Unilateral Supply Side Policies and the Green Paradox*

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Abstract This paper deals with possible foreign reactions to unilateral carbon supply reducing policies. It differentiates between demand and supply side reactions as well as between intra- and intertemporal shifts of greenhouse gas emissions. Ritter & Schopf (2014) integrate stock-dependent marginal physical extraction costs into Eichner & Pethig's (2011) general equilibrium carbon leakage model. Using this model, we change the policy instrument from an emissions trading scheme to a deposit preserving system. The results are as follows: Under similar conditions than those derived by Ritter & Schopf (2014), the *weak green paradox* and the *strong green paradox* arise. In case of acting today, these conditions are tightened due to the energy market channel of carbon leakage. In case of acting tomorrow, the change in the physical user cost of extraction additionally influences the effectiveness of the carbon supply reducing policies. In both cases, it can be more effective to preserve the deposits with the lowest marginal physical extraction costs first.

Keywords Carbon Leakage · Green Paradox · General Equilibrium Model

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1 Introduction

In this chapter, we investigate whether unilateral supply side policies against global warming can have unintended consequences. We contribute to the literature by using a general equilibrium model with endogenously determined total emissions and relating our results to those of comparable demand side measures.

Unilateral carbon demand reducing policies can cause intra- and intertemporal shifts of greenhouse gas emissions. An intratemporal shift is referred to as *carbon leakage*. van der Werf & Di Maria (2012) identify five channels of carbon leakage and find that estimated leakage rates are generally below 30 %. Sinn (2008) refers to an intertemporal shift that steepens the carbon extraction path as *green paradox*. This green paradox occurs if a carbon demand reducing policy is tightened in real terms over time as long as the carbon price is not bounded from above.[1]

One possibility to avoid these phenomena could be to apply supply side policies. Sinn (2008) suggests to tax capital income to lower the real interest rate and to flatten the carbon extraction path. Ritter et al. (2014) find that a unilateral capital income tax leads to less domestic capital demand and thus to a lower interest rate, so that foreign capital demand increases (carbon leakage), but extraction shifts into the future (reversed green paradox).[2] Flattening the carbon extraction path is good but not good enough. Allen et al. (2009) state that global warming depends first and foremost on total emissions and not on their temporal distribution. Along these lines, Gerlagh (2011) refers to an increase in early emissions as *weak green paradox* and to an increase in the cumulative and discounted climate damages as *strong green paradox*.

The recent literature on demand side policies finds that these policies can lead to an increase in total emissions. In a general equilibrium model with stock-dependent marginal

[1] If the carbon price is bounded from above, Hoel (2012) demonstrates that a carbon tax must increase more than in real terms over time for this green paradox to occur. With learning-by-doing in the renewable energy sector, Nachtigall & Rübbelke (2016) find that any future carbon tax leads to less current extraction as long as the slope of the marginal extraction cost curve is not too steep.

[2] If trade-related income effects are sufficiently weak, Eichner & Pethig (2015*d*) find that a present unilateral consumption-based carbon tax shifts domestic commodity demand into the future, so that the future commodity price increases and foreign commodity supply shifts into the future (negative carbon leakage). Since the interest rate is normalized to zero and the present commodity price is normalized to one, the increase in the future commodity price could be interpreted as a decrease in the real interest rate. Note that if trade-related income effects are strong, the results can be reversed (green paradox).

extraction costs, Ritter & Schopf (2014) find that a tighter present unilateral carbon cap can lead to an increase in early and total emissions if the intertemporal elasticity of substitution in consumption is relatively low and if future fossil fuel demand and supply are relatively inelastic. With a tighter future unilateral carbon cap, the weak and the strong green paradox can occur, but total foreign emissions can also decrease (negative cumulative carbon leakage). In a general equilibrium model with international capital markets, van der Meijden et al. (2015) find that a higher future carbon tax can lead to a higher present carbon price if capital-related income effects are relatively strong. In this case, early emissions decrease but with exploration costs, total emissions increase because a higher present carbon price leads to more exploration investment.[3]

Again, supply side policies could be a possibility to avoid higher total emissions. However, although van der Ploeg (2016) confirms the above result that a capital income tax leads to less current extraction, he also finds that cumulative extraction increases.[4] Maybe supply side policies directly reducing the (economically) available deposits are more effective. Examples in the relevant literature, which we will discuss below, are carbon supply taxes and deposit preserving systems. However, as far as we know, there are no general equilibrium models concerning these supply side policies. Since precisely these models can lead to higher total emissions in case of carbon demand reducing policies, we think it is appropriate and necessary to apply general equilibrium models to investigate the effectiveness of, i.e., deposit preserving systems.

In this chapter, we use Ritter & Schopf's (2014) model and change the policy instrument from an emissions trading scheme to a deposit preserving system. We find that purchasing additional deposits today or tomorrow can lead to higher early and total emissions. However, due to directly reducing the available deposits, present supply side policies are more effective than present demand side policies. Due to changes in the physical user cost of extraction, this does not necessarily hold for future policies. In both cases, negative cumulative carbon leakage is possible.

[3] In a partial equilibrium model with two pools having different constant marginal extraction costs and emissions factors, Fischer & Salant (2014) are still investigating whether a higher unilateral carbon tax level can lead to an increase in total emissions.

[4] With different types of fossil fuels, he also finds that a future carbon tax can lead to higher total emissions if coal is a gross substitute for oil. By contrast, Michielsen (2014) then finds that a future renewable energy subsidy leads to lower total emissions.

Bohm (1993) and Hoel (1994) suggest to combine carbon demand and supply reducing policies to avoid intratemporal carbon leakage. In a static partial equilibrium model, Hoel (1994) finds that it is unilaterally optimal to use both, carbon consumption and production taxes (or subsidies). Eichner & Pethig (2015*c*) confirm this result in a dynamic general equilibrium model without extraction costs. Harstad (2012, Section IV.B) and Hoel (2014) take intertemporal effects of carbon supply reducing policies and extraction costs into account. With a market for deposits, Harstad (2012, Section IV.B) finds that it is unilaterally optimal to purchase the deposits with the highest marginal extraction costs. In a Hotelling model, Hoel (2014) finds that any deposit preserving system leads to less current and cumulative extraction. However, with emissions from the extraction process, he finds that early emissions can increase if the deposits with the lowest marginal extraction costs (and emissions) are preserved.

Both authors use partial equilibrium models in which carbon demand and supply depend on the carbon price and exogenously given extraction costs. In our general equilibrium model, carbon demand and supply additionally depend on the commodity price and if this price changes due to carbon supply reducing policies, the cumulative extraction can increase and it can be more effective to preserve the deposits with the lowest marginal extraction costs first.

We close the introduction by mentioning three simulations concerning the effectiveness of unilateral carbon supply reducing policies. Richter et al. (2015) investigate the implications of coal export taxes that maximize the net present value of tax revenues. If such a tax is levied by Australia, domestic demand side leakage and foreign supply side leakage are relatively high. If it is levied by the largest four coal exporting countries, the tax level rises (from 6.7 $\$/tCO_2$ to 10.1 $\$/tCO_2$) and the effectiveness increases (from -37 $MtCO_2$/year to -200 $MtCO_2$/year). Fæhn et al. (2016) investigate the cost-efficient combination of demand and supply side policies to reduce global CO_2 emissions by 5 Mt until 2020 due to domestic measures in Norway. They find that two-thirds of the emissions should be reduced by supply side policies despite higher supply side than demand side leakage because marginal costs of foregone fossil fuel production are much lower than those of foregone fossil fuel consumption. Finally, Hagem & Storrøsten (2016) investigate how the European Economic Area's optimal share of consumer and producer taxes develops until 2060. If the social cost of carbon declines over time, the producer tax's share tends to decline over time because this shifts foreign production into the present.[5]

The outline of the chapter is as follows. Section 2 introduces the model. Section 3 investigates the implications of purchasing additional deposits during the time up to the medium term. Section 4 does the same for purchasing them during the time up to the very long term. Section 5 discusses which deposits should be preserved. Finally, Section 6 concludes.

2 The Model

Using Ritter & Schopf's (2014) modified three-country-two-period-model, we change the policy instrument from an emissions trading scheme to a deposit preserving system. One country ($i = F$) exports fossil fuel and imports and consumes the commodity, which is also used as the only input in the fossil fuel extraction process. The other two countries ($i = A, N$) import fossil fuel, which is used as the only input in the commodity production process, and export and consume the commodity. The two periods represent the time up to the medium term ($t = 1$) and the time up to the very long term ($t = 2$), the market rate of interest is normalized to zero. The abating country ($i = A$) constrains fossil fuel demand via an emissions trading scheme and fossil fuel supply via a deposit preserving system while the non-abating country ($i = N$) does not constrain fossil fuel consumption at all. In Ritter & Schopf's (2014) model, the policy instrument of the abating country is to reduce its traded emissions whereas in our model, it is to increase the preserved deposits.

The preserved deposits are characterized by their hypothetical material extraction costs, which we will discuss further below. All deposits up to the most costly unit that is preserved are denoted by an upper bar ($\overline{e}_{Ft}$), all deposits up to the least costly unit that is preserved are denoted by a lower bar ($\underline{e}_{Ft}$) in each period. We suppose that a deposit preserving system exists (in period one) and persists (in period two). The amount of preserved deposits ($\overline{e}_{Ft} - \underline{e}_{Ft}$) is exogenously given in each period and can converge towards zero. Extraction ($\widetilde{e}_{Ft}$) is equal to fossil fuel supply (e_{Ft}) minus preserved deposits in each period and determines cumulative extraction ($\widetilde{e}_{F\Sigma}$). In period one, the hypothetical material extraction costs or the position of the preserved deposits are exogenously given. In period two, just their intertemporal position ($\overline{e}_{F\Sigma}$, $\underline{e}_{F\Sigma}$) is exogenously given, their intratemporal position ($\overline{e}_{F2}$,

[5] All mentioned simulations use partial equilibrium models. Given the importance of general equilibrium considerations, computable general equilibrium models could allow further insights.

$\underline{e}_{F2}$) depends on present fossil fuel supply. Formally, this can be represented as follows:

$$\widetilde{e}_{Ft} = e_{Ft} - \overline{e}_{Ft} + \underline{e}_{Ft}, \tag{1}$$

$$\widetilde{e}_{F\Sigma} = \widetilde{e}_{F1} + \widetilde{e}_{F2}, \tag{2}$$

$$\overline{e}_{F2} = \overline{e}_{F\Sigma} - e_{F1} \quad \text{and} \quad \underline{e}_{F2} = \underline{e}_{F\Sigma} - e_{F1}. \tag{3}$$

In what follows, we introduce the model in more detail. Thereby, we start with the properties of the fossil fuel supply function and the optimization problem of the fossil fuel extractor, continue with the optimization problem of the commodity producers and that of the households, and close with the properties of the climate damage function.

