Designing a globally acceptable carbon tax scheme to address competitiveness and leakage concerns

Lei Zhu, Lianbiao Cui, Joachim Schleich

School of Economics and Management, Beihang University, Beijing, 100191, China

School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu, 233030, China

Department of Management, Technology and Innovation, Grenoble Ecole de Management, Univ Grenoble Alpes ComUE, 12 rue Pierre Sécard, 38000 Grenoble, France

Department of Energy Policy and Energy Markets, Fraunhofer Institute of Systems and Innovation Research, Breslauer Straße 48, 76139 Karlsruhe, Germany

* Corresponding Author: Joachim Schleich, Ph.D. Email: joachim.schleich@grenoble-em.com, joachim.schleich@isi.fraunhofer.de

Abstract: To address competitiveness and leakage concerns in international climate policy, this paper proposes a differentiated carbon tax scheme (DCT), which largely preserves the relative competitive positions of developed and developing countries. The paper first presents a theoretical model from which to derive the DCT. Then, employing a global trade analysis model, competitiveness and leakage effects under a DCT are simulated and contrasted to those of a unilateral carbon tax, a carbon tariff, and a uniform carbon tax. The results of our analysis suggest that: 1) under the proposed DCT, emission reductions in developed and developing countries are higher and leakage is lower than under a carbon tariff; 2) the DCT has weaker competitiveness effects than a carbon tariff; and 3) the DCT is more favourable to developing countries' output and welfare than a carbon tariff or a uniform global carbon tax. Developing countries may therefore embrace a DCT as an intermediate step towards the implementation of a global carbon tax.

Keywords: differentiated carbon tax scheme; carbon tariffs; cost fairness principle; competitive advantage; global trade analysis model
1. Introduction

To achieve greenhouse gas emissions targets several countries have implemented some type of carbon pricing via carbon taxes or an emissions trading system, including the European Union, China, Korea, Canada, and Mexico. Typically, carbon pricing covers energy sectors and energy-intensive industrial sectors such as steel, cement, and chemicals. Only a few countries are however currently pricing carbon high enough to meet climate targets such as those pledged under the Paris Agreement adopted by parties to the United Nations Framework Convention on Climate change (UNFCCC; see OECD 2018). These pledges, however, would need to be substantially strengthened to limit global warming to 2°C or, even better, 1.5°C (IPCC 2018). Thus, carbon prices need to increase to make a more significant contribution to mitigating climate change. Higher carbon prices, however, will likely reinforce existing concerns about competitiveness and carbon leakage if carbon prices continue to vary substantially across countries (e.g. Paltsev, 2001; Aldy and Pizer, 2015; Levinson and Taylor, 2008; Burniaux and Oliveira Martins, 2012). In particular, carbon leakage occurs when firms shift the carbon output of energy-intensive industries to regions with lower carbon prices (e.g. via relocation).

To address competitiveness and leakage concerns, some developed countries (e.g. France) have long called for border-adjustment measures such as levying taxes on imports from countries with less ambitious climate policies (e.g. carbon tariffs based on carbon content). More recently, in December 2019, the European Commission proposed a European Green Deal that would make the European Union carbon neutral by 2050 (European Commission, 2019). To reduce the risk of carbon leakage, the Commission plans a carbon border adjustment mechanism for selected energy-intensive and trade-exposed industry sectors to be introduced by 2021.

The various border-adjustment measures proposed also differ in their climate and economic effects (e.g. Böhringer et al., 2012, 2017). Notably, Fischer and Fox (2012) have

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1 In this study, ‘competitiveness’ effects are captured by changes in domestic production and exports. As argued by Demailly and Quirion (2008), changes in production may affect industrial relocation, domestic employment, and the stock value of domestic firms. Changes in exports are commonly used to measure the competitiveness of one country's good in international markets.

2 Other measures designed to address competitiveness and leakage include linking emissions trading systems across countries and schemes involving sectoral targets (Gavard et al. 2011; Duscha et al. 2019).
conceptually and empirically explored the effectiveness of four such policies: a border charge on imports (a carbon tariff), a border rebate for exports, full border adjustment (i.e. combining import taxes with export rebates), and domestic output-based rebating (i.e. tying the allocation of certificates in an emissions trading system to output). Their simulations involving the energy-intensive sectors of three countries suggest that full border adjustment is usually most effective. Besides facing opposition from developing countries, however, such border-adjustment measures have also been critically discussed in the academic literature. The main concerns focus on the practicability of implementation, compatibility with WTO rules, and effectiveness (e.g. Babiker and Rutherford, 2005; van Asselt and Brewer, 2010; Kuik and Hofkes, 2010; Dissou and Eyland, 2011; Dong and Whalley, 2011; Winchester et al., 2011). Zhang (2018) argues that border-adjustment measures, even if they could be made WTO-consistent, should only be a short-term solution, at best. Economic efficiency requires marginal abatement costs to be equal across countries through a global price on carbon. Therefore, he proposes a global cooperative sectoral agreement that would reduce differences in carbon costs between countries to supplement the Paris Agreement.

In this paper we conceptually and empirically analyse the effects of differentiated carbon tax (DCT) schemes based on what we refer to as the "cost-fairness principle". Such a scheme implements carbon emissions taxes across countries without altering the countries' relative competitiveness. However, the DCT does not account for historic accountability (e.g. via accumulated greenhouse gas emissions) or other fairness criterions. While the proposed DCT implies a loss in economic efficiency, it is able to maintain the relative competitiveness among countries, so each country’s economic output will not be affected much by the tax scheme. This

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3 Border adjustment measures such as a carbon tariff could be misused for protectionist reasons and may therefore conflict with the core principles of the World Trade Organization (WTO) which, in particular, require equal treatment of similar products and no discrimination between domestic and foreign producers (Article I and III of the Global Agreement on Tariffs and Trade (GATT)). Therefore, compliance with WTO rules would be more likely, if a carbon tariff was matched by a domestic carbon price (e.g. through a carbon tax) (e.g., Pauwelyn, 2009). Yet, it is disputable whether border adjustment measures could be based on production processes rather than products. Should a border adjustment mechanism be found to violate the core principles of the WTO, it may still be permitted under GATT Article XX (Section VI), which allows trade restrictions to 'protect human, animal or plant life or health' (Article XX (b)) or to ensure ‘the conservation of exhaustible natural resources’ (Article XX (g)). Even if a border adjustment measure was found to be effective in protecting the global atmosphere, the introductory clause of GATT Article XX requires that the measures do not constitute an “arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade” (Lockwood and Whalley, 2010; Moore, 2011). This would involve a comparison of climate actions between importing and exporting countries, which may proof difficult in practice (e.g. Zhang, 2018). Implementing border adjustment measures may face additional practical challenges such as information required on the carbon content embodied in traded goods from a wide range of exporting countries (e.g. Monjon and Quirion, 2011).
aspect is particularly important for emerging and developing countries reluctant to agree to climate policy measures because they fear that these measures would impede economic development of their country.

