# Offshoring and Environmental Policy: Firm Selection and Distributional Effects*

Simon J. Bolz† TU Dresden

Fabrice Naumann‡ TU Dresden

Philipp M. Richter§ University of Mannheim CESifo, DIW Berlin, and KCG

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**Abstract**

This paper analyzes the impacts of a unilateral environmental policy reform on emissions, income, and inequality in the context of offshoring. We set up a general equilibrium model of offshoring with heterogeneous firms. Each firm can allocate labor to different production tasks and emission abatement. It also decides whether to offshore an emissions-intensive part of the production to benefit from lower labor and/or emissions costs abroad. We identify international differences in the ratio of input prices as a key determinant of the environmental impact of the offshoring decision. With a policy reform leading to an increase in offshoring, the input price ratio in both countries changes due to general equilibrium effects. This reinforces the relocation of emissions toward the host country of offshoring. Given a high level of offshoring, emissions may increase globally. In an extension, we analyze the introduction of a border carbon adjustment.

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†Technische Universität Dresden, Faculty of Business and Economics, Helmholtzstraße 10, 01069 Dresden, Germany; Email: simon.bolz@tu-dresden.de.

‡Technische Universität Dresden, Faculty of Business and Economics, Helmholtzstraße 10, 01069 Dresden, Germany; Email: fabrice.naumann@tu-dresden.de.

§University of Mannheim, Department of Economics, L7, 3-5, 68131 Mannheim, Germany; Email: philipp.richter@uni-mannheim.de.

# 1 Introduction

The practice of offshoring, encompassing the relocation of production tasks to foreign destinations, is subject to controversial public debates, mainly in the context of distributional and environmental consequences. In the context of man-made global warming, the environmental impact of spatial shifts in global production patterns is a highly relevant field of analysis. As data reveals, shifting of carbon-intensive production follows a certain pattern closely along a North-South division: Most OECD countries are net importers of embodied $CO_2$, while most non-OECD countries are net exporters.This pattern, indicating an outsourcing of pollution towards the Global South strongly intensified over the last 25 years (OECD, 2021). Countries aim to reduce national $CO_2$ emissions, most notably by raising taxation of carbon-intensive production inputs. However, there is substantial heterogeneity with respect to carbon pricing across countries (OECD, 2022), making international price asymmetries a key determinant of production relocation (Cherniwchan, 2017). Thus, stringency in environmental regulation to a great extent could be undermined by the firm-level capability to evade and shift "dirty" parts of its production elsewhere. The question arises how effective unilateral environmental policy can be in a highly globalized economy.

Countries are adopting several approaches to encounter the carbon leakage problem. Border carbon adjustments (BCAs) are clearly among the most widely discussed mechanisms in literature. By imposing a BCA, the national government closes a potential carbon price wedge between production at home versus production in countries with lower environmental stringency. A firm that relocates parts of its production has to pay the carbon price difference at the border upon re-importing the intermediate good. Recent literature reviews the BCA with respect to effectiveness and economic cost (cf. Böhringer et al., 2022; Farrokhi and Lashkaripour, 2021). BCAs are being implemented as policy instruments. Complementing its emission trading scheme, the European Union is currently introducing a Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2021).

Against this background, we aim to depict the firm-level possibility to offshore abroad in the presence of an emission-intensive production process with emissions pricing. By increasing the emission tax in the home country, we firstly analyse how offshoring decisions are affected at the firm-level. 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 regard the firm-level to be a highly important scope of analysis, as changes in the emissions intensities of firms ("technique effect") are identified as the most important channel through which trade impacts aggregate emissions (Cf. Copeland et al., 2022). Secondly, we derive effects on emissions, aggregate income and inequality measures. To build our framework, we 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.

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 Grossman and Rossi-Hansberg (2008) and Acemoglu and Autor (2011) in modelling production as the combination of routine and non-routine tasks 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). 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).

There are several empirical contributions that investigate the impact of offshoring on emissions, such as Hanna (2010), Antonietti et al. (2017); Cherniwchan (2017), Cole et al. (2014), Akerman et al. (2021) and Tanaka et al. (2021). At the example of Japanese manufacturing, Cole et al. (2021) also features the role of carbon pricing on the firm-level decision to offshore.

Capturing general-equilibrium-effects, there are theoretical frameworks that link the dimension of exporting or final goods trade to emissions, such as Kreickemeier and Richter (2014), Forslid et al. (2018), Shapiro and Walker (2018) and LaPlue (2019). Egger et al. (2021) also investigate the role of environmental policy in the context of exporting. However, as we argue, the perspective of final goods trade is insufficient for a comprehensive analysis of the effects of unilateral environmental policy, as it does not take shiftings in the production process into account. To the best of our knowledge, we provide one of the first contributions that analyses environmental stringency in the context of offshoring. Schenker et al. (2018) investigate the effects of environmental policy on firm-level offshoring decisions and market structures. They also show how the introduction of a border carbon adjustment stops production relocation. The model setup strongly deviates from our setting as they incorporate a multi-stage production process with a continuum of goods and do not feature firm heterogeneity.

We derive our findings analytically as well as by numerical simulations. At the firm-level, we show that differences in effective emission taxation (tax-wage ratios) across countries determine the environmental impact of the firm-level decision to offshore. We then increase the source country's emission tax rate in order to derive effects in the economy. The unilateral policy reform incentivizes more firms to offshore, inducing general equilibrium effects on emissions, income and inequality. As the share of offshorers rises, firms adjust their production process at the micro-level. This reduces emissions per unit of output for non-offshoring firms, while emission intensity levels increase among offshorers. At the aggregate level, we show that emissions in the source country (home) reduce while emissions in the host country (abroad) increase substantially. Interestingly, we highlight a non-monotonous effect of the source country's emission tax rate on global emissions: If the source country emission tax rate is sufficiently high, the leakage rate between the two countries may surpass 100%, implying a net increase in global emissions. However, this scenario implies a high initial level of offshoring in the economy.

Extending our view to income and inequality, we show that the increase in offshoring induced by the unilateral environmental policy reform mitigates the income losses associated to the tax increase. Furthermore – via increased offshoring – the environmental policy reform increases inequality within the source country and decreases inequality between the source country and the host country.

In order to assess effectiveness and economic cost of a BCA, we extend our analysis. We show that an emission tax increase – in the presence of a BCA – would no longer increase offshoring. Thus, the environmental policy reform clearly prevents leakage and reduces global emissions. However, under a border adjustment, the loss of global income induced by the unilateral emission tax increase shows to be larger as compared to the previous scenario without the border adjustment.

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 BCA. Section 6 concludes.

## 2 The model setup

We consider an economy that consists of a final goods sector and an intermediate goods sector as in Egger et al. (2015). The production of the final good relies on the processing of different varieties of the intermediate product as 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.[1]

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.[2] 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.

### 2.1 The final goods sector

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

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

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

[1] 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).

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

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 the two countries) and negatively on the variety's own price.

### 2.2 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 $\varphi$, which directly translates into firm productivity. Each entrepreneur decides on worker employment, on offshoring activity, and on the production of her variety $v$.

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,[3] while, in addition, in our framework it can also be used to

[3] 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.

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 $\xi$ 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, subject to entry and sorting (see Section 3 on the selection mechanism).

Taking factor prices exogenously, each non-offshoring firm minimizes her costs, 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 $\tau \geq 1$ 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, the technology-constraint minimization of production costs 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 labor, generating emissions abroad, and, hence, accounting for foreign factor prices $w^*$ and $t^* \in (0;t]$.[4] Under assumed perfect competition, the host country firm offers its product at marginal costs, i.e. at $p^r = (t^*)^\alpha (w^*)^{1-\alpha}$.

We can now express the difference in marginal costs of a firm with productivity $\varphi$ 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, by means of Eqs. (7) and (8) we express a marginal cost savings factor of offshoring as

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

where the last expression follows from replacing $p^r$.[5] Only for $\kappa > 1$, an offshoring equilibrium materialises. Note that $\kappa$ 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 $\tau$ reduce the incentive to offshore. Importantly, emissions taxes $t$ and $t^*$ and transport costs $\tau$ are exogenous model parameters, while wages $w$ and $w^*$ are endogenous and, hence, adjust 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,[6] we can finally express the role of a firm's offshoring status for her price, output and operating profits:[7]

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

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

Within each status (offshoring or non-offshoring), the more productive a firm, the higher her

[4] We, hence, restrict the model to the empirically plausible case that the emissions tax of the host country of offshoring does not exceed that of the source country.
[5] This is a generalisation of Eq. (4) in Egger et al. (2015), which it collapses to in the special case of $\alpha \to 0$.
[6] This follows from the constant price elasticity of demand in Eq. (2) and the assumed monopolistic competition.
[7] In the Online Appendix Section S.1, we additionally derive and compare several labor employment ratios between offshoring and non-offshoring firms.

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 $\varphi$, which perfectly distinguishes the different firms.

Before closing the model and determining the offshoring equilibrium in the next section, let us finally investigate the difference in emissions across firms. Recall that emissions in our model are linked to the routine task only. A purely domestic firm generates emissions in the source country. An offshoring firm, by contrast, does not generate emissions; it does not have to pay an emissions tax directly. Indirectly, however, it causes emissions in the host country by importing the output of the routine task; 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.[8]

For each firm, we define emissions as the product of output and emissions intensity, i.e. $e(\varphi) = y(\varphi)i(\varphi)$. A firm's emissions intensity, we can decompose into three factors: first, the generation of emissions per unit of the routine task's output, second, the production of the routine task's output per unit of the input bundle and, third, the usage of the input bundle per unit of output. Accordingly, with formal derivations deferred to Appendix A.2, we compute the emissions intensity of a non-offshoring and an offshoring firm as:[9]

$$i^d(\varphi) = \alpha \left(\frac{w}{t}\right)^{1-\alpha} \cdot (1-\eta) \left(\frac{w}{t}\right)^{\alpha\eta} \cdot \varphi^{-1} \tag{12}$$

$$i^o(\varphi) = \alpha \left(\frac{w^*}{t^*}\right)^{1-\alpha} \cdot \tau(1-\eta) \left(\frac{w}{\tau(w^*)^{1-\alpha}(t^*)^{\alpha}}\right)^{\eta} \cdot \varphi^{-1}. \tag{13}$$

The emissions intensity of a particular firm is, hence, determined by a combination of economy-wide factor prices, firm behaviour and a firm characteristic, productivity.[10]

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

[9] 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 $\tau$ on the RHS of Eq. (13).

[10] Importantly, productivity level $\varphi$ is exogenous to the firm and cannot be altered. 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.

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, as seen in Eq. (13).

This becomes a crucial feature when highlighting the role of a firm's offshoring status on emissions and emissions intensity. Complementing Eq. (10), we can state the following:

$$\frac{e^o(\varphi)}{e^d(\varphi)} = \frac{t}{t^*}\kappa^{\sigma-1} \qquad \text{and} \qquad \frac{i^o(\varphi)}{i^d(\varphi)} = \frac{t}{t^*}\kappa^{-1}. \tag{14}$$

Accordingly, the decision to offshore is associated with higher emissions,[11] whereas the difference in emissions intensity is ambiguous. While quite intuitive in the context of offshoring, the possibility of a higher emissions intensity of internationally active firms controlling for productivity, i.e. $i^o(\varphi) > i^d(\varphi)$, 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 are characterised by lower emissions intensities due to higher abatement investments (cf. Forslid et al., 2018).

The ambiguity in the difference in emissions intensity levels in our offshoring model is driven by international differences in factor prices.[12] 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 in light of transport costs $\tau$, there must be a sufficiently large difference in the wage rates between the two countries. With $w > w^*$, the wage-tax-ratio is necessarily lower in the host country. Thus, in light of the first channel displayed in Eqs. (12) and (13), the routine task is produced less emissions-intensively if offshored. From Eq. (14) it then becomes apparent that the emissions intensity of an offshoring firm is lower than of a non-offshorer in the case of equal emissions tax rates. This is despite the opposing effect of $\tau$, Importantly, this reasoning also holds for sufficiently small differences in the emissions tax rates with $t > t^*$, while $\kappa > 1$.[13] If, by contrast, the difference in emissions tax rates is sufficiently large, and constitutes the incentive to offshore to begin with, the emissions intensity of an offshoring firm is higher.

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

[12] 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.

[13] It is straightforward to derive the following condition for $i^o(\varphi) < i^d(\varphi)$ from Eqs. (12) and (13): $1 \leq t/t^* < (w/w^*)^{(1-\alpha)(1-\eta)/[1-\alpha(1-\eta)]}(1/\tau)^{(1-\eta)/[1-\alpha(1-\eta)]}$.

Hence, 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 labor costs, the emissions intensity may be lower in case of offshoring. Importantly, such a firm-level clean-up can take place even in case of a lower emissions tax rate in the host country of offshoring, a pollution haven setting, as it is the wage-tax ratio that is the crucial determinant.

Finally, 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.[14]

Let us summarize our findings in the following lemma:

**Lemma 1.** *Controlling for productivity, a firm's emission intensity is smaller in case of offshoring, if the source country's emissions tax exceeds that of the host country only slightly. It is larger otherwise. Controlling for the offshoring status, a more productive firm produces less emissions-intensively.*

# 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 heterogeneity of 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 $w$.[15] 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 assume that each individual chooses her occupation solely based on her expected income originating from the different occupations. Denoting the threshold ability to become a manager by $\varphi^d$, all agents with ability at least as high ($\varphi \geq \varphi^d$) decide to run a firm, while all individuals

[14] The corresponding elasticities w.r.t. productivity are $-1$ for emissions intensity $i(\varphi)$ and $\sigma - 1$ for emissions $e(\varphi)$, respectively.