Analogously to Ritter & Schopf's (2014) model, the analysis is limited to cases in which the cumulative fossil fuel supply is strictly less than the world's physical fossil fuel stock. The material extraction costs ($\widetilde{X}^{Et}$) determine the commodity demand of the fossil fuel extractor (x_{Et}) in each period. With a deposit preserving system, these costs are equal to the material fossil fuel supply costs (X^{Et}) minus the hypothetical material extraction costs of the preserved deposits ($\overline{X}^{Et} - \underline{X}^{Et}$). The former costs depend on current fossil fuel supply (e_{Ft}) in each period and on present fossil fuel supply in the second period. The latter costs are equal to the hypothetical material extraction costs of all deposits up to the most costly unit that is preserved ($\overline{X}^{Et}$) minus those of all deposits up to the least costly unit that is preserved ($\underline{X}^{Et}$). They depend on the intratemporal position of the preserved deposits ($\overline{e}_{Ft}$, $\underline{e}_{Ft}$) in each period and, similar to the future material extraction costs, on present fossil fuel supply in the second period. Formally, this can be represented as follows:

$$x_{E1} = \widetilde{X}^{E1} = X^{E1} - \overline{X}^{E1} + \underline{X}^{E1} := X^{E1}(e_{F1}) - X^{E1}(\overline{e}_{F1}) + X^{E1}(\underline{e}_{F1}), \tag{4}$$

$$x_{E2} = \widetilde{X}^{E2} = X^{E2} - \overline{X}^{E2} + \underline{X}^{E2} := X^{E2}(e_{F1}, e_{F2}) - X^{E2}(e_{F1}, \overline{e}_{F2}) + X^{E2}(e_{F1}, \underline{e}_{F2}). \tag{5}$$

Concerning the material fossil fuel supply costs, we make the same assumptions as Ritter & Schopf (2014). In period one, the marginal physical fossil fuel supply cost ($X^{E1}_{e_{F1}}$) is assumed to be positive and increasing in present fossil fuel supply. In period two, the marginal physical fossil fuel supply cost ($X^{E2}_{e_{F2}}$) and the physical user cost of supply ($X^{E2}_{e_{F1}}$) are assumed to be positive and increasing in both, present and future fossil fuel supply. Formally, this can be represented as follows:

$$X^{Et}_{e_{Ft}} > 0,\ X^{Et}_{e_{Ft}e_{Ft}} > 0, \tag{6}$$

$$X^{E2}_{e_{F1}} > 0,\ X^{E2}_{e_{F1}e_{F1}} > 0,\ X^{E2}_{e_{F1}e_{F2}} = X^{E2}_{e_{F2}e_{F1}} > 0. \tag{7}$$

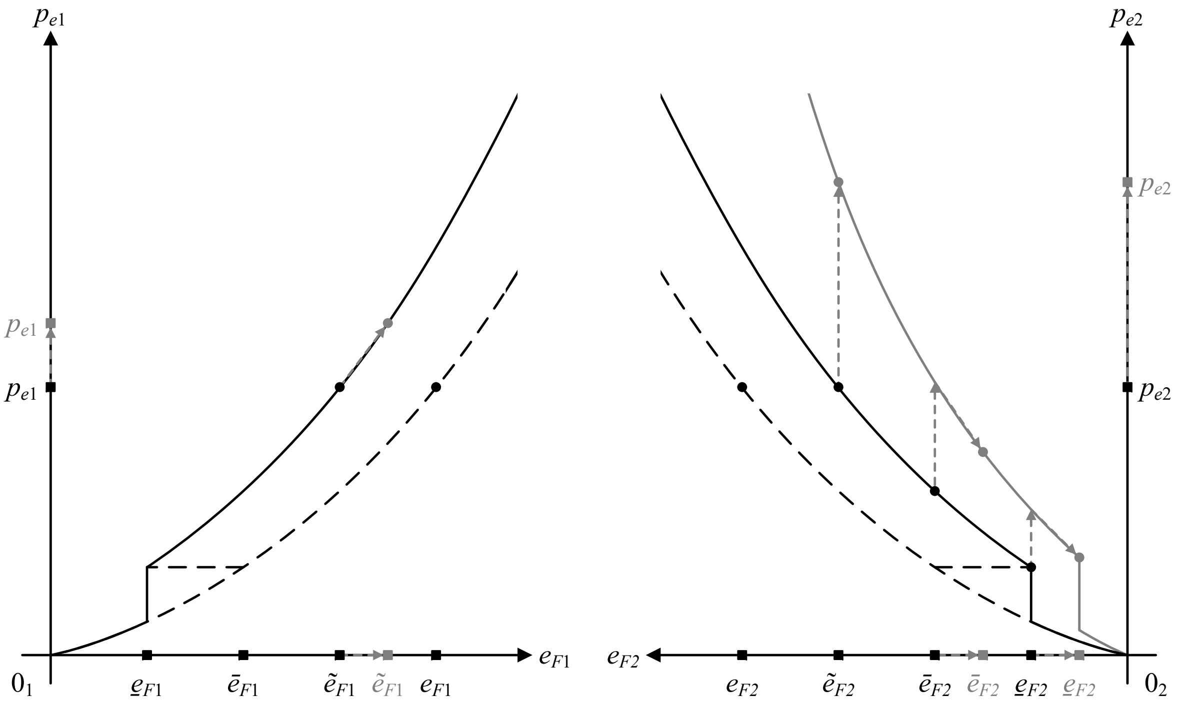

Figure 1: User Cost of Extraction

The intertemporal profit function of the fossil fuel extractor (Π^F) consists of output revenues ($p_{et}(e_{Ft} - \overline{e}_{Ft} + \underline{e}_{Ft})$) and input costs ($p_{xt}\widetilde{X}^{Et}$). The fossil fuel extractor maximizes his intertemporal profit under perfect competition. Then, the fossil fuel supply price is equal to the marginal extraction costs ($p_{xt}\widetilde{X}^{Et}_{e_{Ft}}$) in each period plus the user cost of extraction ($p_{x2}\widetilde{X}^{E2}_{e_{F1}}$) in the first period. The former costs are equal to the marginal fossil fuel supply costs ($p_{xt}X^{Et}_{e_{Ft}}$). Formally, this can be represented as follows:

$$\Pi^F := \sum_t \Big[p_{et}(e_{Ft} - \overline{e}_{Ft} + \underline{e}_{Ft}) - p_{xt}\widetilde{X}^{Et} \Big], \tag{8}$$

$$p_{e1} = p_{x1}X^{E1}_{e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}} \quad \text{and} \quad p_{e2} = p_{x2}X^{E2}_{e_{F2}}. \tag{9}$$

The physical user cost of extraction can be higher or lower than the physical user cost of supply, but given assumptions (6) and (7), they are positive:

$$\begin{aligned} \widetilde{X}^{E2}_{e_{F1}} &= X^{E2}_{e_{F1}} - \overline{X}^{E2}_{e_{F1}} + \underline{X}^{E2}_{e_{F1}} \\ &= X^{E2}_{e_{F1}} - \Big[X^{E2}_{e_{F1}} - X^{E2}_{e_{F2}} \Big]_{e_{F2}=\overline{e}_{F2}} + \Big[X^{E2}_{e_{F1}} - X^{E2}_{e_{F2}} \Big]_{e_{F2}=\underline{e}_{F2}} > 0. \end{aligned} \tag{10}$$

Figure 1 shows the difference between the user cost of extraction and the user cost of supply. To start with, neglect the gray curves and notations. Without a deposit preserving system, extraction would be equal to fossil fuel supply and would be characterized by the dashed curves in the figure. With a deposit preserving system, the present fossil fuel supply curve shifts leftwards in the relevant area by the amount of preserved deposits $(\overline{e}_{F1} - \underline{e}_{F1})$. Given p_{e1}, extraction declines from e_{F1} to $\widetilde{e}_{F1}$. Now consider that $\widetilde{e}_{F1}$ increases. Then, p_{e1} increases for two reasons. On the one hand, the marginal extraction cost in the first period increases. On the other hand, the user cost of extraction increases. This increase is depicted by the gray curve in the right-hand side figure. The future fossil fuel supply curve becomes steeper and the position of the preserved deposits shifts rightwards, because less fossil fuel is left in the second period.

The former effect leads to an increase in the user cost of supply, long up arrow, but also to an increase in the user costs of the most and the least costly units that are preserved, medium and short up arrows. Because of assumption (7), the long up arrow is always longer than the medium up arrow. The rightward-shift of the preserved deposits leads to less marginal extraction costs of the most and the least costly units that are preserved, medium and short right-down arrows. Because of assumption (6), the medium right-down arrow is always longer than the short right-down arrow. In sum, the additional costs of marginal supply and the least costly preserved unit outweigh the additional cost of the most costly preserved unit, and the user cost of extraction are positive. The magnitude of the medium and short arrows determine whether the user cost of extraction is higher or lower than the user cost of supply.

In Ritter & Schopf's (2014) model, total extraction cost, the material fossil fuel supply costs weighted by the commodity prices, is assumed to be the higher the less balanced the extraction path is:[6]

$$\left(\frac{p_{x1}}{p_{x2}} X^{E1}_{e_{F1}e_{F1}} + X^{E2}_{e_{F1}e_{F1}}\right) X^{E2}_{e_{F2}e_{F2}} > X^{E2}_{e_{F1}e_{F2}} X^{E2}_{e_{F2}e_{F1}}. \tag{11}$$

In our model, we make the same assumption, but with a deposit preserving system, extraction and fossil fuel supply are not the same, so that this assumption becomes:

$$\begin{aligned} & \left(\frac{p_{x1}}{p_{x2}} \widetilde{X}^{E1}_{e_{F1}e_{F1}} + \widetilde{X}^{E2}_{e_{F1}e_{F1}}\right) \widetilde{X}^{E2}_{e_{F2}e_{F2}} > \widetilde{X}^{E2}_{e_{F1}e_{F2}} \widetilde{X}^{E2}_{e_{F2}e_{F1}} \\ \Leftrightarrow \quad & \left(\frac{p_{x1}}{p_{x2}} X^{E1}_{e_{F1}e_{F1}} + \widetilde{X}^{E2}_{e_{F1}e_{F1}}\right) X^{E2}_{e_{F2}e_{F2}} > X^{E2}_{e_{F1}e_{F2}} X^{E2}_{e_{F2}e_{F1}}. \end{aligned} \tag{12}$$

$\widetilde{X}^{E2}_{e_{F1}e_{F1}}$ can be greater or smaller than $X^{E2}_{e_{F1}e_{F1}}$:[7]

$$\widetilde{X}^{E2}_{e_{F1}e_{F1}} = X^{E2}_{e_{F1}e_{F1}} - \overline{X}^{E2}_{e_{F1}e_{F1}} + \underline{X}^{E2}_{e_{F1}e_{F1}}$$

[6] X^{E2} being strictly convex is sufficient.

[7] X^{E2} being strictly convex is sufficient for $\overline{X}^{E2}_{e_{F1}e_{F1}}$ and $\underline{X}^{E2}_{e_{F1}e_{F1}}$ being greater than zero.

$$= X^{E2}_{e_{F1}e_{F1}} - \Big[X^{E2}_{e_{F1}e_{F1}} + X^{E2}_{e_{F2}e_{F2}} - 2X^{E2}_{e_{F1}e_{F2}}\Big]_{e_{F2}=\overline{e}_{F2}}$$
$$+ \Big[X^{E2}_{e_{F1}e_{F1}} + X^{E2}_{e_{F2}e_{F2}} - 2X^{E2}_{e_{F1}e_{F2}}\Big]_{e_{F2}=\underline{e}_{F2}}. \tag{13}$$

We close the fossil fuel supply side with the price elasticities of supply for fossil fuel:

$$\widetilde{\eta}_{F1,1} = \frac{p_{x1}X^{E1}_{e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{p_{x1}e_{F1}X^{E1}_{e_{F1}e_{F1}} + p_{x2}e_{F1}\widetilde{X}^{E2}_{e_{F1}e_{F1}}}, \tag{14}$$

$$\widetilde{\eta}_{F2,1} = \frac{p_{x1}X^{E1}_{e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{p_{x2}e_{F2}X^{E2}_{e_{F1}e_{F2}}}, \tag{15}$$

$$\eta_{F1,2} = \widetilde{\eta}_{F1,2} = \frac{p_{x2}X^{E2}_{e_{F2}}}{p_{x2}e_{F1}X^{E2}_{e_{F2}e_{F1}}}, \tag{16}$$

$$\eta_{F2,2} = \widetilde{\eta}_{F2,2} = \frac{p_{x2}X^{E2}_{e_{F2}}}{p_{x2}e_{F2}X^{E2}_{e_{F2}e_{F2}}}, \tag{17}$$

where $\widetilde{\eta}_{Fs,t} := \frac{\mathrm{d}e_{Fs}}{\mathrm{d}p_{et}} \cdot \frac{p_{et}}{e_{Fs}} > 0$ is for $s \neq t$ the intertemporal and for $s = t$ the intratemporal price elasticity of supply for fossil fuel in period s. Note that assumption (12) is equivalent to the product of the intertemporal price elasticities of supply for fossil fuel ($\widetilde{\eta}_{F2,1}\eta_{F1,2}$) being greater than that of the intratemporal price elasticities of supply for fossil fuel ($\widetilde{\eta}_{F1,1}\eta_{F2,2}$).