To provide a conceptual framework for analyzing the DCT and to allow for carbon emission taxes in multiple countries, we first modify the analytical partial equilibrium model developed by Fisher and Fox (2012). We then employ a numerical global general equilibrium model to simulate the effects of DCT on competitiveness, CO₂ emissions and welfare and compare them with the effects of carbon emission tariffs and uniform carbon emission taxes across countries.

Our proposed differentiated carbon-tax scheme can also be linked to current international climate policy, such as the Paris Agreement. In particular, Art. 4 of UNFCCC (2018) foresees a ‘global stock take’ every five years during which policymakers can assess collective progress, acknowledging that both developed and developing countries may provide significant contributions. In this sense, a differentiated carbon tax may be part of a multi-stage design. At each stage, countries may adjust their differentiated carbon-tax levels, for example based on the difference between pledged and observed emissions intensities in the previous stage. Likewise, a differentiated carbon-tax scheme could be implemented as a greenhouse gas emissions-trading scheme in line with the ‘cooperative approaches’ specified in Art. 6 of UNFCCC (2018).

The remainder of this paper is structured as follows: In Section 2 we lay out the conceptual model. In Section 3 we describe our empirical model. In Section 4 we present the policy scenarios and report the results of the model simulations. We discuss the main findings and conclude the study in Section 5.

2. Methodology

In this section, we first present our extension of the theoretical model developed by Fischer and Fox (2012) to allow for a DCT.

2.1 Theoretical model

Following Fischer and Fox (2012), we employ a two-countries, two-goods partial equilibrium model. In contrast to Fischer and Fox (2012), who focus on the effects of border adjustment policies implemented in one country, we consider the effects of implementing
emission prices in both countries.

The developed country and the developing country produce one good each. The developed country produces good $H$ at a per-unit cost of $c_H(r_H)$ that rises with reductions $r_H$ from its baseline emission rate $e_H^0$ per unit of output ($c_H^0 \equiv c_H(0)$). Analogously, the developing country produces good $F$ at a per-unit cost of $c_F(r_F)$ with reductions $r_F$, and baseline emissions $e_F^0$ per unit of output ($c_F^0 \equiv c_F(0)$). In each country, a representative consumer demands particular quantities of both goods. Consumption of good $H$ in the developed and developing countries is represented by $h$ and $x$ (the latter being exported to the developing country), respectively. Similarly, the consumption of good $F$ is represented by $m$ (the latter being exported to the developed country) and $f$, respectively.

Producers are perfectly competitive, and the prices of $H$ and $F$ in turn will equal the (constant) marginal costs of production, including any taxes or rebates, so that the zero-profit condition is satisfied. Global emissions are denoted as $E = e_HH + e_FF$.

Following Fischer and Fox (2012) we implement the price of emissions as a carbon emissions tax, denoted by $t_H$ and $t_F$ in the developed and developing country, respectively.

The prices of $H$ and $F$ will then be $p_H = p_X = c_H(r_H) + t_H e_H$ and $p_F = p_M = c_F(r_F) + t_F e_F$, respectively.

As in Fischer and Fox (2012) we assume constant elasticity of demand functions of the form

$$h = \alpha_h p_H^{\eta h} p_M^{\eta hM}, \quad m = \alpha_m p_H^{\eta m} p_M^{\eta mM}, \quad x = \alpha_x p_X^{\eta x} p_F^{\eta xF}, \quad f = \alpha_f p_X^{\eta fX} p_F^{\eta fF},$$

with negative own-price elasticities and positive cross-price elasticities. In the market equilibrium, $H = h(p_H, p_M) + x(p_X, p_F)$ and $F = m(p_H, p_M) + f(p_X, p_F)$. Changes in domestic production and net exports are employed as indicators of changes in "competitiveness" and we assume that the change in global emissions matters for climate policymaking. Substituting these prices, the changes in the countries’ domestic production

\footnote{In the partial equilibrium theoretical model, the tax revenue is ignored; in particular, it will not be redistributed to the companies. In the subsequent policy simulations with the general equilibrium model GTAP-E, tax revenues are transferred as a lump-sum to the representative household in each country.}
and net exports are:

\[
\begin{align*}
dH &= \frac{dp_H}{P_H} (h \eta_{hlH} + x \eta_{lxH}) + \frac{dp_F}{P_F} (h \eta_{hlM} + x \eta_{lxM}) \\
\end{align*}
\]

\[
\begin{align*}
dF &= \frac{dp_H}{P_H} (f \eta_{fxH} + m \eta_{mfH}) + \frac{dp_F}{P_F} (f \eta_{fxM} + m \eta_{mfM}) \\
\end{align*}
\]

\[
\begin{align*}
dN_H &= \frac{dp_H}{P_H} (x \eta_{lxH} - m \eta_{mfH}) + \frac{dp_F}{P_F} (x \eta_{lxM} - m \eta_{mfM}) \\
\end{align*}
\]

\[
\begin{align*}
dN_F &= \frac{dp_H}{P_H} (m \eta_{mfH} - x \eta_{lxH}) + \frac{dp_F}{P_F} (m \eta_{mfM} - x \eta_{lxM}) \\
\end{align*}
\]

where \( N_H \) and \( N_F \) are the net exports of developed and developing countries, respectively.