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

with lower managerial ability ($\varphi < \varphi^d$) become workers or offshoring consultants. In line with the empirical evidence of self-selection of the most productive firms into offshoring (cf. Paul and Yasar, 2009; Hummels et al., 2014), our least productive firm, i.e. the firm run by the marginal manager, does not offshore. 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. The marginal offshoring firm with productivity $\varphi^o$ is determined by

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

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

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

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

This endogenous variable will turn out to be crucial for highlighting 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 $\chi M$ subsumes all offshoring consultants.

Jointly using Eqs. (15)-(18), we can now solve for the domestic factor allocation depending on $\chi$. 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 $\chi$. Accordingly, as formally shown in Appendix A.3[16], 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 $\chi$, which plausibly highlights the shift of income to the host country with relatively more firms offshoring.[17] Substituting for either $M$ or $L$ by means of the resource constraint Eq. (18), we can solve for the equilibrium factor allocation depending on $\chi$. This yields

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

where $\lambda = [1+(k-\sigma+1)/\gamma^l k(\sigma-1)]^{-1}$ is the share of workers in the source country's population. Accordingly, $L$ is decreasing in $\chi$ via an indirect effect through $\gamma^l$, while a positive indirect dependence of $M$ on $\chi$ (via $\gamma^l$) 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 $\varphi^d$ and the relation between the two cutoff productivity levels $\varphi^d$ and $\varphi^o$ as a function of $\lambda$. 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 for $\varphi^d$ in closed-form.

In contrast to the source country, 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

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

[16] Also see Appendix A.8 for a derivation of Y in closed form.

[17] 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. This share positively depends on $\chi$, as with a rise in offshoring more income is generated in the host country.[18]

### 3.2 The share of offshoring firms

Our main endogenous variable $\chi$, 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 $\chi$ and the marginal cost savings factor $\kappa$. 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:[19]

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

This condition captures a positive relationship between $\kappa$ and $\chi$, 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 $\kappa$ in Eq. (9) to get:

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

This condition shows a negative relation between $\kappa$ and $\chi$. It is an increase in the share of offshoring firms $\chi$ that leads to a rise in labor demand in the host country, *ceteris paribus*. This, in turn, leads to a rise in the host country's wage rate, reducing the attractiveness to offshore, expressed by a declining $\kappa$.

Jointly, these two links, Eqs. (24) and (25), determine $\kappa$ and $\chi$. For an interior equilibrium of offshoring with $\chi \in (0, 1)$ to hold, the level of iceberg trade cost $\tau$ must not be too small and, or the environmental tax differential must not be too large. Otherwise, our assumption of the marginal firm being a purely domestic firm, and, hence, Eq. (15), would be violated. In Appendix A.4.2, we derive the necessary conditions for $\tau$ and $t/t^*$ in order to guarantee

[18] For $\chi \to 0$ (autarky) it holds that $\gamma^{l*} = 0$, while it converges to $(1-\alpha)(1-\eta)$ with $\chi \to 1$.
[19] See appendix A.4.1 for a detailed derivation.

$\chi \in (0, 1)$. Figure 1 illustrates an interior offshoring equilibrium.

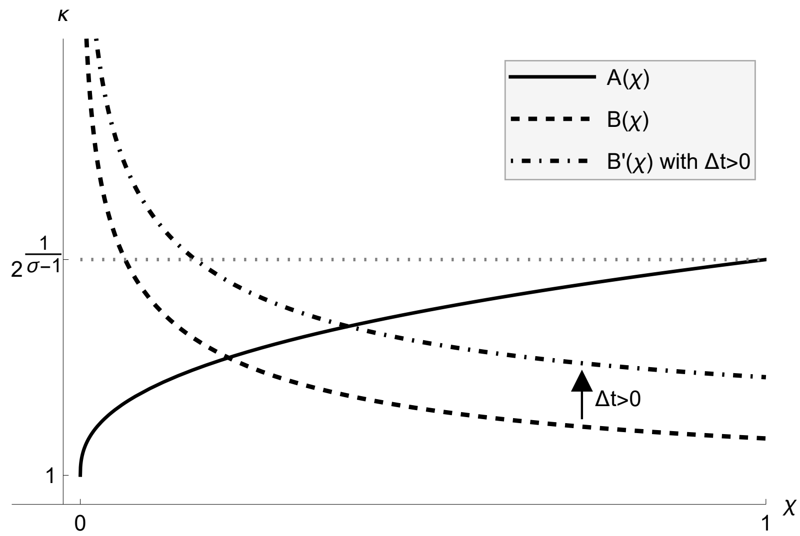


Figure 1: Determining the offshoring equilibrium

# 4 Unilateral environmental policy reform

In this section, we analyse the effects of a unilateral environmental policy reform in an offshoring equilibrium as derived in the previous sections. To this end, we focus on an increase in the source country's emissions tax, while the emissions tax in the host country remains unchanged.

## 4.1 Effects on occupational choices and firm selection into offshoring

Let us first analyse how individuals respond to the emissions tax reform by altering their occupational choices and how firms adjust their decisions to offshore. On aggregate, this determines the change in the factor allocation and gives valuable insights on how the economy will be affected by a unilateral increase in the emissions tax.

Acknowledging the importance of $\chi$, we begin our analysis with an investigation on how this variable is altered by a rise in $t$. We apply the implicit function theorem to derive the change in $\chi$ w.r.t. a rise in $t$, as it is not possible to solve the model in closed-forms (see above). To this end, we make use of Eqs. (24) and (25), the two links between $\kappa$ and $\chi$, and define the following implicit function:

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

Implicit differentiation yields $d\chi/dt = -(\partial F/\partial t)/(\partial F/\partial \chi) > 0$, as formally shown in Appendix A.4.3. Hence, 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 makes offshoring the emissions-intensive routine task more attractive for a larger share of firms; $\kappa$, the marginal cost savings factor increases. At the extensive margin, more firms avoid to pay the domestic emissions tax by offshoring part of the production process. Formally, this can be seen by a direct effect of $t$ on $B(\chi)$ in (25), whereas $A(\chi)$ in Eq. (24) remains unaffected. Figure 1 highlights this new offshoring equilibrium from the upward shift from $B(\chi)$ to $B'(\chi)$ (the dashed-dotted line) resulting in an increase in both $\chi$ and $\kappa$.

We can use this result to derive 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 $\chi$. 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 labor income share $\gamma^l$ that ultimately determines $\lambda$, the share of workers in the population.

Consequently, $1 - \lambda$, the share of non-workers (managers and offshoring consultants) increases. For our discussion on emissions later it is useful to distinguish between purely domestic firms $(1 - \chi)M$ and offshoring firms $\chi M$. We can relate both to the two cutoff productivities using Pareto:

$$(1 - \chi)M = N\left[(\varphi^d)^{-k} - (\varphi^o)^{-k}\right] \qquad \text{and} \qquad \chi M = N(\varphi^o)^{-k} \tag{27}$$

The rise in source country production costs opens up the possibility of offshoring for the most productive purely domestic firms, meaning the cutoff productivity of the marginal offshoring firm falls, $d\varphi^o/dt < 0$, hence the mass of offshoring firms increases $d(\chi M)/dt > 0$. The implication of this result is remarkable, although not surprising in our model framework of self-selection into offshoring: it is the most productive domestic firms and, hence, those domestic firms with the lowest emissions intensity (see Lemma 1) that start to offshore in response to a rise in the emissions tax rate. This runs against the common perception of the dirtiest firms to offshore and is a direct consequence of fixed costs of offshoring in our model.[20]

[20] We acknowledge the possibility of across-sector differences in emissions-intensities with an emissions tax rise potentially leading to offshoring of firms particularly from dirty sectors. This is not featured in our one

While firms leave on the upper end of the domestic firms distribution, the effect on the lower end is ambiguous. This result is known from Egger et al. (2015) and we link it to an increase in the source country emission tax rate. The following threshold represents the level of $\chi$ where the sign of the effect changes:

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

such that for $\chi < \tilde{\chi}$ an increase in the source country's emissions tax leads to a decrease in the cutoff productivity of the marginal firm, while for $\chi > \tilde{\chi}$ it leads to an increase.[21] That means, in the second case both cutoffs decrease the mass of purely domestic firms as we have exit on both ends of the domestic productivity distribution. In the first case, however, the total effect is ex ante not clear as firms enter the market at the lower end.

With knowledge on the emissions tax-induced changes in occupational choices and firm selection, we can finally analyse the impact on average productivity of both domestic and offshoring firms. To this end, and with formal derivations in Appendix A.5, we first compute

$$\bar{\varphi}^d = \frac{k-\sigma+1}{k-\sigma} \frac{1-\chi^{(k-\sigma)/k}}{1-\chi^{(k-\sigma+1)/k}} \varphi^d \qquad \text{and} \qquad \bar{\varphi}^o = \frac{k-\sigma+1}{k-\sigma} \varphi^o. \tag{29}$$

We show that both averages decline in t, i.e. $d\bar{\varphi}^d/dt < 0$ and $d\bar{\varphi}^o/dt < 0$.[22] New offshoring firms (see Proposition 1) are less productive than the existing ones leading to a decline in the average output of offshoring firms $d\bar{y}^o/dt < 0$.

We can summarize these 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. If this share is sufficiently high, the effect on the mass of managers is negative, corresponding to a tax-induced increase in the marginal productivity. A unilateral increase in the source country's emissions tax rate unambiguously leads to a rising share of offshoring firms.*

(intermediate) sector model.

[21] See Appendix A.9.1 for a derivation of the threshold level $\tilde{\chi}$.

[22] Preliminary analytical proof in Appendix A.9.2 supported by numerical simulations.

### 4.2 Effects on emissions

#### 4.2.1 Domestic aggregate emissions

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

$$E = M(1-\chi)\bar{y}^d\bar{i}^d, \tag{30}$$

which is the product of the mass of domestic firms, their average production volume and their average emissions intensity. In detail, as shown in Appendix A.5 and A.6, we derive the averages as follows:

$$\bar{y}^d = \frac{k(\sigma-1)}{k-\sigma+1}\frac{1-\chi^{(k-\sigma+1)/k}}{1-\chi}\left(\frac{w}{t}\right)^{\alpha(1-\eta)}\bar{\varphi}^d \quad \text{and} \tag{31}$$

$$\bar{i}^d = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)}\frac{1}{\bar{\varphi}^d} \tag{32}$$

Importantly, it is both the decision of each individual firm on labor allocation, abatement and production volumes (Section 2), and the composition of the heterogeneous firms that determine the averages among purely domestic firm.[23]

Both the academic literature and the public debate pay great attention to the change in average emissions intensity, the *technique effect*. Our expectations of a decline in this measure seems to be satisfied by the direct effect of $t$ in Eq. (32). However, it is general equilibrium effects that we have to account for, as both the economy-wide wage rate and the average productivity of domestic firms adjust to the tax. As we have shown above, domestic firms are less productive on average, which increases the average emissions intensity, *ceteris paribus*. By contrast, a decline in the economy-wide wage rate enforces the reducing impact of the tax reform. The wage-tax-ratio unambiguously decline, leading to a less emissions intensive production of the routine task and a shift towards the non-routine task. With formal derivations deferred to the Appendix A.9.3, we show that the net impact of $t$ on $\bar{i}^d$ is negative, domestic firms become cleaner on average.

[23] The product of average output and average emissions intensity, in turn, gives the average generation of emissions of domestic firms:

$$\bar{e}^d = \bar{y}^d\bar{i}^d = \frac{k(\sigma-1)}{k-\sigma+1}\alpha(1-\eta)\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}\frac{w}{t}.$$

Moreover, this cleaning effect is complemented by a decline in average output, and a reduction in the mass of domestic firms. Hence, three partial effects that all lead to the reduction in domestic aggregate emissions.

We summarize our findings as follows

**Proposition 2.** *A unilateral increase in the source country's emissions tax leads to a decline in aggregate domestic emissions. This effect jointly originates from a tax-induced reduction in the mass of purely domestic firms, a decline in average production and a decline in average emissions intensity.*

#### 4.2.2 Emission leakage and global emissions

In order to understand the total environmental consequences of the source country's emissions tax reform, we have to look at aggregate emissions in the host country also. In case of a global pollutant what matters are aggregate world emissions, $E^W \equiv E + E^*$.

In analogy to the derivation of $E$, we compute aggregate emissions from production in the host country as:[24]

$$E^* = M\chi\bar{i}^o\bar{y}^o, \tag{33}$$

with

$$\bar{y}^o = \frac{k(\sigma-1)}{k-\sigma+1}\frac{\left(1+\chi^{(\sigma-1)/k}\right)^{\sigma/(\sigma-1)}}{\chi^{(\sigma-1)/k}}\left(\frac{w}{t}\right)^{\alpha(1-\eta)}\bar{\varphi}^o. \tag{34}$$

$$\bar{i}^o = \tau\alpha(1-\eta)\left(\frac{w^*}{t^*}\right)^{1-\alpha(1-\eta)}\left(\frac{w}{\tau w^*}\right)^{\eta}\frac{1}{\bar{\varphi}^o}. \tag{35}$$

Since there is no change in $t^*$ (by construction of our analysis), only indirect effects are at work when looking at (35). With an increase in offshoring, labor demand in the host country rises leading to an increase in the host country wage. Accordingly, the wage-tax ratio is increasing. Put differently, the *effective emissions tax* in the host country is decreasing; generating emissions gets relatively cheaper. Accordingly, emissions per unit of the routine task's output are increasing. Yet, there is a second opposing channel working via $w/w^*$. Due to the reduced difference in wages, offshoring firms rely to a larger extent on the emissions-free non-routine task

[24] Average emissions of offshoring firms:

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

(similarly to domestic firms). Finally, as shown above, offshoring firms become less productive on average. Accounting for all these general equilibrium effects, we can prove that the average emissions intensity of offshoring firms is increasing in $t$ (see Appendix A.9.4).

