative relation between κ and χ. It is an increase in the number of offshoring firms that leads to a rise in labor demand and, thus, in the wage rate in the host country inducing κ to decline, *ceteris paribus*.

Jointly, these two links, Eqs. (24) and (25), determine the two endogenous variables κ and χ. For an interior equilibrium of offshoring with $\chi \in (0, 1)$, the level of iceberg trade cost τ must not be too small and, or the environmental tax differential too large. Otherwise, all firms would opt for offshoring. In Appendix A.5, we show the necessary conditions for τ and t/t^* in order to guarantee $\chi \in (0, 1)$. Figure 1 exemplarily illustrates this equilibrium for specific parameter values.

[26] For $\chi \to 0$ (autarky) it holds that $\gamma^l = 0$, while it converges to $(1-\alpha)(1-\eta)$ with $\chi \to 1$.

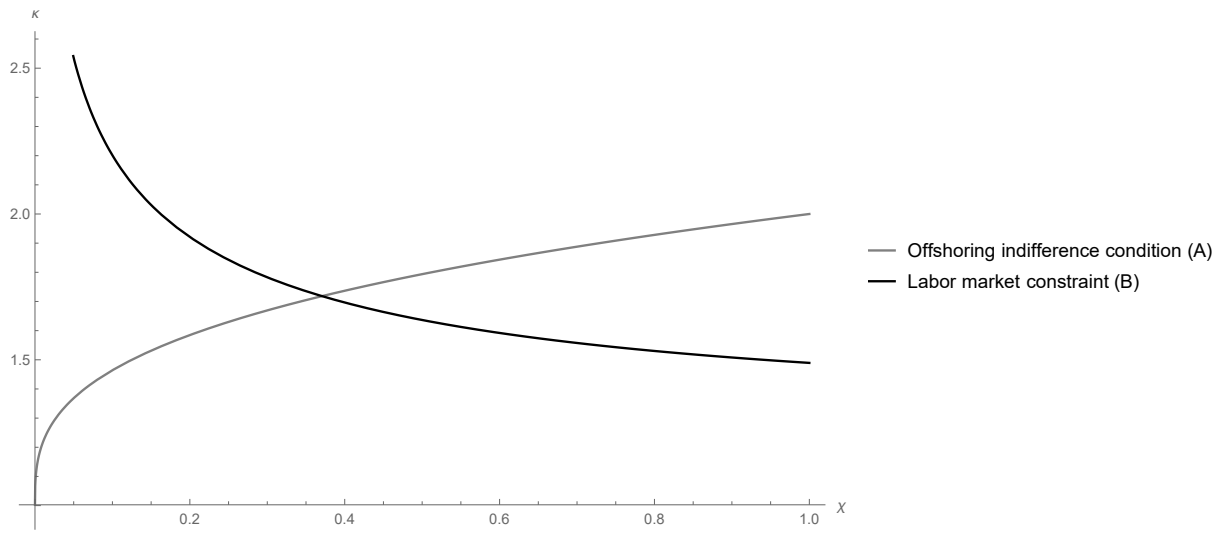

Figure 1: Determining the share of offshoring firms

Note: The assumed parameter values are $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $\tau = 1.2$, $t = 1.5$, $t^* = 1$, $(N/N^*) = 1$.

4 Unilateral environmental policy reform

In this section, we analyse the effects of a unilateral increase in the source country's emissions tax in the context of offshoring. We thereby evaluate a change in t in an offshoring equilibrium as derived in the previous sections.

4.1 Effects on occupational choices and firm selection into offshoring

Let us first focus on the occupational choice decision of individuals and the offshoring decision of managers. On aggregate, this determines the change in the factor allocation and gives valuable insights on how the economy will be affected by an increase in the emissions tax.

Acknowledging the importance of the key variable χ, we begin our analysis with an investigation on how this is altered by a rise in t. While it is not possible to solve for χ analytically (see above), we apply the implicit function theorem to derive the change in χ w.r.t. a rise in t. To this end, we make use of Eqs. (24) and (25), the two links between κ and χ, and define the following implicit function that gives an interior offshoring equilibrium:

$$F(\chi, \tau, t, t^*) \equiv B(\chi, \tau, t, t^*) - A(\chi) = 0. \tag{26}$$

Implicit differentiation, as formally shown in Appendix A.6, yields $d\chi/dt > 0$. A rise in the source country's emissions tax monotonously increases the share of offshoring firms. This is

intuitive, as it is the rise in production costs in the source country that increases the marginal cost savings factor κ in Eq. (9), *ceteris paribus*. Hence, offshoring the emissions-intensive routine task becomes more attractive for a larger share of firms. Formally, this can be seen by a direct effect of t on B in (25), which would lead to an upward shift in the depiction in Figure 1.

We can use this result to derive emissions tax-induced changes in the factor allocation. Note from Eq. (21) that t neither directly affects the mass of managers M nor the mass of workers L. All effects run indirectly via χ.[27] We derive the tax-induced change in L and M as follows:

$$\frac{dL}{dt} = \underbrace{\left[\frac{\partial L}{\partial \gamma^l}\frac{\partial \gamma^l}{\partial \chi}\right]}_{<0}\underbrace{\frac{d\chi}{dt}}_{>0} < 0 \qquad \text{and} \qquad \frac{dM}{dt} = \underbrace{\left[\underbrace{\frac{\partial M}{\partial \chi}}_{<0} + \underbrace{\frac{\partial M}{\partial \gamma^l}}_{<0}\underbrace{\frac{\partial \gamma^l}{\partial \chi}}_{<0}\right]}_{\gtreqless 0}\underbrace{\frac{d\chi}{dt}}_{>0} \gtreqless 0. \tag{27}$$

Eq. (27) shows that an increase in t unambiguously leads to a decline in the mass of workers. It is both the rise in production costs and 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, thereby decreasing the mass of workers. Put differently, we can observe a decline in the labour income share γ^l that ultimately determines λ, the share of workers in the population. Consequently, $1-\lambda$, the share of non-workers (managers and offshoring consultants) increases, thereby leading to a rise in M, *ceteris paribus*. However, there is second, opposing effect of t on M via χ, observable in the squared brackets of dM/dt in Eq. (27). This second effect corresponds to the relation between managers and offshoring consultants. Accordingly, a rise in t leads to a decline in M due to a shift of managers to offshoring consultants, *ceteris paribus*.

Hence, the sign of the total effect of t on M is ambiguous. It depends, however, clearly on the initial level of χ. Let us define the threshold level

$$\tilde{\chi} = \left[\frac{(\sigma-1)(k-\sigma+1)(1-\alpha)(1-\eta)}{k-\sigma+1+k\eta(\sigma-1)}\right]^{\frac{k}{\sigma-1}}, \tag{28}$$

that allows us to state the following: M increases in t for $\chi < \tilde{\chi}$, while it decreases in t for $\chi > \tilde{\chi}$. Accordingly, for low levels of χ, an increase in the source country's emissions tax leads to an increase in the mass of managers. By contrast, it leads to a decrease in the mass of managers, if the initial share of offshoring firms is high.

Importantly, this directly translates into the effect on the marginal productivity level φ^d

[27] Recall that also λ is a function of χ.

according to Eq. (22). Hence, for low levels of the initial share of offshoring firms, an increase in the emissions tax leads to a reduction in φ^d; less productive firms enter. By contrast, if the share of offshoring is high initially, the least productive firms exit the market, only individuals with relatively higher ability decide to become managers.

We can summarize these key findings as follows:

Proposition 1. *A unilateral increase in the source country's emissions tax leads to a decline in the mass of workers, while the effect on the mass of managers (and, hence, the mass of active firms) depends on the initial share of offshoring. Only in case of a sufficiently high share of offshoring, the emissions tax-induced effect on the mass of managers is negative, corresponding to a tax-induced increase in the marginal productivity. Independent of the emissions tax-induced impact of the mass of managers, a unilateral increase in the source country's emissions tax rate unambiguously leads to an increase in the share of offshoring firms.*

4.2 Effects on emissions

4.2.1 Firm-level emissions

The production location choice of a firm does not only affect local employment but also local emissions.

To examine the effects of offshoring, in the following, we first make use of a counterfactual comparison to compare the emissions of a firm with productivity φ in case of being domestic and in case of offshoring.[28] Decomposed, we express this comparison by $e^o(\varphi)/e^d(\varphi) = i^o(\varphi)/i^d(\varphi)y^o(\varphi)/y^d(\varphi)$ The first term on the RHS of this equation captures the difference in the emission intensity of the particular firm, the *technique effect* of the marginal offshoring firm. The second term illustrates the difference in emissions from different output levels, a *scale effect* for the marginal offshoring firms. This is due to offshoring firms facing a cost advantage in marginal production costs leading to higher output levels.

In closed form and after taking logs we end at:

$$\ln e^o(\varphi) - \ln e^d(\varphi) = \underbrace{\ln\left[\frac{t}{t^*}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{1-\sigma}}\right]}_{technique} + \underbrace{\ln\left[\left((1+\chi^{\frac{\sigma-1}{k}})\right)^{\frac{\sigma}{\sigma-1}}\right]}_{scale}. \tag{29}$$

The firm-level *scale effect* of offshoring is zero in the absence of offshoring and increasing in χ because if there is any incentive to offshore production, ($\kappa > 1$) offshoring firms can generate

[28] In the Online Appendix Section S.1 we additionally derive and compare several labour employment ratios between offshoring and non-offshoring firms.

more output and therefore, *ceteris paribus*, cause higher emissions. However, the *technique effect* is declining with the level of offshoring since the routine task labour input for emissions gets more expensive in the host country when more firms produce there and local demand is high. As a result, firms move away from emission-generation to abatement. The size of the emission-intensity effect and hence the total effect depend on the ratio of the emission taxes and the level of offshoring. In line with our motivation we assume a pollution haven setting with $t > t^*$.[29][30] Hence, we have the condition for an (additional) incentive to offshore coming from emission tax differential. While offshoring their emission-generating production parts, firms can pollute at lower costs. This leads to a shift from abatement to production and emissions. That is why the change in emission intensity at the firm-level is positive at low levels of offshoring, indicating an increase in emission use. With increasing offshoring labour demand in the host country increases, that means labour used in the emission generating production part is getting more expensive due to an increase of the host country wage. This deteriorates the emission cost savings. It depends on the initial emission tax ratio at which level of offshoring the *technique effect* turns negative.

4.2.2 Aggregate emissions

Similar to the factor allocation, we can determine aggregate emissions. After all and according to Eq. (6) emissions are treated as an input into the production process that is imperfectly substitutable with labour. Making use of the decomposition of aggregate income, we can derive aggregate emissions of the two countries as

$$E = \gamma^e \frac{\sigma - 1}{\sigma} \frac{Y}{t} \qquad \text{and} \qquad E^* = \gamma^{e*} \frac{\sigma - 1}{\sigma} \frac{Y}{t^*} \tag{30}$$

$$\text{with} \qquad \gamma^e \equiv \frac{\alpha(1-\eta)(1-\chi^{\frac{k-\sigma+1}{k}})}{1+\chi} \qquad \text{and} \qquad \gamma^{e*} \equiv \frac{\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{1+\chi}. \tag{31}$$

The terms γ^e and γ^{e*} share of aggregate income net of aggregate operating profits that is linked to the source country's emissions taxation.[31]

[29] Our model additionally allows to look at a setting where the incentive to offshore is solely driven by a wage differential, while the emissions tax is larger in the foreign country ($t < t^*$). In this case, relocating the routine task production to the host country makes the firm face a higher (implicit) emissions tax which why this effect is immediately negative at $\chi = 0$.

[30] In the special of symmetric environmental policies $t = t^*$ the emission-intensity effect is zero in the absence of offshoring. The *scale effect* dominates at all levels of offshoring meaning that emissions of the marginal offshoring firm are higher than in the domestic counterfactual. Furthermore, the offshoring firm's demand of emissions increases in the share of offshoring firms χ.

[31] In Appendix A.4 we derive Y to get closed form solution for E.