Regarding the changes in global emissions, we get:

\[
dE = -dr_H H - dr_F F \\
+ c_H \left[ \frac{dp_H}{H_H} (h \eta_{hlH} + x \eta_{lxH}) + \frac{dp_F}{P_F} (h \eta_{hlM} + x \eta_{lxM}) \right] \\
+ c_F \left[ \frac{dp_H}{P_H} (f \eta_{fxH} + m \eta_{mfH}) + \frac{dp_F}{P_F} (f \eta_{fxM} + m \eta_{mfM}) \right]
\]

(3)

While expressions (1) and (2) are identical to the respective generic expressions proposed in Fischer and Fox (2012), equation (3) includes an additional term \((-dr_F F)\) because our model also allows for emission reductions in the developing country.

As a special case, equations (1) and (2) also hold when the taxes are set according to our operationalization of the cost-fairness principle, i.e. the cost ratio and the relative prices of the goods remain the same as they were without emissions taxes:

\[
\frac{c_{H} + t_{H} e_{H}}{c_{F} + t_{F} e_{F}} = \frac{c^0_{H}}{c^0_{F}}
\]

(4)

With equation (4) we have \( \frac{dp_H}{P_H} = \frac{dp_F}{P_F} \). Hence, under DCT, the cost pressure is the same in both countries.

2.2 Policy Comparisons

We analyse the changes in domestic production, net exports and global emissions under DCT by comparing them with what would happen under two alternative scenarios; in one
alternative scenario a carbon tax is imposed in the developed country only \((Ctax)\), while in the other a carbon tax is combined with an carbon tariff in the developed country only \((ImpTax)\). The carbon tariff is based on the carbon intensity in \(F\) (reflecting production-based accounting).

The difference between the \(DCT\) and the \(Ctax\) cases regarding the change in output in the developed country is then

\[
dH_{DCT} - dH_{Ctax} = \left( h\eta_{HH} + x\eta_{sx} \right) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left[ \frac{dp_H}{p_H} \right]^{Ctax} + \left( h\eta_{HM} + x\eta_{sF} \right) \left( \frac{dp_F}{p_F} \right)^{DCT} \tag{5} \]

The sum of the own price elasticities is negative, and the sum of the cross price elasticities is positive. Because the increase in the price of the developed country's good may be higher or lower under \(DCT\) than under \(Ctax\), the bracketed term cannot be signed. Therefore, we cannot generally determine the sign of equation (5). But if we set (as a special case),

\[
\left( \frac{dp_H}{p_H} \right)^{DCT} = \left( \frac{dp_H}{p_H} \right)^{Ctax}, \text{ we end up with the second part only. In this case, we get:} \]

\[
dH_{DCT} - dH_{Ctax} = \left( h\eta_{HM} + x\eta_{sF} \right) \left( \frac{dp_F}{p_F} \right)^{DCT} = \left( h\eta_{HM} + x\eta_{sF} \right) \left[ \frac{c_F^{DCT} + t_F^{DCT} + DCT}{c_F^0} \right] \tag{6} \]

Because the cross prices elasticities are positive, equation (6) is positive, and the \(DCT\) leads to a smaller loss in domestic output for the developed country than \(Ctax\) does in the special case.

Similarly, the comparison of \(DCT\) with \(ImpTax\) yields:

\[
dH_{DCT} - dH_{ImpTax} = \left( h\eta_{HH} + x\eta_{sx} \right) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left[ \frac{dp_H}{p_H} \right]^{ImpTax} + \left( h\eta_{HM} + x\eta_{sF} \right) \left( \frac{dp_F}{p_F} \right)^{DCT} - h\eta_{HM} \left( \frac{dp_F}{p_F} \right)^{ImpTax} \tag{7} \]
Again, we cannot generally sign equation (7). Assuming $DCT_{ImpTax}$ 

$\begin{align*}
\frac{dH_{DCT} - dH_{ImpTax}}{dp_H} &= \left( x\eta_d + h\eta_{hm} \right) \left[ c_F^{DCT} + t_F^{DCT} e_F^{DCT} - c_F^{0} \right] \\
&- h\eta_{hm} t_H^{ImpTax} e_F^{0} c_F^{0} 
\end{align*}$

(8)

We note that equation (8) differs from equation (6) by the term 

$-h\eta_{hm} t_H^{ImpTax} e_F^{0} c_F^{0}$

is negative because the cross price derivative is positive. This term captures the protective effect of the import tax on the developed country’s output. Thus, equation (8) cannot be generally signed. Comparing equations (8) and (6) further illustrates that for the special case, the output loss under $DCT$ is larger when compared to $ImpTax$ rather than to $Ctax$.

For the developing country, the results of comparing the effects of $DCT$ with those of $Ctax$ and $ImpTax$ are presented in the Appendix. For the special case, the findings show that, $dF_{DCT} - dF_{Ctax} < 0$. $DCT$ reduces the developing country’s production while $Ctax$ increases it. However, whether $ImpTax$ or $DCT$ leads to a smaller loss in domestic output for the developing country is ambiguous, even for the special case.

In the Appendix we show that for the special case in which relative price changes are identical, the $DCT$ will increase the net export of the developed country compared with what $Ctax$ would do ($dN_{H_{DCT}} - dN_{H_{Ctax}} > 0$) and decrease the net export of the developing country ($dN_{F_{DCT}} - dN_{F_{Ctax}} < 0$). So, the $DCT$ scheme largely avoids the distortionary effects on global trade that occur when developed countries implement carbon taxes alone or carbon taxes together with carbon tariffs.

Finally, in the Appendix we also show the changes in global emissions for the special case. Accordingly, $DCT$ may lead to a greater reduction in global emissions than $Ctax$. In addition, $DCT$ may better address carbon leakage than $ImpTax$. It should be mentioned here that the proposed $DCT$ is neither a first-best nor second-best solution for meeting global climate targets. Instead, $DCT$ may generate superior outcomes than unilateral emission policies such as a carbon tax or tariffs implemented in developed countries. In particular, $DCT$ may be
perceived as “fair” insofar as it preserves every country’s competitiveness and prevents carbon leakage.

Insofar as the effects of DCT depend on the relative price elasticities of demand, the levels of output, and emission intensities, in the following sections we next employ a global numerical general equilibrium model, GTAP-E, to simulate the effects of DCT for comparison with those of Ctax and ImpTax. To allow for comparability, some of these simulations require identical global emission reductions across these scenarios. i.e., \( dE_{DCT} = dE_{ImpTax} = dE_{Ctax} \).