Depending on the difference between the emissions tax rates across countries, this increase might well take place at a lower average emissions intensity of offshoring firms than domestic firms, i.e. at $\bar{\imath}^o < \bar{\imath}^d$. This follows from Lemma 1 and the fact that $\bar{\varphi}^o > \bar{\varphi}^d$ from self-selection of the most productive firms into offshoring.

The increased share of offshoring firms, their larger market share and the fact that offshoring firms become more emissions-intensive on average, all contribute to a rise in aggregate host country's emissions. We, hence, observe emissions leakage via the possibility to offshore.

Remarkably this emissions leakage can exceed the decline in domestic emissions, i.e. leakage of more than 100%. We show this by expressing for global emissions as the product of three channels, i.e. the mass of firms, average output and average emission intensity.[25]

$$E^W = M\bar{e} = M\bar{y}\bar{\imath} = M\left[(1-\chi)\bar{y}^d + \chi\bar{y}^o\right]\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{\imath}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{\imath}^o\right]. \tag{36}$$

The first channel, displaying the mass of firms, decreases in the source country's emission tax rate provided the initial share of offshoring firms is sufficiently high (cf. Proposition 1). The second channel (first squared bracket) features the scale effect. We can show that average output per firm $\bar{y}$ decreases in response to the source country's emission tax increase. However, at the same time, the increased level of offshoring $\chi$ causes some production inputs to relocate across firm types, i.e. from non-offshorers towards offshorers.

This relocation of production inputs towards offshoring firms turns out to be a decisive mechanism when discussing the impact of the third channel, featuring average emission intensity across all firms (technique effect, second squared bracket): As we explain in the discussion of (32) and (35), an increase in the level of offshoring (induced by the unilateral environmental policy reform) causes labor market responses in both countries. This incentivizes firms to adjust their production process. With this general equilibrium effect at work, emission intensity levels among non-offshoring firms $\bar{\imath}^d$ fall, while average embedded emission intensity levels of offshorers $\bar{\imath}^o$ rise. Thus, at low levels of $\chi$, the environmental policy reform causes production inputs to be relocated towards (very few), relatively low emission-intensive offshoring firms. In this scenario,

[25] See Appendix A.7.1 for a derivation of average emission intensity across all firms as well as Appendix A.7.2 for a derivation of global emissions in closed form.

this type of across-firm relocation lowers aggregate emission levels. On the contrary, at high levels of $\chi$, resources are shifted towards (many), relatively high emission-intensive offshoring firms. In this case, across-firm relocation is likely to raise aggregate emissions.

In numerical simulations, this ambiguous mechanism (hinging on the initial level of offshoring $\chi$) proves to be decisive channel for the overall effect of the unilateral environmental policy reform on global emissions: While the unilateral emission tax increase in our simulation exercise generates a net decrease in global emissions at low levels of offshoring, a net increase is generated at higher levels of offshoring, implying a leakage rate of more than 100%. As $\chi$ is an endogenous value, there is a threshold level of $t$[26], inducing a sufficiently high level of offshoring for an increase in global emissions.[27]

We summarize our findings as follows

**Proposition 3.** *A unilateral increase in the source country's emissions tax leads to an increase in aggregate emissions in the host country. More than complete emissions leakage is possible due to the shift of production of offshoring firms, given a sufficiently high level of offshoring.*

## 4.3 Effects on aggregate income and income inequality

### 4.3.1 Aggregate income

The nested Cobb-Douglas production function in the intermediate goods sector and the CES-aggregate in the final goods sector generate the single consumption good and form the basis how income is defined and shared by the different groups in the source country. Having an exogenously fixed amount of individuals $N$ and a price of the final good normalized to unity aggregate output $Y$ is equal to total revenue. This belongs to three different groups, each of them receive a constant share of the revenue: $1/\sigma$ is earned by firms and offshoring consultants and $(\sigma-1)/\sigma$ by workers as labor income and governments as emission tax income. Since offshoring firms additionally hire host country worker and pay host country emission tax, the share of offshoring firms determines how much of the total labor and emission tax income is alloted to the source country groups. We expressed these revenue share as $\gamma^l$ and $\gamma^e$ which pins down our aggregate income measure for the source country as follows:

$$I = \left[\frac{1}{\sigma} + \gamma^l \frac{\sigma-1}{\sigma} + \gamma^e \frac{\sigma-1}{\sigma}\right] Y \tag{37}$$

[26] In our simulations, this threshold level is at around 0.5 for $\chi$ as well as 3.3 for $t$ in our baseline scenario.

[27] Interestingly, as our simulations suggest, emission intensity levels of offshorers show to be below those of non-offshoring firms even at those threshold levels for $t$ and $\chi$.

An increase of the source country emission tax rate generates two counteracting effects on aggregate output. First, it makes production in the source country more expensive which forces domestic firms to reduce output, which is the direct effect. Second, this increase in source country production costs makes offshoring production more attractive leading to a higher share of firms who choose to produce abroad. This indirect effect is production enhancing since these newly offshoring firms make use of cheaper foreign production inputs. In the Appendix A.9.6 we show that the negative direct effect dominates the positive indirect effect, so aggregate output falls in $t$.

Furthermore, if more firms relocate their production abroad a lower share of total revenue stays in the source country. Both shares of worker and emission tax income decrease in the share of offshoring firms, hence magnify the negative direct effect of the emission tax increase. In sum aggregate income in the source country is harmed by a unilateral emission tax rate increase ($dI/dt < 0$, see A.9.7).

#### 4.3.2 Source country inequality

Our model allows to look at several perspectives of inequality, between- and within-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:

$$\Theta \equiv \frac{\bar{\pi} - \chi w + b}{w + b} \tag{38}$$

We have post-transfer managerial income minus service labor 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:

$$\Theta = \frac{[k + \chi(\sigma - 1)][k - \sigma + 1 + \gamma^l k(\sigma - 1)] + \gamma^e k(\sigma - 1)(k - \sigma + 1)}{(k - \sigma + 1)[k - \sigma + 1 + \gamma^e k(\sigma - 1) + \gamma^l k(\sigma - 1)]} \tag{39}$$

First result is immediately clear: The emission tax rate does not impact this inequality measure directly, only indirectly via the share of offshoring firms. As shown in Appendix (A.10), the between-group inequality increases with the share of offshoring firms, hence also with the 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 more than 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.[28]

#### 4.3.3 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:

$$\Xi \equiv \frac{w+b}{w^*+b^*}, \tag{40}$$

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 (A.93) on aggregate emissions and the income share of the emissions tax revenues:

$$\Xi = \frac{\gamma^l \frac{\sigma-1}{\sigma} \frac{k-\sigma+1+\gamma^l k(\sigma-1)}{\gamma^l k(\sigma-1)} \frac{Y}{N} + \frac{\gamma^e \frac{\sigma-1}{\sigma} Y}{N}}{\gamma^{l*} \frac{\sigma-1}{\sigma} \frac{Y}{N^*} + \frac{\gamma^{e*} \frac{\sigma-1}{\sigma} Y}{N^*}}. \tag{41}$$

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:

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

Analysing the effect of an increase in $t$ we get:

$$\frac{d\Xi}{dt} = \underbrace{\frac{\partial\Xi}{\partial\gamma}}_{>0} \underbrace{\frac{\partial\gamma}{\partial\chi}}_{<0} \underbrace{\frac{d\chi}{dt}}_{>0} < 0 \tag{43}$$

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 (mean-

[28] In Appendix A.10 we also illustrate source country inequality and the effect of offshoring on it by deriving and plotting the Lorenz Curve.

ing 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: Policy Reform with Border Carbon Adjustment

## 5.1 Introducing a BCA

In this chapter, we extent our asymmetric two-country model in order to investigate the implementation of a BCA. 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 border adjustment and $I = 1$ in the presence of such a mechanism. Hence, the offshorer faces the (implicit) emission tax $\tilde{t^*} = t^*$ without a border adjustment as well as $\tilde{t^*} = t^* + \hat{t} = t$ post the introduction of the adjustment mechanism. Furthermore, we strictly assume that $t > \tilde{t^*}$ holds prior to the introduction of the border adjustment. Consequently, the introduction of the border adjustment makes emission-intensive intermediate imports more expensive from the perspective of the offshorer.

## 5.2 Effects of implementation

Using $t/\tilde{t^*} = 1$, the ratio of emission levels and intensities between an offshoring and a non-offshoring firm of equal productivity as provided in Eq. (14) can be re-stated as follows:

$$\frac{e^o(\varphi)}{e^d\varphi)} = \kappa_{I=1}^{\sigma-1} \qquad \text{and} \qquad \frac{i^o(\varphi)}{i^d(\varphi)} = \kappa_{I=1}^{-1} \tag{44}$$

As $\kappa > 1$ has to hold for any firm to offshore, the change in emission use induced by the offshoring decision is still positive, but clearly smaller than before the implementation of the border adjustment. This comes due to two reasons: Firstly, the multiplier $\frac{t}{t^*} > 1$ in Eq. (14) collapses to 1 and therefore no longer affects the ratio $\frac{e^o}{e^d}$. Secondly, the elimination of the environmental tax differential to $t/\tilde{t^*} = 1$ induced by implementation of the border adjustment also reduces the offshoring cost savings factor $\kappa$ to:

$$\kappa_{I=1} \equiv \frac{C^d}{C^o} = \left[\frac{1}{\tau}\left(\frac{w}{w^*}\right)^{1-\alpha}\right]^{1-\eta} > 1. \tag{45}$$

As $\kappa_{I=0} > \kappa_{I=1}$, a source country firm's offshoring decision unambiguously increases its embedded emission use to a smaller extent as compared to the previous scenario without the border adjustment. At the same time, as the second expression in (44) shows, the firm's offshoring decision now unambiguously decreases its emission intensity. Hence, in contrast to Lemma 1 as stated at the end of Section 2, the offshoring decision always reduces a firm's emission intensity in the presence of a border adjustment.

Recalling Section 3, the equilibrium share of offshoring firms in the source country is given at the intersection of two conditions: *offshoring indifference (A)* (Eq. (24)) and *labor market constraint (B)* (Eq. (25)). The A-condition is not affected by a change of the host country's emission tax from $t^* < t$ to $\tilde{t^*} = t$ induced by the border adjustment. However, as seen when comparing (25) to (45), the B-condition reacts to the change of the host country's emission tax to $\tilde{t^*}$. As B reduces from $\kappa_{I=0}$ to $\kappa_{I=1}$, its curve shifts downwards, lowering the share of offshoring firms in equilibrium.

**Proposition 4.** *The introduction of the border adjustment reduces production cost advantage of the host country. A new equilibrium is set with a lower share of offshoring firms. Facing the BCA, the firm's decision to offshore unambiguously decreases its (embedded) emission intensity.*

### 5.3 Environmental policy reform under a BCA

In this subsection, we repeat parts of the comparative static analysis of Section 4 which features the unilateral increase of the source country's emission tax rate $t$. However, we importantly extend our setting to the presence of a BCA, which – as we show – significantly changes the impact of the environmental policy reform on emissions and income.

With a BCA in place (i.e. $I = 1$), an increase of the source country's emission tax equally applies to the embedded emissions of the offshoring firm as the emission tax differential is to be paid at the border by the importer. Hence, $\tilde{t^*} = t$ now holds for offshorers, eliminating differences environmental taxation as offshoring incentive.