It is common in the literature to decompose aggregate emissions (cf. Grossman and Krueger, 1995; Antweiler et al., 2001) to isolate the partial effects of a policy reform. Accordingly, and following the derivations in Section 2, we can express aggregate emissions in the source and host country as

$$E = M(1-\chi)\bar{i}^d\bar{y}^d \qquad \text{and} \qquad E^* = M\chi\bar{i}^o\bar{y}^o, \tag{32}$$

where the bars indicate group averages. Importantly, it is both the behavior of all individual firms and the composition of active firms that determine the average emissions intensities among purely domestic and offshoring firms. Formally, we derive

$$\bar{i}^d = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)}\frac{1}{\bar{\varphi}^d} \qquad \text{and} \qquad \bar{i}^o = \tau\alpha(1-\eta)\left(\frac{w^*}{t^*}\right)^{1-\alpha(1-\eta)}\left(\frac{w}{\tau w^*}\right)^{\eta}\frac{1}{\bar{\varphi}^o}. \tag{33}$$

We can now express aggregate world emissions, $E^W \equiv E + E^*$ in two ways. First, making use of Eqs. (30) and (31), we derive

$$E^W = \alpha(1-\eta)\left(\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1+\chi}\frac{1}{t} + \frac{\chi+\chi^{\frac{k-\sigma+1}{k}}}{1+\chi}\frac{1}{\tilde{t}^*}\right)\frac{\sigma-1}{\sigma}Y. \tag{34}$$

Second, by means of Eq. (32), we can express aggregate world emissions as

$$\begin{aligned} E^W &= M\underbrace{\left[(1-\chi)\bar{y}^d + \chi\bar{y}^o\right]}_{\bar{y}}\underbrace{\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right]}_{\bar{i}} \\ &= M\bar{y}\bar{i} = M\bar{y}\underbrace{\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right]}_{\bar{i}}. \end{aligned} \tag{35}$$

Using the last equality, we can now analyse the effect of the unilateral environmental policy reform on global aggregate emissions. In the expression shown below, the first line features the extensive margin, i.e. effects on aggregate emissions induced by changes in the mass of source country firms.The second line represents the scale effect, denoting changes in intermediate output caused by the environmental policy reform. The third line expresses the technique effect, capturing changes in average emission intensity levels of non-offshoring and offshoring firms. Additionally, a rise in the share of offshoring firms implies that some (relatively productive) non-offshoring firms at the margin start offshoring, confronting them with a different cost structure and emission intensity. This selection effect among active firms is outlined in the fourth line.

$$\frac{dE^W}{dt} = \frac{\partial M}{\partial \chi}\frac{d\chi}{dt}\,\bar{y}\underbrace{\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right]}_{\bar{i}} \tag{36}$$
$$+ M\frac{d\bar{y}}{dt}\underbrace{\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right]}_{\bar{i}}$$
$$+ M\bar{y}\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\frac{d\,\bar{i}^d}{dt} + \frac{\chi\bar{y}^o}{\bar{y}}\frac{\partial\,\bar{i}^o}{\partial\chi}\frac{d\chi}{dt}\right]$$
$$+ M\bar{y}\left[\frac{d\chi}{dt}\left(\underbrace{\bar{i}^o\bar{y}^o}_{\bar{e}^o} - \underbrace{\bar{i}^d\bar{y}^d}_{\bar{e}^d}\right)\right].$$

Finally, we express the international distribution of aggregate emissions by the ratio of host to source country emissions as

$$\frac{E^*}{E} = \frac{\chi + \chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma+1}{k}}}\frac{t}{t^*}. \tag{37}$$

Quite intuitively, this ratio depends positively both on the share of offshoring χ and on the ratio of source to host emissions taxes.

Offshoring drives the international distribution of emissions. As a first exercise we want to look at the relation of host country and source country emissions. This ratio can be regarded as an expression for international emission leakage. Making use of Eq. (37), we identify a direct emission tax effect and an indirect effect via the share of offshoring firms.

$$\frac{d\frac{E^*}{E}}{dt} = \underbrace{\frac{\partial\frac{E^*}{E}}{\partial t}}_{>0} + \underbrace{\frac{\partial\frac{E^*}{E}}{\partial\chi}}_{>0}\underbrace{\frac{d\chi}{dt}}_{>0} > 0 \tag{38}$$

The interpretation is straightforward. The direct effect of an environmental tax increase in the source country makes emissions more costly and reduces emission input in favor of abatement among non-offshoring firms. As source country emissions decrease, the ratio between host country and source country emissions unambiguously grows. The additional indirect effect works as follows: If the costs for emissions in the source country increase, additional firms relocate routine production to the host country, ceasing to generate emissions at home. Thus, host country emissions further increase relative to source country emissions.

4.3 Effects on income inequality

Our model allows to look at several perspectives of inequality.

4.3.1 Source country inequality

In the source country, individuals are either paid the economy-wide wage rate or earn firm-profits. Additionally, emissions tax revenues are redistributed to all individuals equally in a lump-sum fashion. Therefore, we define between-group inequality as follows:

$$\Theta \equiv \frac{\bar{\pi} - \chi w + b}{w + b} \tag{39}$$

We have post-transfer managerial income minus service labour income for the offshoring consultant as the numerator and wage income plus transfer as the denominator. Using our solutions for average profits, wage and transfer we get the closed form:

$$\Theta = \frac{[k + \chi(\sigma - 1)][k - \sigma + 1 + \gamma^l k(\sigma - 1)] + \gamma^e k(\sigma - 1)(k - \sigma + 1)}{(k - \sigma + 1)[k - \sigma + 1 + \gamma^e k(\sigma - 1) + \gamma^l k(\sigma - 1)]} \tag{40}$$

First result is immediately clear: The emission tax rate does not impact this inequality measure directly, only indirectly via the share of offshoring firms. After tedious calculations[32] we have revealed that between-group inequality increases with the share of offshoring firms, hence also with source country emission tax.

This result is driven by two components: the relative income ratio profits over wage and the per-capita transfer. It is easy to see that inequality between the two groups decreases with the transfer capturing the redistributing facet of this scheme. Workers benefit over-proportionally from the transfer. Offshoring reduces the role of the transfer increasing the inequality measure.

Second, the relative ratio of profit and wage income increases with offshoring. Managers benefit relatively more from an increase in the share of offshoring firms which captures the productivity gain for offshoring firms on the one side and downward pressure on source country wages due to production relocation on the other side. In Appendix A.9 we also illustrate source country inequality and the effect of offshoring on it by deriving and plotting the Lorenz Curve.

[32] See (A.9).

4.3.2 Between-country inequality

We look at between-country inequality as a relation of net wages and assume that both governments redistribute their emission tax income via lump-sum transfers to all individuals in their country. Our measure is defined as follows:

$$\Xi \equiv \frac{w+b}{w^*+b^*}, \tag{41}$$

where the transfers equal emission tax income per capita, $b = tE/N$ in the source and $b^* = t^*E^*/N^*$ in the host country, respectively. We make use of Eqs. (19) and (23), which show the two countries' wage rates and the income share of workers, as well as Eqs. (37) and (31) on aggregate emissions and the income share of the emissions tax revenues:

$$\Xi = \frac{\gamma^l \frac{\sigma-1}{\sigma} \frac{k-\sigma+1+\gamma^l k(\sigma-1)}{\gamma^l k(\sigma-1)} \frac{Y}{N} + \frac{\gamma^e \frac{\sigma-1}{\sigma} Y}{N}}{\gamma^{l*} \frac{\sigma-1}{\sigma} \frac{Y}{N^*} + \frac{\gamma^{e*} \frac{\sigma-1}{\sigma} Y}{N^*}}. \tag{42}$$

For convenience, we define $\gamma \equiv \gamma^e + \gamma^l$ and $1-\gamma \equiv \gamma^{e*} + \gamma^{l*}$, where we know $\partial\gamma/\partial\chi < 0$. We end at:

$$\Xi = \frac{N^*}{N} \frac{(k-\sigma+1)+\gamma k(\sigma-1)}{k(\sigma-1)(1-\gamma)} \tag{43}$$

Analysing the effect of an increase in t we get:

$$\frac{d\Xi}{dt} = \underbrace{\frac{\partial\Xi}{\partial\gamma}}_{>0} \underbrace{\frac{\partial\gamma}{\partial\chi}}_{<0} \underbrace{\frac{d\chi}{dt}}_{>0} < 0 \tag{44}$$

Between-country inequality negatively depends on the level of offshoring. Workers in both countries gain from offshoring via an increase in total output (Y) but since production (meaning emissions) is shifted from source to host country the share of income linked to emission tax increase (decreases) in the host (source country). That means, the effect on the source country transfer is ambiguous. Additionally, labor demand in the host country (source country) increases (decreases) thereby raising (lowering) host country (source country) worker wages. All parameters which increase (decrease) the amount of offshoring magnify (harm) this effect. Interestingly from the redistribution policy perspective: A unilateral increase in emissions tax which aims to increase the local transfer actually harms the own workers relative to the other country's workers due to the shift of production and the following decrease in local labor demand/wages.

5 Extension: CBAM

In this chapter, we extent our asymmetric two-country model in order to investigate the implementation of a carbon border adjustment mechanism (CBAM a.k.a. BCA). After outlining how we introduce the border adjustment in the context of our setting, we will demonstrate its impacts on offshoring, welfare, inequality and emissions. Finally, analogously to Section 4 the effects of a source country environmental policy reform will be analysed in the presence of a CBAM. Only in this section, the host country emission tax shall be denoted by $\tilde{t^*} = t^* + I\,\hat{t}$ with $\hat{t} = t - t^*$. I is a dummy variable with $I = 0$ in absence of a CBAM and $I = 1$ in the presence of a CBAM. Hence, the host country firm emission tax is given as $\tilde{t^*}_{I=0} = t^*$ without a CBAM and as $\tilde{t^*}_{I=1} = t^* + \hat{t} = t$ post the introduction of the CBAM. Furthermore, we strictly assume that $t > \tilde{t^*}$ holds prior to the introduction of the CBAM. Hence, $\tilde{t^*}_{I=1} > \tilde{t^*}_{I=0}$ holds, i.e. the host country firm's effective emission tax bill increases with the introduction of the CBAM.

5.1 Effects of CBAM implementation

5.1.1 On the host country firm and the incentive to offshore

With our new notation and analogously to Eqs. (A.27), (A.28) and (A.29), the host country firm's cost minimizing inputs are given by:

$$l^{r*} = x_r^*(1-\alpha)\left(\frac{\tilde{t^*}}{w^*}\right)^{\alpha} \qquad \text{and} \qquad e^{r*} = x_r^*(\alpha)\left(\frac{w^*}{\tilde{t^*}}\right)^{1-\alpha} \tag{45}$$

The implementation of a CBAM lifts $\tilde{t^*}$ and thus directly affects input ratio and cost structure of the host country firm. As emissions in the host country become more costly, host country firms shift labour from emission-intensive production to abatement. Since the CBAM closes down the emission tax differential as an offshoring channel, any offshoring level requires a wage differential in favor of the host country (i.e. $w > w^*$). With reference to Eqs. (45) and (A.28), this implies that emission inputs of host country firms are below those of any source country firm:

Proposition 2. *In the presence of offshoring, the introduction of a CBAM enforces an even stricter environmental regime on the (formerly pollution-haven) host country.*

Eq. (45) leads to an adjusted cost function of the host country firm which can be related to

Eq. (**??**) to solve for the cost savings factor:

$$\kappa_{I=1} \equiv \frac{C^d}{C^o} = \left[\frac{1}{\tau}\frac{t^\alpha\, w^{1-\alpha}}{p_r^*}\right]^{1-\eta} = \left[\frac{1}{\tau}\left(\frac{t}{\tilde{t^*}}\right)^\alpha \left(\frac{w}{w^*}\right)^{1-\alpha}\right]^{1-\eta} > 1. \tag{46}$$

From Eq. (46) it can be easily seen that $\kappa_{I=0} > \kappa_{I=1}$, i.e. a firms cost-saving due to offshoring is strictly larger in the absence of a CBAM ($I = 0$) Hence, *ceteris paribus*, a firm in the source country is less incentivized to opt for offshoring due to the border adjustment. We now turn to CBAM-induced effects on source country firm emissions. Using $t/\tilde{t^*} = 1$, the ratio of emission levels and intensities between offshoring and non-offshoring firms Eq. (14) can be re-stated as follows:

$$\frac{e^o(\varphi)}{e^d\varphi)} = \kappa^{\sigma-1} \qquad \text{and} \qquad \frac{i^o(\varphi)}{i^d(\varphi)} = \kappa^{-1} \tag{47}$$

Due to $\kappa_{I=0} > \kappa_{I=1} > 1$, a source country firm's offshoring decision still increases its use of emissions, but to a smaller extent as compared to the baseline scenario without the CBAM. At the same time, the firm's offshoring decision now unambiguously decreases its emission intensity.

5.1.2 On the offshoring equilibrium

Via its impact on κ, the introduction of the CBAM influences the share of offshoring firms: As in Section 3, the equilibrium share of offshoring firms in the source country is given at the intersection of the *offshoring indifference condition (A)* Eq. (24) and the *labour market constraint (B)* Eq. (25). The latter directly depends on the international emission tax differential $\frac{t}{\tilde{t^*}}$. As we assume that $t > \tilde{t^*}$ holds prior to the introduction of the CBAM, offshoring is incentivized by lower emission taxation in the source country. After imposing the CBAM $\tilde{t^*} = t$ holds. Hence, the expression for the emission tax differential collapses to $\left(\frac{t}{t}\right)^\alpha = 1$. and B reduces to:

$$\kappa = B(\tau, t, \tilde{t^*}_{I=1}, \chi) \equiv \left[\frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta}. \tag{48}$$

From $\left(\frac{t}{t^*}\right)^\alpha > 1$ it follows that $B_{I=0} > B_{I=1}$. Thus, the introduction of the CBAM leads to a downward shift of the labour market constraint (see Figure 2).