In addition, the first-best option, i.e. a uniform carbon tax in both developed and developing countries, has also been simulated to provide the reference case for comparing policy impacts. In Section 3 we describe the model and in section 4 we present the simulation results.

3. Model description

We adopt the GTAP-E model to simulate the economic and environmental impact of the DCT scheme and compare the findings with what occurs in alternative climate-policy scenarios. The GTAP-E is a static, multi-region, multi-sector, applied general equilibrium model (Burniaux and Truong, 2002). Compared with the standard GTAP model, GTAP-E includes energy inputs and CO2 emissions from the combustion of fossil fuels. The empirical analysis is based on the GTAP 9.0 database and the base year is 2011. While the base data for GTAP-E come from GTAP, we have incorporated information on carbon emissions from all forms of fossil fuel combustion, including coal, oil, gas, and petroleum products. Following Ludena (2007), we adapted the CO2 emissions from the energy commodities consumption of a firm's intermediate use as well as household and government use, as applied to both domestic and imported sources, from Lee (2007).

For the policy simulations, we consolidated the 140 regions of the world into three groups. The first group, Annex I, includes 42 regions/countries including the USA, Japan, Germany, the United Kingdom, France, and Australia, accounting for 47% of global CO2 emissions, and 67% of global GDP. The second group, major developing countries (MdevCs), includes China, India,
Brazil, and South Africa, accounting for 51% of global CO₂ emissions and 31% of global GDP). The third group includes the least developed countries (LDCs), as defined by the United Nations Economic and Social Council (ECOSOC), and the DCT will be imposed on Annex I countries and MdevCs, but not on LDCs. Furthermore, the 57 sectors in GTAP have been consolidated into 13 sectors\(^7\). In particular, manufacturing sectors with high energy intensities (sector codes: omn, crp, nmm, i_s, nfm, ele, ome) have been combined into one sector (HeavyMnfc). The simulations will focus on the competitiveness effects on this sector under the various policy scenarios.

### 3.2 Calculation of the tax rates

Because production costs and emission intensities also depend on \( t_H \) and \( t_F \), these tax rates cannot be calculated from equation (4). Assuming that the tax rates are low, \( r_H \) and \( r_F \) and hence \( C_H \) and \( C_F \) do not change much from their base levels. In this case, the following holds

\[
t_F = t_H \frac{\epsilon_H^0}{\epsilon_H} \frac{\epsilon_F^0}{\epsilon_F} \tag{9}
\]

So, given \( t_H \), \( t_F \) may then be calculated from equation (9). The ratios \( \epsilon_H^0/\epsilon_H \) and \( \epsilon_F^0/\epsilon_F \) can be interpreted as carbon intensities (i.e. emissions per unit of GDP) in the developed and developing countries, respectively, if each country produces one good only (as in our conceptual model), or if all the sectors in a country are aggregated to a single sector. In line with the conceptual model, the carbon tax is levied per unit of CO₂ emissions (e.g. $/ton CO₂) for all sectors. To determine the tax rates in DCT, we follow an iterative process. In the first step, we start with a particular (small) value for \( t_H \) and solve Equation (9) for \( t_F \). In the second step, these tax rates are substituted into Equation (4) to solve for the carbon tax.

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\(^7\) Using the notation for sectors are used in the GTAP data base "omn" refers to Other Mining (mining of metal ores, uranium, gems, other mining and quarrying); "crp" refers to Chemical Rubber Products (basic chemicals, other chemical products, rubber and plastics products); "nmm" refers to Non-Metallic Minerals (cement, plaster, lime, gravel, concrete); "i_s" refers to Iron & Steel (basic production and casting); "nfm" refers to Non-Ferrous Metals (production and casting of copper, aluminium, zinc, lead, gold, and silver); "ele" refers to Electronic Equipment (office, accounting and computing machinery, radio, television and communication equipment and apparatus); and "ome" refers to Other Machinery & Equipment (electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks).
intensities. Substituting these carbon intensities into Equation (9) yields an updated set of taxes. We apply this procedure until the emissions reduction target is achieved. By adjusting the tax rates in $DCT$, we can compare the policy effects among $DCT$, $Ctax$, and $ImpTax$ under a given emission reduction target (for instance, by setting $dE_{DCT} = dE_{Ctax}$ or $dE_{DCT} = dE_{ImpTax}$).

Furthermore, we added a carbon tariff in one of the policy scenarios to the existing import taxes in the GTAP-E model. More precisely, in the policy simulations we assume that developed countries (Annex I countries) impose carbon taxes on imports from MdevCs if they latter fail to adopt any emissions reduction measures in their domestic markets. To do so, we first calculate the carbon emissions intensities for all sectors of MdevCs, then identify the exports embodying carbon emissions from MdevCs to Annex I countries, and eventually transform the specific carbon tariffs into equivalent ad valorem tariffs. Following the accounting rules of the Intergovernmental Panel on Climate Change (IPCC, 2007) we employ production-based (rather than consumption-based) accounting and we base our estimation of the carbon emissions embodied in exports on the production technology in MdevCs.

4. Simulations

We analyse the effects of five policy scenarios on CO$_2$ emissions, competitiveness and welfare. Two scenarios involve $DCT$, which are compared with three scenarios involving a unilateral carbon tax in Annex I, a carbon tax in Annex I combined with an import tax, and a uniform carbon tax. Table 1 provides an overview of these scenarios. All scenario results are evaluated in comparison with the baseline, which is a pre-determined consistent representation of the world economy of the year 2011 implemented in the GTAP 9.0 database.

4.1 Policy scenarios

As in Fischer and Fox (2011), $Ctax I$ assumes that Annex I countries adopt a carbon tax of 15 US$ per ton of CO$_2$ in their domestic markets (see overview in Table 1). $DCT I$ maintains the carbon tax of $Ctax I$ for Annex I countries and imposes an emission tax on MdevCs according

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8 In comparison, Fischer and Fox (2012) do not impose this condition, rendering comparisons of policy simulations difficult.
to the DCT principle. In addition to the emissions tax in Ctax I, ImpTax assumes that Annex I countries impose a carbon tariff of the same level on imports from MdevCs. To avoid double taxation, the fossil fuel imports are not subject to the tariff.