How does the source country's environmental policy reform impact the offshoring equilibrium in the presence of the border adjustment? As seen in (45), the labor market constraint (B-condition) is no longer directly determined by source country's emission tax rate. However, it still depends on both countries' wage rates $w$ and $w^*$. As both wage rates depend on final good output $Y$[29], each of them is negatively affected by emission taxation. However, their ratio $w/w^*$ does not react to changes in environmental policy, as the BCA the level offshoring from rising:

$$\begin{aligned} F(\chi,\tau) &\equiv B(\chi,\tau) - A(\chi) \\ &= \left[\frac{1}{\tau}\left(\frac{w}{w^*}\right)^{1-\alpha}\right]^{1-\eta} - (1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}} \\ &= \left[\frac{1}{\tau}\left(\frac{\gamma^l}{\lambda\gamma^{l*}}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} - (1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}} \end{aligned} \tag{46}$$

Hence, the offshoring equilibrium in the presence of a BCA is insensitive to the environmental policy reform in the source country:

$$\frac{d\chi}{dt} = -\underbrace{\frac{\partial F/\partial t}{\partial F/\partial \chi}}_{\substack{=0\\<0}} = 0. \tag{47}$$

**Proposition 5.** *In the presence of a BCA, an environmental policy reform in the source country does not influence the level of offshoring in the economy.*

This finding has immediate implications for our subsequent comparative static analysis. As the share of offshoring firms $\chi$ becomes insensitive to unilateral changes in environmental policy ($\frac{d\chi}{dt} = 0$) in presence of the BCA, the mass of workers ($L$) as well as firms ($M$) do not react to a change in the emission tax either. Consequently, also cut-off productivities $\varphi^d$ and $\varphi^o$ as well as average productivities $\bar{\varphi}^d$ and $\bar{\varphi}^o$ turn out to be insensitive to changes in $t$. Equipped with these insights, we now turn to the analysis of average intermediate output levels of non-offshoring and offshoring firms, as provided by (31) and (34). Both expressions only react to the environmental policy reform via changes to their wage-tax ratio, or inversely, their effective emission tax. Hence, the analysis is identical for both types of averages:

$$\frac{d\bar{y}i}{dt} = \underbrace{\frac{d\bar{y}^i}{dt}}_{<0} + \underbrace{\frac{\partial \bar{y}^i}{\partial w}}_{>0}\underbrace{\frac{dw}{dt}}_{<0} < 0 \quad \text{with}\, i \in d, o \tag{48}$$

Whereas average outputs of non-offshoring and offshoring firms decrease in the source country's emission tax rate (denominator of wage-tax-ratio), both expressions increase in the source coun-

[29] Cf. expressions (19) and (23) as well as Appendix A.9.5

try's wage rate. Appendix A.9.5 investigates the effect of the environmental policy reform on the source country's wage rate , identifying a negative direct effect of the emission tax $\frac{dw}{dt} < 0$ as well as a (weaker) positive indirect effect via increased offshoring $\frac{\partial w}{\partial \chi}\frac{d\chi}{dt} > 0$. As the BCA eliminates the positive indirect effect of offshoring, we can state that the environmental policy reform lowers the source country's wage rate even stronger in the presence of a border adjustment. Thus, average output unambiguously decreases for both firm types.

Next, we investigate the impact of the environmental policy reform on average emission intensities of both firm types. The analysis of the effect on the average emission inesity level for non-offshoring firms (as displayed in 32) is straightforward and analogous to the previous exercise:

$$\frac{d\bar{i}^d}{dt} = \underbrace{\frac{d\bar{i}^d}{dt}}_{<0} + \underbrace{\frac{\partial \bar{i}^d}{\partial w}}_{>0} \underbrace{\frac{dw}{dt}}_{<0} < 0 \tag{49}$$

For the average emission intensity level of offshoring firms, we take a closer look at its closed form expression in the context of the BCA:

$$\bar{i}^o = \tau\alpha(1-\eta)\left(\frac{w^*}{\tilde{t^*}}\right)^{1-\alpha(1-\eta)}\left(\frac{w}{\tau w^*}\right)^{\eta}\frac{1}{\bar{\varphi}^o} \tag{50}$$

As $t = \tilde{t^*}$ holds in the presence of the CBAM, the source country's environmental policy reform also raises the host country's emission tax from the perspective of the offshorer. Furthermore, the increase in $\tilde{t^*}$ lowers the host country's wage rate. Hence, the wage-tax-ratio (displayed in the second bracket) decreases due to both channels, lowering the emission content of the offshored routine task. Furthermore, as explained in the discussion of (46), the ratio of both countries' wage rates (displayed in the third bracket) does not react to changes in emission taxation in the the presence of the border adjustment. Hence, the weight of the offshored routine task in the production process remains unchanged. To sum up, – with the border adjustment in place – also the offshorer's average embedded emission intensity level decreases post source country's environmental policy reform .

Having discussed these channels, the discussion of the unilateral environmental policy reform's impact on global emissions is straightforward. Let us recall the expression for global emissions as summed up as the sum of (embedded) emissions over all non-offshoring and offshoring firms:

$$E^W = M\bar{e} = M\bar{y}\bar{i} = M\left[(1-\chi)\bar{y}^d + \chi\bar{y}^o\right]\left[\frac{(1-\chi)\bar{y}^d}{\bar{y}}\bar{i}^d + \frac{\chi\bar{y}^o}{\bar{y}}\bar{i}^o\right]. \tag{51}$$

Global Emissions are defined as the product of the mass of firms, average output per firm as well as average emission intensity per firm. As identified in the previous analysis, the mass of firms $M$ does not react to the environmental policy change in the presence of the border adjustment. Furthermore, the share of offshoring firms $\chi$ remains constant. However, average output $\bar{y}$ as well as average (embedded) emission intensity $\bar{i}$ falls for both types of firms. Hence, emissions decrease unambiguously in both countries, leading to a non-monotonous decline in global emissions in the presence of the border adjustment.[30]

**Proposition 6.** *In the presence of a BCA, an environmental policy reform in the source country lowers emissions in both countries.*

Finally, we analyse the impact of the policy reform in on income and its distribution in the presence of the border adjustment. Let us recall that aggregate income in the source country is given by:

$$I = \left[\frac{1}{\sigma} + \gamma^l \frac{\sigma - 1}{\sigma} + \gamma^e \frac{\sigma - 1}{\sigma}\right] Y \tag{52}$$

Firstly, aggregate income $I$ of the source country depends on (global) final goods output $Y$. As shown in Appendix (A.9.6), $Y$ decreases in the emission tax $t$ (direct effect). However, in absence of the border adjustment, the policy reform $dt > 0$ leads to an increase in offshoring, which partly offsets the reduction in aggregate final good output (indirect effect). However, in the presence of a BCA, the latter channel is absent ($\frac{\partial Y}{\partial \chi}\frac{d\chi}{dt} = 0$). Hence, with a border adjustment in place, environmental policy reform turns out to reduce aggregate final good output more strongly. Secondly, aggregate income in the source country depends on the endogenous income shares for labor ($\gamma_l$) and emissions ($\gamma_e$) in the source country. As we explain in Appendix (A.9.7), in absence of a border adjustment, the unilateral environmental policy reform – by raising the level of offshoring – may cause income shares to move to the host countries. This effect is eliminated by the presence of a BCA. Consequently, due to the BCA, the environmental policy reform induces a stronger decrease of global income (proxied by final good output $Y$): On the other hand, a larger share of global income is kept within the source country. Thus, there is ambiguity about whether the presence of the BCA makes the environmental policy reform more or less harmful for source country income.[31]

**Proposition 7.** *With a BCA in place, the decline in global income induced by the policy reform is unambiguously larger. Some ambiguity remains w.r.t. the source country's income loss.*

[30] See expression (A.95) in the Appendix for global emissions in closed form in the presence of a border adjustment.
[31] This is also influenced by the choice of $\eta$ for the cost weight of the non-routine task in the production process.

## 6 Conclusion

This paper investigates the effects of a unilateral environmental policy reform on emissions, income and inequality in the presence of offshoring. 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. They can allot routine labor to emission-intensive production as well as to abatement efforts. Firms differ in their productivity, hence in profits and only the most productive ones offshore parts of the production.

At the firm-level, we show that differences in effective emission taxation (tax-wage ratios) across countries determine the environmental impact of firms' decision to offshore. The unilateral policy reform, modelled as a rise in the source country emission tax rate, incentivizes more firms to offshore, causing effects on emissions, income and inequality. Firms adjust their production input mix due to direct and general equilibrium channels. This reduces emissions per unit of output for non-offshoring firms, while embedded emission intensity levels among offshorers increase.

At the aggregate level, we show that the environmental policy reform reduces emissions in the source country while emissions in the host country increase due to leakage. As a major insight, we highlight a non-monotonous effect of the unilateral policy reform on global emissions: If the initial level of offshoring is sufficiently high, the higher emission tax rate might increase global emissions, implying a leakage rate of more than 100%.

Extending our analysis to income and inequality, we show that the increase in offshoring induced by the environmental policy reform mitigates losses in terms of aggregate income associated to the tax increase. Furthermore, via increases in the level of offshoring, inequality within the source country rises and inequality between the source country and the host country falls.

In order to assess effectiveness and economic costs of a BCA, we extend our analysis. As we show, an emission tax increase no longer increases offshoring. Thus, the environmental policy reform does not lead to leakage and reduces global emissions. However, under a BCA, the loss of global income induced by the unilateral emission tax increase shows to be larger.

# A Appendix

## A.1 Derivation of cost functions

### A.1.1 Non-offshoring firm (Eq. (7))

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 $\beta$ 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 costs of the purely domestic firm and simplifying yields the cost function of such a firm:

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

which is determined by the firm's productivity, factor prices and the Cobb-Douglas parameters $\eta$ and $\alpha$.

### A.1.2 Offshoring firm (Eq. (8))

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 costs of the offshoring firm yields the cost function of the offshoring firm, with marginal costs given in Eq. (8).

In order to specify $p^r$, we finally derive the 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 emission intensity of the marginal firm

### A.2.1 Non-offshoring firm

In order to derive the expression for emission intensity level of the non-offshoring firm as shown in (12), we make use of the cost-minimizing emission input of the non-offshoring firm as depicted in A.14. We slightly transform this expression by adding superscript $d$ and omitting index $v$. This yields:

$$e^d(\varphi) = \alpha\,(1-\eta)\,\frac{y^d(\varphi)}{\varphi}\,\left(\frac{t}{w}\right)^{(1-\eta)\alpha-1} \tag{A.30}$$

Dividing this expression by the non-offshoring firm's intermediate output $y^d(\varphi)$, inverting the $t/w$-ratio and decomposing it into two expressions yields equation (12) for the non-offshoring firm's emission intensity level.

### A.2.2 Offshoring firm

We make use of the expression for the non-offshoring firm's cost-minimizing emission input as derived in A.28. Here, we replace superscript $r*$ by $o$, so that we have $e^o(\varphi)$.

$$e^o = x^r\alpha\left(\frac{w^*}{t^*}\right)^{1-\alpha} \tag{A.31}$$

We then insert the explicit expression for the imported routine task good $x^r$ as provided in A.23, omitting index $v$. This yields:

$$e^o(\varphi) = (1-\eta)\frac{y^o(\varphi)}{\varphi}\left[\frac{w}{\tau\,p^r}\right]^\eta\alpha\left(\frac{w^*}{t^*}\right)^{1-\alpha} \tag{A.32}$$

Inserting the explicit expression for the imported routine task $p^r = (t^*)^\alpha(w^*)^{1-\alpha}$, rearranging and dividing by the offshoring firm's intermediate output $y^o(\varphi)$ yields equation (13) being the non-offshoring firm's emission intensity level.

## A.3 Derivation of wage rates and labor income share

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

$$\pi^d(\varphi^d) = \frac{k-\sigma+1}{k}\frac{1}{1+\chi}\bar{\pi}. \tag{A.33}$$

Making use of $M\bar{\pi} = \sigma^{-1}Y$, i.e. the result that aggregate operating profits are a constant share of aggregate income, we get the LHS of expression (19) in the main text.

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 $\eta$ of both offshoring and non-offshoring firms into non-routine task labor. Accordingly, aggregate labor income is determined as

$$wL = N\frac{\sigma-1}{\sigma}\left[((1-\alpha)(1-\eta)+\eta)\int_{\varphi^d}^{\varphi^o} r^d(\varphi)dG(\varphi) + \eta\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi)\right]. \tag{A.34}$$

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 the RHS of expression (19) in the main text, where $\frac{[1-\alpha(1-\eta)]+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}}}{1+\chi} = \gamma^l$ as in (20).

We can express labor income in the host country as

$$w^*N^* = \frac{\sigma-1}{\sigma}N(1-\alpha)(1-\eta)\int_{\varphi^o}^{\infty} r^o(\varphi)dG(\varphi) \tag{A.35}$$

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), where $\frac{(1-\alpha)(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{1+\chi} = \gamma^{l*}$.

## A.4 Offshoring Equilibrium

### A.4.1 Derivation of offshoring indifference condition

In order to derive the upward-sloping offshoring indifference condition (A-condition), we first need the indifference condition of the marginal offshoring firm as provided by (16):

$$\pi^o(\varphi^o) - \pi^d(\varphi^o) = w \tag{A.36}$$

We re-arrange it to:

$$\pi^o(\varphi^o) - w = \pi^d(\varphi^o) \tag{A.37}$$

Using the occupational choice condition of the marginal entrepreneur as provided in (15), we can eliminate $w$ and transform the expression to:

$$\pi^o(\varphi^o) - \pi^d(\varphi^d) = \pi^d(\varphi^o) \tag{A.38}$$

Note that the lump-sum transfer $b$ cancels out. We now divide both sides of the equation by $\pi^d(\varphi^o)$.

$$\frac{\pi^o(\varphi^o)}{\pi^d(\varphi^o)} - \frac{\pi^d(\varphi^d)}{\pi^d(\varphi^o)} = 1 \tag{A.39}$$

Due to $\frac{\pi^o(\varphi)}{\pi^d(\varphi)} = \kappa^{\sigma-1}$, $\frac{\pi^d(\varphi^d)}{\pi^d(\varphi^o)} = \left(\frac{\varphi^d}{\varphi^o}\right)^{\sigma-1}$ as well as $\frac{\varphi^d}{\varphi^o} = \chi^{\frac{1}{k}}$, the expression transforms to:

$$\kappa^{\sigma-1} - \chi^{\frac{\sigma-1}{k}} = 1 \tag{A.40}$$

Solving for $\kappa$ yields the offshoring indifference condition as provided in (24).