Consequently, the share of offshoring firms decreases with the introduction of the CBAM mechanism. This change in the economy-wide level of offshoring further impacts several inequal-

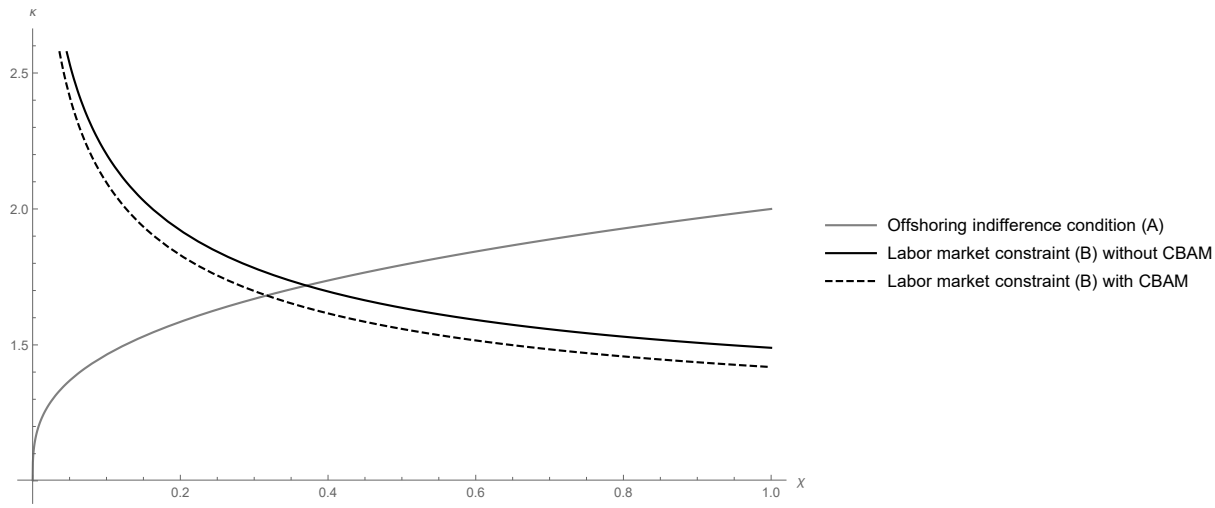

Figure 2: Share of offshoring firms prior and post introduction of a CBAM

Note: The assumed parameter values are $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $\tau = 1.2$, $t = 1.5$, $t^* = 1.5$, $(N/N^*) = 1$.

ity and welfare equilibria.[33]

Proposition 3. *The introduction of the CBAM reduces production cost advantage of the host country, illustrated in a downward shift of the labor market constraint. A new equilibrium is set at a lower share of offshoring firms as since some firms have to bring back their production to the source country.*

5.2 Source country environmental policy reform under a CBAM

5.2.1 On the offshoring equilibrium

In the presence of a CBAM, a source country emission tax increase requires an identical increase of the effective host country emission tax. Hence, the decision to offshore driven by κ is unaffected as $\tilde{t^*} = t$ strictly holds. Hence, the emission tax differential remains fixed to 1. Consequently, under the CBAM, a soure country emission tax increase does not affect the labor market constraint, as the CBAM fixes the emission tax differential to 1. Hence, the share of

[33] *Source country inequality* decreases, *international inequality* between workers in the source country and the host cost country increases due to lower labour demand in the host country. With external increasing returns to scale and $\alpha < \frac{1}{\eta k + \frac{k}{\sigma - 1}}$, overall *aggregate income* decreases. *Aggregate emissions* decrease due to two channels: firstly, due to decreased offshoring and secondly, due to the effective elimination of the international emission tax differential. See Sections A.9, 4.3.2, A.8 and 4.2 for a detailed formal analysis of offshoring-induced effects on source country inequality, international between-worker inequality, aggregate income as well as aggregate emissions.

offshoring firms in equilibrium remains unaffected by the environmental policy change.

$$\begin{aligned} F(\chi,\tau) &\equiv B(\chi,\tau) - A(\chi) \\ &= \left[\frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} - (1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}. \end{aligned} \tag{49}$$

$$\frac{d\chi}{dt} = -\underbrace{\frac{\partial F/\partial t}{\partial F/\partial \chi}}_{\substack{=0\\<0}} = 0. \tag{50}$$

Proposition 4. *In the presence of a CBAM, a source country emission tax increase does not impact the economy-wide share of offshoring firms.*

5.2.2 On the host country firm's emission input

Straightforwardly, the source country emission tax increase impacts the source country non-offshoring firm's cost minimizing inputs and cost structure. Additionally, due to the CBAM, the reform also transmits to the effective host country emission tax rate. Hence, the firm allots less labour towards emission-intensive production and more labour towards abatement efforts. This decreases its cost-minimizing unit emission input as provided in Eq. (45). [34]

$$\frac{de^{r*}}{dt} = \underbrace{\frac{\partial e^{r*}}{\partial \tilde{t}^*}}_{<0}\underbrace{\frac{d\tilde{t}^*}{dt}}_{>0} < 0 \tag{51}$$

Proposition 5. *In the presence of a CBAM, the source country emission tax increase makes the host country firm less emission-intensive.*

5.2.3 On global emissions

The leakage effects of unilateral environmental policy changes in absence of a CBAM mechanism are shown and discussed in Section 4.2. As we show, the presence of a CBAM greatly matters with respect to international emission leakage induced by unilateral environmental policy.

Let us first recall the ratio of emissions between the host country and the source country as provided in Eq. (37). By exploiting $\tilde{t}^* = t$ due to the CBAM, it simplifies to

[34] Furthermore, with a CBAM, there is no indirect channel increasing host country emission intensity: Without a CBAM, the emission tax increase in the source country would raise the share of offshoring firms and increase labour demand in the host country (cf. Section 4), leading to a higher source country wage rate w^*. Via Eq. (45), this would increase the host country firm's emissions per unit of output.

$$\frac{E^*}{E} = \frac{\chi + \chi^{\frac{k-\sigma+1}{k}}}{1 - \chi^{\frac{k-\sigma+1}{k}}} \tag{52}$$

which no longer depend on either of the emission tax rates, but only on the level of offshoring and parameter values. Furthermore, as the economy-wide offshoring level remains unaffected by the source country environmental policy reform, the increase in the source country's emission tax rate no longer impacts the ratio of emissions between the two countries.

$$\frac{d\frac{E^*}{E}}{dt} = \underbrace{\frac{\partial \frac{E^*}{E}}{\partial \chi}}_{>0} \underbrace{\frac{d\chi}{dt}}_{=0} = 0 \tag{53}$$

Hence, the carbon border adjustment effectively prevents leakage in the context of unilateral environmental stringency. Under a CBAM, we can further easily identify the overall effect of a unilateral environmental policy reform on aggregate world emission, which, due to $\tilde{t^*} = t$, reduces from Eq. (34) to:

$$E^W = \alpha(1-\eta)\frac{\sigma-1}{\sigma} Y \frac{Y}{t} \tag{54}$$

It can now be seen that global aggregate emissions directly increase in the source country's emission tax rate. Using the explicit expression for Y Eq. (A.44), we further note that aggregate output itself decreases in the source country emission tax rate. Hence, there is a direct and an indirect effect associated to the environmental policy reform, both reducing global emissions.

$$\frac{dE^W}{dt} = \underbrace{\frac{\partial E^W}{\partial t}}_{<0} + \underbrace{\frac{\partial E^W}{\partial Y}}_{>0} \underbrace{\frac{\partial Y}{\partial t}}_{<0} < 0 \tag{55}$$

Proposition 6. *In the presence of a CBAM, an environmental policy reform in the source country avoids international carbon leakage and unambiguously reduces global aggregate emissions.*

5.2.4 On aggregate income and inequality measures

We refer to the closed form solution for aggregate Income as provided in A.60. Firstly, there is a direct negative effect of the source country's emission tax rate on aggregate Income. Secondly, there is a potentially positive indirect effect via the economy-wide level of offshoring. However, changes in either of the emission tax rates leave the economy-wide level of offshoring unaffected

under the CBAM. Hence, the source country environmental policy reform unambiguously reduces aggregate Income:

$$\frac{dI}{dt} = \underbrace{\frac{\partial I}{\partial t}}_{<0} + \underbrace{\frac{\partial I}{\partial \chi}}_{\gtrless 0} \underbrace{\frac{d\chi}{dt}}_{=0} < 0 \tag{56}$$

With regards to *source country inequality*, we recall its explicit expression provided in Eq. (40): The inequality measure is affected by environmental policy only indirectly via the level of offshoring as well as the source country income shares for labour and emissions.

$$\frac{d\Theta}{dt} = \underbrace{\frac{\partial \Theta}{\partial \chi}}_{>0} \underbrace{\frac{d\chi}{dt}}_{=0} + \underbrace{\frac{\partial \Theta}{\partial \gamma}}_{\gtrless 0} \underbrace{\frac{\partial \gamma}{\partial \chi}}_{>0} \underbrace{\frac{d\chi}{dt}}_{=0} = 0 \tag{57}$$

As the environmental policy change ($dt > 0$) does not affect the level of offshoring given the CBAM regime, it has no impact on Source Country Inequality. The same holds for *international inequality between workers*, provided that the host country government instantly increases its emission tax rate to the level of the source country[35]:

$$\frac{d\Xi}{dt} = \underbrace{\frac{\partial \Xi}{\partial \gamma}}_{>0} \underbrace{\frac{\partial \gamma}{\partial \chi}}_{<0} \underbrace{\frac{d\chi}{dt}}_{=0} = 0 \tag{58}$$

Thus, a unilateral environmental policy change under carbon border adjustment decreases aggregate Income but does not affect its distribution within or between the countries.

Proposition 7. *In the presence of a CBAM, the source country's environmental policy reform decreases aggregate Income and leaves Inequality measures unaffected.*

6 Conclusion

This paper studies the nexus between offshoring and the environment. The analysis builds on an asymmetric two-country general equilibrium model with heterogeneous firms and occupational choice. In the source country, firms use labor to perform a non-routine task and a routine task, where latter production is subject to taxed emission generation and can be offshored. Firms can allot routine labour to emission-intensive production as well as to abatement efforts. Firms differ in their productivity, hence in profits and only the most productive ones will offshore

[35] If the host country would leave its emisison tax rate unadjusted following the source country's environmental policy reform, the source country could collect the difference $t - t^*$ upon importing the intermediate good at the border. In this scenario, the unilateral increase in the source country's emission tax rate would augment the host country's carbon border tax revenue, driving up inequality between the countries.

parts of the production, since it includes some fixed costs to hire an offshoring consultant. This consultant gives offshoring firms access to host country subcontractors which are homogeneous and produce the routine task good at lower marginal production costs, induced by either lower emission tax, lower wages or both which is one novelty of our paper since it widens potential drivers of offshoring. The production cost differential between the two countries is expressed by the cost savings factor of offshoring, which proves to be crucial in determining the level of offshoring in the economy.

Illustrating the difference to final goods trade we recap the effect of trade liberalization on source country labour demand recognizing our modified production technology with emissions. We identify the well-known counteracting *international relocation* and *productivity* effects at the firm-level, latter being dominant at low levels and former at high levels of offshoring leading to a non-monotonic aggregate effect on factor allocation. We turn firm-level analysis to embedded emissions of the marginal offshoring firm. Due to cost advantages, offshoring firms increase output and pollution levels. This *scale effect* is found to dominate the overall change in firm-level emission use. At the same time, the offshoring-induced effect on firm-level emission intensity is more differentiated: Relocating production lets the firm face a different wage-emission tax ratio which leads to an adjustment of its embedded emission intensity in production. At low levels of offshoring, this *technique effect* strongly depends on the across-country wedge in emission taxes, being positive in a pollution haven setting. With the share of offshoring firms increasing, host country labour demand rises, driving up the host country's wage rate. Due to this general equilibrium effect, routine task labour input for emissions gets more expensive in the host country, incentivizing firms to move away from emission-generation towards abatement. Hence, firm-level embedded emissions per unit of output reduce with the level of offshoring.

Next, we analyse the effects of a unilateral source country environmental policy reform. As we show, an increase in the source country emission tax rate makes emission generation more expensive domestically, making it attractive for source country firms to allot more labour to abatement efforts, lowering emission levels among non-offshorers. However, the outside option of offshoring becomes more attractive, motivating additional firms to offshore and thus raising emission levels in the host country.

Source country environmental policy reforms also affect welfare and income distribution in both countries. Due to increased offshoring, we can show that aggregate income increases in most scenarios. With respect to inequality measures, we can outline some counter-intuitive mechanisms induced by a unilateral emission tax increase in the source country: As it raises

the level of offshoring, an emission tax increase in the source country lifts wage levels in the host country, resulting into reduced income inequality between workers of both countries. Simultaneously, due to the increase in the share of offshoring firms, inequality between workers and managers within the source country intensifies. Hence, as we can depict through firm heterogeneity and occupational choice, an environmental policy reform in the source country may be likely to come specially at the expense of its own workers. In an extension to our model, we show how the source country government can reduce emission leakage and worker income outflow by implementing a carbon border adjustment. As we outline, the CBAM enforces a stricter environmental policy on the (formerly pollution-haven) host country firm. Furthermore, under the CBAM, an emission tax increase no longer impacts the level of offshoring, avoiding undesired environmental and distributional effects. However, as the CBAM makes offshoring less attractive, growth of aggregate income and welfare may be attenuated.