The abating country constrains fossil fuel demand via an emissions trading scheme ($e_{At} = \overline{e}_{At}$), but does not reduce its traded emissions ($\mathrm{d}\overline{e}_{At} = 0$). Although we could switch to a two-country-model and skip the emissions trading scheme, we stick to the three-country-model for two reasons. First, if just one country imported fossil fuel, this country could effectively and cost-efficiently reduce fossil fuel demand via an emissions trading scheme. Thus, it would not be convenient to reduce fossil fuel supply via a deposit preserving system. Second, we want to compare under which conditions the green paradoxes arise with carbon demand and supply reducing policies, respectively. Thus, we remain as close as possible to Ritter & Schopf's (2014) model.

The commodity production functions (X^{At}, X^{Nt}) determine the commodity supply of the commodity producers (x^s_{At}, x^s_{Nt}) and depend on current fossil fuel demand ($\overline{e}_{At}, e_{Nt}$) in each country and period. They are assumed to be identical, increasing, and strictly concave. The intertemporal profit functions of the commodity producers (Π^A, Π^N) consist of output revenues ($p_{xt}X^{At}, p_{xt}X^{Nt}$), input costs ($p_{et}\overline{e}_{At}, p_{et}e_{Nt}$), and, for the commodity producer in the abating country, emission trading costs ($\pi_t\overline{e}_{At}$). Both types of costs depend on fossil fuel demand ($\overline{e}_{At}, e_{Nt}$), the input costs additionally depend on fossil fuel prices (p_{et}) whereas the emission trading costs additionally depend on permit prices (π_t). The commodity producers maximize their intertemporal profits under perfect competition. Formally, this can be represented as follows:

$$x^s_{At} = X^{At} := X^{At}(\overline{e}_{At}), \tag{18}$$

$$x^s_{Nt} = X^{Nt} := X^{Nt}(e_{Nt}), \tag{19}$$

$$\Pi^A := \sum_t \Big[p_{xt}X^{At} - (p_{et} + \pi_t)\overline{e}_{At}\Big], \tag{20}$$

$$\Pi^N := \sum_t \Big[p_{xt}X^{Nt} - p_{et}e_{Nt}\Big], \tag{21}$$

$$\pi_1 = p_{x1}X^{A1}_{\overline{e}_{A1}} - p_{e1} \geq 0 \quad \text{and} \quad \pi_2 = p_{x2}X^{A2}_{\overline{e}_{A2}} - p_{e2} \geq 0, \tag{22}$$

$$p_{x1}X^{N1}_{e_{N1}} = p_{e1} \quad \text{and} \quad p_{x2}X^{N2}_{e_{N2}} = p_{e2}. \tag{23}$$

In equilibrium, extraction is equal to fossil fuel demand of the commodity producers ($\overline{e}_{At} + e_{Nt}$) in each period, and commodity supply is equal to commodity demand of the households ($x_{At} + x_{Nt} + x_{Ft}$) plus that of the fossil fuel extractor (x_{Et}) in each period:

$$e_{Ft} - \overline{e}_{Ft} + \underline{e}_{Ft} = \overline{e}_{At} + e_{Nt}, \tag{24}$$

$$x^s_{At} + x^s_{Nt} = x_{At} + x_{Nt} + x_{Ft} + x_{Et}. \tag{25}$$

The intertemporal utility functions of the households (U) depend on present and future commodity consumption (x_{i1}, x_{i2}) in each country. They are assumed to be identical and their intertemporal elasticity of substitution ($\sigma := 1/(-b-1)$) to be constant. In Ritter & Schopf's (2014) model, total consumption expenses ($p_{x1}x_{i1} + p_{x2}x_{i2}$) are covered by the maximized intertemporal profits (Π^{i*}) in each country plus emission trading revenues ($\pi_1\overline{e}_{A1} + \pi_2\overline{e}_{A2}$) in the abating country. In our model, total incomes additionally consist of deposit purchasing costs and revenues ($\tau_1(\overline{e}_{F1} - \underline{e}_{F1}) + \tau_2(\overline{e}_{F2} - \underline{e}_{F2})$) in the abating country and the fossil fuel exporting country, respectively. These costs and revenues depend on the demand for deposits ($\overline{e}_{Ft} - \underline{e}_{Ft}$) and their prices ($\tau_t$). The relative commodity demand of the households (x_{i1}/x_{i2}) depends on the relative commodity price (p_{x1}/p_{x2}) and is identical in each country. Formally, this can be represented as follows:

$$U(x_{i1}, x_{i2}) = \Big(\alpha_1 x_{i1}^{-b} + \alpha_2 x_{i2}^{-b}\Big)^{-\frac{h}{b}}, \qquad i = A, N, F, \tag{26}$$

$$\sum_t p_{xt}x_{At} = \Pi^{A*} + \sum_t \Big[\pi_t\overline{e}_{At} - \tau_t(\overline{e}_{Ft} - \underline{e}_{Ft})\Big], \tag{2.27a}$$

$$\sum_t p_{xt}x_{Nt} = \Pi^{N*}, \tag{2.27b}$$

$$\sum_t p_{xt}x_{Ft} = \Pi^{F*} + \sum_t \Big[\tau_t(\overline{e}_{Ft} - \underline{e}_{Ft})\Big], \tag{2.27c}$$

$$\frac{x_{i1}}{x_{i2}} = \left(\frac{\alpha_2 p_{x1}}{\alpha_1 p_{x2}}\right)^{\sigma}, \qquad i = A, N, F. \tag{28}$$

When to preserve which deposits is unilaterally determined in the abating country. The prices of these deposits are bilaterally negotiated with the fossil fuel exporting country. Neither the demand for deposits nor their prices change the relative commodity demand of the households. This is also true for the emissions trading scheme. While the demand for deposits changes the commodity demand of the fossil fuel extractor and his fossil fuel supply, their prices just alter the allocation of total incomes. Since the abating country does not reduce its traded emissions, this is also true for the emissions trading scheme. Thus, neither the prices of the deposits nor the emissions trading scheme are distorting.

Analogously to Ritter & Schopf's (2014) model, we weight changes of present and cumulative emissions with the following climate damage function:

$$\widetilde{D}(\widetilde{e}_{F1}, \widetilde{e}_{F\Sigma}) = \left(c_1 \widetilde{e}_{F1}^{d} + c_2 \widetilde{e}_{F\Sigma}^{d}\right)^{\frac{\iota}{d}}, \tag{29}$$

$$\mathrm{d}\widetilde{D}(\widetilde{e}_{F1}, \widetilde{e}_{F\Sigma}) \gtreqless 0 \quad \Leftrightarrow \quad \mathrm{d}\widetilde{e}_{F1} + \lambda\, \mathrm{d}\widetilde{e}_{F\Sigma} \gtreqless 0, \tag{30}$$

where $\lambda := \frac{c_2}{c_1} \cdot \left(\frac{\widetilde{e}_{F\Sigma}}{\widetilde{e}_{F1}}\right)^{d-1} > 0$ is the relative weight attached to changes in cumulative emissions.

3 Acting Today

In the following two sections, we analyze under which conditions the green paradoxes arise when the abating country purchases additional high-cost deposits ($\mathrm{d}\overline{e}_{Ft} > 0$) either today (Section 3) or tomorrow (Section 4). Purchasing additional high-cost deposits leads to the same qualitative results as purchasing additional low-cost deposits ($\mathrm{d}\underline{e}_{Ft} < 0$).[8] However, the quantitative results differ and additionally depend on the initial position of the preserved deposits, which we will discuss further below (Section 5).

Purchasing additional high-cost deposits in the first period ($\mathrm{d}\overline{e}_{F1} > 0$) causes positive intratemporal carbon leakage ($\mathrm{d}e_{F1}/\,\mathrm{d}\overline{e}_{F1} > 0$) and can even lead to the weak green paradox ($\mathrm{d}\widetilde{e}_{F1}/\,\mathrm{d}\overline{e}_{F1} > 0$). A cumulative extraction expansion ($\mathrm{d}\widetilde{e}_{F\Sigma}/\,\mathrm{d}\overline{e}_{F1} > 0$) and the strong green paradox ($\mathrm{d}\widetilde{D}/\,\mathrm{d}\overline{e}_{F1} > 0$) can emerge, given that the weak green paradox occurs. Nevertheless, there can also be negative cumulative carbon leakage ($\mathrm{d}e_{F\Sigma}/\,\mathrm{d}\overline{e}_{F1} < 0$).[9] The solution

[8] See Appendix A.3.

[9] More precisely, the abating country purchases additional high-cost deposits in the first period and pre-

strategy for the comparative statics is as follows: We start with analyzing the changes on the commodity market, proceed with observing the effects on the fossil fuel market, and close by combining our results. On the former market, purchasing additional deposits affects the future commodity price:[10]

$$\mathrm{d}p_{x2} = \frac{p_{x2}}{\sigma}\Big(\widetilde{\Theta}\,\mathrm{d}e_{F1} - \overline{\mu}_1\,\mathrm{d}\overline{e}_{F1} + \overline{\mu}_2\,\mathrm{d}\overline{e}_{F2}\Big), \tag{31}$$

where $\widetilde{\Theta} := \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{x^s_{A1}+x^s_{N1}-x_{E1}} + \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{p_{x2}(x^s_{A2}+x^s_{N2}-x_{E2})}$ and $\overline{\mu}_t := \frac{p_{et}-p_{xt}\overline{X}^{Et}_{\overline{e}_{Ft}}}{p_{xt}(x^s_{At}+x^s_{Nt}-x_{Et})}$.

The first term in brackets reflects the change in the physical user cost of extraction and its intertemporal impact on the commodity market. If present fossil fuel supply and thus the physical user cost of extraction increased, the fossil fuel extractor would shift extraction and thus commodity demand into the future. The commodity would become scarcer in the second period. The other terms comprise the changes in the marginal physical extraction costs and their intratemporal impacts on the commodity market. If present extraction did not change and the abating country purchased additional high-cost deposits in the first period, the fossil fuel extractor would save some of the commodity for the preserved deposits, but he would need more of the commodity to maintain present extraction. The former effect is always outweighed by the latter so that the commodity would become scarcer in the first period.[11]

On the fossil fuel market, purchasing additional high-cost deposits in the first period affects present extraction:[12]

$$\mathrm{d}\widetilde{e}_{F1} = -\,\mathrm{d}\overline{e}_{F1} + \overline{\gamma}_{\widetilde{1}}\,\mathrm{d}\overline{e}_{F1} - \frac{\overline{\gamma}_{\widetilde{1}}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}p_{x2}, \tag{32}$$

where $\overline{\gamma}_{\widetilde{1}} := \frac{p_{e1}[p_{e2}+p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}|\eta_{N2}|]}{\widetilde{\Gamma}_0} \in (0,1)$ is the intratemporal leakage rate of the energy market channel, $\eta_{Nt} := \frac{X^{Nt}_{e_{Nt}}}{e_{Nt}X^{Nt}_{e_{Nt}e_{Nt}}} < 0$ is the price elasticity of demand for fossil fuel of the commodity producer in the non-abating country in period t and $\widetilde{\Gamma}_0 > 0$ is defined in Appendix A.4.

The first term reflects the carbon supply reduction of the abating country. The second term is the energy market channel of carbon leakage. Due to the carbon supply reduction of

serves them in the second period ($\mathrm{d}\overline{e}_{F1} > 0$), which is credibly announced today. For strategic action on the deposit market, see Harstad (2012) and Eichner & Pethig (2015*a*, 2015*b*).

[10]See Appendix A.2, equation (A.23). Throughout the rest of the chapter the commodity in period one is chosen as numeraire.

[11]Note that the nominator of $\overline{\mu}_t$ is also the opportunity cost of preserving additional high-cost deposits in period t and thus a lower bound for the price of these deposits.

[12]See Appendix A.1, equation (A.15).

the abating country, the present fossil fuel price would rise so that the fossil fuel extractor would increase present fossil fuel extraction if the future commodity price did not change.[13] The fraction is positive but smaller than one so that this channel causes positive intratemporal carbon leakage but cannot cause the weak green paradox.[14] The third term is the terms of trade channel of carbon leakage. If the future commodity price decreased, the commodity producer in the non-abating country would shift production and thus fossil fuel demand into the present. Furthermore, the user cost of extraction and the future marginal extraction cost would fall so that the fossil fuel extractor would increase fossil fuel supply in both periods.