### A.4.2 Interior solution to offshoring equilibrium

We have to solve for the condition on the minimum level of iceberg trade cost $\tau$ 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 $\kappa$-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:

$$\kappa = B(\tau, t, t^*, 1) = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} < \kappa = A(1) = 2^{\frac{1}{\sigma-1}} \tag{A.41}$$

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

$$\left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} < 2^{\frac{1}{\sigma-1}} \tag{A.42}$$

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

$$\tau > 2^{\frac{1}{(1-\sigma)(1-\eta)}}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\eta k(\sigma-1)}{(1-\eta)(1-\alpha)k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}. \tag{A.43}$$

Additionally, solving (A.42) 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.

$$\frac{t}{t^*} < 2^{\frac{1}{\alpha(\sigma-1)(1-\eta)}}\tau^{\frac{1}{\alpha}}\left(\frac{(1-\eta)(1-\alpha)k(\sigma-1)}{(k-\sigma+1)+\eta k(\sigma-1)}\frac{N}{N^*}\right)^{\frac{1-\alpha}{\alpha}} \tag{A.44}$$

Hence, for any interior equilibrium of offshoring, both (A.43) and (A.44) need to hold.

### A.4.3 Comparative statics: implicit function theorem

The implicit function is given by:

$$F(\chi, \tau, t, t^*) = \left[\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{1-\alpha}\right]^{1-\eta} - (1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}} = 0. \tag{A.45}$$

The effect of $t$ on $F$ is derived as:

$$\begin{aligned}\frac{\partial F}{\partial t} &= (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta} \\ &\times \frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\alpha\left(\frac{t}{t^*}\right)^{\alpha-1}\frac{1}{t^*} > 0\end{aligned} \tag{A.46}$$

The effect of $\chi$ is given by:

$$\begin{aligned}\frac{\partial F}{\partial \chi} =&(1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta}\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{N^*}{N}\right)^{1-\alpha}(1-\alpha)\left[\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\right]^{-\alpha} \\ &\times\left[\frac{\frac{\partial\gamma^l}{\partial\chi}k(\sigma-1)[(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]+\frac{\partial\gamma^l}{\partial\chi}k(\sigma-1)[(k-\sigma+1)+\gamma^l k(\sigma-1)]}{[(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]^2}\right] \\ &-\frac{1}{\sigma-1}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}-1}\frac{\sigma-1}{k}\chi^{\frac{\sigma-1}{k}-1} < 0\end{aligned} \tag{A.47}$$

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

$$\frac{d\chi}{dt} = -\underbrace{\frac{\partial F/\partial t}{\partial F/\partial \chi}}_{\frac{>0}{<0}} > 0. \tag{A.48}$$

## A.5 Derivation of average output levels and average productivities

### A.5.1 Non-offshoring firms

We start with deriving the average output level of non-offshoring firms:

$$\bar{y}^d = \int_{\varphi^d}^{\varphi^o} y^d(\varphi)\frac{g(\varphi)}{G(\varphi^o)-G(\varphi^d)}d\varphi \tag{A.49}$$

Using

$$\frac{y^d(\varphi)}{y^d(\varphi^d)} = \left(\frac{\varphi}{\varphi^d}\right)^{\sigma}, \tag{A.50}$$

we arrive at:

$$\bar{y}^d = \int_{\varphi^d}^{\varphi^o} y^d(\varphi^d)\left(\frac{\varphi}{\varphi^d}\right)^{\sigma}k\varphi^{-k-1}\frac{(\varphi^d)^k}{1-\chi}d\varphi \tag{A.51}$$

Rearranging and solving the integral yields the expression for the average output level of non-offshoring firms:

$$\bar{y}^d = \frac{k}{k-\sigma}\frac{(1-\chi^{\frac{k-\sigma}{k}})}{(1-\chi)}y^d(\varphi^d) \tag{A.52}$$

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

$$\frac{1}{\bar{\varphi}^d} = \int_{\varphi^d}^{\varphi^o}\frac{y^d(\varphi)}{\bar{y}^d}\frac{1}{\varphi}\frac{g(\varphi)}{G(\varphi^o)-G(\varphi^d)}d\varphi \tag{A.53}$$

Rearranging and solving the integral yields:

$$\frac{1}{\bar{\varphi}^d} = \frac{1}{\bar{y}^d}\int_{\varphi^d}^{\varphi^o} y^d(\varphi^d)\left(\frac{\varphi}{\varphi^d}\right)^{\sigma}\frac{1}{\varphi}k\varphi^{-k-1}\frac{(\varphi^d)^k}{1-\chi}d\varphi \tag{A.54}$$

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

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

We make use (A.52) for $y^d(\varphi^d)/\bar{y}^d$ and arrive at:

$$\frac{1}{\bar{\varphi}^d} = \frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}\frac{k-\sigma}{k}\frac{1-\chi}{1-\chi^{\frac{k-\sigma}{k}}}\frac{1}{\varphi^d} \tag{A.57}$$

Cancelling out leads to the inverse of (29):

$$\frac{1}{\bar{\varphi}^d} = \frac{k-\sigma}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}}\frac{1}{\varphi^d} \tag{A.58}$$

### A.5.2 Offshoring Firms

Similarly, we now start with deriving the average output level of offshoring firms:

$$\bar{y}^o = \int_{\varphi^o}^{\infty} y^o(\varphi)\frac{g(\varphi)}{1-G(\varphi^o)}d\varphi \tag{A.59}$$

using
$y^o(\varphi) = y^d(\varphi)\kappa^{\sigma}$, $y^d(\varphi) = y^d(\varphi^d)\left(\frac{\varphi}{\varphi^d}\right)^{\sigma}$, $g(\varphi) = k\varphi^{-k-1}$ and $1-G(\varphi^o) = (\varphi^o)^{-k}$ we get:

$$\bar{y}^o = \int_{\varphi^o}^{\infty} y^d(\varphi^d)\left(\frac{\varphi}{\varphi^d}\right)^{\sigma}\kappa^{\sigma}\frac{k\varphi^{-k-1}}{(\varphi^o)^{-k}}d\varphi \tag{A.60}$$

Rearranging and solving the integral leads to:

$$\bar{y}^o = y^d(\varphi^d)\frac{k}{k-\sigma}\frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}} \tag{A.61}$$

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

$$\frac{1}{\bar{\varphi}^o} = \int_{\varphi^o}^{\infty}\frac{y^o(\varphi)}{\bar{y}^o}\frac{1}{\varphi}\frac{g(\varphi)}{1-G(\varphi^o)}d\varphi \tag{A.62}$$

we use the same equations as above and get

$$\frac{1}{\bar{\varphi}^o} = \frac{y^d(\varphi^d)}{\bar{y}^o}\frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}}\frac{k}{k-\sigma+1}\frac{1}{\varphi^o} \tag{A.63}$$

insert $y^d(\varphi^d)/\bar{y}^o$ from (A.112) yields:

$$\frac{1}{\bar{\varphi}^o} = \frac{k-\sigma}{k} \frac{\chi^{\frac{\sigma}{k}}}{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}} \frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}} \frac{k}{k-\sigma+1} \frac{1}{\varphi^o} \tag{A.64}$$

Which simplifies to

$$\frac{1}{\bar{\varphi}^o} = \frac{k-\sigma}{k-\sigma+1} \frac{1}{\varphi^o} \tag{A.65}$$

being the inverse of the expression shown in (29).

## A.6 Derivation of average emission intensity levels

### A.6.1 Non-offshoring firms

We start by aggregating over all non offshoring firms' emission intensity levels.

$$\bar{i}^d = \int_{\varphi^d}^{\varphi^o} i^d(\varphi) \frac{y^d(\varphi)}{\bar{y}^d} \frac{g(\varphi)}{G(\varphi^o) - G(\varphi^d)} d\varphi \tag{A.66}$$

Using

$$g(\varphi) = k\varphi^{-k-1} \tag{A.67}$$

$$G(\varphi^o) = 1 - (\varphi^o)^{-k} \tag{A.68}$$

$$G(\varphi^d) = 1 - (\varphi^d)^{-k} \tag{A.69}$$

$$\frac{y^d(\varphi)}{y^d(\varphi^d)} = \left(\frac{\varphi}{\varphi^d}\right)^{\sigma} \tag{A.70}$$

the expression can be rearranged to:

$$\bar{i}^d = \int_{\varphi^d}^{\varphi^o} i^d(\varphi^d) y^d(\varphi^d) \left(\frac{\varphi}{\varphi^d}\right)^{\sigma-1} \frac{1}{\bar{y}^d} k\varphi^{-k-1} \frac{(\varphi^d)^k}{1-\chi} d\varphi \tag{A.71}$$

Solving the integral and simplifying yields:

$$\bar{i}^d = i^d(\varphi^d) y^d(\varphi^d) \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi} \frac{k}{k-\sigma+1} \frac{1}{\bar{y}^d} \tag{A.72}$$

Inserting the expression for $\bar{y}^d$ from (A.52) yields:

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

Using the explicit expression for the marginal firm's emission intensity level $i^d(\varphi^d) = e^d(\varphi^d)/y^d(\varphi^d)$ from cost minimization finally gives:

$$\bar{i}^d = \alpha(1-\eta) \left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \frac{1}{\varphi^d} \frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}} \frac{k-\sigma}{k-\sigma+1} \tag{A.74}$$

As the last three terms equal $\frac{1}{\bar{varphi}^d}$, we arrive at the expression provided in the main text.

### A.6.2 Offshoring firms

Again, we integrate over all offshoring firms' emission intensity levels:

$$\bar{i}^o = \int_{\varphi^o}^{\infty} i^o(\varphi) \frac{y^o(\varphi)}{\bar{y}^o} \frac{g(\varphi)}{1 - G(\varphi^o)} d\varphi \tag{A.75}$$

We use the following equalities:

$$i^o(\varphi) = i^d(\varphi) \frac{t}{t^*} \kappa^{-1} \tag{A.76}$$

$$i^d(\varphi) = i^d(\varphi^d) \frac{\varphi^d}{\varphi} \tag{A.77}$$

$$y^o(\varphi) = y^d(\varphi) \kappa^\sigma \tag{A.78}$$

$$y^d(\varphi) = y^d(\varphi^d) \left(\frac{\varphi}{\varphi^d}\right)^\sigma \tag{A.79}$$

$$g(\varphi) = k\varphi^{-k-1} \tag{A.80}$$

$$1 - G(\varphi^o) = (\varphi^o)^{-k} \tag{A.81}$$

Thus, we arrive at the following expression:

$$\bar{i}^o = \int_{\varphi^o}^{\infty} i^d(\varphi^d) \frac{\varphi^d}{\varphi} \frac{t}{t^*} \kappa^{-1} \frac{y^d(\varphi^d) \left(\frac{\varphi}{\varphi^d}\right)^\sigma \kappa^\sigma}{\bar{y}^o} \frac{k\varphi^{-k-1}}{(\varphi^o)^{-k}} d\varphi \tag{A.82}$$

Extracting $i^d(\varphi^d), \varphi^d, t/t^*, \kappa, \varphi^o$ out of the integral as well as solving the integral yields:

$$\bar{i}^o = i^d(\varphi^d) \frac{y^d(\varphi^d)}{\bar{y}^o} \kappa^{\sigma-1} (\varphi^d)^{1-\sigma} (\varphi^o)^k \frac{t}{t^*} \frac{k}{k - \sigma + 1} (\varphi^o)^{-k+\sigma-1} \tag{A.83}$$

Using $(\varphi^d)^{1-\sigma} = (\varphi^o)^{1-\sigma} \chi^{\frac{1-\sigma}{k}}$ and combining the $\varphi^o$-terms yields:

$$\bar{i}^o = i^d(\varphi^d) \frac{y^d(\varphi^d)}{\bar{y}^o} \kappa^{\sigma-1} \frac{1}{\chi^{\frac{\sigma-1}{k}}} \frac{t}{t^*} \frac{k}{k - \sigma + 1} \tag{A.84}$$

Making use of the offshoring indifference condition for $\kappa$ and inserting the expression for emission intensity of the marginal non-offshoring firm $i^d(\varphi^d)$ yields:

$$\bar{i}^o = \alpha(1-\eta) \left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \frac{1}{\varphi^d} \frac{y^d(\varphi^d)}{\bar{y}^o} \frac{1 + \chi^{\frac{\sigma-1}{k}}}{\chi^{\frac{\sigma-1}{k}}} \frac{t}{t^*} \frac{k}{k - \sigma + 1} \tag{A.85}$$

We now use

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

in order to arrive at:

$$\bar{i}^o = \alpha(1-\eta) \left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \frac{1}{\varphi^d} \frac{\chi^{\frac{1}{k}}}{(1 + \chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}} \frac{t}{t^*} \frac{k - \sigma}{k - \sigma + 1} \tag{A.86}$$

Using $\chi^{\frac{1}{k}}/\varphi^d = 1/\varphi^o$, using $\kappa$ for the RHS of the offshoring indifference condition, as well as replacing $\frac{k-\sigma}{k-\sigma+1}\frac{1}{\varphi^o}$ by $\frac{1}{\bar{\varphi}^o}$ gives:

$$\bar{i}^o = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \kappa^{-1}\frac{t}{t^*}\frac{1}{\bar{\varphi}^o} \tag{A.87}$$

This expression is equal to the one in the main text when inserting the definition of $\kappa$ (Offshoring Cost Savings Factor).