A Appendix

A.1 Cost minimization

A.1.1 Cost minimization of a non-offshoring firm

From inserting (6) into (3), we derive the production function of variety v of a non-offshoring firm as

$$y^d(v) = \varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} \left[\frac{\beta e(v)^{\alpha} l^r(v)^{1-\alpha}}{1-\eta}\right]^{1-\eta}, \tag{A.1}$$

i.e. as a nested Cobb-Douglas production function.

A purely domestic firm minimizes its costs $wl^n(v) + wl^r(v) + te(v)$ subject to the Cobb-Douglas production technology in (A.1). This results into the following Lagrangian:

$$\mathcal{L}(\cdot) = w\, l^n(v) + w\, l^r(v) + t\, e(v) + \lambda \left\{ y^d(v) - \varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} \left[\frac{\beta\, e(v)^{\alpha}\, l^r(v)^{1-\alpha}}{1-\eta}\right]^{1-\eta} \right\} \tag{A.2}$$

This results in three FOCs:

$$I: \frac{\partial \mathcal{L}}{\partial l^n} = w - \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta-1} \left[\frac{\beta\, e(v)^{\alpha}\, l^r(v)^{1-\alpha}}{1-\eta}\right]^{1-\eta} \stackrel{!}{=} 0 \tag{A.3}$$

$$II: \frac{\partial \mathcal{L}}{\partial l^r} = w - \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} (1-\eta)^{\eta}\, (1-\alpha)\, l^r(v)^{(\alpha-1)\eta-\alpha}\, \beta^{1-\eta}\, e(v)^{\alpha(1-\eta)} \stackrel{!}{=} 0 \tag{A.4}$$

$$III: \frac{\partial \mathcal{L}}{\partial e} = t - \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} (1-\eta)^{\eta}\, \alpha\, l^r(v)^{(\alpha-1)\eta+1-\alpha}\, \beta^{1-\eta}\, e(v)^{\alpha(1-\eta)-1} \stackrel{!}{=} 0 \tag{A.5}$$

Solving these expressions for the factor costs yields:

$$I: w = \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta-1} \left[\frac{\beta\, e(v)^{\alpha}\, l^r(v)^{1-\alpha}}{1-\eta}\right]^{1-\eta} \tag{A.6}$$

$$II: w = \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} (1-\eta)^{\eta}\, (1-\alpha)\, l^r(v)^{(\alpha-1)\eta-\alpha}\, \beta^{1-\eta}\, e(v)^{\alpha(1-\eta)} \tag{A.7}$$

$$III: t = \lambda\varphi(v) \left[\frac{l^n(v)}{\eta}\right]^{\eta} (1-\eta)^{\eta}\, \alpha\, l^r(v)^{(\alpha-1)\eta+1-\alpha}\, \beta^{1-\eta}\, e(v)^{\alpha(1-\eta)-1} \tag{A.8}$$

Further re-arranging (by dividing by each other) gives the following expressions:

$$\frac{I}{II}: 1 = \frac{\eta}{(1-\eta)\,(1-\alpha)} \frac{l^r(v)}{l^n(v)} \tag{A.9}$$

$$\frac{I}{III}: \frac{w}{t} = \frac{\eta}{(1-\eta)\alpha} \frac{e(v)}{l^n(v)} \tag{A.10}$$

$$\frac{II}{III} : \frac{w}{t} = \frac{1-\alpha}{\alpha} \frac{e(v)}{l^r(v)} \tag{A.11}$$

Note that β dissolves in these operations.

Solving (A.9) for $l^r(v)$ and (A.10) for $e(v)$ and inserting both expressions into (A.1) allows to solve for the cost minimizing level of $l^n(v)$.

$$l^n(v) = \eta \frac{y^d(v)}{\varphi(v)} \left(\frac{t}{w}\right)^{(1-\eta)\alpha} \tag{A.12}$$

Solving (A.9) for $l^n(v)$ and (A.11) for $e(v)$ and inserting both expressions into (A.1) allows to solve for the cost minimizing level of $l^r(v)$.

$$l^r(v) = (1-\eta)(1-\alpha)\frac{y^d(v)}{\varphi(v)} \left(\frac{t}{w}\right)^{(1-\eta)\alpha} \tag{A.13}$$

Solving (A.10) for $l^n(v)$ and (A.11) for $l^r(v)$ and inserting both expressions into (A.1) allows to solve for the cost minimizing level of $e(v)$.

$$e(v) = (1-\eta)\,\alpha \frac{y^d(v)}{\varphi(v)} \left(\frac{t}{w}\right)^{(1-\eta)\alpha-1} \tag{A.14}$$

Inserting (A.12), (A.13) and (A.14) into the cost minimization of the purely domestic firm and simplifying yields the cost function of such a firm.

$$C^d = \left[y^d(v)\,\frac{w}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta}\right]\left[\eta + (1-\eta)(1-\alpha) + (1-\eta)\,\alpha\right] \tag{A.15}$$

As the term in the second square bracket collapses to 1, the cost function of the domestic firm, as in (**??**), is simply given by its productivity, factor and the Cobb-Douglas parameters η and α.

A.1.2 Cost minimization of an offshoring firm

Accordingly, for an offshoring firm we can specify the production function from (3) as

$$y^o(v) = \varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta}\left[\frac{x^r(v)}{1-\eta}\right]^{1-\eta}. \tag{A.16}$$

An offshoring firms minimizes its costs $wl^n(v) + \tau p^{r*}x^{r*}(v)$ subject to (A.16), which yields the following Lagrangian optimization problem:

$$\mathcal{L}(\cdot) = w\,l^n(v) + \tau\,p^{r*}x^{r*} + \lambda\left\{y^o(v) - \varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta}\left[\frac{x^{r*}}{1-\eta}\right]^{1-\eta}\right\} \tag{A.17}$$

This results in two FOCs:

$$I: \frac{\partial \mathcal{L}}{\partial l^n} = w - \lambda\varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta-1}\left[\frac{x^{r*}}{1-\eta}\right]^{1-\eta} \stackrel{!}{=} 0 \tag{A.18}$$

$$II: \frac{\partial \mathcal{L}}{\partial x^{r*}} = \tau\, p^{r*} - \lambda\varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta}\left[\frac{x^{r*}}{1-\eta}\right]^{-\eta} \stackrel{!}{=} 0 \tag{A.19}$$

Rearranging these expressions yields:

$$I: w = \lambda\varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta-1}\left[\frac{x^{r*}}{1-\eta}\right]^{1-\eta} \tag{A.20}$$

$$II: \tau\, p^{r*} = \lambda\varphi(v)\left[\frac{l^n(v)}{\eta}\right]^{\eta}\left[\frac{x^{r*}}{1-\eta}\right]^{-\eta} \tag{A.21}$$

Further simplifying (by dividing by each other) gives the following expression:

$$\frac{w}{\tau\, p^{r*}} = \frac{\eta}{(1-\eta)}\frac{x^{r*}}{l^n(v)} \tag{A.22}$$

Solving A.22 for $l^n(v)$ and inserting into A.16 yields the cost minimizing demand of the imported intermediate good x^{r*}. Similarly, solving A.22 for x^{r*} and inserting into A.16 yields the cost minimizing input of non-offshorable non-routine task labor $l^n(v)$:

$$x^{r*} = (1-\eta)\frac{y^o(v)}{\varphi(v)}\left[\frac{w}{\tau\, p^{r*}}\right]^{\eta} \tag{A.23}$$

$$l^n(v) = \eta\frac{y^o(v)}{\varphi(v)}\left[\frac{\tau\, p^{r*}}{w}\right]^{1-\eta} \tag{A.24}$$

Inserting these two cost-minimizing demands into the cost minimization of the offshoring firm and simplifying yields (**??**), being the cost function of the offshoring firm:

A.1.3 Cost minimization of the host country firm

Minimizing production cost $w^* l^{r*} + t^* e^*$ subject to technology, we get the following Lagrangian optimization problem:

$$\mathcal{L}(\cdot) = l^{r*}\, w^* + e^*\, t^* + \lambda\left\{x^{r*} - \beta\,(e^*)^{\alpha}\,(l^{r*})^{1-\alpha}\right\} \tag{A.25}$$

Taking FOCs and dividing by each other yields the following expression:

$$\frac{t^*}{w^*} = \frac{\alpha}{1-\alpha}\frac{l^{r*}}{e^*} \tag{A.26}$$

Rearranging (A.26) and inserting into the routine task's production function yields the cost minimizing (routine task) inputs of the homogeneous host country firm:

$$l^{r*} = x^{r*}(1-\alpha)\left(\frac{t^*}{w^*}\right)^{\alpha} \tag{A.27}$$

$$e^{r*} = x^{r*}\alpha\left(\frac{w^*}{t^*}\right)^{1-\alpha} \tag{A.28}$$

Inserting (A.27) and (A.28) into the host country firm's cost minimization yields the cost function of the homogeneous host country firm:

$$C^* = x^{r*}(t^*)^{\alpha}(w^*)^{1-\alpha}. \tag{A.29}$$

A.2 Derivation of the factor allocation

We account for the property of the Pareto distribution, according to which the average operating profits are a constant multiple of the marginal firm's operating profits. This yields

$$\pi^d(\varphi^d) = \frac{k-\sigma+1}{k}\frac{1}{1+\chi}\bar{\pi} = \frac{k-\sigma+1}{k}\frac{1}{1+\chi}\frac{1}{\sigma}\frac{Y}{M}. \tag{A.30}$$

where the second equality follows from $M\bar{\pi} = \sigma^{-1}Y$, i.e. from the result that aggregate operating profits are a constant share of aggregate income.

In order to derive the wage rate we compute labor income in the source country. For this purpose, we aggregate revenue shares of purely domestic and offshoring firms. We know from the Cobb-Douglas production technology that a share of $(1-\alpha)(1-\eta)$ of non-offshoring firms' revenue goes into routine task labor and the share η of both offshoring and non-offshoring firms into non-routine task labor. Accordingly, aggregate labor income is determined as

$$wL = N\frac{\sigma-1}{\sigma}\left[((1-\alpha)(1-\eta)+\eta)\int_{\varphi^d}^{\varphi^o} r^d(\varphi)dG(\varphi) + \eta\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi)\right]. \tag{A.31}$$

Solving this for the wage rate by means of $dG(\varphi) = k\varphi^{-(k+1)}$, $r^d(\varphi)/r^d(\varphi^d) = \left(\varphi/\varphi^d\right)^{\sigma-1}$, and $r^o(\varphi)/r^o(\varphi^o) = (\varphi/\varphi^o)^{\sigma-1}$ respectively, we get (**??**) in the main text.

We can express labor income in the host country as

$$w^*N^* = \frac{\sigma-1}{\sigma}N(1-\alpha)(1-\eta)\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi) \tag{A.32}$$

for which we use the link between revenues and productivity levels. With $(1-G(\varphi^o))\chi = (1-G(\varphi^d))$, $r^o(\varphi^o) = \sigma\pi^o(\varphi^o)$ and $\pi^o(\varphi^o) = (1+\chi^{-\frac{\sigma-1}{k}})\pi^d(\varphi^d)$, $Y/M = \sigma\bar{\pi}$ we solve for the host country's wage in (23).

A.3 Derivation of decomposed aggregate emissions

All domestic firms have the same input ratio $e(\varphi)/l^r(\varphi) = \bar{e}/\bar{l} = (w/t)[\alpha/(1-\alpha)]$. To derive $\bar{l}$ we use the integral for purely domestic firms:

$$\bar{l} = \int_{\varphi^d}^{\varphi^o} l^r(\varphi)\frac{dG(\varphi)}{G(\varphi^o)-G(\varphi^d)}. \tag{A.33}$$

Following similar steps as for the wage rate, using $\frac{l^r(\varphi^o)}{l^r(\varphi^d)} = \left(\frac{\varphi^o}{\varphi^d}\right)^{\sigma-1}$ and then again $\frac{\varphi^d}{\varphi^o}^{-(\sigma-1)} = \chi^{-\frac{\sigma-1}{k}}$ we end at:

$$\bar{l} = l^r(\varphi^d)\frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}. \tag{A.34}$$

The result includes all routine labor used by source country firms minus routine labor which has been offshored. We further know that a constant fraction $(1-\alpha)(1-\eta)(\sigma-1)/\sigma$ of revenues is earned by routine task labor. This implies for the marginal firm $l^r(\varphi^d) = (1-\alpha)(1-\eta)(\sigma-1)$ using the indifference condition of the marginal firm. Insert into $\bar{l}$:

$$\bar{l} = \frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}(1-\alpha)(1-\eta)(\sigma-1) \tag{A.35}$$

We can then derive average emissions as:

$$\bar{e} = \frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}\alpha(1-\eta)(\sigma-1)\frac{w}{t}. \tag{A.36}$$

A.4 Derivation of Y

To get a closed form solution we must derive Y. We start with $Y = (M(1+\chi))^{\frac{\sigma}{\sigma-1}}q(\bar{\varphi})$. We can use pareto and insert $q(\bar{\varphi}) = (\frac{\bar{\varphi}}{\varphi^d})^{\sigma}q(\varphi^d)$. Solve it for $q(\varphi^d)$ and insert into $q(\varphi^d) = Y/Pp^{-\sigma}/P$ with $P = 1$.

$$\frac{Y}{(M(1+\chi))^{\frac{\sigma}{\sigma-1}}}\left(\frac{\bar{\varphi}}{\varphi^d}\right)^{-\sigma} = Yp(\varphi^d)^{-\sigma} \tag{A.37}$$

Solve it for the price and insert the price equation

$$\frac{\sigma}{\sigma-1}\frac{w}{\varphi^d}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} = \left(\frac{\bar{\varphi}}{\varphi^d}\right)(M(1+\chi))^{\frac{1}{\sigma-1}} \tag{A.38}$$

We can now use Pareto for average productivity

$$\frac{\sigma}{\sigma-1}\frac{w}{\varphi^d}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} = \left(\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}(M(1+\chi))^{\frac{1}{\sigma-1}} \tag{A.39}$$

Next, we solve it for the wage rate

$$w = \left[\frac{\sigma-1}{\sigma}\varphi^d\left(M(1+\chi)\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.40}$$

We now use the marginal firm indifference condition (S.39) and insert the profits of the marginal firm into (S.41). Solve it for Y:

$$Y = \left[\frac{\sigma-1}{\sigma}\varphi^d\left(M(1+\chi)\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}}M(1+\chi)\frac{k}{k-\sigma+1}\sigma \tag{A.41}$$

$$Y = \sigma\left[M(1+\chi)\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.42}$$

We use that $\varphi^d = M^{-\frac{1}{k}} N^{\frac{1}{k}}$ and combine both expressions of M.