Additionally, cumulative extraction is affected:[15]

$$\mathrm{d}\widetilde{e}_{F\Sigma} = -\,\mathrm{d}\overline{e}_{F1} + \overline{\gamma}_{\widetilde{\Sigma}}\,\mathrm{d}\overline{e}_{F1} - \frac{\overline{\gamma}_{\widetilde{\Sigma}}\widetilde{X}^{E2}_{e_{F1}} e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}p_{x2}, \tag{33}$$

where $\overline{\gamma}_{\widetilde{\Sigma}} := \frac{p_{e1}\Gamma_1}{\widetilde{\Gamma}_0} < \overline{\gamma}_{\widetilde{1}}$ is the intertemporal leakage rate of the energy market channel and Γ_1 is defined in Appendix A.4.

Intertemporally, both channels of carbon leakage are weakened. Due to the energy market channel, present fossil fuel extraction increases, which leads to higher marginal physical extraction cost and thus lower fossil fuel supply in the second period. If the future commodity price decreased, the terms of trade channel would lead to lower fossil fuel demand in the second period.

Whether the weak and the strong green paradox occur or not crucially depends on the intertemporal elasticity of substitution in consumption. For example, if it was very high ($\sigma \to \infty$), the commodity price in period two would hardly change so that the terms of trade channel of carbon leakage would nearly disappear, see equation (31). Then, there would be positive intratemporal carbon leakage and there could be positive cumulative carbon leakage, but present and cumulative emissions would decline, see equation (32) and (33). Nevertheless, combining the results from the commodity market with those from the fossil fuel market, we can infer the following proposition without taking the intertemporal elasticity of substitution in consumption into account:

Proposition 3.1 *If the abating country purchases additional high-cost deposits in period one,*

[13] If there was a carbon demand reduction of the abating country and the future commodity price did not change, the present fossil fuel price would fall so that the non-abating country would increase present fossil fuel consumption. See Ritter & Schopf (2014).

[14] See Appendix A.4.

[15] See Appendix A.1, equation (A.17).

- *the future commodity price rises if and only if* $\overline{\gamma}_{\widetilde{1}} \cdot \widetilde{\Theta} > \overline{\mu}_1$*,*
- *the present fossil fuel price rises if* $\widetilde{\Theta} \geq \overline{\mu}_1$ *and the future fossil fuel price rises if the future commodity price rises,*
- *the present fossil fuel supply increases (positive intratemporal carbon leakage), the future fossil fuel supply decreases, and the cumulative fossil fuel supply decreases if and only if* $\overline{\gamma}_{\widetilde{\Sigma}} < 0$ *(negative cumulative carbon leakage),*
- *the emissions in the first period decline if and only if the present fossil fuel price rises and the cumulative emissions decline if* $\overline{\gamma}_{\widetilde{1}} \cdot \widetilde{\Theta} \geq \overline{\gamma}_{\widetilde{\Sigma}} \cdot \overline{\mu}_1$*.*

Proof. See Appendix A.3, equation (A.36); Appendix A.3, equation (A.38) and (A.39); Appendix A.3, equation (A.24), (A.26), and (A.27); Appendix A.3, equation (A.25) and (A.28). □

Due to the carbon supply reduction of the abating country in the first period, present fossil fuel supply increases. Thus, the intertemporal effect on the commodity market leads to a shift of commodity demand into the second period whereas the intratemporal effect leads to an increase of commodity demand in the first period. The future commodity price rises whenever the former effect outweighs the latter. This is the case when the intratemporal energy market channel of carbon leakage is relatively strong ($\overline{\gamma}_{\widetilde{1}} \uparrow$), the physical user cost of extraction is relatively high ($\widetilde{\Theta} \uparrow$), and the increase of commodity demand in the first period is relatively low ($\overline{\mu}_1 \downarrow$).

Due to positive intratemporal carbon leakage, the marginal physical extraction cost rises and fossil fuel supply decreases in the second period. Thereby, the physical user cost of extraction falls and present fossil fuel supply increases. Nevertheless, the fossil fuel price in the first period rises whenever the commodity price in the second period does not decrease too much or does even increase so that the future fossil fuel demand does not fall too much or does even rise ($\widetilde{\Theta} \geq \overline{\mu}_1$). The future fossil fuel price rises whenever the fossil fuel supply decrease outweighs the possible fossil fuel demand decrease in the second period. This is definitely the case when the future commodity price rises so that the future fossil fuel demand increases.

Negative cumulative carbon leakage occurs when the intertemporal leakage rate of the energy market channel is negative ($\overline{\gamma}_{\widetilde{\Sigma}} < 0$). This is the case if Γ_1 is smaller than zero, i.e., if the sum of the reciprocals of the intratemporal price semi-elasticities of demand and supply for fossil fuel in period two $\left(\frac{1}{e_{N2}|\eta_{N2}|} + \frac{1}{e_{F2}\eta_{F2,2}}\right)$ is smaller than the reciprocal of the

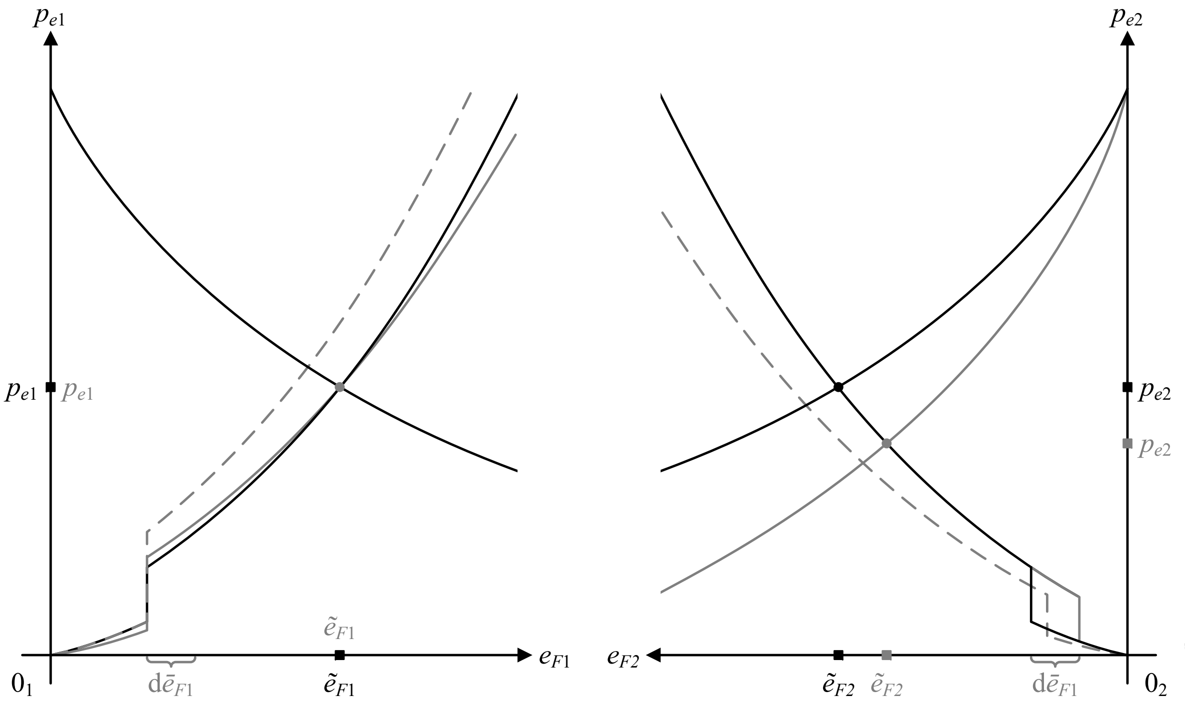

Figure 2: Purchasing Additional High-Cost Deposits Today

intertemporal price semi-elasticity of supply for fossil fuel in period one $\left(\frac{1}{e_{F1}\eta_{F1,2}}\right)$. In this case, the demand and supply reactions in the second period are relatively strong and the feedback mechanism to the first period is relatively weak.

Since fossil fuel demand is stationary in the first period, the emissions in the first period decline if and only if the present fossil fuel price rises. Since fossil fuel supply and thus extraction decreases in the second period, the cumulative emissions decline if the emissions in the first period decline. For the cumulative emissions to decline, it is also sufficient that the future commodity price does not fall or that negative cumulative carbon leakage occurs.

Figure 2 shows a "green" policy that leads to perfect intratemporal carbon leakage. By acting today, the present fossil fuel supply curve shifts leftwards (dashed gray curve in the left-hand side figure), whereby fossil fuel supply and the marginal physical extraction cost increase in the first period. Due to the former effect, the fossil fuel extractor shifts commodity demand into the future, while due to the latter effect, he increases present commodity demand. With perfect intratemporal carbon leakage, the intertemporal effect is outweighed by the intratemporal effect so that the future commodity price falls. Thereby, the future fossil fuel demand and supply curves turn leftwards (solid and dashed gray curves in the right-hand side figure) and the fossil fuel supply decreases in the second period.[16] This leads to a fall in the

[16]The future fossil fuel supply curve would turn rightwards if the increase in the future marginal physical

physical user cost of extraction so that the present fossil fuel supply curve turns rightwards (solid gray curve in the left-hand side figure) and the fossil fuel supply increases in the first period. Thereby, the marginal physical extraction cost increases in the second period and the future fossil fuel supply curve turns rightwards (solid black curve in the right-hand side figure).

Taking the intertemporal elasticity of substitution in consumption into account, the weak and the strong green paradox occur under the following conditions:[17]

$$\frac{\mathrm{d}\widetilde{e}_{F1}}{\mathrm{d}\overline{e}_{F1}} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr \overline{\sigma}_{\widetilde{1}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} \right), \tag{34}$$

$$\frac{\mathrm{d}\widetilde{D}}{\mathrm{d}\overline{e}_{F1}} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr \overline{\sigma}_{\widetilde{D}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{1-\overline{\gamma}_{\widetilde{D}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}} \right), \tag{35}$$

where $\overline{\gamma}_{\widetilde{D}} := \frac{\overline{\gamma}_{\widetilde{1}}+\lambda\overline{\gamma}_{\widetilde{\Sigma}}}{1+\lambda} \in (\overline{\gamma}_{\widetilde{\Sigma}}, \overline{\gamma}_{\widetilde{1}})$ is the weighted leakage rate of the energy market channel.

From equation (34) and (35), we can infer the following proposition:

Proposition 3.2 *If the abating country purchases additional high-cost deposits in period one, the weak and the strong green paradox occur under the following conditions:*

	$\mathrm{d}\widetilde{e}_{F1} > 0$	$\mathrm{d}\widetilde{e}_{F1} < 0$
$\mathrm{d}\widetilde{D} > 0$	$\sigma < \overline{\sigma}_{\widetilde{D}}$	$\lightning$
$\mathrm{d}\widetilde{D} < 0$	$\overline{\sigma}_{\widetilde{D}} < \sigma < \overline{\sigma}_{\widetilde{1}}$	$\sigma > \overline{\sigma}_{\widetilde{1}}$

Analogously to Ritter & Schopf (2014), the present emissions will increase if the intertemporal elasticity of substitution (σ) is relatively low and the physical user cost of extraction in real terms ($p_{x2}\widetilde{X}^{E2}_{e_{F1}}/p_{e1} < 1$) as well as the present price elasticity of demand for fossil fuel ($e_{N1}|\eta_{N1}|$) are relatively high. Different from Ritter & Schopf (2014), the conditions do not depend on the present permit price (π_1), but on the intratemporal ($\overline{\mu}_1$) and intertemporal ($\widetilde{\Theta}$) reactions of the fossil fuel extractor on the carbon supply reduction of the abating country. Furthermore, the condition for the weak green paradox is tightened due to the intratemporal leakage rate of the energy market channel ($\overline{\gamma}_{\widetilde{1}}$). Different from Ritter & Schopf (2014), the condition for the strong green paradox is always tighter than that for the weak green paradox.

extraction cost outweighed the fall in the future commodity price.

[17]See Appendix A.1, equation (A.25) and (A.29). The weak and the strong green paradox can only occur if $\overline{\sigma}_{\widetilde{1}} > 0$ and $\overline{\sigma}_{\widetilde{D}} > 0$, respectively. Otherwise, the present emissions and the cumulative damages will always decline, respectively.