## A.7 Global Emissions

### A.7.1 Derivation of average emissions across all firms

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:

$$\bar{l} = \int_{\varphi^d}^{\varphi^o} l^r(\varphi)\frac{dG(\varphi)}{G(\varphi^o)-G(\varphi^d)}. \tag{A.88}$$

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:

$$\bar{l} = l^r(\varphi^d)\frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}. \tag{A.89}$$

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 $\bar{l}$:

$$\bar{l} = \frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}(1-\alpha)(1-\eta)(\sigma-1) \tag{A.90}$$

We can then derive average emissions as:

$$\bar{e} = \frac{k}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi}\alpha(1-\eta)(\sigma-1)\frac{w}{t}. \tag{A.91}$$

### A.7.2 Aggregate emissions in closed form via income shares

Making use of the decomposition of aggregate income, we can derive aggregate emissions of the two countries as

$$E = \gamma^e\frac{\sigma-1}{\sigma}\frac{Y}{t} \quad \text{and} \quad E^* = \gamma^{e*}\frac{\sigma-1}{\sigma}\frac{Y}{t^*} \tag{A.92}$$

$$\text{with} \quad \gamma^e \equiv \frac{\alpha(1-\eta)(1-\chi^{\frac{k-\sigma+1}{k}})}{1+\chi} \quad \text{and} \quad \gamma^{e*} \equiv \frac{\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{1+\chi}. \tag{A.93}$$

The terms $\gamma^e$ and $\gamma^{e*}$ share of aggregate income net of aggregate operating profits that is linked to the source country's emissions taxation.[32]

[32] In Appendix A.8 we derive $Y$ to get closed form solution for $E$.

Making use of Eqs. (A.92) and (A.93), we derive

$$E^W = \frac{\sigma-1}{\sigma}\left(\frac{\gamma^e}{t}+\frac{\gamma^{e*}}{t^*}\right)Y = \alpha(1-\eta)\left(\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1+\chi}\frac{1}{t}+\frac{\chi+\chi^{\frac{k-\sigma+1}{k}}}{1+\chi}\frac{1}{t^*}\right)\frac{\sigma-1}{\sigma}Y. \tag{A.94}$$

Furthermore, in the context of a BCA, due to $\tilde{t^*}=t$, this expression reduces from Eq. (A.94) to:

$$(E^W)_{I=1} = \alpha(1-\eta)\frac{\sigma-1}{\sigma}Y\frac{Y}{t} \tag{A.95}$$

## A.8 Derivation of final good output Y in closed form

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 $P=1$.

$$\frac{Y}{(M(1+\chi))^{\frac{\sigma}{\sigma-1}}}\left(\frac{\bar{\varphi}}{\varphi^d}\right)^{-\sigma} = Yp(\varphi^d)^{-\sigma} \tag{A.96}$$

Solve it for the price and insert the price equation

$$\frac{\sigma}{\sigma-1}\frac{w}{\varphi^d}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} = \left(\frac{\bar{\varphi}}{\varphi^d}\right)(M(1+\chi))^{\frac{1}{\sigma-1}} \tag{A.97}$$

We can now use Pareto for average productivity

$$\frac{\sigma}{\sigma-1}\frac{w}{\varphi^d}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} = \left(\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}(M(1+\chi))^{\frac{1}{\sigma-1}} \tag{A.98}$$

Next, we solve it for the wage rate

$$w = \left[\frac{\sigma-1}{\sigma}\varphi^d\left(M(1+\chi)\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.99}$$

We now use the marginal firm indifference condition (S.38) and insert the profits of the marginal firm into (S.40). Solve it for $Y$:

$$Y = \left[\frac{\sigma-1}{\sigma}\varphi^d\left(M(1+\chi)\frac{k}{k-\sigma+1}\right)^{\frac{1}{\sigma-1}}\left(\frac{1}{t}\right)^{\alpha(1-\eta)}\right]^{\frac{1}{1-\alpha(1-\eta)}} M(1+\chi)\frac{k}{k-\sigma+1}\sigma \tag{A.100}$$

$$Y = \sigma\left[M(1+\chi)\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{\sigma-1}{\sigma}\varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.101}$$

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

$$Y = \sigma\left[(1+\chi)\frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}}\left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{\sigma-1}{\sigma}\right]^{\frac{1}{1-\alpha(1-\eta)}} M^{1+\frac{1}{1-\alpha(1-\eta)}\left(\frac{1}{\sigma-1}-\frac{1}{k}\right)}N^{\frac{1}{k(1-\alpha(1-\eta))}} \tag{A.102}$$

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

$$Y = \left(\frac{1}{\sigma t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}(1+\chi)^{\frac{1}{k(1-\alpha(1-\eta))}}\left[\frac{k-\sigma+1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}}(\sigma-1)^{\frac{1}{1-\alpha(1-\eta)}}\left(\frac{k}{k-\sigma+1}N\right)^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \tag{A.103}$$

## A.9 Comparative Statics: Effects of $dt > 0$

### A.9.1 Effects of $dt > 0$ on the factor allocation

The factor allocation is only indirectly affected by the source country emission tax rate, namely via the share of offshoring firms with $d\chi/dt > 0$. With this result and $\partial\gamma^l/\partial\chi < 0$ we can state:

$$\frac{d\lambda}{dt} < 0, \tag{A.104}$$

hence, the mass of workers decreases in t

$$\frac{dL}{dt} < 0 \quad \text{with} \quad L = \lambda N \tag{A.105}$$

and the mass of offshoring firms increases in t

$$\frac{d\chi M}{dt} > 0 \quad \text{with} \quad \chi M = \frac{\chi}{1+\chi}(1-\lambda)N. \tag{A.106}$$

The effect on mass of total firms depends on the initial level of $\chi$ where we can solve for the threshold given by (28) by setting the derivative equal to zero and solving it for $\chi$:

$$\frac{dM}{d\chi} = \frac{-(k-\sigma+1)[(k-\sigma+1)] + (\sigma-1)(k-\sigma+1)[(k-\sigma+1)\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta) - k\eta)]}{[(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]]^2}. \tag{A.107}$$

### A.9.2 On average firm productivity levels

Average Productivity of non-offshoring firms is given by:

$$\bar{\varphi}^d = \frac{k-\sigma+1}{k-\sigma}\frac{1-\chi^{(k-\sigma)/k}}{1-\chi^{(k-\sigma+1)/k}}\varphi^d \tag{A.108}$$

An increase in $t$ raises $\chi$. While the term $\frac{1-\chi^{(k-\sigma)/k}}{1-\chi^{(k-\sigma+1)/k}}$ clearly decreases in $\chi$, $\varphi^d$ falls in $\chi$ when $\chi$ is near 0 and rises in $\chi$ if $\chi$ is sufficiently large. Hence, $\bar{\varphi}^d$ unambiguously decreases at low levels of $\chi$, while there are opposing effects at higher levels of $\chi$. Simulations suggest that the negative effect dominates even at higher levels of $\chi$, so that we have reasonable ground to assume that $\frac{d\bar{\varphi}^d}{dt} < 0$ holds.

We also investigate the impact of the environmental tax reform on the average intermediate output quantity of non-ofshoring firms:

$$\bar{y}^d = \frac{k}{k-\sigma}\frac{(1-\chi^{\frac{k-\sigma}{k}})}{(1-\chi)}y^d(\varphi^d) \tag{A.109}$$

The term $\frac{(1-\chi^{\frac{k-\sigma}{k}})}{(1-\chi)}$ clearly decreases in $\chi \in 0, 1$. Next, we look into the expression for the intermediate output of the marginal non-offshoring firm, $y^d(\varphi^d)$, derived in cost minimization:

$$y^d(\varphi^d) = (\sigma-1)\varphi^d\left(\frac{w}{t}\right)^{\alpha(1-\eta)} \tag{A.110}$$

The increase in $t$ directly lowers $y^d(\varphi^d)$. Furthermore, as shown in Appendix A.9.5, the increase in $t$ lowers $w$ through general equilibrium effects. This further reduces $y^d(\varphi^d)$. Finally, the increase in $t$ (via $\chi$) also raises $\varphi^d$ as well as $y^d(\varphi^d)$, but the first two effects dominate. Hence, quite intuitively, average intermediate output of non-offshorers falls due to the environmental policy reform.

Average productivity of offshoring firms is given by:

$$\bar{\varphi}^o = \frac{k-\sigma+1}{k-\sigma}\,\varphi^o \tag{A.111}$$

As the productivity level of the marginal offshoring firm $\varphi^0$ decreases in the source country's emission tax rate $t$ via $\chi$, it can be easily seen that the same applies for the average productivity, i.e. $\frac{d\bar{\varphi}^o}{dt} < 0$.

We now turn to the average intermediate output level of offshoring firms which is given by:

$$\bar{y}^o = y^d(\varphi^d)\frac{k}{k-\sigma}\frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}} \tag{A.112}$$

As $t$ raises the level of offshoring, we know that the marginal non-offshoring firm's intermediate output $y^d(\varphi^d)$ decreases in $\chi$. Furthermore, the term $\frac{(1+\chi^{\frac{\sigma-1}{k}})^{\frac{\sigma}{\sigma-1}}}{\chi^{\frac{\sigma}{k}}}$ decreases in $\chi$. Hence, we can conclude that $\frac{d\bar{y}^o}{dt} < 0$.

### A.9.3 Effect on average emission intensity domestic firms

The emission intensity level of the non-offshoring firm is given by:

$$\bar{i}^d = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)}\frac{1}{\varphi^d}\frac{k-\sigma}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{1-\chi^{\frac{k-\sigma}{k}}} \tag{A.113}$$

Which we rewrite by using the definition of the marginal firm's emission intensity $i^d(\varphi^d)$ as well as extending by $\frac{\chi^{\frac{1}{k}}}{\chi^{\frac{1}{k}}}$:

$$\bar{i}^d = i^d(\varphi^d)\chi^{\frac{1}{k}}\frac{k-\sigma}{k-\sigma+1}\frac{1-\chi^{\frac{k-\sigma+1}{k}}}{\chi^{\frac{1}{k}}-\chi^{\frac{k-\sigma+1}{k}}} \tag{A.114}$$

There is direct effect of $t$ as well as an indirect effect via $\chi$. Totally differentiating this expression with respect to $t$ yields:

$$\begin{aligned}
\frac{d\bar{i}^d}{dt} &= \alpha(1-\eta)\frac{\sigma-1}{\sigma}\left[\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right]^{\frac{1}{\sigma-1}}\frac{1}{t}\frac{k-\sigma}{k-\sigma+1}\chi^{\frac{1}{k}} \\
&\times\left[-\frac{1}{t}+\left[\frac{(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}+\frac{1}{k}\frac{1}{\chi}\right]\right. \\
&\times\left.\frac{\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}\alpha(1-\eta)\frac{1}{t}}{\left[\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}(1-\alpha)(1-\eta)\left(\frac{-\frac{\partial\gamma^l}{\partial\chi}k(\sigma-1)[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]}{[k-\sigma+1+\gamma^l k(\sigma-1)][(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]}\right)+\frac{1}{k}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}\frac{1}{\chi^{\frac{k-\sigma+1}{k}}+\chi}\right]}\right]
\end{aligned} \tag{A.115}$$

The $\chi$ effect of same denumerator

$$
\begin{aligned}
&\alpha(1-\eta)\frac{\sigma-1}{\sigma}\left[\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right]^{\frac{1}{\sigma-1}}\frac{1}{t}\frac{k-\sigma}{k-\sigma+1}\chi^{\frac{1}{k}} \\
&\times\left[-\frac{1}{t}+\left[\frac{\chi k\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]+(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}{\chi k(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]\right. \\
&\left.\times\frac{\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}\alpha(1-\eta)\frac{1}{t}}{\left[\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}(1-\alpha)(1-\eta)\left(\frac{-\frac{\partial\gamma^l}{\partial\chi}k(\sigma-1)[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]}{[k-\sigma+1+\gamma^l k(\sigma-1)][(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)]}\right)+\frac{1}{k}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}\frac{1}{\chi^{\frac{k-\sigma+1}{k}}+\chi}\right]}\right] \\
&\gtrless 0
\end{aligned}
\tag{A.116}
$$

Direct effect to RHS. Then, B-term back to LHS, rearranging and extracting B-term. Ignore first row

$$
\begin{aligned}
&\left[\frac{\chi k\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]+(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}{\chi k(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\alpha(1-\eta)\right. \\
&\left.-\frac{[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)][(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]}{[k-\sigma+1+\gamma^l k(\sigma-1)](\chi+\chi^{\frac{k-\sigma+1}{k}})k}\right] \\
&\times\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}\frac{1}{t} \\
&\gtrless \\
&\frac{1}{k}(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}\frac{1}{\chi^{\frac{k-\sigma+1}{k}}+\chi}\frac{1}{t}
\end{aligned}
\tag{A.117}
$$

First two rows of same denumerator. Canceling out $1/t$, $(\chi+\chi^{\frac{k-\sigma+1}{k}})$ and $k$ on both sides.

$$
\begin{aligned}
&\left[\frac{\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})\left[\chi k\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]+(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\right. \\
&\left.-\frac{(1+\chi)\chi\left[[(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)][(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\right] \\
&\times\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta} \\
&\gtrless \\
&(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}}
\end{aligned}
\tag{A.118}
$$

Except of the last term in the first row, LHS is the same as in the calculation of the marginal firm multiplied by $\chi$. Hence we can rearrange in a similar way

$$\Bigg[\frac{\chi\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]\left[(\chi+\chi^{\frac{k-\sigma+1}{k}})k\alpha(1-\eta)-(1+\chi)[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$+\frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\Bigg]$$
$$\times\left[\left(\frac{1}{\tau}\right)\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{k-\sigma+1+\gamma^l k(\sigma-1)}{(1-\gamma^l-\alpha(1-\eta))k(\sigma-1)}\frac{N^*}{N}\right)^{(1-\alpha)}\right]^{1-\eta}$$
$$\gtrless$$
$$(1+\chi^{\frac{\sigma-1}{k}})^{\frac{1}{\sigma-1}} \tag{A.119}$$

We have shown that first is negative. Setting A=B we can move RHS to LHS, of same denumerator

$$\frac{\chi\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]\left[(\chi+\chi^{\frac{k-\sigma+1}{k}})k\alpha(1-\eta)-(1+\chi)[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$+\frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]\alpha(1-\eta)(\chi+\chi^{\frac{k-\sigma+1}{k}})-(1+\chi)\chi[k-\sigma+1+\gamma^l k(\sigma-1)]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$\gtrless$$
$$0 \tag{A.120}$$

Rearrange second row

$$\frac{\chi\left[(k-\sigma+1)(1-\eta)(1-\alpha)\chi^{\frac{k-\sigma+1}{k}-1}+k(\gamma^l-\eta)\right]\left[(\chi+\chi^{\frac{k-\sigma+1}{k}})k\alpha(1-\eta)-(1+\chi)[(1-\alpha(1-\eta))k(\sigma-1)+k-\sigma+1]\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$+\frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]\left[\alpha(1-\eta)\chi^{\frac{k-\sigma+1}{k}}-(1-\alpha(1-\eta))\chi\right]}{\chi(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}$$
$$\gtrless$$
$$0 \tag{A.121}$$

The total effect of t on average emission intensity for domestic firms is negative if second row is negative (as well). This holds if

$$\left[\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\right]^{\frac{k}{\sigma-1}}<\chi \tag{A.122}$$

which already holds for very low levels of offshoring.