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

By inserting the explicit expression for M, we can rearrange to

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

A.5 Interior solution to offshoring equilibrium

We have to solve for the condition on the minimum level of iceberg trade cost τ as well as for the maximum international emissions tax differential t/t^*.

For the offshoring indifference and the labor market constraint to intersect within the interval $\chi(0,1)$, the κ-value of the downward-sloping labor market constraint $\kappa = B(\tau, t, t^*, \chi)$ at $\chi = 1$ has to be smaller than the respective value of the upward-sloping offshoring indifference condition $A(\chi)$. At $\chi = 1$ we get:

$$\kappa = B(\tau, t, t^*, 1) = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} < \kappa = A(1) = 2^{\frac{1}{\sigma-1}} \tag{A.45}$$

As γ^l collapses to η at $\chi = 1$, this inequality simplifies to:

$$\left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} < 2^{\frac{1}{\sigma-1}} \tag{A.46}$$

Solving for τ yields the minimum level of trade cost which guarantees an interior equilibrium with $\chi < 1$:

$$\tau > 2^{\frac{1}{(1-\sigma)(1-\eta)}}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}. \tag{A.47}$$

Additionally, solving (A.46) for the emission tax ratio t/t^* yields the maximum international emission tax ratio permissible for an interior equilibrium at a given level of trade costs.

$$\frac{t}{t^*} < 2^{\frac{1}{\alpha(\sigma-1)(1-\eta)}}\tau^{\frac{1}{\alpha}}\left(\frac{(1-\eta)(1-\alpha)k(\sigma-1)}{(k-\sigma+1)+\eta k(\sigma-1)}\frac{N}{N^*}\right)^{\frac{1-\alpha}{\alpha}} \tag{A.48}$$

Hence, for any interior equilibrium of offshoring, both (A.47) and (A.48) need to hold.

A.6 Comparative statics: implicit function theorem

The implicit function is given by:

$$F(\chi, \tau, t, t^*) = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} - (1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}} = 0. \tag{A.49}$$

The effect of t on F is derived as:

$$\begin{aligned}\frac{\partial F}{\partial t} &= (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta} \\ &\times \frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\alpha\left(\frac{t}{t^*}\right)^{\alpha-1}\frac{1}{t^*} > 0\end{aligned} \tag{A.50}$$

The effect of χ is given by:

$$\begin{aligned}\frac{\partial F}{\partial \chi} =&(1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta}\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{N^*}{N}\right)^{1-\alpha}(1-\alpha)\left[\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\right]^{-\alpha} \\ &\times\left[\frac{\frac{\partial\gamma^l}{\chi}k(\sigma-1)[(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]+\frac{\partial\gamma^l}{\partial\chi}k(\sigma-1)[(k-\sigma+1)+\gamma^l k(\sigma-1)]}{[(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]^2}\right] \\ &-\frac{1}{\sigma-1}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}-1}\frac{\sigma-1}{k}\chi^{\frac{\sigma-1}{k}-1} < 0\end{aligned} \tag{A.51}$$

because of $\partial\gamma^l/\partial\chi < 0$. Accordingly,

$$\frac{d\chi}{dt} = -\underbrace{\frac{\partial F/\partial t}{\partial F/\partial\chi}}_{\substack{\geq 0\\ <0}} > 0. \tag{A.52}$$

A.7 Effect on the factor allocation

For the indirect effect of χ on L we get:

$$\frac{\partial L}{\partial\gamma^l}\frac{\partial\gamma^l}{\partial\chi} = -\frac{k(\sigma-1)(k-\sigma+1)}{(k-\sigma+1+\gamma^l k(\sigma-1))}\frac{(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)+k(\gamma-\eta)}{k(1+\chi)} < 0 \tag{A.53}$$

For the direct effect of χ on M we get:

$$\frac{\partial M}{\partial\chi} = -\frac{(k-\sigma+1)[(k-\sigma+1)+\gamma^l k(\sigma-1)]N}{[(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]]^2} < 0, \tag{A.54}$$

while for the indirect effect we get:

$$\frac{\partial M}{\partial\gamma^l}\frac{\partial\gamma^l}{\partial\chi} = \frac{(1+\chi)k(\sigma-1)(k-\sigma+1)N}{[(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]]^2}\frac{(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)+k(\gamma^l-\eta)}{k(1+\chi)} > 0. \tag{A.55}$$

Jointly, the total effect of χ is given by:

$$\frac{dM}{d\chi} = \frac{-(k-\sigma+1)[(k-\sigma+1)]+(\sigma-1)(k-\sigma+1)[(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)-k\eta)]}{[(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]]^2}, \tag{A.56}$$

whose sign is *ex ante* ambiguous due to $((k-\sigma+1)/1)-1 < 0$.

A.8 Aggregate Income and Effect of unilateral emission tax increase

Aggregate Income is separated into profit income (including service income), labor income and emission tax income:

$$I = \bar{\pi}M + wL + tE \tag{A.57}$$

rewritten as shares of revenues

$$I = \left[\frac{1}{\sigma} + \gamma^l \frac{\sigma - 1}{\sigma} + \gamma^e \frac{\sigma - 1}{\sigma}\right] Y \tag{A.58}$$

Inserting Y:

$$I(\chi) = \left[\frac{1 + \gamma^l(\sigma - 1) + \gamma^e(\sigma - 1)}{\sigma}\right] \sigma \left[\frac{\sigma - 1}{\sigma} \varphi^d \left[M(1+\chi)\frac{k}{k - \sigma + 1}\right]^{\frac{1}{\sigma - 1}} \left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1}}\right]^{\frac{1}{1-\alpha(1-\eta)}} \left[M(1+\chi)\frac{k}{k - \sigma + 1}\right] \tag{A.59}$$

Closed form:

$$\begin{aligned} I(\chi) = & \left[\frac{1 + \gamma^l(\sigma - 1) + \gamma^e(\sigma - 1)}{\sigma}\right] \sigma \\ & \times \left[\frac{\sigma - 1}{\sigma} \left[\frac{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}{(k - \sigma + 1)}\right]^{\frac{1}{k}} \left[\left(\frac{(k - \sigma + 1)N}{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}\right)(1+\chi)\frac{k}{k - \sigma + 1}\right]^{\frac{1}{\sigma - 1}} \left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1}}\right]^{\frac{1}{1-\alpha(1-\eta)}} \\ & \times \left[\left(\frac{(k - \sigma + 1)N}{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}\right)(1+\chi)\frac{k}{k - \sigma + 1}\right] \end{aligned} \tag{A.60}$$

Doing comparative statics with respect to t we find:

$$\frac{dI}{dt} = \underbrace{\frac{\partial I}{\partial t}}_{<0} + \underbrace{\frac{\partial I}{\partial \chi}}_{\gtrless 0} \underbrace{\frac{d\chi}{dt}}_{>0} \tag{A.61}$$

The direct effect of t is rather obvious since an increase in the source country emission tax rates makes production (i.e. emission generation) more expensive and firms shift away from production to abatement efforts which decreases output. The indirect effect via the share of offshoring is derived as follows.

We start with two source country aggregate income equations, open economy and autarky:

$$\begin{aligned} I(\chi) = & \left[\frac{1 + \gamma^l(\sigma - 1) + \gamma^e(\sigma - 1)}{\sigma}\right] \sigma \\ & \times \left[\frac{\sigma - 1}{\sigma} \left[\frac{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}{(k - \sigma + 1)}\right]^{\frac{1}{k}} \left[\left(\frac{(k - \sigma + 1)N}{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}\right)(1+\chi)\frac{k}{k - \sigma + 1}\right]^{\frac{1}{\sigma - 1}} \left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1}}\right]^{\frac{1}{1-\alpha(1-\eta)}} \\ & \times \left[\left(\frac{(k - \sigma + 1)N}{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}\right)(1+\chi)\frac{k}{k - \sigma + 1}\right] \end{aligned} \tag{A.62}$$

$$\begin{aligned} I(0) = \sigma & \left[\frac{\sigma - 1}{\sigma} \left[\frac{[k - \sigma + 1 + (1 - \alpha(1-\eta))k(\sigma - 1)]}{(k - \sigma + 1)}\right]^{\frac{1}{k}} \left[\left(\frac{(k - \sigma + 1)N}{[k - \sigma + 1 + (1 - \alpha(1-\eta))k(\sigma - 1)]}\right)\frac{k}{k - \sigma + 1}\right]^{\frac{1}{\sigma - 1}} \left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1}}\right]^{\frac{1}{1-\alpha(1-\eta)}} \\ & \times \left[\left(\frac{(k - \sigma + 1)N}{[k - \sigma + 1 + (1 - \alpha(1-\eta))k(\sigma - 1)]}\right)\frac{k}{k - \sigma + 1}\right] \end{aligned} \tag{A.63}$$

We define $\psi(\chi) = \frac{I(\chi)}{I(0)}$

$$\begin{aligned} \psi(\chi) = & \underbrace{\left[\frac{[k - \sigma + 1 + (1 - \alpha(1-\eta))k(\sigma - 1)][1 + \gamma^e(\sigma - 1) + \gamma^l(\sigma - 1)]}{\sigma[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}\right]}_{T_1} \times \underbrace{\left[\frac{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma - 1)]}{k - \sigma + 1 + (1 - \alpha(1-\eta))k(\sigma - 1)}\right]^{\frac{\sigma - 1 - k}{k(\sigma - 1)(1 - \alpha(1-\eta))}}}_{T_2} \\ & \times \underbrace{(1+\chi)^{\frac{1}{(\sigma - 1)(1 - \alpha(1-\eta))}}}_{T_3} \end{aligned} \tag{A.64}$$

Taking the derivative with respect to χ we end after tedious calculations at:

$$\psi\prime(\chi) = \frac{T_1 \times T_2 \times T_3}{[1+\gamma(\sigma-1)][1-\alpha(1-\eta)]} \times$$
$$\left[\frac{\left[(k-\sigma+1)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1} + k(\gamma-\eta)\right]\left[(1-\alpha(1-\eta))(\sigma-1)^2[1-\alpha k\eta - \alpha\frac{k}{\sigma-1}] + (1-\alpha)(1+\gamma(\sigma-1))(k-\sigma+1)\right]}{(1+\chi)k[k-\sigma+1+[(1-\alpha)\gamma+\alpha\eta]k(\sigma-1)]} \right.$$
$$\left. + \frac{(1+\gamma(\sigma-1))[k-\sigma+1+k(\sigma-1)[(1-\alpha)\gamma+\alpha\eta]]}{(1+\chi)k[k-\sigma+1+[(1-\alpha)\gamma+\alpha\eta]k(\sigma-1)]} \right] \tag{A.65}$$

All terms are always positive except of $[1-\alpha k\eta - \alpha\frac{k}{\sigma-1}]$. Therefore, we can at least conclude that source country welfare is increasing with offshoring if $\alpha < \frac{1}{\eta k + \frac{k}{\sigma-1}}$.