4 Acting Tomorrow

In what follows, the effects of a change in the future deposit preserving system are analyzed. This action is credibly announced today and thus influences consumption and production decisions in the first period. Analogously to the supply reduction in the present, purchasing additional high-cost deposits in the second period ($\mathrm{d}\overline{e}_{F2} > 0$) can lead to the weak green paradox ($\mathrm{d}e_{F1}/\,\mathrm{d}\overline{e}_{F2} > 0$). In contrast to the analysis in the previous section, there can also be negative intratemporal carbon leakage ($\mathrm{d}e_{F1}/\,\mathrm{d}\overline{e}_{F2} < 0$). A cumulative extraction expansion ($\mathrm{d}\widetilde{e}_{F\Sigma}/\,\mathrm{d}\overline{e}_{F2} > 0$) and the strong green paradox ($\mathrm{d}\widetilde{D}/\,\mathrm{d}\overline{e}_{F2} > 0$) can still emerge. Nevertheless, there can also still be negative cumulative carbon leakage ($\mathrm{d}e_{F\Sigma}/\,\mathrm{d}\overline{e}_{F2} < 0$).[18]

On the commodity market, purchasing additional deposits affects the future commodity price according to equation (31). The effects are equivalent to those in case of acting today. The only difference is that the intratemporal impacts on the commodity market now lead to an increase of commodity demand in the second period.

On the fossil fuel market, purchasing high-cost deposits in the second period affects present and cumulative extraction:[19]

$$\begin{aligned}
\mathrm{d}e_{F1} = {} & \frac{p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}|\eta_{N2}|\,p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}|\eta_{N1}|}{\widetilde{\Gamma}_0}\,\mathrm{d}\overline{e}_{F2} - \frac{\overline{\gamma}_{\widetilde{1}}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}p_{x2} \\
& - \frac{\overline{\gamma}_{\widetilde{1}}p_{x2}[X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}]e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}\overline{e}_{F2},
\end{aligned} \tag{36}$$

$$\begin{aligned}
\mathrm{d}\widetilde{e}_{F\Sigma} = {} & -\frac{p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}|\eta_{N2}|\,\widetilde{\Gamma}_2}{\widetilde{\Gamma}_0}\,\mathrm{d}\overline{e}_{F2} - \frac{\overline{\gamma}_{\widetilde{\Sigma}}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}p_{x2} \\
& - \frac{\overline{\gamma}_{\widetilde{\Sigma}}p_{x2}[X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}]e_{N1}|\eta_{N1}|}{p_{e1}}\,\mathrm{d}\overline{e}_{F2},
\end{aligned} \tag{37}$$

where $\widetilde{\Gamma}_2$ is defined in Appendix A.4.

The first terms comprise the carbon supply reduction of the abating country and the energy market channel of carbon leakage. Together, these effects would lead to less extraction in the second period, which in turn would lead to lower physical user cost of extraction and thus to more extraction in the first period. The cumulative emissions would decline if $\widetilde{\Gamma}_2$ is greater than zero, i.e., if the sum of the reciprocals of the intratemporal price semi-elasticities of demand and supply for fossil fuel in period one $\left(\frac{1}{e_{N1}|\eta_{N1}|} + \frac{1}{e_{F1}\widetilde{\eta}_{F1,1}}\right)$ is greater than the reciprocal of the intertemporal price semi-elasticity of supply for fossil fuel in period two

[18] Analogously, the abating country could purchase additional high-cost deposits in the first period and preserve them in the second period ($\mathrm{d}\overline{e}_{F2} > 0$), which is credibly announced today.

[19] See Appendix A.1, equation (A.15) and (A.17).

$\left(\frac{1}{e_{F2}\widetilde{\eta}_{F2,1}}\right)$. In this case, the demand and supply reactions in the first period are relatively weak and the feedback mechanism to the second period is relatively strong. The second terms reflect the terms of trade channel of carbon leakage, which is equivalent to that in case of acting today.

We refer to the third terms as the *extraction cost channel* of carbon leakage. If future extraction did not change and the abating country purchased additional high-cost deposits in the second period, the physical user cost of extraction could increase, because additional units would be supplied ($X^{E2}_{e_{F1}e_{F2}}$), but could also decline, because additional units would be preserved ($\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$). If it increased, present fossil fuel supply would decline so that the future marginal physical extraction cost would decline and future fossil fuel supply would increase, and vice versa. The magnitude of the extraction cost channel depends on the magnitude of the energy market channel of carbon leakage in the first period because it is triggered by a change in the present fossil fuel supply.

Combining the results from the commodity market with those from the fossil fuel market, we can infer the following proposition without taking the intertemporal elasticity of substitution in consumption into account:

Proposition 4.1 *If the abating country purchases additional high-cost deposits in period two,*

- *the future commodity price rises if* $X^{E2}_{e_{F1}e_{F2}} \leq \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$*,*
- *the emissions in the first period decline if and only if the present fossil fuel price rises and the cumulative emissions decline if* $X^{E2}_{e_{F1}e_{F2}} \geq \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$ *and* $\Gamma_1, \widetilde{\Gamma}_2 \geq 0$.

Proof. See Appendix A.3, equation (A.37); Appendix A.3, equation (A.41); Appendix A.3, equation (A.30), (A.40), (A.32) and (A.34). □

Due to the carbon supply reduction of the abating country in the second period, the future commodity price rises if the physical user cost of supply does not increase. Then, the extraction cost channel of carbon leakage leads to more present and less future fossil fuel supply so that fossil fuel and thus the commodity, which is produced with fossil fuel, become scarcer in the second period.

Since fossil fuel demand is stationary in the first period, the emissions in the first period decline if and only if the present fossil fuel price rises. For the cumulative emissions to decline, it is sufficient that the physical user cost of supply dos not decrease, so that present fossil fuel supply does not increase due to the extraction cost channel of carbon leakage, and that Γ_1 and $\widetilde{\Gamma}_2$ are not negative, so that the energy market channel and the extraction cost channel lead to less cumulative extraction, see equation (37).

Taking the intertemporal elasticity of substitution in consumption into account, the weak and the strong green paradox occur under the following conditions:[20]

$$\frac{\mathrm{d}e_{F1}}{\mathrm{d}\bar{e}_{F2}} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \gtreqless \widetilde{\sigma}_{\widetilde{1}} = \frac{\frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{F2}\eta_{F2,2}}{p_{e1}} \cdot \overline{\mu}_2 \cdot \left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|} + \frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)}{1 - \delta \cdot \left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|} + \frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)}, \tag{38}$$

$$\frac{\mathrm{d}\widetilde{D}}{\mathrm{d}\bar{e}_{F2}} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \begin{cases} \lesseqgtr \widetilde{\sigma}_{\widetilde{D}} = \dfrac{\frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{F2}\eta_{F2,2}}{p_{e1}} \cdot \overline{\mu}_2}{\left(\frac{\frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} - \frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|}}{\frac{\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} + \frac{\widetilde{\Theta}}{\overline{\mu}_2 e_{F2}\eta_{F2,2}}}\right)} & \text{if} \quad \dfrac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|} > \dfrac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|}, \\ \\ \gtreqless \widetilde{\sigma}_{\widetilde{D}} = \dfrac{\frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{F2}\eta_{F2,2}}{p_{e1}} \cdot \overline{\mu}_2}{\left(\frac{\frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} - \frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|}}{\frac{\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} + \frac{\widetilde{\Theta}}{\overline{\mu}_2 e_{F2}\eta_{F2,2}}}\right)} & \text{if} \quad \dfrac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|} < \dfrac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|}, \end{cases} \tag{39}$$

where $\delta := \frac{p_{x2}[X^{E2}_{e_{F1}e_{F2}} - \widetilde{X}^{E2}_{e_{F1}\bar{e}_{F2}}]e_{F2}\eta_{F2,2}}{p_{e1}}$ and $\Gamma_1^D > \Gamma_1$ as well as $\widetilde{\Gamma}_2^D < \widetilde{\Gamma}_2$ are defined in Appendix A.4.

From equation (38) and (39), we can infer the following proposition:

Proposition 4.2 *If the abating country purchases additional high-cost deposits in period two, the weak and the strong green paradox occur under the following conditions:*

	$\mathrm{d}e_{F1} > 0$	$\mathrm{d}e_{F1} < 0$
$\mathrm{d}\widetilde{D} > 0$	$\sigma > \widetilde{\sigma}_{\widetilde{D}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} < \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$	$\sigma < \widetilde{\sigma}_{\widetilde{D}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} > \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$
$\mathrm{d}\widetilde{D} < 0$	$\widetilde{\sigma}_{\widetilde{D}} > \sigma > \widetilde{\sigma}_{\widetilde{1}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} < \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$ *or* $\sigma > \widetilde{\sigma}_{\widetilde{1}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} > \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$	$\widetilde{\sigma}_{\widetilde{D}} < \sigma < \widetilde{\sigma}_{\widetilde{1}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} > \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$ *or* $\sigma < \widetilde{\sigma}_{\widetilde{1}}$ *and* $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}\lvert\eta_{N1}\rvert} < \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}\lvert\eta_{N2}\rvert}$

[20] See Appendix A.3, equation (A.30) and (A.35). The weak green paradox can only occur if $\widetilde{\sigma}_{\widetilde{1}} > 0$. Otherwise, the present emissions will always decline.

Proof. If $\widetilde{\sigma}_{\widetilde{1}} > 0$, $\widetilde{\sigma}_{\widetilde{1}} \gtreqless \widetilde{\sigma}_{\widetilde{D}}$ is equivalent to $\frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|} \gtrless \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|}$ because

$$\widetilde{\sigma}_{\widetilde{1}} \gtreqless \widetilde{\sigma}_{\widetilde{D}} \quad \Leftrightarrow \quad \frac{\left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|} + \frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)}{1 - \delta \cdot \left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|} + \frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)} \gtreqless \left(\frac{\frac{\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} + \frac{\widetilde{\Theta}}{\overline{\mu}_2 e_{F2}\eta_{F2,2}}}{\frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|} - \frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|}}\right)$$

$$\Leftrightarrow \quad 0 \begin{cases} \lesseqgtr \frac{\frac{\frac{\widetilde{\Gamma}_0}{p_{e1}e_{N1}|\eta_{N1}|p_{e2}e_{N2}|\eta_{N2}|}}{e_{F2}\overline{\eta}_{F2,1}}}{1-\delta\cdot\left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|}+\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)} + \frac{\widetilde{\Theta}}{\overline{\mu}_2 e_{F2}\eta_{F2,2}} & \text{if} \quad \frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|} > \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|}, \\ \gtreqless \frac{\frac{\frac{\widetilde{\Gamma}_0}{p_{e1}e_{N1}|\eta_{N1}|p_{e2}e_{N2}|\eta_{N2}|}}{e_{F2}\overline{\eta}_{F2,1}}}{1-\delta\cdot\left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N2}|\eta_{N2}|}+\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F2}\eta_{F2,2}}\right)} + \frac{\widetilde{\Theta}}{\overline{\mu}_2 e_{F2}\eta_{F2,2}} & \text{if} \quad \frac{\widetilde{\Gamma}_2^D}{p_{e1}e_{N1}|\eta_{N1}|} < \frac{-\delta\Gamma_1^D}{p_{e2}e_{N2}|\eta_{N2}|}. \end{cases} \qquad \square$$

Analogously to Ritter & Schopf (2014), the present emissions will increase if the intertemporal elasticity of substitution (σ) is relatively high and the physical user cost of extraction in real terms ($p_{x2}\widetilde{X}^{E2}_{e_{F1}}/p_{e1} < 1$) is relatively low. The intratemporal price semi-elasticity of demand for fossil fuel ($e_{N2}|\eta_{N2}|$) is partially replaced by the intratemporal price semi-elasticity of supply for fossil fuel ($e_{F2}\eta_{F2,2}$). Different from Ritter & Schopf (2014), the conditions do not depend on the future permit price (π_2), but on the intratemporal ($\overline{\mu}_2$) reaction of the fossil fuel extractor on the carbon supply reduction of the abating country. Furthermore, the condition for the weak green paradox is tightened if the physical user cost of supply increases ($X^{E2}_{e_{F1}e_{F2}} > \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$), and vice versa.