Table 1: Policy scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ctax I</td>
<td>Unilateral carbon tax of $15/ton CO₂ in Annex I.</td>
</tr>
<tr>
<td>DCT I</td>
<td>DCT scheme, in which a tax rate of $15/ton CO₂ is set in Annex I, and a tax rate of $6.42/ton CO₂ is levied in MdevCs according to Equation (9).</td>
</tr>
<tr>
<td>ImpTax</td>
<td>Unilateral carbon tax of $15/ton CO₂ in Annex I Carbon tariff of $15/ton CO₂ on imports from MdevCs in Annex I.</td>
</tr>
<tr>
<td>DCT II</td>
<td>DCT scheme in Annex I and MdevC, which guarantees the same level of global emissions as ImpTax. The tax rates are calculated by GTAP-E through an iterative process involving Equation (9) (i.e. 6.65 $/ton CO₂ for Annex I and 2.84 $/ton CO₂ for MdevCs).</td>
</tr>
<tr>
<td>Ctax II</td>
<td>Uniform carbon tax of $3.93/ton CO₂ in Annex I and MdevC, which guarantees the same level of global emissions as ImpTax. The tax rate is calculated by GTAP-E through an iterative approach.</td>
</tr>
</tbody>
</table>

The DCT scheme in DCT II involves emissions taxes for Annex I countries and MdevCs, which ensure the same level of global emissions as ImpTax. Finally, Ctax II can be viewed as a quasi-first-best solution. To allow for comparability, the carbon tax in Ctax II is chosen such that global emissions are the same as in DCT II and ImpTax. However, since MdevCs will oppose such a policy, Ctax II will likely be infeasible.

4.2 Environmental and economic effects

4.2.1 Carbon emissions

In Table 2 we focus on the regional carbon emissions associated with the various scenarios. Different regions experience different carbon emissions reductions in the five scenarios. First, compared with Ctax I, carbon tariff has only a small effect on carbon leakage prevention (the carbon leakage in ImpTax is 11.61%, which prevented only 18.76% of leakage compared with Ctax I). Second, DCT II can achieve the same global emissions reduction target as ImpTax but without causing serious carbon leakage, and this leakage rate is close that in Ctax II. The leakage rate will remain at a very low level (0.22%) even if we increase the tax rate in DCT I.

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9 For a true first-best solution, the carbon tax would also need to be applied in LDCs. Because LDCs account for less than 2% of global CO₂ emissions, though, the additional efficiency gains would likely be small.
Thus, the proposed DCT quite effectively prevents carbon leakage.

Table 2: Change in CO₂ emissions compared with the baseline (in %)

<table>
<thead>
<tr>
<th></th>
<th>Ctax I</th>
<th>DCT I</th>
<th>ImpTax</th>
<th>DCT II</th>
<th>Ctax II</th>
</tr>
</thead>
<tbody>
<tr>
<td>MdevCs</td>
<td>1.10</td>
<td>-7.27</td>
<td>0.87</td>
<td>-3.26</td>
<td>-4.83</td>
</tr>
<tr>
<td>LDCs</td>
<td>0.59</td>
<td>0.95</td>
<td>0.68</td>
<td>0.42</td>
<td>0.37</td>
</tr>
<tr>
<td>World</td>
<td>-3.43</td>
<td>-7.54</td>
<td>-3.47</td>
<td>-3.47</td>
<td>-3.47</td>
</tr>
<tr>
<td>Carbon leakage *</td>
<td>14.28</td>
<td>0.22</td>
<td>11.61</td>
<td>0.21</td>
<td>0.19</td>
</tr>
<tr>
<td>(Compared with Ctax I)</td>
<td>-</td>
<td>98.48</td>
<td>18.76</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carbon leakage prevented (Compared with ImpTax)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>98.19</td>
<td>98.41</td>
</tr>
</tbody>
</table>

* Carbon leakage is defined as the ratio of increased emissions in countries (compared with baseline emissions) without climate policies to emissions reductions in countries with climate policies (compared with baseline emissions).

The carbon emissions associated with MdevCs in ImpTax show an increase compared to the baseline. This does not however imply that the carbon tariff policy causes an increase in MdevCs’ carbon emissions. In fact, MdevCs’ carbon emissions would decrease by 0.23% when compared with what occurs in Ctax I. Referring to previous analyses (Gerlagh and Kuik, 2007; Burniaux and Oliveira, 2012), we note that imposing a carbon tax in Annex I countries decreases the domestic consumption of fossil energy in those countries, and prices on the world energy market may decline due to the supply-and-demand balance (a terms-of-trade effect). Thus, the consumption of fossil fuels in MdevCs and LDCs will increase to some extent. With the implementation of carbon tariffs, export demand for MdevCs will decrease, which will result in reducing production in MdevCs. Both factors (energy prices and export demand) will affect carbon emissions from MdevCs in ImpTax, and, based on our simulation results, energy prices will play a more significant role in changes in MdevCs.

4.2.2 Competitiveness

To assess the effects of the various policies on competitiveness, we calculated the changes in exports and domestic output. In particular, we explore the effects on energy-intensive sectors.

4.2.2.1 Exports

Figure 1 presents the changes in exports by region in the various scenarios. For Annex I, a
carbon tariff increases import prices and final output, and thus leads to lower exports. *DCT II* can avoid 40.81% of the export loss that Annex I countries experiences under *ImpTax*. For MdevCs, the export change in *DCT II* is -0.07%, which means that 89.70% of the export losses experienced under *ImpTax* can be avoided.

![Figure 1: Changes in exports and CO2 emissions for multiple policy scenarios (compared with the baseline in %).](image)

The export changes in MdevCs and Annex I countries under *DCT II* are quite similar in relative terms. Only if we increase the tax rate in *DCT I* such that global carbon emissions decrease by 7.54% would the changes in exports in MdevCs and Annex I countries be comparable to those under *Ctax I*, *ImpTax* and *Ctax II*. In sum, the findings suggest that *DCT* effectively avoids the distortion in export competitiveness that is commonly associated with carbon taxes and import taxes schemes, leading to comparable emissions reductions.