A.9 Source Country Inequality

A.9.1 Between-group inequality

We look at source country inequality in two ways. First, we define inter-group inequality as a relative measure of secondary managerial income and net worker income:

$$\Theta = \frac{\bar{\pi} - \chi w + b}{w + b}. \tag{A.66}$$

In closed form we get:

$$\Theta = \frac{\frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d) - \chi\pi^d(\varphi^d) + \frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d)\frac{(k-\sigma+1)N}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\frac{1}{N}\gamma^e(\sigma-1)}{\pi^d(\varphi^d) + \frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d)\frac{(k-\sigma+1)N}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\frac{1}{N}\gamma^e(\sigma-1)} \tag{A.67}$$

We can cancel out $\pi^d(\varphi^d)$ and some terms in b:

$$\Theta = \frac{\frac{k+\chi(\sigma-1)}{k-\sigma+1} + \frac{\gamma^e k(\sigma-1)}{[k-\sigma+1+\gamma^l k(\sigma-1)]}}{1 + \frac{\gamma^e k(\sigma-1)}{[k-\sigma+1+\gamma^l k(\sigma-1)]}} \tag{A.68}$$

Since we do have the transfer on both levels, a constant at denumerator and a term which depends positively on χ we can easily confirm that inter-group Inequality is increasing with χ.

$$\frac{d\Theta}{dt} = \underbrace{\frac{\partial\Theta}{\partial\chi}}_{>0}\underbrace{\frac{d\chi}{dt}}_{>0} > 0 \tag{A.69}$$

A.9.2 Lorenz Curve

Second, we calculate the Lorenz curve. It consists of three parts:

$$Q(\mu;\chi) \equiv \begin{cases} Q_1(\mu;\chi) & \text{if} \quad \mu \in [0, b_1(\chi)) \\ Q_2(\mu;\chi) & \text{if} \quad \mu \in [b_1(\chi), b_2(\chi)) \\ Q_3(\mu;\chi) & \text{if} \quad \mu \in [b_2(\chi), 1]. \end{cases} \tag{A.70}$$

The first part of the curve includes (non-)production workers only. Their income share is given by:

$$\frac{I_1}{I} = \frac{wL + w\chi M + bL + b\chi M}{wL + \bar{\pi}M + bN} \tag{A.71}$$

The first segment of the curve:

$$Q_1 = \frac{\gamma^e k(\sigma-1) + \gamma^l k(\sigma-1) + (k-\sigma+1)}{\gamma^l k(\sigma-1) + k + \gamma^e k(\sigma-1)}\mu \tag{A.72}$$

The share of population is given by:

$$b_1(\chi) = 1 - \frac{M}{N} = \left(\frac{(1+\chi)\gamma^l k(\sigma-1) + \chi(k-\sigma+1)}{(1+\chi)[(k-\sigma+1) + \gamma^l k(\sigma-1)]}\right) \tag{A.73}$$

To get the second part we add income of non-offshorers to $Q_1(b_1)$. Individuals earning less than or equal $\pi(\bar{\varphi}), \bar{\varphi} \in [\varphi^d, \varphi^o)$ receive:

$$\frac{I_2}{I} = \frac{\Pi(\bar{\varphi}) + bM(\bar{\varphi})}{wL + \bar{\pi}M + bN} \tag{A.74}$$

The second segment of the curve is given by:

$$Q_2(\mu,\chi) = \frac{[(1+\chi)\gamma^l k(\sigma-1) + \chi(k-\sigma+1)] + k\left[1 - \left[[1-\mu]\frac{(1+\chi)[(k-\sigma+1)+\gamma^l k(\sigma-1)]}{(k-\sigma+1)}\right]^{\frac{k-\sigma+1}{k}}\right] + \mu(1+\chi)\gamma^e k(\sigma-1)}{[\gamma^l k(\sigma-1) + k + \gamma^e k(\sigma-1)](1+\chi)} \tag{A.75}$$

The share of all individuals except owners of offshoring firms relative to the total population is equal to:

$$b_2(\chi) = \frac{N - \chi M}{N} = \frac{(1+\chi)\gamma^l k(\sigma-1) + k - \sigma + 1}{(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma-1)]} \tag{A.76}$$

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

$$\frac{I_3}{I} = \frac{\Pi(\bar{\varphi}) - w(M(\bar{\varphi}) - M(\varphi^o)) + b(M(\bar{\varphi}) - M(\varphi^o))}{wL + \bar{\pi}M + bN} \tag{A.77}$$

The third part of curve is given by:

$$Q_3(\mu,\chi) = \frac{(1+\chi)[k + \gamma^l k(\sigma-1) + \gamma^e k(\sigma-1)] - k(1+\chi^{\frac{\sigma+1}{k}})\left[\left((1-\mu)\frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}{(k-\sigma+1)}\right)^{\frac{k-\sigma+1}{k}}\right] + (1-\mu)(1+\chi)[k - \sigma + 1 + \gamma^l k(\sigma-1) - \gamma^e k(\sigma-1)]}{[\gamma^l k(\sigma+1) + k + \gamma^e k(\sigma-1)](1+\chi)} \tag{A.78}$$

Figure 3 depicts the source country's Lorenz Curve for each share μ of the population. The Lorenz Curve in the Open Economy ($\chi > 0$) is based on the derived income segments Q_1, Q_2 and Q_3 for workers, non-offshoring managers and offshoring managers respectively. Note that the Lorenz Curve in Autarky ($\chi > 0$) only consists of two segments, as the income segment Q_3 for offshoring managers collapses to zero at $\chi = 0$.

It can be easily seen that inequality in the source country with offshoring is strictly larger than under autarky.

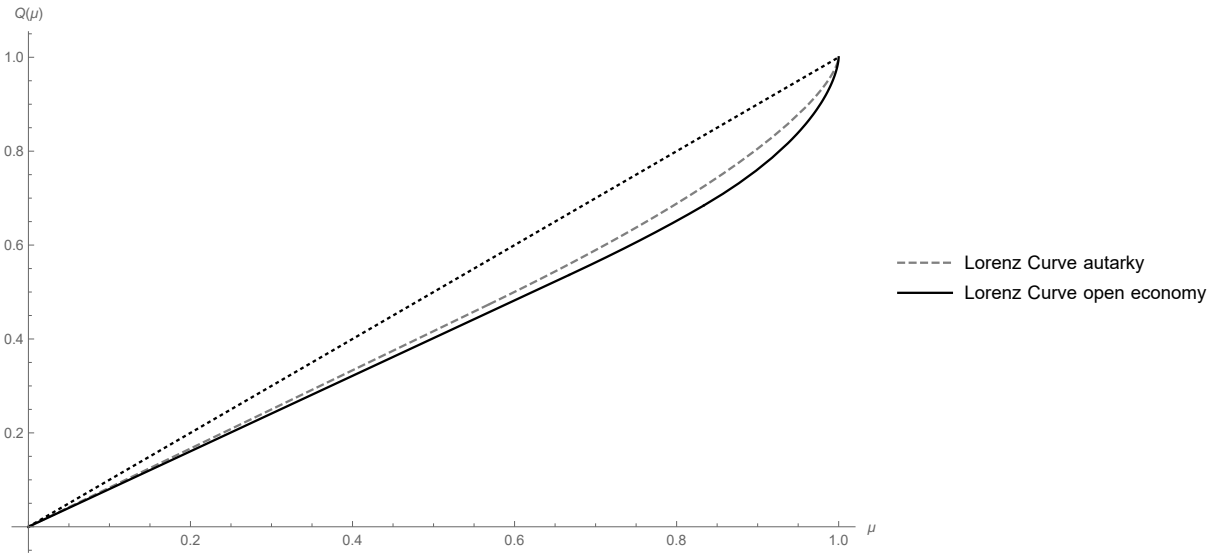

Figure 3: Source Country Lorenz Curve in Autarky and in the Open Economy

Note: The assumed parameter values are $\sigma = 2$, $k = 3$, $\alpha = 0.3$, $\eta = 0.6$, $(N/N^*) = 1$, with $\chi = 0$ under autarky and $\chi = 0.5$ in the open economy.

References

Acemoglu, D. and D. Autor (2011): "Skills, tasks and technologies: Implications for employment and earnings," in *Handbook of labor economics*, Elsevier, vol. 4, 1043–1171.

Aichele, R. and G. Felbermayr (2015): "Kyoto and carbon leakage: An empirical analysis of the carbon content of bilateral trade," *Review of Economics and Statistics*, 97, 104–115.

Akerman, A., R. Forslid, and O. Prane (2021): "Imports and the CO2 Emissions of Firms," .

Amiti, M. and J. Konings (2007): "Trade liberalization, intermediate inputs, and productivity: Evidence from Indonesia," *American Economic Review*, 97, 1611–1638.

Antonietti, R., V. De Marchi, and E. Di Maria (2017): "Governing offshoring in a stringent environmental policy setting: Evidence from Italian manufacturing firms," *Journal of cleaner production*, 155, 103–113.

Antras, P. and E. Helpman (2004): "Global sourcing," *Journal of Political Economy*, 112, 552–580.

Antràs, P., L. Garicano, and E. Rossi-Hansberg (2006): "Offshoring in a Knowledge Economy*," *The Quarterly Journal of Economics*, 121, 31–77.

Antweiler, W., B. R. Copeland, and M. S. Taylor (2001): "Is Free Trade Good for the Environment?" *American Economic Review*, 91, 877–908.

Becker, S. O., K. Ekholm, and M.-A. Muendler (2013): "Offshoring and the onshore composition of tasks and skills," *Journal of International Economics*, 90, 91–106.

Böhringer, C., B. Bye, T. Fæhn, and K. E. Rosendahl (2017): "Targeted carbon tariffs: Export response, leakage and welfare," *Resource and Energy Economics*, 50, 51–73.

Böhringer, C., J. C. Carbone, and T. F. Rutherford (2018): "Embodied carbon tariffs," *The Scandinavian Journal of Economics*, 120, 183–210.

Carluccio, J., A. Cunat, H. Fadinger, and C. Fons-Rosen (2019): "Offshoring and skill-upgrading in French manufacturing," *Journal of International Economics*, 118, 138–159.

Cherniwchan, J. (2017): "Trade Liberalization and the Environment: Evidence from NAFTA and U.S. Manufacturing," *Journal of International Economics*, 105, 130–149.

Cherniwchan, J., B. R. Copeland, and M. S. Taylor (2017): "Trade and the environment: New methods, measurements, and results," *Annual Review of Economics*, 9, 59–85.

Cole, M. A., R. J. Elliott, and T. Okubo (2014): "International environmental outsourcing," *Review of World Economics*, 150, 639–664.

Cole, M. A., R. J. Elliott, T. Okubo, and L. Zhang (2021): "Importing, outsourcing and pollution offshoring," *Energy Economics*, 105562.

Copeland, B. R. and M. S. Taylor (1994): "North-South Trade and the Environment," *Quarterly Journal of Economics*, 109, 755–787.

——— (2003): *Trade and the Environment: Theory and Evidence*, Princeton Series in International Economics. Princeton and Oxford: Princeton University Press.

Dechezleprêtre, A., C. Gennaioli, R. Martin, M. Muûls, and T. Stoerk (2021): "Searching for carbon leaks in multinational companies," *Journal of Environmental Economics and Management*, 102601.

Egger, H., U. Kreickemeier, C. Moser, and J. Wrona (2019): "Exporting and Offshoring with Monopsonistic Competition," Tech. rep.

Egger, H., U. Kreickemeier, and P. M. Richter (2021): "Environmental Policy and Firm Selection in the Open Economy," *Journal of the Association of Environmental and Resource Economists*, 8, 655–690.

Egger, H., U. Kreickemeier, and J. Wrona (2015): "Offshoring domestic jobs," *Journal of International Economics*, 97, 112–125.

Elliott, J., I. Foster, S. Kortum, T. Munson, F. Perez Cervantes, and D. Weisbach (2010): "Trade and carbon taxes," *American Economic Review*, 100, 465–69.

Ethier, W. J. (1982): "National and International Returns to Scale in the Modern Theory of International Trade," *American Economic Review*, 72, 389.

European Commission (2021): "Carbon Border Adjustment Mechanism," Available at: https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_de.

Farrokhi, F. and A. Lashkaripour (2021): "Can Trade Policy Mitigate Climate Change?" .

Feenstra, R. C. and G. H. Hanson (1997): "Foreign Direct Investment and Relative Wages: Evidence from Mexico's Maquiladoras," *Journal of International Economics*, 42, 371 – 393.

Fischer, C. and A. K. Fox (2012): "Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates," *Journal of Environmental Economics and management*, 64, 199–216.

Forslid, R., T. Okubo, and K. H. Ulltveit-Moe (2018): "Why are firms that export cleaner? International trade, abatement and environmental emissions," *Journal of Environmental Economics and Management*, 91, 166–183.

Grossman, G. M. and A. B. Krueger (1995): "Economic Growth and the Environment," *Quarterly Journal of Economics*, 110, 353–377.

Grossman, G. M. and E. Rossi-Hansberg (2008): "Trading tasks: A simple theory of offshoring," *American Economic Review*, 98, 1978–97.

Halpern, L., M. Koren, and A. Szeidl (2015): "Imported inputs and productivity," *American Economic Review*, 105, 3660–3703.

Hecht, M. and W. Peters (2019): "Border adjustments supplementing nationally determined carbon pricing," *Environmental and Resource Economics*, 73, 93–109.

Hummels, D., R. Jørgensen, J. Munch, and C. Xiang (2014): "The Wage Effects of Offshoring: Evidence from Danish Matched Worker-Firm Data," *American Economic Review*, 104, 1597–1629.

Kortum, S. and D. A. Weisbach (2021): "Optimal unilateral carbon policy," Tech. rep., Working Paper.

Kreickemeier, U. and P. M. Richter (2014): "Trade and the environment: The role of firm heterogeneity," *Review of International Economics*, 22, 209–225.

Kuik, O. and M. Hofkes (2010): "Border adjustment for European emissions trading: Competitiveness and carbon leakage," *Energy policy*, 38, 1741–1748.