5 Discussion

In the previous two sections, we found that the qualitative results in case of reducing carbon supply are quite similar to those in case of reducing carbon demand. Specifically, purchasing additional deposits today or tomorrow can lead to the green paradoxes. In the following, we will discuss whether additional high-cost or low-cost deposits should be preserved and which initial position of the preserved deposits should be chosen to tighten the conditions for an increase in the present emissions and the cumulative damages.

In case of acting today and tomorrow, the initial position of the preserved deposits in the second period influences the conditions for the green paradoxes via the physical user cost of extraction ($\widetilde{X}^{E2}_{e_{F1}}$) and its derivative with respect to present fossil fuel supply ($\widetilde{X}^{E2}_{e_{F1}e_{F1}}$). Since the impact of the initial position on $\widetilde{X}^{E2}_{e_{F1}}$ and $\widetilde{X}^{E2}_{e_{F1}e_{F1}}$ as well as the impact of $\widetilde{X}^{E2}_{e_{F1}}$ and $\widetilde{X}^{E2}_{e_{F1}e_{F1}}$ on the conditions for the green paradoxes are ambiguous, we will not discuss them in detail.[21] Nevertheless, the qualitative result that the configuration of the future deposit

[21]See equation (10) and (13) as well as Appendix A.5.

preserving system influences the effectiveness of present carbon supply reducing policies is interesting per se. Note that the physical user cost of extraction converges to the physical user cost of supply, which does not depend on $\overline{e}_{F2}$ and $\underline{e}_{F2}$, if the amount of preserved deposits in the second period converges to zero.

In case of acting today, the type of the deposit preserving system also influences the opportunity cost of preserving additional deposits in the first period ($\overline{\mu}_1$ or $\underline{\mu}_1$). If this cost is high, the fossil fuel extractor would need much more of the commodity to maintain present extraction. Then, there would be a strong upward pressure on the relative price of the commodity (p_{x1}/p_{x2}), so that present fossil fuel demand could increase and future fossil fuel demand could decline, which could lead to the weak green paradox. If the former effect outweighs the latter, i.e., if the weighted leakage rate of the energy market channel ($\overline{\gamma}_{\widetilde{D}}$) is positive, this could also lead to the strong green paradox. In this case, the opportunity cost should be as low as possible. Otherwise, if the weighted leakage rate of the energy market channel is negative, the cumulative damages will always decline and they will decline the more the higher the opportunity cost.

In conclusion, if $\overline{\gamma}_{\widetilde{D}}$ is positive, $\overline{\mu}_1$ or $\underline{\mu}_1$ should be small. The opportunity cost is low if the fossil fuel extractor saves much of the commodity for the preserved deposits and this is the case if the hypothetical material extraction costs of the preserved deposits are high. Thus, the abating country should first purchase the highest-cost deposits and then purchase additional low-cost deposits ($\mathrm{d}\underline{e}_{F1} < 0$) to tighten the conditions for an increase in the present emissions and the cumulative damages.[22] By implication, if $\overline{\gamma}_{\widetilde{D}}$ is negative, the abating country should first purchase the lowest-cost deposits and then purchase additional high-cost deposits ($\mathrm{d}\overline{e}_{F1} > 0$) to increase the effectiveness of the carbon supply reducing policy.[23]

In case of acting tomorrow, the relevant thresholds for the intertemporal elasticity of substitution in consumption can be rearranged to:

$$\widetilde{\sigma}_{\widetilde{1}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{\widetilde{\gamma}_{\widetilde{1}} - \delta\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}, \tag{40}$$

[22] More precisely, the abating country should first purchase the highest-cost deposits that would otherwise be extracted.

[23] Note that the former policy is probably less expensive than the latter because high-cost deposits are less valuable than low-cost deposits for the fossil fuel extractor.

$$\widetilde{\sigma}_{\widetilde{D}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}} + \frac{\lambda\widetilde{\Theta}}{1+\lambda} \cdot \frac{\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N2}|\eta_{N2}|}{e_{N2}|\eta_{N2}|+e_{F2}\eta_{F2,2}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}} \right), \qquad (41)$$

where $\widetilde{\gamma}_{\widetilde{D}} := \frac{p_{x2}X^{E2}_{e_{F2}e_{F2}} e_{N2}|\eta_{N2}|[p_{x2}X^{E2}_{e_{F1}e_{F2}} e_{N1}|\eta_{N1}| - \lambda\widetilde{\Gamma}_2]}{[1+\lambda]\widetilde{\Gamma}_0}$.

Now, the type of the deposit preserving system also influences the opportunity cost of preserving additional deposits in the second period ($\overline{\mu}_2$ or $\underline{\mu}_2$). If this cost is high, there would be a strong downward pressure on the relative price of the commodity (p_{x1}/p_{x2}), so that the condition for the weak green paradox would be tightened. If $\overline{\gamma}_{\widetilde{D}}$ is positive, the condition for the strong green paradox would also be tightened, and vice versa.

Furthermore, the initial position of the preserved deposits in the second period influences the magnitude of the extraction cost channel of carbon leakage. If the physical user cost of the additionally preserved deposits ($\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$ or $\underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}$) is low, the downward pressure on the physical user cost of extraction would be low, so that the downward pressure on present fossil fuel supply would be high. Then, the present emissions would decline and, if $\overline{\gamma}_{\widetilde{D}}$ is positive, the condition for an increase in the cumulative damages would be tightened, and vice versa.[24]

In conclusion, if $\overline{\gamma}_{\widetilde{D}}$ is positive, $\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}$ or $\underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}$ should be small. Thus, if $X^{E2}_{e_{F1}e_{F2}e_{F2}}$ is positive, the abating country should first purchase the lowest-cost deposits and then purchase additional high-cost deposits ($d\overline{e}_{F2} > 0$). By implication, if $\overline{\gamma}_{\widetilde{D}}$ is negative, the abating country should first purchase the highest-cost deposits and then purchase additional low-cost deposits ($d\underline{e}_{F2} < 0$). These implications coincide with those from the opportunity cost considerations. By contrast, if $X^{E2}_{e_{F1}e_{F2}e_{F2}}$ is negative, the extraction cost channel of carbon leakage and the opportunity cost considerations speak in favor of different types of deposit preserving systems.

6 Concluding Remarks

We change the policy instrument from an emissions trading scheme to a deposit preserving system in Ritter & Schopf's (2014) model. The qualitative results concerning the green paradoxes are quite similar and the intertemporal elasticity of substitution as well as the physical user cost of extraction in real terms are still key determinants. The permit prices

[24]See Appendix A.3, equation (A.30) and (A.35).

are replaced by the opportunity costs of preserving additional deposits.[25]

Acting today, the leakage rates of the energy market channel tighten the conditions for an increase in the present emissions and the cumulative damages. In contrast to the analysis in Ritter & Schopf's (2014) model, purchasing additional deposits today can lead to negative cumulative carbon leakage. Acting tomorrow, the price elasticity of demand is partially replaced by the price elasticity of supply. We find that the change in the physical user cost of extraction due to purchasing additional deposits influences the conditions for the green paradoxes. If the physical user cost of extraction is convex ($X^{E2}_{e_{F1}e_{F2}e_{F2}} > 0$) (concave ($X^{E2}_{e_{F1}e_{F2}e_{F2}} < 0$)), the extraction cost channel of carbon leakage leads to less (more) present emissions and, if the weighted leakage rate of the energy market channel is positive ($\overline{\gamma}_{\tilde{D}} > 0$), to less (more) cumulative damages, and vice versa.

If the weighted leakage rate of the energy market channel is negative ($\overline{\gamma}_{\tilde{D}} < 0$), acting today is very effective. Then, there is negative cumulative carbon leakage and the cumulative damages decline. In this case, it is more effective first to purchase the lowest-cost deposits and then to purchase additional high-cost deposits ($\mathrm{d}\overline{e}_{F1} > 0$). If $\overline{\gamma}_{\tilde{D}}$ is positive and the intertemporal elasticity of substitution is low, purchasing additional deposits in the first period leads to the green paradoxes. In this case and if the physical user cost of extraction is convex, acting tomorrow leads to less cumulative damages. Then, it is again more effective first to purchase the lowest-cost deposits and then to purchase additional high-cost deposits ($\mathrm{d}\overline{e}_{F2} > 0$).

This chapter has two main points. First, in a general equilibrium model, not only unilateral demand side policies but also unilateral supply side policies can lead to the green paradoxes. And second, although probably more expensive, it can be more effective first to purchase the lowest-cost deposits than to start with the highest-cost deposits. In conclusion, unilateral supply side policies are no panacea against global warming. However, without global climate agreement, supply side measures are most likely components of second-best policies. It is all the more important to use general equilibrium models with endogenously determined total emissions and various instruments to find appropriate policies and avoid disastrous outcomes.

[25]Note that the permit prices are the opportunity costs of emitting additional emissions.

A Appendix

A.1 The Fossil Fuel Market

Throughout the appendix the commodity in period one is chosen as numeraire. Rearranging (9), (23), and (24) yields:

$$p_{e1} - X^{E1}_{e_{F1}} - p_{x2}\widetilde{X}^{E2}_{e_{F1}} = 0, \tag{A.1}$$

$$p_{e2} - p_{x2}X^{E2}_{e_{F2}} = 0, \tag{A.2}$$

$$X^{N1}_{e_{N1}} - p_{e1} = 0, \tag{A.3}$$

$$p_{x2}X^{N2}_{e_{N2}} - p_{e2} = 0, \tag{A.4}$$

$$e_{Ft} - \overline{e}_{Ft} + \underline{e}_{Ft} - \overline{e}_{At} - e_{Nt} = 0. \tag{A.5}$$

Total differentiation of (A.1) to (A.5) yields:

$$\begin{aligned} \mathrm{d}p_{e1} - \widetilde{X}^{E2}_{e_{F1}}\,\mathrm{d}p_{x2} - [X^{E1}_{e_{F1}e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}e_{F1}}]\,\mathrm{d}e_{F1} - p_{x2}X^{E2}_{e_{F1}e_{F2}}\,\mathrm{d}e_{F2} \\ + p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - p_{x2}\underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2} = 0, \end{aligned} \tag{A.6}$$

$$\mathrm{d}p_{e2} - X^{E2}_{e_{F2}}\,\mathrm{d}p_{x2} - p_{x2}X^{E2}_{e_{F2}e_{F1}}\,\mathrm{d}e_{F1} - p_{x2}X^{E2}_{e_{F2}e_{F2}}\,\mathrm{d}e_{F2} = 0, \tag{A.7}$$

$$\mathrm{d}e_{N1} - e_{N1}\eta_{N1}\widehat{p}_{e1} = 0, \tag{A.8}$$

$$\mathrm{d}e_{N2} - e_{N2}\eta_{N2}[\widehat{p}_{e2} - \widehat{p}_{x2}] = 0, \tag{A.9}$$

$$\mathrm{d}e_{Ft} - \mathrm{d}\overline{e}_{Ft} + \mathrm{d}\underline{e}_{Ft} - \mathrm{d}\overline{e}_{At} - \mathrm{d}e_{Nt} = 0, \tag{A.10}$$

where $\eta_{Nt} \coloneqq \frac{X^{Nt}_{e_{Nt}}}{e_{Nt}X^{Nt}_{e_{Nt}e_{Nt}}} < 0$.