### A.9.4 Effect on average emission intensity offshoring firms

First, we aim to get a closed form solution for the emission intensity level of the marginal non-offshoring firm:

$$i^d(\varphi^d)=\alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)}\frac{1}{\varphi^d} \tag{A.123}$$

We use the following

To get a closed form solution we use the following:

$$w = \gamma^l \frac{\sigma - 1}{\sigma} \frac{Y}{L} \tag{A.124}$$

$$L = \lambda N \tag{A.125}$$

$$\varphi^d = \left(\frac{1+\chi}{1-\lambda}\right)^{\frac{1}{k}} \tag{A.126}$$

$$M = \frac{1-\lambda}{1+\chi} N \tag{A.127}$$

$$Y = (1-\lambda)^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} \left[N \frac{k}{k-\sigma+1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{1}{t\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \left((1+\chi)^{\frac{1}{k}} (\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.128}$$

and – after simplifying – arrive at:

$$i^d(\varphi^d) = \alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right)^{\frac{1}{\sigma-1}} \tag{A.129}$$

We can rewrite this expression for the marginal offshoring firm

$$i^d(\varphi^o) = \alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right)^{\frac{1}{\sigma-1}} \chi^{\frac{1}{k}} \tag{A.130}$$

using $i^o(\varphi) = i^d(\varphi) \frac{t}{t^*} \kappa^{-1}$ we get

$$i^o(\varphi^o) = \alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right)^{\frac{1}{\sigma-1}} \chi^{\frac{1}{k}} \frac{t}{t^*} \kappa^{-1} \tag{A.131}$$

We can rewrite $\chi^{\frac{1}{k}}$ using offshoring indifference condition and combine it with $\kappa^{-1}$

$$\chi = \left[\kappa^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}}$$

$$\chi^{\frac{1}{k}} = \left[\kappa^{\sigma-1} - 1\right]^{\frac{1}{\sigma-1}} \tag{A.132}$$

$$i^o(\varphi^o) = \alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right)^{\frac{1}{\sigma-1}} \frac{t}{t^*} \kappa^{-1} \left[\kappa^{\sigma-1} - 1\right]^{\frac{1}{\sigma-1}} \tag{A.133}$$

$$i^o(\varphi^o) = \alpha(1-\eta) \frac{\sigma-1}{\sigma} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right)^{\frac{1}{\sigma-1}} \frac{1}{t^*} \kappa^{-1} \left[\kappa^{\sigma-1} - 1\right]^{\frac{1}{\sigma-1}} \tag{A.134}$$

$$i^o(\varphi^o)^{\sigma-1} = \left[\alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t^*}\right]^{\sigma-1} \left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right) \frac{1}{\kappa^{\sigma-1}} \left[\kappa^{\sigma-1} - 1\right] \tag{A.135}$$

$$i^o(\varphi^o)^{\sigma-1} = \left[\alpha(1-\eta) \frac{\sigma-1}{\sigma} \frac{1}{t^*}\right]^{\sigma-1} \left[\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)} N\right] \left[1 - \frac{1}{\kappa^{\sigma-1}}\right] \tag{A.136}$$

From the last expression, it is evident that $i^o(\varphi^o)$ rises in $t$. The first squared bracket is independent of $t$. As $t$ raises $\chi$ and lowers $\gamma_l$, we know that the second squared bracket (with $\gamma_l$ in the denominator) has to increase. Also the third squared bracket has to increase, as $\kappa$ in the denominator is subtracted. Hence, emission intensity of the marginal offshoring must increase due to an increase of the source country emission tax rate.

Since this cutoff term is linked to its average solely via the pareto multiplier we thus also confirm that the average emission intensity of the offshoring firm increases as well.

$$\bar{i}^o = \alpha(1-\eta)\left(\frac{w}{t}\right)^{1-\alpha(1-\eta)} \kappa^{-1}\frac{t}{t^*}\frac{k-\sigma}{k-\sigma+1}\frac{1}{\varphi^o} \tag{A.137}$$

Rearranging the expression for average offshorer's emission intensity yields a term equal to expression (A.131) multiplied by $\frac{k-\sigma}{k-\sigma+1}$.

$$\bar{i}^o = \alpha(1-\eta)\frac{\sigma-1}{\sigma}\frac{1}{t}\left(\frac{k}{k-\sigma+1+\gamma^l k(\sigma-1)}N\right)^{\frac{1}{\sigma-1}} \chi^{\frac{1}{k}}\frac{t}{t^*}\kappa^{-1}\frac{k-\sigma}{k-\sigma+1} \tag{A.138}$$

As the multiplier does not depend on $t$, it can be concluded that $\bar{i}^o$ increases in $t$ as well.

### A.9.5 Effect on source country wage

We use (19), (21) and (A.103) to get our starting equation for $w$:

$$w = \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{1-\alpha(1-\eta)}} \left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} (1+\chi)^{\frac{1}{k(1-\alpha(1-\eta))}} \tag{A.139}$$

Comparative statics reveal a negative direct effect of t

$$\frac{\partial w}{\partial t} = -\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}\left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}-1}\frac{1}{t^2}\left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{1-\alpha(1-\eta)}} (1+\chi)^{\frac{1}{k(1-\alpha(1-\eta))}} \tag{A.140}$$

and an opposing positive indirect effect of t via $\chi$ with $d\chi/dt > 0$ and

$$\frac{\partial w}{\partial \chi} = \left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}\left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{\sigma-1}{\sigma}\right)^{\frac{1}{1-\alpha(1-\eta)}} (1+\chi)^{\frac{1}{k(1-\alpha(1-\eta))}}$$
$$\times\left[\frac{(k-\sigma+1)(k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1} + (k-\sigma+1)k(\gamma^l-\eta) + k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]. \tag{A.141}$$

After tedious calculations we can show that the negative direct effect dominates the positive indirect effect for all $\chi \in (0,1)$, hence $\frac{dw}{dt} < 0$.

### A.9.6 Effect on aggregate final goods output

We can use and rewrite (A.103) to get our starting equation:

$$Y = \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{1}{t\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}}(\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}} \tag{A.142}$$

Similar to the effect on source country wage rate, comparative statics reveal a negative direct and a positive indirect effect (via $\chi$ with $d\chi/dt$):

$$\frac{\partial Y}{\partial t} = -\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)} \left(\frac{1}{t}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}-1} \frac{1}{t^2} \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{1}{\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}}$$
$$\times \left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}} (\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}} < 0 \tag{A.143}$$

$$\frac{\partial Y}{\partial \chi} = \left[\frac{1}{k-\sigma+1+\gamma^l k(\sigma-1)}\right]^{\frac{k(\sigma-1)(1-\alpha(1-\eta))+k-\sigma+1}{k(\sigma-1)(1-\alpha(1-\eta))}} [Nk]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(\frac{1}{t\sigma}\right)^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)}} \left(\left(\frac{1+\chi}{k-\sigma+1}\right)^{\frac{1}{k}} (\sigma-1)\right)^{\frac{1}{1-\alpha(1-\eta)}}$$
$$\times \left[\frac{[k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)](k-\sigma+1)(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}-1} + [k(\sigma-1)(1-\alpha(1-\eta))+(k-\sigma+1)]k(\gamma^l-\eta)+k-\sigma+1+\gamma^l k(\sigma-1)}{k(1+\chi)(1-\alpha(1-\eta))[k-\sigma+1+\gamma^l k(\sigma-1)]}\right]$$
$$> 0 \tag{A.144}$$

Similar to source country wage rate, after tedious calculations we can show that the negative direct effect dominates the positive indirect effect for all $\chi \in (0,1)$, hence $dY/dt < 0$.

### A.9.7 Effect on aggregate income

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

$$I = \bar{\pi}M + wL + tE \tag{A.145}$$

rewritten as shares of revenues

$$I = \left[\frac{1}{\sigma} + \gamma^l \frac{\sigma-1}{\sigma} + \gamma^e \frac{\sigma-1}{\sigma}\right] Y \tag{A.146}$$

Since we have shown that $\frac{dY}{dt} < 0$ and together with $\frac{\partial \gamma^e}{\partial \chi} < 0$ and $\frac{\partial \gamma^l}{\partial \chi} < 0$ we can state that aggregate income decreases in source country emission tax rate: $\frac{dI}{dt} < 0$.

## A.10 Source Country Inequality

### A.10.1 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:

$$\Theta = \frac{\bar{\pi} - \chi w + b}{w + b}. \tag{A.147}$$

In closed form we get:

$$\Theta = \frac{\frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d) - \chi\pi^d(\varphi^d) + \frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d)\frac{(k-\sigma+1)N}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\frac{1}{N}\gamma^e(\sigma-1)}{\pi^d(\varphi^d) + \frac{k}{k-\sigma+1}(1+\chi)\pi^d(\varphi^d)\frac{(k-\sigma+1)N}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}\frac{1}{N}\gamma^e(\sigma-1)} \tag{A.148}$$

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

$$\Theta = \frac{\frac{k+\chi(\sigma-1)}{k-\sigma+1} + \frac{\gamma^e k(\sigma-1)}{[k-\sigma+1+\gamma^l k(\sigma-1)]}}{1 + \frac{\gamma^e k(\sigma-1)}{[k-\sigma+1+\gamma^l k(\sigma-1)]}} \tag{A.149}$$

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

$$\frac{d\Theta}{dt} = \underbrace{\frac{\partial\Theta}{\partial\chi}}_{>0}\underbrace{\frac{d\chi}{dt}}_{>0} > 0 \tag{A.150}$$

### A.10.2 Lorenz Curve

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

$$Q(\mu;\chi) \equiv \begin{cases} Q_1(\mu;\chi) & \text{if} \quad \mu \in [0, b_1(\chi)) \\ Q_2(\mu;\chi) & \text{if} \quad \mu \in [b_1(\chi), b_2(\chi)) \\ Q_3(\mu;\chi) & \text{if} \quad \mu \in [b_2(\chi), 1]. \end{cases} \tag{A.151}$$

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

$$\frac{I_1}{I} = \frac{wL + w\chi M + bL + b\chi M}{wL + \bar{\pi}M + bN} \tag{A.152}$$

The first segment of the curve:

$$Q_1 = \frac{\gamma^e k(\sigma-1) + \gamma^l k(\sigma-1) + (k-\sigma+1)}{\gamma^l k(\sigma-1) + k + \gamma^e k(\sigma-1)}\mu \tag{A.153}$$

The share of population is given by:

$$b_1(\chi) = 1 - \frac{M}{N} = \left(\frac{(1+\chi)\gamma^l k(\sigma-1) + \chi(k-\sigma+1)}{(1+\chi)[(k-\sigma+1) + \gamma^l k(\sigma-1)]}\right) \tag{A.154}$$

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:

$$\frac{I_2}{I} = \frac{\Pi(\bar{\varphi}) + bM(\bar{\varphi})}{wL + \bar{\pi}M + bN} \tag{A.155}$$

The second segment of the curve is given by:

$$Q_2(\mu,\chi) = \frac{[(1+\chi)\gamma^l k(\sigma-1) + \chi(k-\sigma+1)] + k\left[1 - \left[[1-\mu]^{\frac{(1+\chi)[(k-\sigma+1)+\gamma^l k(\sigma-1)]}{(k-\sigma+1)}}\right]^{\frac{k-\sigma+1}{k}}\right] + \mu(1+\chi)\gamma^e k(\sigma-1)}{[\gamma^l k(\sigma-1) + k + \gamma^e k(\sigma-1)](1+\chi)} \tag{A.156}$$

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

$$b_2(\chi) = \frac{N - \chi M}{N} = \frac{(1+\chi)\gamma^l k(\sigma-1) + k - \sigma + 1}{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]} \tag{A.157}$$

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

$$\frac{I_3}{I} = \frac{\Pi(\bar{\varphi}) - w(M(\bar{\varphi}) - M(\varphi^o)) + b(M(\bar{\varphi}) - M(\varphi^o))}{wL + \bar{\pi}M + bN} \tag{A.158}$$

The third part of curve is given by:

$$Q_3(\mu, \chi) = \frac{(1+\chi)[k+\gamma^l k(\sigma-1)+\gamma^e k(\sigma-1)] - k(1+\chi^{\frac{\sigma+1}{k}}) \left[ \left( (1-\mu) \frac{(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)]}{(k-\sigma+1)} \right)^{\frac{k-\sigma+1}{k}} \right] + (1-\mu)(1+\chi)[k-\sigma+1+\gamma^l k(\sigma-1)-\gamma^e k(\sigma-1)]}{[\gamma^l k(\sigma+1)+k+\gamma^e k(\sigma-1)](1+\chi)} \tag{A.159}$$

Figure 2 depicts the source country's Lorenz Curve for each share $\mu$ 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 $\chi = 0$.