LaPlue, L. D. (2019): "The Environmental Effects of Trade Within and Across Sectors," *Journal of Environmental Economics and Management*, 94, 118–139.

Larch, M. and J. Wanner (2017): "Carbon tariffs: An analysis of the trade, welfare, and emission effects," *Journal of International Economics*, 109, 195–213.

Lucas, R. E. (1978): "On the Size Distribution of Business Firms," *The Bell Journal of Economics*, 9, 508–523.

Markusen, J. R. (1975): "International externalities and optimal tax structures," *Journal of international economics*, 5, 15–29.

Matusz, S. J. (1996): "International Trade, the Division of Labor, and Unemployment," *International Economic Review*, 37, 71–84.

McAusland, C. and N. Najjar (2015): "Carbon footprint taxes," *Environmental and resource Economics*, 61, 37–70.

Melitz, M. J. (2003): "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 71, 1695–1725.

Najjar, N. and J. Cherniwchan (2021): "Environmental Regulations and the Cleanup of Manufacturing: Plant-Level Evidence," *Review of Economics and Statistics*, 103, 476–491.

Nordhaus, W. (2015): "Climate clubs: Overcoming free-riding in international climate policy," *American Economic Review*, 105, 1339–70.

OECD (2018): "OECD-WTO Trade in Value Added (TiVA) database," Available at: https://stats.oecd.org/Index.aspx?DataSetCode=TIVA_2018_C3.

OECD (2021): "Carbon dioxide emissions embodied in International Trade," Available at: https://www.oecd.org/industry/ind/carbondioxideemissionsembodiedininternationaltrade.htm.

OECD (2021): "Effective Carbon Rates (ECR)," Available at: https://stats.oecd.org/?datasetcode=ecr#.

Paul, C. J. M. and M. Yasar (2009): "Outsourcing, Productivity, and Input Composition at the Plant Level," *The Canadian Journal of Economics / Revue canadienne d'Economique*, 42, 422–439.

Shapiro, J. S. and R. Walker (2018): "Why Is Pollution from US Manufacturing Declining? The Roles of Environmental Regulation, Productivity, and Trade," *American Economic Review*, 108, 3814–54.

Online Appendix for

Offshoring and Environmental Policy: Firm Selection and Distributional Effects

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

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S.1 The offshoring equilibrium

S.1.1 The role of offshoring on firm-level employment

S.1.2 Derivation of non-offshoring firm employment

The firm-level labor demand of a non-offshoring firm l^d is the sum over its demand for non-routine task and routine task labor.

$$l^d = l_n^d + l_r^d \tag{S.1}$$

As domestic labor is used for both tasks at the same factor cost (domestic wage rate), it is yielded by deriving its unit cost function with respect to its factor price w and multiplying by firm-level output y^d:

$$l^d(\varphi) = (1 - \alpha(1-\eta))\frac{y^d}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} \tag{S.2}$$

The decomposition into non-routine task labor demand l_n^d and routine-task labor demand l_r^d is shown simply by multiplying S.2 by the parameter η and $(1-\eta)$ respectively, governing the cost share of the non-routine task.

$$l_n^d(\varphi) = \eta(1 - \alpha(1-\eta))\frac{y^d}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} \tag{S.3}$$

$$l_r^d(\varphi) = (1-\eta)(1 - \alpha(1-\eta))\frac{y^d}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} \tag{S.4}$$

S.1.3 Derivation of offshoring firm employment

Similarly, the offshoring firm's overall labor demand l^o is the sum over its demand for non-routine task labor l_n^o as well as for routine task labor l_{r*}^o:

$$l^o(\varphi) = l_n^o + l_{r*}^o \tag{S.5}$$

As the non-routine task cannot be offshored, the offshoring firm's labor demand for non-routine task labor is to be entirely satisfied by domestic workers. Hence, its non-routine task labor demand l_n^o is to be derived by deriving its unit cost function by the domestic factor cost w and multiplying by firm-level output[36]:

[36] Note that l_n^o in this notation equals l^o in the former notation (without decomposition into non-routine task and routine task labor demand).

$$l_n^o(\varphi) = \eta \frac{y^o}{\varphi} \left(\frac{\tau w^*}{w}\right)^{1-\eta} \left(\left(\frac{t^*}{w^*}\right)^{\alpha}\right)^{1-\eta} \tag{S.6}$$

As the offshoring firm shifts its routine task abroad, its demand for routine task labor l_{r*}^o is entirely satisfied by workers in the host country, i.e. by foreign workers. Hence, l_{r*}^o is yielded by deriving the offshoring firm's unit cost function by the foreign wage rate w^* and multiplying by firm-level output:

$$l_{r*}^o(\varphi) = (1-\eta)(1-\alpha)\frac{y^o}{\varphi}\tau \left(\frac{w}{\tau w^*}\right)^{\eta} \left(\left(\frac{t^*}{w^*}\right)^{\alpha}\right)^{1-\eta} \tag{S.7}$$

It is to be noted that S.6 differs from S.7 not only in the multiplicators connected to the parameters α and η, but also in the direction of the effect of w and w^*.

S.1.4 Decomposition of per-firm input demand difference

The ratio of total factor demand between offshoring firms and domestic firms is one of the determinants of offshoring-induced changes on output at the firm-level and ultimately on income at the aggregate level.

$$\frac{L^o}{L^d} = \frac{l_o^n + l_o^r + e_o}{\underbrace{l_d^n + l_d^r}_{labor-demand} + \underbrace{e_d}_{emission-demand}} = \left(1 + \chi^{\frac{\sigma-1}{k}}\right) \frac{\left[\eta + (1-\alpha)(1-\eta)\frac{w}{w^*\tau} + \alpha(1-\eta)\frac{w}{t^*\tau}\right]}{\left[\eta + (1-\alpha)(1-\eta) + \alpha(1-\eta)\frac{w}{t}\right]} \tag{S.8}$$

Whether the second term is larger or smaller than 1 is mainly decided by the factor and trade cost ratios $\frac{w}{w^*\tau}$ and $\frac{w}{t^*\tau}$ in the numerator. To differentiate labour demand changes according to country (source country/host country) as well as type of task (routine/non-routine), S.8 can further be decomposed.

S.1.5 Source country labour employment difference

Analogous to the derivation of emission demand, we obtain firm-level labor for offshoring l^o and non-offshoring l^d firms by making use of the cost minimizing labour inputs as derived in Appendix A.1:[37]

$$l^d(\varphi) = (1-\alpha(1-\eta))\frac{y^d}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta}, \tag{S.9}$$

$$l^o(\varphi) = \eta \frac{y^o}{\varphi} \left(\frac{\tau w^*}{w}\right)^{1-\eta} \left(\left(\frac{t^*}{w^*}\right)^{\alpha}\right)^{1-\eta}. \tag{S.10}$$

Note that while the source country labour input of the offshoring firm just includes non-routine task employment (l_o^n in notation of S.8), the source country employment of the non-offshoring firm contains non-routine task as well as routine task employment ($l_d^n + l_d^r$ in notation of S.8). Constructing a ratio between both expressions for source country labor demand provides insights on the offshoring-induced source country employment effect:

$$\frac{l^o(\varphi)}{l^d(\varphi)} = \frac{\eta \frac{y^o}{\varphi}\left(\frac{\tau w^*}{w}\right)^{1-\eta}\left(\left(\frac{t^*}{w^*}\right)^{\alpha}\right)^{1-\eta}}{(1-\alpha(1-\eta))\frac{y^d}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta}} = \frac{\eta}{1-\alpha(1-\eta)}\frac{y^o(\varphi)}{y^d(\varphi)}\frac{1}{\kappa}, \tag{S.11}$$

where the second equality follows from (9).

[37] While adding up (A.12) and (A.13) gives the domestic (non-routine and routine) labor demand of the non-offshoring firm, using (A.24) and inserting $p^{r*} = (t^*)^{\alpha}(w^*)^{1-\alpha}$ for the price of the imported routine task yields the domestic (non-routine) labor demand of the offshoring firm.

Next, using price and cost equation to reach $y^o/y^d = \kappa^\sigma$, which can be inserted:

$$\frac{l^o(\varphi)}{l^d(\varphi)} = \frac{\eta}{1-\alpha(1-\eta)}\kappa^{\sigma-1}. \tag{S.12}$$

Transform κ into χ using offshoring indifference condition (24):

$$\frac{l^o(\varphi)}{l^d(\varphi)} = \frac{\eta}{1-\alpha(1-\eta)}(1+\chi^{\frac{\sigma-1}{k}}). \tag{S.13}$$

We can split the overall effect into:

$$\frac{l^o(\varphi)}{l^d(\varphi)} = \left[\frac{l^o(\varphi)/y^o(\varphi)}{l^d(\varphi)/y^d(\varphi)}\right]\left[\frac{y^o(\varphi)}{y^d(\varphi)}\right] \tag{S.14}$$

$$= \left[\frac{\eta}{1-\alpha(1-\eta)}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{1-\sigma}}\right]\left[\left((1+\chi^{\frac{\sigma-1}{k}})\right)^{\frac{\sigma}{\sigma-1}}\right]. \tag{S.15}$$

Finally, taking logs we get:

$$\ln l^o(\varphi) - \ln l^d(\varphi) = \underbrace{\ln\left[\frac{\eta}{1-\alpha(1-\eta)}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{1-\sigma}}\right]}_{IR} + \underbrace{\ln\left[\left((1+\chi^{\frac{\sigma-1}{k}})\right)^{\frac{\sigma}{\sigma-1}}\right]}_{FP}. \tag{S.16}$$

The first effect is called *international relocation effect* (IR) and dominates at low level of offshoring. The second effect is the *firm productivity effect* (FP), starting at zero with no offshoring and increases in the share of offshoring. Compared to Egger et al. (2015) the IR effect is lower for all levels of offshoring due to the production technology (abatement).

S.1.6 International (total) employment difference

The international employment difference induced by offshoring refers to the firm-level difference in labor demand between a purely domestic and an offshoring firm of same productivity. While a purely domestic firm only employs domestic labor for the routine and non-routine task, the offshoring firm employ foreign abour for the routine task.

$$\frac{l_o^n + l_o^r}{l_d^n + l_d^r} = \underbrace{\left(1+\chi^{\frac{\sigma-1}{k}}\right)}_{A}\underbrace{\left(\frac{\left[\eta + (1-\alpha)(1-\eta)\frac{w}{w^*\tau}\right]}{\left[\eta+(1-\alpha)(1-\eta)\right]}\right)}_{B} \tag{S.17}$$

The term A is as in Egger et al. (2015). With any positive l_o^r, the term B can be assumed to be larger than η[38] and it can be assumed to be larger than 1 iff $\frac{w}{w^*\tau} > 1$. In this case, the offshoring-induced international labor employment difference is positive at any level of offshoring χ. However, if the term B is smaller than 1 (due to $\frac{w}{w^*\tau} < 1$) the firm's offshoring decision is to be purely attributed to a large environmental tax differential $\frac{t}{t^*}$ and the international labor employment difference at the firm-level can be negative at small levels of offshoring χ.

S.1.7 Source country non-routine task employment difference

$$\frac{l_o^n}{l_d^n} = \underbrace{\left(1+\chi^{\frac{\sigma-1}{k}}\right)}_{A}\underbrace{\left(\frac{\eta}{\eta}\right)}_{B=1} \tag{S.18}$$

[38] The second summand of the term B's numerator reaches its lower bound near zero. Thus, the term B reaches its lower bound at $\frac{\eta}{[\eta+(1-\alpha)(1-\eta)]}$ (equal to term B of **??**) which (at $\alpha = 0$) has its lower bound at η.

The firm-level non-routine task employment difference provides the change in domestic non-routine task labor demand induced by the offshoring decision. As the term B collapses to 1, only the term A remains. With B=1, it can clearly be stated that the offshoring-induced non-routine task employment difference in non-routine labor demand per firm is positive and monotonously increases in the share of offshoring firms χ: Due to offshoring-related cost saving, firms increase their output for which they demand larger quantities of non-routine task labor at home.

S.1.8 International routine task employment difference

$$\frac{l_o^r}{l_d^r} = \underbrace{\left(1+\chi^{\frac{\sigma-1}{k}}\right)}_{A} \underbrace{\left(\frac{\left[(1-\alpha)(1-\eta)\frac{w}{w^*\tau}\right]}{\left[(1-\alpha)(1-\eta)\right]}\right)}_{B} \tag{S.19}$$

The offshoring-induced international difference in (offshorable) firm-level routine-task labor demand is provided by the ratio between an offshoring firm's foreign routine task labor demand and a non-offshoring firm's domestic routine task labor demand. The term B reaches its lower bound near zero (with $\frac{w}{w^*\tau}$ close to zero[39]) and it reaches its upper bound near infinity (with $\frac{w}{w^*\tau}$ close to infinity, i.e. the home wage being extremely larger than $w^*\tau$). If the term B is smaller than 1 (i.e. $w < w^*\tau$), it can be said that the offshoring decision is solely driven by the environmental tax difference. If the term B is smaller than 1 and larger than 1/2, the offshoring-induced firm-level routine-task employment difference can be negative at low levels of χ.