Inserting (A.8) and (A.9) in (A.10) and afterwards inserting in (A.6) and (A.7) yields:

$$\begin{aligned} \mathrm{d}p_{e1} - \widetilde{X}^{E2}_{e_{F1}}\,\mathrm{d}p_{x2} - [X^{E1}_{e_{F1}e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}e_{F1}}][\mathrm{d}\overline{e}_{F1} + \mathrm{d}\overline{e}_{A1} + e_{N1}\eta_{N1}\widehat{p}_{e1}] \\ -p_{x2}X^{E2}_{e_{F1}e_{F2}}[\mathrm{d}\overline{e}_{F2} + \mathrm{d}\overline{e}_{A2} + e_{N2}\eta_{N2}[\widehat{p}_{e2} - \widehat{p}_{x2}]] + p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - p_{x2}\underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2} = 0, \end{aligned} \tag{A.11}$$

$$\begin{aligned} \mathrm{d}p_{e2} - X^{E2}_{e_{F2}}\,\mathrm{d}p_{x2} - p_{x2}X^{E2}_{e_{F2}e_{F1}}[\mathrm{d}\overline{e}_{F1} + \mathrm{d}\overline{e}_{A1} + e_{N1}\eta_{N1}\widehat{p}_{e1}] \\ -p_{x2}X^{E2}_{e_{F2}e_{F2}}[\mathrm{d}\overline{e}_{F2} + \mathrm{d}\overline{e}_{A2} + e_{N2}\eta_{N2}[\widehat{p}_{e2} - \widehat{p}_{x2}]] = 0. \end{aligned} \tag{A.12}$$

Inserting (A.11) in (A.12) yields:

$$\begin{aligned} \mathrm{d}p_{e1} = & -\frac{\frac{p_{e1}}{e_{N1}\eta_{N1}}[\widetilde{\Gamma}_0 - p_{e1}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]]}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A1} + \mathrm{d}\overline{e}_{F1} - \mathrm{d}\underline{e}_{F1}) \\ & + \frac{p_{e1}p_{e2}p_{x2}X^{E2}_{e_{F1}e_{F2}}}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A2} + \mathrm{d}\overline{e}_{F2} - \mathrm{d}\underline{e}_{F2}) + \frac{p_{e1}p_{x2}\widetilde{X}^{E2}_{e_{F1}}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\widetilde{\Gamma}_0}\widehat{p}_{x2} \\ & - \frac{p_{e1}p_{x2}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\widetilde{\Gamma}_0}(\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - \underline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2}), \end{aligned} \tag{A.13}$$

$$
\begin{aligned}
\mathrm{d}p_{e2} = &-\frac{\frac{p_{e2}}{e_{N2}\eta_{N2}}[\widetilde{\Gamma}_0 - p_{e2}[\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}]]}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A2} + \mathrm{d}\overline{e}_{F2} - \mathrm{d}\underline{e}_{F2}) \\
&+ \frac{p_{e1}p_{e2}p_{x2}X^{E2}_{e_{F2}e_{F1}}}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A1} + \mathrm{d}\overline{e}_{F1} - \mathrm{d}\underline{e}_{F1}) + \frac{p_{e2}[\widetilde{\Gamma}_0 + p_{x2}\widetilde{X}^{E2}_{e_{F1}}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N1}\eta_{N1}]}{\widetilde{\Gamma}_0}\widehat{p}_{x2} \\
&- \frac{p_{e2}p_{x2}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N1}\eta_{N1}}{\widetilde{\Gamma}_0}(\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - \underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2}),
\end{aligned} \tag{A.14}
$$

where $\widetilde{\Gamma}_0$, Γ_1, and $\widetilde{\Gamma}_2$ are defined in Appendix A.4.

Inserting (A.8) and (A.9) in (A.10) and afterwards inserting (A.13) and (A.14) yields:

$$
\begin{aligned}
\mathrm{d}e_{F1} = &\frac{p_{e1}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A1} + \mathrm{d}\overline{e}_{F1} - \mathrm{d}\underline{e}_{F1}) \\
&+ \frac{p_{e2}p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A2} + \mathrm{d}\overline{e}_{F2} - \mathrm{d}\underline{e}_{F2}) + \frac{\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\widetilde{\Gamma}_0}\,\mathrm{d}p_{x2} \\
&- \frac{p_{x2}e_{N1}\eta_{N1}[\Gamma_1 - p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\widetilde{\Gamma}_0}(\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - \underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2}),
\end{aligned} \tag{A.15}
$$

$$
\begin{aligned}
\mathrm{d}e_{F2} = &\frac{p_{e2}[\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}]}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A2} + \mathrm{d}\overline{e}_{F2} - \mathrm{d}\underline{e}_{F2}) \\
&+ \frac{p_{e1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A1} + \mathrm{d}\overline{e}_{F1} - \mathrm{d}\underline{e}_{F1}) + \frac{\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}}{\widetilde{\Gamma}_0}\,\mathrm{d}p_{x2} \\
&- \frac{p_{x2}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}}{\widetilde{\Gamma}_0}(\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - \underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2}).
\end{aligned} \tag{A.16}
$$

Adding (A.15) and (A.16) yields:

$$
\begin{aligned}
\mathrm{d}e_{F\Sigma} = &\frac{p_{e1}\Gamma_1}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A1} + \mathrm{d}\overline{e}_{F1} - \mathrm{d}\underline{e}_{F1}) + \frac{p_{e2}\widetilde{\Gamma}_2}{\widetilde{\Gamma}_0}(\mathrm{d}\overline{e}_{A2} + \mathrm{d}\overline{e}_{F2} - \mathrm{d}\underline{e}_{F2}) \\
&+ \frac{\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}\Gamma_1}{\widetilde{\Gamma}_0}\,\mathrm{d}p_{x2} - \frac{p_{x2}e_{N1}\eta_{N1}\Gamma_1}{\widetilde{\Gamma}_0}(\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}\,\mathrm{d}\overline{e}_{F2} - \underline{X}^{E2}_{e_{F1}\underline{e}_{F2}}\,\mathrm{d}\underline{e}_{F2}).
\end{aligned} \tag{A.17}
$$

A.2 The Commodity Market

The relative commodity demand of A, N, F and E is equal to:

$$
q^d = \frac{\sum x_{i1}}{\sum x_{i2}} = \frac{x_{A1} + x_{N1} + x_{F1} + \widetilde{X}^{E1}}{x_{A2} + x_{N2} + x_{F2} + \widetilde{X}^{E2}}, \qquad i = A, N, F, E. \tag{A.18}
$$

Inserting (4), (5), (18), (19), (25) and (28) in (A.18) yields:

$$
q^d = \left(\frac{\alpha_1 p_{x2}}{\alpha_2}\right)^{\sigma} - \left(\frac{\alpha_1 p_{x2}}{\alpha_2}\right)^{\sigma}\frac{\widetilde{X}^{E2}}{X^{A2} + X^{N2}} + \frac{\widetilde{X}^{E1}}{X^{A2} + X^{N2}}. \tag{A.19}
$$

Total differentiation of (A.19) and afterwards inserting (4), (5), (9), (18), (19), (22), (23), (25), (28) and (A.10) yields:

$$
\mathrm{d}q^d = \left(\frac{\alpha_1 p_{x2}}{\alpha_2}\right)^{\sigma}\sigma\widehat{p}_{x2} - \left(\frac{\alpha_1 p_{x2}}{\alpha_2}\right)^{\sigma}\sigma\widehat{p}_{x2}\frac{\widetilde{X}^{E2}}{X^{A2} + X^{N2}} \tag{A.20}
$$

$$
\begin{aligned}
&- \left(\frac{\alpha_1 p_{x2}}{\alpha_2}\right)^{\sigma} \frac{\mathrm{d}\widetilde{X}^{E2}[X^{A2}+X^{N2}] - \widetilde{X}^{E2}[\mathrm{d}X^{A2}+\mathrm{d}X^{N2}]}{[X^{A2}+X^{N2}]^2} \\
&+ \frac{\mathrm{d}\widetilde{X}^{E1}[X^{A2}+X^{N2}] - \widetilde{X}^{E1}[\mathrm{d}X^{A2}+\mathrm{d}X^{N2}]}{[X^{A2}+X^{N2}]^2} \\
= &\frac{x^s_{A1}+x^s_{N1}-x_{E1}}{x^s_{A2}+x^s_{N2}} \sigma \widehat{p}_{x2} - \frac{\frac{\pi_2}{p_{x2}}\left(\frac{x^s_{A1}+x^s_{N1}}{x^s_{A2}+x^s_{N2}} - \frac{x^s_{A1}+x^s_{N1}-x_{E1}}{x^s_{A2}+x^s_{N2}-x_{E2}}\right)}{x^s_{A2}+x^s_{N2}} \mathrm{d}\overline{e}_{A2} \\
&+ \frac{X^{E1}_{e_{F1}} - \widetilde{X}^{E2}_{e_{F1}} \cdot \frac{x^s_{A1}+x^s_{N1}-x_{E1}}{x^s_{A2}+x^s_{N2}-x_{E2}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}e_{F1} - \frac{X^{E2}_{e_{F2}} \cdot \frac{x^s_{A1}+x^s_{N1}}{x^s_{A2}+x^s_{N2}}}{x^s_{A2}+x^s_{N2}} (\mathrm{d}e_{F2} - \mathrm{d}\overline{e}_{F2} + \mathrm{d}\underline{e}_{F2}) \\
&- \frac{\overline{X}^{E1}_{\overline{e}_{F1}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}\overline{e}_{F1} - \frac{[X^{E2}_{e_{F2}} - \overline{X}^{E2}_{\overline{e}_{F2}}] \frac{x^s_{A1}+x^s_{N1}-x_{E1}}{x^s_{A2}+x^s_{N2}-x_{E2}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}\overline{e}_{F2} \\
&+ \frac{\underline{X}^{E1}_{\underline{e}_{F1}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}\underline{e}_{F1} + \frac{[X^{E2}_{e_{F2}} - \underline{X}^{E2}_{\underline{e}_{F2}}] \frac{x^s_{A1}+x^s_{N1}-x_{E1}}{x^s_{A2}+x^s_{N2}-x_{E2}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}\underline{e}_{F2}
\end{aligned}
$$

The relative commodity supply of A and N is equal to:

$$
q^s = \frac{\sum x^s_{i1}}{\sum x^s_{i2}} = \frac{X^{A1}+X^{N1}}{X^{A2}+X^{N2}}, \qquad i = A, N. \tag{A.21}
$$

Total differentiation of (A.21) and afterwards inserting (9), (18), (19), (22), (23) and (A.10) yields:

$$
\begin{aligned}
\mathrm{d}q^s &= \frac{[X^{A1}_{\overline{e}_{A1}}\,\mathrm{d}\overline{e}_{A1} + X^{N1}_{e_{N1}}\,\mathrm{d}e_{N1}][X^{A2}+X^{N2}] - [X^{A1}+X^{N1}][X^{A2}_{\overline{e}_{A2}}\,\mathrm{d}\overline{e}_{A2} + X^{N2}_{e_{N2}}\,\mathrm{d}e_{N2}]}{[X^{A2}+X^{N2}]^2} \qquad (A.22) \\
&= \frac{\pi_1}{x^s_{A2}+x^s_{N2}} \mathrm{d}\overline{e}_{A1} - \frac{\frac{\pi_2}{p_{x2}} \cdot \frac{x^s_{A1}+x^s_{N1}}{x^s_{A2}+x^s_{N2}}}{x^s_{A2}+x^s_{N2}} \mathrm{d}\overline{e}_{A2} + \frac{X^{E1}_{e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{x^s_{A2}+x^s_{N2}} (\mathrm{d}e_{F1} - \mathrm{d}\overline{e}_{F1} + \mathrm{d}\underline{e}_{F1}) \\
&- \frac{X^{E2}_{e_{F2}} \cdot \frac{x^s_{A1}+x^s_{N1}}{x^s_{A2}+x^s_{N2}}}{x^s_{A2}+x^s_{N2}} (\mathrm{d}e_{F2} - \mathrm{d}\overline{e}_{F2} + \mathrm{d}\underline{e}_{F2}).
\end{aligned}
$$

Equating (A.20) and (A.22) yields:

$$
\begin{aligned}
\mathrm{d}p_{x2} = \frac{p_{x2}}{\sigma} \Bigg(&\frac{\pi_1}{x^s_{A1}+x^s_{N1}-x_{E1}} \mathrm{d}\overline{e}_{A1} - \frac{\pi_2}{p_{x2}(x^s_{A2}+x^s_{N2}-x_{E2})} \mathrm{d}\overline{e}_{A2} + \widetilde{\Theta}\,\mathrm{d}e_{F1} \qquad (A.23) \\
&- \overline{\mu}_1\,\mathrm{d}\overline{e}_{F1} + \overline{\mu}_2\,\mathrm{d}\overline{e}_{F2} + \underline{\mu}_1\,\mathrm{d}\underline{e}_{F1} - \underline{\mu}_2\,\mathrm{d}\underline{e}_{F2} \Bigg),
\end{aligned}
$$

where $\widetilde{\Theta} := \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{x^s_{A1}+x^s_{N1}-x_{E1}} + \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}}{p_{x2}(x^s_{A2}+x^s_{N2}-x_{E2})}$, $\overline{\mu}_t := \frac{p_{et}-p_{xt}\overline{X}^{Et}_{\overline{e}_{Ft}}}{p_{xt}(x^s_{At}+x^s_{Nt}-x_{Et})}$ and $\underline{\mu}_t := \frac{p_{et}-p_{xt}\underline{X}^{Et}_{\underline{e}_{Ft}}}{p_{xt}(x^s_{At}+x^s_{Nt}-x_{Et})}$.