### 4.2.2.2 Domestic output

Figure 2 shows the changes in domestic output as measured by real GDP. Annex I countries’ output decreases slightly under *Ctax I* compared with *DCT II*, but in *DCT II* (-0.01%) Annex I countries experienced the lowest output loss in all policy scenarios (in *DCT II*, 80.30% of the output loss can be avoided compared with the outcome under *ImpTax*). If a uniform carbon tax is implemented (*Ctax II*), output in Annex I countries increases marginally by 0.001%. For MdevCs, output decreases by 0.01% in *DCT II*, which is lower than the 0.02% decrease in
output in *Ctax II*. Thus, for the same global emissions reductions, the output loss in Annex I countries is smaller in *DCT* than in *ImpTax*. The relative output changes in MdevCs and Annex I countries in *DCT II* and *DCT I* are also rather similar.

![Figure 2: Change in output and CO₂ emissions for multiple policy scenarios (compared with the baseline in %).](image-url)
4.2.2.3 Energy-intensive sectors

Taking a closer look into the competitiveness effects on energy-intensive sectors in Annex I countries and MdevCs, we analyse in detail the effects on the HeavyMnfc sector. This carbon-intensive sector is particularly affected by carbon policies. HeavyMnfc accounts for 9.59% and 14.80% of total value added in Annex I countries and MdevCs, respectively.

Figure 3 shows the changes in production and net exports for HeavyMnfc in Annex I countries and MdevCs. The unilateral emissions-reduction measure (Ctax I) will substantially lower output in and exports from HeavyMnfc in Annex I countries, while leading to gains in output and exports in MdevCs. The carbon tariff does not restore the competitiveness of HeavyMnfc firms between those in Annex I countries and those in MdevCs and, as expected, hurts exports from MdevCs in particular. In DCT II, HeavyMnfc firms in Annex I countries experience a smaller loss in competitiveness than under ImpTax. For HeavyMnfc firms in MdevCs, neither DCT II and nor even DCT I will provide the substantial competitive advantage HeavyMnfc firms experience in MdevCs in Ctax I. In sum, the policy simulations suggest that DCT may preserve the competitiveness of firms in energy-intensive sectors in Annex I countries and MdevCs.
multiple policy scenarios (compared to baseline in %).

Figure 4 shows the findings employing the same indicator for competitiveness as Fischer and Fox (2012), i.e. changes in net exports as a share of changes in output. This indicator more clearly highlights the differences between HeavyMnfC and Ely (refers to electricity generation, transmission and distribution) in the GTAP data base). As DCT is designed to maintain relative competitiveness across countries, under DCT I and DCT II changes in net exports relative to changes in output are to some extent equal for HeavyMnfC and Ely. This again illustrates that DCT can effectively maintain competitiveness in Annex I countries and MdevCs in energy-intensive sectors.

Figure 4: Changes in net exports as a share of changes in output for multiple policy scenarios

4.2.3 Welfare

In Table 3 we report changes in welfare per region, which we measure in GTAP-E using the Hicksian equivalent variation (EV\textsuperscript{10}). Compared with the baseline, global welfare decreases in all five scenarios; for the same level of global emissions, ImpTax is associated with the largest welfare loss. In Annex I countries, ImpTax, DCT I, and DCT II improve welfare compared with Ctax I. In Mdevs the reverse holds, i.e. Mdevs are better off in Ctax I than in ImpTax, DCT I, or DCT II. ImpTax leads to the greatest welfare gains for Annex I countries mainly because the revenue generated by the carbon tariffs under ImpTax belongs to Annex I countries, thus

\textsuperscript{10} In GTAP-E, the equivalent variation does not account for welfare changes that stem from changes in global warming (or other environmental effects).
alleviating the burden on consumers caused by the increase in import prices. Furthermore, although MdevCs under DCT I impose carbon taxes on all economic activities that use fossil fuels, the tax rate is relatively lower in MdevCs than in Annex I countries. Since MdevCs keep those tax revenues, losses under DCT I are even smaller than under ImpTax.

Table 3: Changes in regional welfare (in Millions of U.S. dollars compared with baseline)

<table>
<thead>
<tr>
<th></th>
<th>Ctax I</th>
<th>DCT I</th>
<th>ImpTax</th>
<th>DCT II</th>
<th>Ctax II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annex I</td>
<td>-14195.57</td>
<td>-934.31</td>
<td>9042.87</td>
<td>2238.95</td>
<td>6567.02</td>
</tr>
<tr>
<td>MdevCs</td>
<td>2461.11</td>
<td>-15710.30</td>
<td>-24717.91</td>
<td>-6048.86</td>
<td>-9664.52</td>
</tr>
<tr>
<td>LDCs</td>
<td>-839.31</td>
<td>-1312.74</td>
<td>-635.56</td>
<td>-561.20</td>
<td>-488.77</td>
</tr>
<tr>
<td>World</td>
<td>-12573.78</td>
<td>-17957.35</td>
<td>-16310.60</td>
<td>-4371.11</td>
<td>-3586.27</td>
</tr>
</tbody>
</table>

4.4 Comparison of policies

In Table 4 we compare the outcomes of the policy scenarios for Annex I countries and MdevCs based on five criteria: output, EV, exports, carbon emissions, and carbon leakage. Accordingly, for the same global carbon-emissions target, MdevCs and Annex I countries prefer DCT II to ImpTax. MdevCs are also better off in DCT I than in ImpTax. Moreover, choosing between DCT II and Ctax II entails weighing the advantages and disadvantages of both schemes for both regions. Although Annex I countries prefer Ctax II to DCT II, MdevCs may oppose such a carbon tax scheme.

Table 4: Comparison of scenarios

<table>
<thead>
<tr>
<th></th>
<th>Annex I</th>
<th>MdevCs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ImpTax</td>
<td>DCT II</td>
</tr>
<tr>
<td>Carbon leakage</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Export</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Output</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>EV</td>
<td>√</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ImpTax</th>
<th>DCT I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon leakage</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Export</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Output</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>EV</td>
<td>√</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>DCT II</th>
<th>Ctax II</th>
<th>DCT II</th>
<th>Ctax II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon leakage</td>
<td>X</td>
<td>√</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Export</td>
<td>X</td>
<td>√</td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Output</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>X</td>
</tr>
<tr>
<td>EV</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>X</td>
</tr>
</tbody>
</table>

Notes: “√” stands for ‘relatively preferred policy’; “X” stands for ‘not relatively preferred policy’.
In sum, we find that carbon tariffs provide only limited benefits for restoring competitiveness and avoiding leakage. In comparison, DCT as proposed in this paper appears to be more effective on both accounts. Moreover, DCT is also expected to be more acceptable politically. In particular, MdevCs are more likely to commit to emissions targets under a DCT than under carbon tariffs, insofar as the former involves a smaller loss in output, exports and EV.