S.2 Comparative Statics: Change in transport costs τ

S.2.1 Effects on offshoring

To model marginal trade liberalization we look at effects of a change in the variable transport costs τ. For that, we have to solve

$$\frac{d\chi}{d\tau} = -\frac{\partial F/\partial\tau}{\partial F/\partial\chi}. \tag{S.20}$$

The effect of τ is:

$$\begin{aligned}\frac{\partial F}{\partial\tau} &= (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta} \\ &\times\left(-\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)\frac{1}{\tau^2} < 0\end{aligned} \tag{S.21}$$

Inserted jointly with (A.51) into (S.20) our total effect is:

$$\frac{d\chi}{d\tau} = -\underbrace{\frac{\partial F/\partial\tau}{\partial F/\partial\chi}}_{\substack{\leq 0\\ <0}} < 0. \tag{S.22}$$

Accordingly, an increase of the variable transport costs reduces the marginal cost savings factor for every level of offshoring making offshoring less attractive.

[39] With $w^*\tau$ being much larger than w, the offshoring decision would need to be driven by an immense difference between t and t^*.

S.2.2 Factor allocation

$$\frac{dM}{d\tau} = \underbrace{\left[\underbrace{\frac{\partial M}{\partial \chi}}_{<0} + \underbrace{\frac{\partial M}{\partial \gamma^l}}_{<0}\underbrace{\frac{\partial \gamma^l}{\partial \chi}}_{<0}\right]}_{\gtreqless 0}\underbrace{\frac{d\chi}{d\tau}}_{<0} \tag{S.23}$$

For low levels of χ, an increase in τ leads to a decrease in the mass of managers in the source country and vice versa if we have high levels of offshoring.

$$\frac{dL}{d\tau} = \underbrace{\left[\frac{\partial L}{\partial \gamma^l}\frac{\partial \gamma^l}{\partial \chi}\right]}_{<0}\underbrace{\frac{d\chi}{d\tau}}_{<0} > 0 \tag{S.24}$$

An increase in τ leads to an increase in the mass of workers. A higher τ makes offshoring less attractive leading to higher labor demand in the source country which increases the mass of workers in the source country.

$$\frac{d\Xi}{dt} = \underbrace{\frac{\partial \Xi}{\partial \gamma}}_{>0}\underbrace{\frac{\partial \gamma}{\partial \chi}}_{<0}\underbrace{\frac{d\chi}{dt}}_{>0} < 0 \tag{S.25}$$

S.3 Comparative Statics: Change host country's emissions tax t^*

S.3.1 Effects on offshoring

Finally, we analyse the effect on the foreign country's emissions tax on the share of offshoring firms:

$$\frac{d\chi}{dt^*} = -\frac{\partial F/\partial t^*}{\partial F/\partial \chi} \tag{S.26}$$

$$\begin{aligned}\frac{\partial F}{\partial t^*} &= (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta} \\ &\times \frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\alpha\left(\frac{t}{t^*}\right)^{\alpha-1}\left(-\frac{t}{t^{*2}}\right) < 0.\end{aligned} \tag{S.27}$$

We already know $\partial F/\partial \chi$, hence:

$$\frac{d\chi}{dt^*} = -\underbrace{\frac{\partial F/\partial t^*}{\partial F/\partial \chi}}_{\substack{\leq 0\\ <0}} < 0 \tag{S.28}$$

An increase of the host country emission tax increases the cost of production in the host country and therefore decreases the marginal cost savings factor making offshoring less attractive. It is intuitive that host country emission tax rate and transport costs are going in the same direction when it comes to their effect on the share of offshoring firms, since they make offshoring production more costly relative to source country production. They shift the $\kappa - \chi$-function B (25) downwards. The source country emission tax rate acts in the opposite direction and shifts B upwards.

S.3.2 Factor allocation

$$\frac{dM}{dt^*} = \underbrace{\left[\underbrace{\frac{\partial M}{\partial \chi}}_{<0} + \underbrace{\frac{\partial M}{\partial \gamma^l}}_{<0} \underbrace{\frac{\partial \gamma^l}{\partial \chi}}_{<0}\right]}_{\gtreqless 0} \underbrace{\frac{d\chi}{dt^*}}_{<0} \tag{S.29}$$

For low levels of χ, an increase in the host country's emissions tax leads to a decrease in the mass of managers in the source country and vice versa if we have high levels of offshoring.

$$\frac{dL}{dt^*} = \underbrace{\left[\frac{\partial L}{\partial \gamma^l} \frac{\partial \gamma^l}{\partial \chi}\right]}_{<0} \underbrace{\frac{d\chi}{dt^*}}_{<0} > 0 \tag{S.30}$$

$$\frac{\partial \frac{E}{E^*}}{\partial t^*} = \underbrace{\frac{\partial \frac{E}{E^*}}{\partial t^*}}_{>0} + \underbrace{\frac{\partial \frac{E}{E^*}}{\partial \chi}}_{<0} \underbrace{\frac{d\chi}{dt^*}}_{<0} > 0 \tag{S.31}$$

$$\frac{d\Xi}{d\tau} = \underbrace{\frac{\partial \Xi}{\partial \gamma}}_{>0} \underbrace{\frac{\partial \gamma}{\partial \chi}}_{<0} \underbrace{\frac{d\chi}{d\tau}}_{<0} > 0 \tag{S.32}$$

S.4 Allocation of l^r into production and abatement - non-offshoring firms

While only a part ξ of routine task labor is used for production, the other part $(1-\xi)$ is allotted to emission abatement efforts. Solving 5 for ξ yields:

$$\xi = \beta \left[\frac{e(v)}{l^r(v)}\right]^{\alpha} \qquad \text{with} \quad \beta \equiv (1-\alpha)^{-(1-\alpha)}\alpha^{-\alpha} \tag{S.33}$$

Inserting the non-offshoring firm's cost minimizing inputs of $e(v)$ and $l^r(v)$ simplifies this expression to:

$$\xi = \frac{1}{1-\alpha}\left(\frac{w}{t}\right)^{\alpha} \tag{S.34}$$

Hence, the share of routine task labor allotted to production increases in the wage rate as well as in the Cobb-Douglas emission parameter α while it decreases in the environmental tax rate.

In order to decompose routine task labor into its parts allotted to production ξ as well as abatememt $(1-\xi)$, the share is to be multiplied by the cost-minimizing input $l^r(v)$:

$$l^r(v)\,\xi = (1-\eta)\,\frac{y(v)}{\varphi(v)}\left(\frac{w}{t}\right)^{\alpha\eta} \tag{S.35}$$

$$l^r(v)\,(1-\xi) = \left[(1-\eta)\,\frac{y(v)}{\varphi(v)}\left(\frac{w}{t}\right)^{\alpha\eta}\right]\left[(1-\alpha)\left(\frac{t}{w}\right)^{\alpha} - 1\right] \tag{S.36}$$

Note that the right side of both of the equations is generated by inserting S.34 and A.13 (non-offshoring firm's cost-minimizing $l^r(v)$). While the wage-tax ratio w/t is clearly increasing the share of routine task labor allotted to production, the effect of w/t is ambiguous regarding the share of labor allotted to abatement efforts.

S.5 Autarky

production technology is identical to open economy hence optimization leads to the same cost function as a domestic firm

$$c_a = \left[y(v) \frac{w}{\alpha} \left(\left(\frac{t}{w} \right)^{\alpha} \right)^{1-\eta} \right] \tag{S.37}$$

$$p_a = \frac{\sigma}{\sigma - 1} \frac{w}{\varphi} \left(\left(\frac{t}{w} \right)^{\alpha} \right)^{1-\eta} \tag{S.38}$$

Occupational choice

$$\pi_a(\varphi^d) = w \tag{S.39}$$

$$\bar{\pi}_a = \pi_a(\varphi^d) \frac{k}{k - \sigma + 1} \tag{S.40}$$

using $Y/M = \sigma\bar{\pi}$ to solve for RHS in marginal firm indifference condition

$$\pi_a(\varphi^d) = \frac{k - \sigma + 1}{k} \frac{1}{\sigma} \frac{Y_a}{M_a} \tag{S.41}$$

wage income is a constant fraction $\frac{\sigma-1}{\sigma}(1 - \alpha(1 - \eta))$ of firms revenue

$$w_a L_a = \frac{\sigma - 1}{\sigma}(1 - \alpha(1 - \eta))Y_a \tag{S.42}$$

using (S.41) and (S.42) in (S.39) to solve for L

$$L_a = \frac{k(\sigma - 1)}{k - \sigma + 1}(1 - \alpha(1 - \eta))M_a \tag{S.43}$$

resource constraint

$$L_a = N - M_a \tag{S.44}$$

combine both to get equilibrium factor allocation

$$L_a = \frac{k(\sigma - 1)(1 - \alpha(1 - \eta))}{k - \sigma + 1 + k(\sigma - 1)(1 - \alpha(1 - \eta))} N \tag{S.45}$$

$$M_a = \frac{k - \sigma + 1}{k - \sigma + 1 + k(\sigma - 1)(1 - \alpha(1 - \eta))} N \tag{S.46}$$

using $M_a = (1 - G(\varphi^d))N$ we get the cutoff productivity of the marginal firm

$$\varphi_a^d = \left[\frac{k - \sigma + 1 + k(\sigma - 1)(1 - \alpha(1 - \eta))}{(k - \sigma + 1)} \right]^{\frac{1}{k}} \tag{S.47}$$

Aggregate Emissions

$$t_a E_a = Y_a \frac{\sigma - 1}{\sigma} \alpha(1 - \eta) \tag{S.48}$$

To get a closed form solution we must derive Y. We start with $Y = M^{\frac{\sigma}{\sigma-1}} q(\bar{\varphi})$. We can use pareto and insert $q(\bar{\varphi}) = (\frac{\bar{\varphi}}{\varphi^d})^{\sigma} q(\varphi^d)$. Solve it for $q(\varphi^d)$ and insert into $q(\varphi^d) = Y/Pp^{-\sigma}/P$ with $P = 1$.

$$\frac{Y}{M^{\frac{\sigma}{\sigma-1}}} \left(\frac{\bar{\varphi}}{\varphi^d} \right)^{-\sigma} = Yp(\varphi^d)^{-\sigma} \tag{S.49}$$

Solve it for the price and insert the price equation

$$\frac{\sigma}{\sigma - 1} \frac{w}{\varphi^d} \left(\left(\frac{t}{w} \right)^{\alpha} \right)^{1-\eta} = \left(\frac{\bar{\varphi}}{\varphi^d} \right) M^{\frac{1}{\sigma-1}} \tag{S.50}$$

We can now use pareto for average productivity

$$\frac{\sigma}{\sigma-1}\frac{w}{\varphi^d}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta}=\left(\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}M^{\frac{1}{\sigma-1}} \tag{S.51}$$

Next, we solve it for the wage rate

$$w=\left[\frac{\sigma-1}{\sigma}\varphi^d\left(M\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{S.52}$$

We now use the marginal firm indifference condition (S.39) and insert the profits of the marginal firm into (S.41). Solve it for Y:

$$Y_a=\left[\frac{\sigma-1}{\sigma}\varphi^d\left(M\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}}M\frac{k}{k-\sigma+1}\sigma \tag{S.53}$$

$$Y_a=\sigma\left[M\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{S.54}$$

Use it in aggregate emissions

$$E_a=(\sigma-1)\alpha(1-\eta)\left[M\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{S.55}$$

S.5.1 Autarky - Comparative Statics

$$\frac{\partial Y_a}{\partial t}=\sigma\left[M\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left(-\frac{1}{t^2}\right)\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}-1}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}}<0 \tag{S.56}$$

A change of emission tax affects the aggregate emissions:

$$\frac{\partial E_a}{\partial t}=-\frac{1}{1-\alpha(1-\eta)}\left(\frac{1}{t}\right)^{\frac{1}{1-\alpha(1-\eta)}-1}(\sigma-1)\alpha(1-\eta)\left[M\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}}<0 \tag{S.57}$$

S.5.2 Derivation of $\partial\gamma/\partial\chi$

$$\frac{\partial\gamma}{\partial\chi}=\frac{(\eta-\frac{k-\sigma+1}{k}\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta))(1+\chi)-(1-\alpha(1-\eta)+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}})}{(1+\chi)^2} \tag{S.58}$$

splitting up

$$\frac{\eta-\frac{k-\sigma+1}{k}\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)}{(1+\chi)}-\frac{1-\alpha(1-\eta)+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}}}{(1+\chi)^2} \tag{S.59}$$

splitting up the first term

$$-\frac{(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)}{k(1+\chi)}-\frac{1-\alpha(1-\eta)+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}}}{(1+\chi)^2}+\frac{\eta}{(1+\chi)} \tag{S.60}$$

second term is equal to $\gamma/(1+\chi)$; multiply second and third term by k/k splitting up the first term

$$-\frac{(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)}{k(1+\chi)}-\frac{k\gamma}{k(1+\chi)}+\frac{k\eta}{k(1+\chi)} \tag{S.61}$$

combine to one term

$$\frac{\partial \gamma}{\partial \chi} = -\frac{(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta)+k(\gamma-\eta)}{k(1+\chi)} \tag{S.62}$$

since α and $\eta < 1$, $k > \sigma - 1$ and $\gamma > \eta$ this term is negative so $\partial\gamma/\partial\chi < 0$.