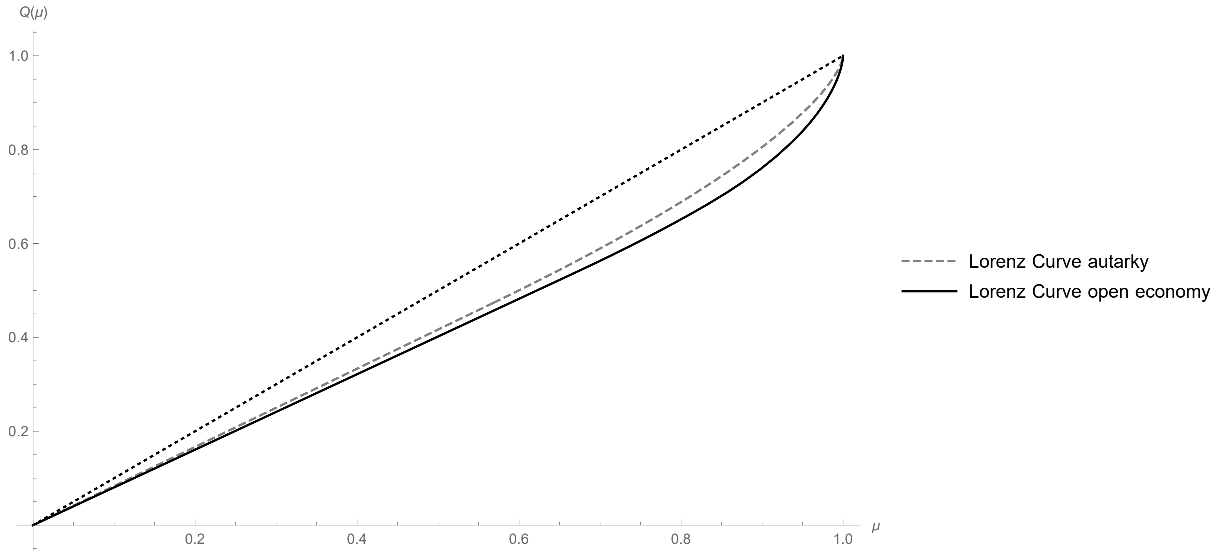


Figure 2: Source Country Lorenz Curve in Autarky and in the Open Economy

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.

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

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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 role of offshoring on firm-level employment

### S.1.1 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 $\eta$ 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.1.2 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[33]:

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

[33] 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).

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 $\alpha$ and $\eta$, but also in the direction of the effect of $w$ and $w^*$.

### S.1.3 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 labor 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.1.4 Source country labor 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 labor inputs as derived in Appendix S.1.1 and S.1.2:[34]

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

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

Note that while the source country labor 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).

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

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

[34] 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.

Transform $\kappa$ into $\chi$ 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:

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

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

Borrowing from Egger et al. (2015), the first effect (first squared brackets) is called *international relocation effect* (IR) and dominates at low level of offshoring. The second effect (second squared brackets) is the *firm productivity effect* (FP). It increases in the share of offshoring.

### S.1.5 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.

$$\frac{l_o^n + l_o^r}{l_d^n + l_d^r} = \underbrace{\left(1+\chi^{\frac{\sigma-1}{k}}\right)}_{A}\underbrace{\left(\frac{[\eta+(1-\alpha)(1-\eta)\frac{w}{w^*\tau}]}{[\eta+(1-\alpha)(1-\eta)]}\right)}_{B} \tag{S.16}$$

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 $\eta$[35] 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 $\chi$. 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 $\chi$.

### S.1.6 Source country non-routine task employment difference

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

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 $\chi$: Due to offshoring-related cost saving, firms increase their output for which they demand larger quantities of non-routine task labor at home.

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

### S.1.7 International routine task employment difference

$$\frac{l_o^r}{l_d^r} = \underbrace{\left(1+\chi^{\frac{\sigma-1}{k}}\right)}_{A} \underbrace{\left(\frac{\left[(1-\alpha)(1-\eta)\frac{w}{w^*\tau}\right]}{[(1-\alpha)(1-\eta)]}\right)}_{B} \tag{S.18}$$

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[36]) 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 $\chi$.

[36] 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 Comparative Statics: Change in transport costs $\tau$

### S.2.1 Effects on offshoring

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

$$\frac{d\chi}{d\tau} = -\frac{\partial F/\partial \tau}{\partial F/\partial \chi}. \tag{S.19}$$

The effect of $\tau$ is:

$$\begin{aligned} \frac{\partial F}{\partial \tau} &= (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta} \\ &\times \left(-\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)\frac{1}{\tau^2} < 0 \end{aligned} \tag{S.20}$$

Inserted jointly with (A.47) into (S.19) our total effect is:

$$\frac{d\chi}{d\tau} = -\underbrace{\frac{\partial F/\partial \tau}{\partial F/\partial \chi}}_{\frac{<0}{<0}} < 0. \tag{S.21}$$

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

### S.2.2 Factor allocation

$$\frac{dM}{d\tau} = \underbrace{\left[\underbrace{\frac{\partial M}{\partial \chi}}_{<0} + \underbrace{\frac{\partial M}{\partial \gamma^l}}_{<0}\underbrace{\frac{\partial \gamma^l}{\partial \chi}}_{<0}\right]}_{\gtrless 0}\underbrace{\frac{d\chi}{d\tau}}_{<0} \tag{S.22}$$

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

$$\frac{dL}{d\tau} = \underbrace{\left[\frac{\partial L}{\partial \gamma^l}\frac{\partial \gamma^l}{\partial \chi}\right]}_{<0}\underbrace{\frac{d\chi}{d\tau}}_{<0} > 0 \tag{S.23}$$

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

$$\frac{d\Xi}{dt} = \underbrace{\frac{\partial \Xi}{\partial \gamma}}_{>0}\underbrace{\frac{\partial \gamma}{\partial \chi}}_{<0}\underbrace{\frac{d\chi}{dt}}_{>0} < 0 \tag{S.24}$$

## 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:

$$\frac{d\chi}{dt^*} = -\frac{\partial F/\partial t^*}{\partial F/\partial \chi} \tag{S.25}$$

$$\frac{\partial F}{\partial t^*} = (1-\eta)\left(\frac{1}{\tau}\left(\frac{t}{t^*}\right)^{\alpha}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\right)^{-\eta}$$
$$\times\frac{1}{\tau}\left(\frac{(k-\sigma+1)+\gamma^l k(\sigma-1)}{1-\gamma^l-\alpha(1-\eta)}\frac{N^*}{N}\right)^{1-\alpha}\alpha\left(\frac{t}{t^*}\right)^{\alpha-1}\left(-\frac{t}{t^{*2}}\right) < 0. \tag{S.26}$$

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

$$\frac{d\chi}{dt^*} = -\underbrace{\frac{\partial F/\partial t^*}{\partial F/\partial \chi}}_{\frac{\leq 0}{<0}} < 0 \tag{S.27}$$

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

$$\frac{dM}{dt^*} = \underbrace{\left[\underbrace{\frac{\partial M}{\partial \chi}}_{<0} + \underbrace{\frac{\partial M}{\partial \gamma^l}}_{<0}\underbrace{\frac{\partial \gamma^l}{\partial \chi}}_{<0}\right]}_{\gtreqless 0}\underbrace{\frac{d\chi}{dt^*}}_{<0} \tag{S.28}$$

For low levels of $\chi$, 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.

$$\frac{dL}{dt^*} = \underbrace{\left[\frac{\partial L}{\partial \gamma^l}\frac{\partial \gamma^l}{\partial \chi}\right]}_{<0}\underbrace{\frac{d\chi}{dt^*}}_{<0} > 0 \tag{S.29}$$

$$\frac{\partial \frac{E}{E^*}}{\partial t^*} = \underbrace{\frac{\partial \frac{E}{E^*}}{\partial t^*}}_{>0} + \underbrace{\frac{\partial \frac{E}{E^*}}{\partial \chi}}_{<0}\underbrace{\frac{d\chi}{dt^*}}_{<0} > 0 \tag{S.30}$$

$$\frac{d\Xi}{d\tau} = \underbrace{\frac{\partial \Xi}{\partial \gamma}}_{>0}\underbrace{\frac{\partial \gamma}{\partial \chi}}_{<0}\underbrace{\frac{d\chi}{d\tau}}_{<0} > 0 \tag{S.31}$$

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

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

$$\xi = \beta\left[\frac{e(v)}{l^r(v)}\right]^{\alpha} \qquad \text{with} \quad \beta \equiv (1-\alpha)^{-(1-\alpha)}\alpha^{-\alpha} \tag{S.32}$$

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

$$\xi = \frac{1}{1-\alpha}\left(\frac{w}{t}\right)^{\alpha} \tag{S.33}$$

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

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

$$l^r(v)\,\xi = (1-\eta)\,\frac{y(v)}{\varphi(v)}\left(\frac{w}{t}\right)^{\alpha\eta} \tag{S.34}$$

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

Note that the right side of both of the equations is generated by inserting S.33 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

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

$$p_a = \frac{\sigma}{\sigma-1}\frac{w}{\varphi}\left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} \tag{S.37}$$

Occupational choice

$$\pi_a(\varphi^d) = w \tag{S.38}$$

$$\bar{\pi}_a = \pi_a(\varphi^d)\frac{k}{k-\sigma+1} \tag{S.39}$$

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

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

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

$$w_a L_a = \frac{\sigma-1}{\sigma}(1-\alpha(1-\eta))Y_a \tag{S.41}$$

using (S.40) and (S.41) in (S.38) to solve for $L$

$$L_a = \frac{k(\sigma-1)}{k-\sigma+1}(1-\alpha(1-\eta))M_a \tag{S.42}$$

resource constraint

$$L_a = N - M_a \tag{S.43}$$

combine both to get equilibrium factor allocation

$$L_a = \frac{k(\sigma-1)(1-\alpha(1-\eta))}{k-\sigma+1+k(\sigma-1)(1-\alpha(1-\eta))}N \tag{S.44}$$

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

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

$$\varphi_a^d = \left[\frac{k - \sigma + 1 + k(\sigma - 1)(1 - \alpha(1 - \eta))}{(k - \sigma + 1)}\right]^{\frac{1}{k}} \tag{S.46}$$

Aggregate Emissions

$$t_a E_a = Y_a \frac{\sigma - 1}{\sigma} \alpha(1 - \eta) \tag{S.47}$$

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 $P = 1$.

$$\frac{Y}{M^{\frac{\sigma}{\sigma-1}}} \left(\frac{\bar{\varphi}}{\varphi^d}\right)^{-\sigma} = Y p(\varphi^d)^{-\sigma} \tag{S.48}$$

Solve it for the price and insert the price equation

$$\frac{\sigma}{\sigma - 1} \frac{w}{\varphi^d} \left(\left(\frac{t}{w}\right)^{\alpha}\right)^{1-\eta} = \left(\frac{\bar{\varphi}}{\varphi^d}\right) M^{\frac{1}{\sigma-1}} \tag{S.49}$$

We can now use pareto for average productivity

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

Next, we solve it for the wage rate

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

We now use the marginal firm indifference condition (S.38) and insert the profits of the marginal firm into (S.40). Solve it for $Y$:

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

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

Use it in aggregate emissions

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

### S.5.1 Autarky - Comparative Statics

$$\frac{\partial Y_a}{\partial t} = \sigma \left[M \frac{k}{k - \sigma + 1}\right]^{\frac{(\sigma-1)(1-\alpha(1-\eta))+1}{(\sigma-1)(1-\alpha(1-\eta))}} \left(-\frac{1}{t^2}\right) \frac{\alpha(1 - \eta)}{1 - \alpha(1 - \eta)} \left[\frac{1}{t}\right]^{\frac{\alpha(1-\eta)}{1-\alpha(1-\eta)} - 1} \left[\frac{\sigma - 1}{\sigma} \varphi^d\right]^{\frac{1}{1-\alpha(1-\eta)}} < 0 \tag{S.55}$$

A change of emission tax affects the aggregate emissions:

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

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

$$\frac{\partial\gamma}{\partial\chi} = \frac{(\eta - \frac{k-\sigma+1}{k}\chi^{\frac{k-\sigma+1}{k}-1}(1-\alpha)(1-\eta))(1+\chi) - (1-\alpha(1-\eta)+\eta\chi-(1-\alpha)(1-\eta)\chi^{\frac{k-\sigma+1}{k}})}{(1+\chi)^2} \tag{S.57}$$

splitting up

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

splitting up the first term

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

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

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

combine to one term

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

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