5. Discussion and conclusion

In this paper, we propose an alternative mechanism to commonly discussed tax or tax-and-tariff schemes addressing competitiveness and carbon-leakage concerns associated with unilateral climate policy. This alternative mechanism involves a differentiated carbon tax scheme in which each country adopts a carbon tax in its domestic market that results in very similar relative cost pressures across all regions (applying our cost-fairness principle). Employing comparative static analyses for a theoretical trade model and simulations with a stylized standard numerical general equilibrium model offers several insights.

First, a differentiated carbon-tax scheme may effectively avoid carbon leakage, reducing global CO₂ emissions to a greater extent than a comparable carbon tariff. When MdevCs determine a carbon tax with the cost-fairness principle in place, the carbon-leakage rate is much lower than it would be under a carbon tariff, while reducing emissions at a rate that is similar to that of a uniform carbon-tax scenario (leading to identical global emissions reductions).

Second, for Annex I countries and MdevCs, a differentiated carbon tax should affect domestic production and international trade to a lesser extent than a unilateral carbon tax or import tax scheme, with lower trade distortions than occur in a uniform carbon-tax scenario (for identical global emissions reductions).

Third, the differentiated carbon-tax scheme we propose may be viewed as an extension of the ‘common but differentiated responsibilities’ principle. It has a weaker impact on output and social welfare in developing countries than a unilateral carbon tax or import tax scheme. Compared with such a scheme, a differentiated carbon-tax scheme would also enable
policymakers to anticipate emissions targets for developing countries while also accommodating further economic development in these countries. Therefore, the proposed differentiated carbon tax should also be more attractive to developing and emerging countries than the first-best solution, i.e. a uniform tax.

While a differentiated carbon tax as proposed and analysed in this paper has desirable properties, there are caveats to consider. In particular, to keep the analysis relatively simple we separated the world into three groups (Annex I countries, MdevCs, and LDCs). Thus, the results may not be meaningful for some individual countries. Similarly, combining heterogeneous energy-intensive sectors into HeavyMnfc, our sector aggregation is rather crude and may not be informative for individual sectors. In addition, the GTAP-E model used in this paper is a static model and cannot account for the dynamic effects of policy. Likewise, to calculate our DCT we used CO₂ emissions per unit of GDP, which may only roughly reflect the actual carbon intensity of individual sectors in Annex I countries and MdevCs. Finally, yet importantly, the fairness criterion employed in this paper focuses on competitiveness only. To garner support in international climate policymaking, a differentiated carbon tax could be combined with other fairness criteria such as accountability for climate change (the ‘polluter pays’ principle), capability (ability to pay) or egalitarian principles (equal initial rights to use the atmosphere) (e.g. Schleich et al. 2016). These principles relate strongly to redistributive justice and have been stressed by emerging and developing countries in particular as guiding principles for sharing future climate costs, following the fundamental principle of common but differentiated responsibilities and respective capabilities (CBDR&RC) originally established in the UNFCCC (UNFCCC 1992).

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References


using GTAP. Purdue University: Center for Global Trade Analysis.


37. United Nations Framework Convention on Climate Change (UNFCCC). 2011. Outcome of
the work of the Ad Hoc Working Group on Long-term Cooperative Action under the


Appendix. Detailed Policy Comparison for the developing country in the model

Comparing the effects of DCT with those of Ctax on domestic output in the developing country yields:

\[
\begin{align*}
\begin{cases}
dH_{DCT} - dH_{Ctax} = (h\eta_{hH} + x\eta_{sx}) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left( \frac{dp_H}{p_H} \right)^{Ctax} \\
+ (h\eta_{hM} + x\eta_{sx}) \left( \frac{dp_F}{p_F} \right)^{DCT} \\
\end{cases}
\end{align*}
\]

\[dF_{DCT} - dF_{Ctax} = \left( f\eta_{fx} + m\eta_{mH} \right) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left( \frac{dp_H}{p_H} \right)^{Ctax} \]

\[+ \left( f\eta_{fM} + m\eta_{mM} \right) \left( \frac{dp_F}{p_F} \right)^{DCT}\]  

(A.1)

and

\[
\begin{align*}
\begin{cases}
dN_{HDCT} - dN_{HCtax} = (x\eta_{cx} - m\eta_{mH}) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left( \frac{dp_H}{p_H} \right)^{Ctax} \\
+ (x\eta_{xM} - m\eta_{mM}) \left( \frac{dp_F}{p_F} \right)^{DCT} \\
\end{cases}
\end{align*}
\]

\[dN_{FDCT} - dN_{FCtax} = \left( m\eta_{mH} - x\eta_{sx} \right) \left[ \frac{dp_H}{p_H} \right]^{DCT} - \left( \frac{dp_H}{p_H} \right)^{Ctax} \]

\[+ \left( m\eta_{mM} - x\eta_{sx} \right) \left( \frac{dp_F}{p_F} \right)^{DCT}\]  

(A.2)

Setting \(\frac{dp_H}{p_H}^{DCT} = \frac{dp_H}{p_H}^{Ctax}\), we get:

\[
\begin{align*}
\begin{cases}
dH_{DCT} - dH_{Ctax} = (h\eta_{hH} + x\eta_{sx}) \left( \frac{dp_F}{p_F} \right)^{DCT} \\
= \left( h\eta_{hH} + x\eta_{sx} \right) \left( \frac{c_F^{DCT} + \epsilon_F^{DCT} c_F^{DCT} - c_0^F}{c_0^F} \right) \\
\end{cases}
\end{align*}
\]

\[dF_{DCT} - dF_{Ctax} = \left( f\eta_{fx} + m\eta_{mH} \right) \left( \frac{dp_F}{p_F} \right)^{DCT} \]

\[= \left( f\eta_{fx} + m\eta_{mH} \right) \left( \frac{c_F^{DCT} + \epsilon_F^{DCT} c_F^{DCT} - c_0^F}{c_0^F} \right)\]  

(A.3)

and
\[
\begin{align*}
\begin{cases}
dN_{HDCT} - dN_{HCtax} = (x_{\eta_{xF}} - m_{\eta_{mM}}) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} \\
= (x_{\eta_{xX}} - m_{\eta_{mH}}) \left[ \frac{(c_{F}^{DCT} + t_{F}^{DCT} e_{F}^{DCT} DCT)}{c_{0}^{F}} \right] 
\end{cases} \\
\begin{cases}
dN_{FDCT} - dN_{FCtax} = (m_{mM} - x_{\eta_{xF}}) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} \\
= (m_{mH} - x_{\eta_{xX}}) \left[ \frac{(c_{F}^{DCT} + t_{F}^{DCT} e_{F}^{DCT} DCT)}{c_{0}^{F}} \right] 
\end{cases}
\end{align*}
\]

(A.4)

The comparison of DCT with ImpTax yields:

\[
\begin{align*}
\begin{cases}
dH_{DCT} - dH_{ImpTax} = (h_{\eta_{hH}} + x_{\eta_{xX}}) \left( \frac{dp_{H}}{p_{H}} \right)_{DCT} - \left( \frac{dp_{H}}{p_{H}} \right)_{ImpTax} \\
+ (h_{\eta_{hM}} + x_{\eta_{xtF}}) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} - h_{\eta_{hH}} \left( \frac{dp_{F}}{p_{F}} \right)_{ImpTax} 
\end{cases} \\
\begin{cases}
dF_{DCT} - dF_{ImpTax} = \left( f_{\eta_{fF}} + m_{mM} \right) \left( \frac{dp_{H}}{p_{H}} \right)_{DCT} - \left( \frac{dp_{H}}{p_{H}} \right)_{ImpTax} \\
+ \left( f_{\eta_{fF}} + m_{mM} \right) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} - m_{mM} \left( \frac{dp_{F}}{p_{F}} \right)_{ImpTax} 
\end{cases}
\end{align*}
\]

(A.5)

and

\[
\begin{align*}
\begin{cases}
dN_{HDCT} - dN_{HImpTax} = (x_{\eta_{xX}} - m_{\eta_{mH}}) \left( \frac{dp_{H}}{p_{H}} \right)_{DCT} \left( \frac{dp_{H}}{p_{H}} \right)_{ImpTax} \\
+ (x_{\eta_{xF}} - m_{\eta_{mM}}) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} + m_{mM} \left( \frac{dp_{F}}{p_{F}} \right)_{ImpTax} 
\end{cases} \\
\begin{cases}
dN_{FDCT} - dN_{FImpTax} = (m_{mM} - x_{\eta_{xX}}) \left( \frac{dp_{H}}{p_{H}} \right)_{DCT} \left( \frac{dp_{H}}{p_{H}} \right)_{ImpTax} \\
+ (m_{mH} - x_{\eta_{xF}}) \left( \frac{dp_{F}}{p_{F}} \right)_{DCT} - m_{mH} \left( \frac{dp_{F}}{p_{F}} \right)_{ImpTax} 
\end{cases}
\end{align*}
\]

(A.6)

Setting \( \left( \frac{dp_{H}}{p_{H}} \right)_{DCT} = \left( \frac{dp_{H}}{p_{H}} \right)_{ImpTax} \) yields:
\[
\begin{align*}
\frac{dH_{DCT} - dH_{ImpTax}}{dH_{ImpTax}} &= \left( h\eta_{hM} + x\eta_{xF} \right) \left( \left( c_F^{DCT} + t_F^{DCT} e_F^{DCT} - c_0^{DCT} \right) \right) \\
&\quad - h\eta_{hM} t_H^{ImpTax} e_F^0 c_F^0 \\
\frac{dF_{DCT} - dF_{ImpTax}}{dF_{ImpTax}} &= \left( f\eta_{fF} + m\eta_{mM} \right) \left( \left( c_F^{DCT} + t_F^{DCT} e_F^{DCT} - c_0^{DCT} \right) \right) \\
&\quad - m\eta_{mM} t_F^{ImpTax} e_F^0 c_F^0
\end{align*}
\]

(A.7)

and

\[
\begin{align*}
\frac{dN_{HDCT} - dN_{HImpTax}}{dN_{HImpTax}} &= \left( x\eta_{xF} - m\eta_{mM} \right) \left( \frac{dp_F^{DCT}}{P_F} \right) + m\eta_{mM} \left( \frac{dp_F^{ImpTax}}{P_F} \right) \\
\frac{dN_{FDCT} - dN_{FImpTax}}{dN_{FImpTax}} &= \left( m\eta_{mM} - x\eta_{xF} \right) \left( \frac{dp_F^{DCT}}{P_F} \right) - m\eta_{mM} \left( \frac{dp_F^{ImpTax}}{P_F} \right)
\end{align*}
\]

(A.8)

Comparing changes in global emissions in the two special cases yields:

\[
dE_{DCT} - dE_{Ctax} = -dF_F^{DCT} F \\
+ e_H \left( \frac{dp_F^{DCT}}{P_F} \right) \left( h\eta_{hM} + x\eta_{xF} \right) \\
+ e_F \left( \frac{dp_F^{DCT}}{P_F} \right) \left( f\eta_{fF} + m\eta_{mM} \right)
\]

(A.9)

and

\[
dE_{DCT} - dE_{ImpTax} = -dF_F^{DCT} F \\
+ e_H \left( \frac{dp_F^{DCT}}{P_F} \right) \left( h\eta_{hM} + x\eta_{xF} \right) \\
- e_H \left( \frac{dp_F^{ImpTax}}{P_F} \right) \eta_{hM} \\
+ e_F \left( \frac{dp_F^{DCT}}{P_F} \right) \left( f\eta_{fF} + m\eta_{mM} \right) \\
- e_F \left( \frac{dp_F^{ImpTax}}{P_F} \right) \eta_{mM}
\]

(A.10)