A.3 The Combined Market

For the combined market, we need (A.13), (A.14), (A.15), (A.16), (A.17) and (A.23). Looking at these equations, we can see that setting $\mathrm{d}\underline{e}_{Ft}$ equal to zero is equivalent to setting $\mathrm{d}\overline{e}_{Ft}$ equal to zero, multiplying each $\mathrm{d}\underline{e}_{Ft}$ with minus one and replacing each lower bar by an upper bar, apart from $\overline{e}_{At}$. Thus, purchasing additional high-cost deposits ($\mathrm{d}\overline{e}_{Ft} > 0$) leads to the same qualitative results as purchasing additional low-cost deposits ($\mathrm{d}\underline{e}_{Ft} < 0$). To save space, we focus on purchasing additional high-cost deposits in the following.

A.3.1 The Quantities on the Combined Market

Inserting (A.23) in (A.15) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F2} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$\begin{aligned}\frac{\mathrm{d}e_{F1}}{\mathrm{d}\overline{e}_{F1}} &= \frac{[\sigma p_{e1} - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\overline{\mu}_1 e_{N1}\eta_{N1}][p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\gtreqless 0 \quad \Leftrightarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0.\end{aligned} \tag{A.24}$$

Subtracting one from (A.24) yields:

$$\begin{aligned}\frac{\mathrm{d}\widetilde{e}_{F1}}{\mathrm{d}\overline{e}_{F1}} &= -\frac{\sigma[\widetilde{\Gamma}_0 - p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\widetilde{\Theta} - \overline{\mu}_1][p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_1.\end{aligned} \tag{A.25}$$

Inserting (A.23) in (A.16) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F2} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ and afterwards inserting (A.24) yields:

$$\begin{aligned}\frac{\mathrm{d}e_{F2}}{\mathrm{d}\overline{e}_{F1}} &= \frac{[\sigma p_{e1} - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\overline{\mu}_1 e_{N1}\eta_{N1}]p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\lesseqgtr 0 \quad \Leftrightarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0.\end{aligned} \tag{A.26}$$

Adding (A.24) and (A.26) yields:

$$\begin{aligned}\frac{\mathrm{d}e_{F\Sigma}}{\mathrm{d}\overline{e}_{F1}} &= \frac{[\sigma p_{e1} - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\overline{\mu}_1 e_{N1}\eta_{N1}]\Gamma_1}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\gtreqless 0 \quad \Leftrightarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0 \text{ and } \Gamma_1 \geq 0.\end{aligned} \tag{A.27}$$

Subtracting one from (A.27) yields:

$$\begin{aligned}\frac{\mathrm{d}\widetilde{e}_{F\Sigma}}{\mathrm{d}\overline{e}_{F1}} &= -\frac{\sigma[\widetilde{\Gamma}_0 - p_{e1}\Gamma_1] - p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\widetilde{\Theta}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] - \overline{\mu}_1\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_1 \cdot \frac{\Gamma_1}{p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}}.\end{aligned} \tag{A.28}$$

Inserting (A.25) and (A.28) in (30) yields:

$$\mathrm{d}\widetilde{D}(\widetilde{e}_{F1}, \widetilde{e}_{F\Sigma}) \gtreqless 0 \tag{A.29}$$

$$
\begin{aligned}
\Leftrightarrow \quad & \Big(\sigma[p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} + \Gamma_1\lambda] - \widetilde{\Gamma}_0[1+\lambda]] \\
& - p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}\overline{\mu}_1[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} + \Gamma_1\lambda] \\
& + p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}\widetilde{\Theta}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}][1+\lambda]\Big)\,\mathrm{d}\overline{e}_{F1} \gtreqless 0.
\end{aligned}
$$

Inserting (A.23) in (A.15) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F1} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$
\begin{aligned}
\frac{\mathrm{d}e_{F1}}{\mathrm{d}\overline{e}_{F2}} &= \frac{\sigma[p_{e2}p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1} - p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\quad + \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}\overline{\mu}_2 e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} \cdot \frac{p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}}{p_{e2}} \geq 0.
\end{aligned} \tag{A.30}
$$

Inserting (A.23) in (A.16) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F1} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ and afterwards inserting (A.30) yields:

$$
\begin{aligned}
\frac{\mathrm{d}e_{F2}}{\mathrm{d}\overline{e}_{F2}} &= \frac{\sigma[p_{e2}[\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}] - p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\quad - \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[p_{e2}\widetilde{\Theta} - \overline{\mu}_2 p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} \cdot \frac{-p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}}{p_{e2}} \geq 0 \text{ and } \widetilde{\Gamma}_2 \geq 0.
\end{aligned} \tag{A.31}
$$

Subtracting one from (A.31) yields:

$$
\begin{aligned}
\frac{\mathrm{d}\widetilde{e}_{F2}}{\mathrm{d}\overline{e}_{F2}} &= -\frac{\sigma[\widetilde{\Gamma}_0 - p_{e2}[\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}] + p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\quad - \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\widetilde{\Theta}p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} - \overline{\mu}_2 p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_2 \cdot \frac{X^{E2}_{e_{F2}e_{F1}}}{X^{E2}_{e_{F2}e_{F2}}}.
\end{aligned} \tag{A.32}
$$

Adding (A.30) and (A.31) yields:

$$
\begin{aligned}
\frac{\mathrm{d}e_{F\Sigma}}{\mathrm{d}\overline{e}_{F2}} &= \frac{\sigma[p_{e2}\widetilde{\Gamma}_2 - p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\quad - \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[p_{e2}\widetilde{\Theta} - \overline{\mu}_2\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\
&\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_2 \cdot \frac{\Gamma_1}{p_{e2}} \text{ and } \Gamma_1, \widetilde{\Gamma}_2 \geq 0,
\end{aligned} \tag{A.33a}
$$

$$
= \frac{\sigma[\widetilde{\Gamma}_0 + p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}\widetilde{\Gamma}_2 + p_{x2}[X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}]e_{N1}\eta_{N1}\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \tag{A.33b}
$$

$$
- \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}} e_{N1}\eta_{N1}[p_{e2}\widetilde{\Theta} - \overline{\mu}_2\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}
$$
$$
\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_2 \cdot \frac{\Gamma_1}{p_{e2}} \text{ and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}, \widetilde{\Gamma}_2 \leq 0.
$$

Subtracting one from (A.33) yields:

$$
\frac{\mathrm{d}\widetilde{e}_{F\Sigma}}{\mathrm{d}\overline{e}_{F2}} = - \frac{\sigma[\Gamma_0 - p_{e2}\Gamma_2 + p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \tag{A.34a}
$$
$$
- \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\widetilde{\Theta}p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} - \overline{\mu}_2\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}
$$
$$
\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_2 \cdot \frac{\Gamma_1}{p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}} \text{ and } \Gamma_1 \leq 0,
$$
$$
= \frac{\sigma[p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}\widetilde{\Gamma}_2 + p_{x2}[X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}]e_{N1}\eta_{N1}\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \tag{A.34b}
$$
$$
- \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\widetilde{\Theta}p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} - \overline{\mu}_2\Gamma_1]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}
$$
$$
\lesseqgtr 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} \geq 0 \text{ and } \Gamma_1, \widetilde{\Gamma}_2 \geq 0.
$$

Inserting (A.30) and (A.34) in (30) yields:

$$
\mathrm{d}\widetilde{D}(\widetilde{e}_{F1}, \widetilde{e}_{F\Sigma}) \gtreqless 0 \tag{A.35}
$$
$$
\begin{aligned}
\Leftrightarrow \quad \Big(& \sigma p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}[p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1} + \widetilde{\Gamma}_2\lambda] \\
& - \sigma p_{x2}[\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} - X^{E2}_{e_{F1}e_{F2}}]e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} + \Gamma_1\lambda] \\
& + p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}\eta_{N1}[\overline{\mu}_2[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2} + \Gamma_1\lambda] - \widetilde{\Theta}p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}\lambda]\Big) \,\mathrm{d}\overline{e}_{F2} \gtreqless 0.
\end{aligned}
$$

A.3.2 The Prices on the Combined Market

Inserting (A.24) in (A.23) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F2} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$
\frac{\mathrm{d}p_{x2}}{\mathrm{d}\overline{e}_{F1}} = - \frac{p_{x2}\overline{\mu}_1\widetilde{\Gamma}_0 - p_{e1}p_{x2}\widetilde{\Theta}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \tag{A.36}
$$
$$
\gtreqless 0 \quad \Leftrightarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_1 \cdot \frac{\widetilde{\Gamma}_0}{p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}.
$$

Inserting (A.30) in (A.23) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F1} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$
\frac{\mathrm{d}p_{x2}}{\mathrm{d}\overline{e}_{F2}} = \frac{p_{x2}\overline{\mu}_2\widetilde{\Gamma}_0}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \tag{A.37}
$$
$$
+ \frac{p_{x2}\widetilde{\Theta}[p_{e2}p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1} - p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}
$$

$$\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} \cdot \frac{p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}}{p_{e2}} \leq 0.$$

Inserting (A.36) in (A.13) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F2} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$\begin{aligned}\frac{\mathrm{d}p_{e1}}{\mathrm{d}\overline{e}_{F1}} &= -\frac{\frac{\sigma p_{e1}}{e_{N1}\eta_{N1}}[\widetilde{\Gamma}_0 - p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{e1}p_{x2}\widetilde{X}^{E2}_{e_{F1}}[\widetilde{\Theta} - \overline{\mu}_1][p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &= \frac{p_{e1}}{e_{N1}\eta_{N1}} \cdot \frac{\mathrm{d}\widetilde{e}_{F1}}{\mathrm{d}\overline{e}_{F1}} \gtreqless 0 \quad \Leftrightarrow \quad \frac{\mathrm{d}\widetilde{e}_{F1}}{\mathrm{d}\overline{e}_{F1}} \lesseqgtr 0.\end{aligned} \tag{A.38}$$

Inserting (A.36) in (A.14) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F2} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$\begin{aligned}\frac{\mathrm{d}p_{e2}}{\mathrm{d}\overline{e}_{F1}} &= \frac{\sigma p_{e1}p_{e2}p_{x2}X^{E2}_{e_{F2}e_{F1}}}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{e2}[p_{e1}\widetilde{\Theta}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] - \overline{\mu}_1[\widetilde{\Gamma}_0 + p_{x2}\widetilde{X}^{E2}_{e_{F1}}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N1}\eta_{N1}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F1} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_1 \cdot \frac{\widetilde{\Gamma}_0 + p_{x2}\widetilde{X}^{E2}_{e_{F1}}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N1}\eta_{N1}}{p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}.\end{aligned} \tag{A.39}$$

Inserting (A.37) in (A.13) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F1} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$\begin{aligned}\frac{\mathrm{d}p_{e1}}{\mathrm{d}\overline{e}_{F2}} &= \frac{\sigma p_{e1}[p_{e2}p_{x2}X^{E2}_{e_{F1}e_{F2}} - p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{e1}p_{x2}\widetilde{X}^{E2}_{e_{F1}}\overline{\mu}_2[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &= \frac{p_{e1}}{e_{N1}\eta_{N1}} \cdot \frac{\mathrm{d}e_{F1}}{\mathrm{d}\overline{e}_{F2}} \gtreqless 0 \quad \Leftrightarrow \quad \frac{\mathrm{d}e_{F1}}{\mathrm{d}\overline{e}_{F2}} \lesseqgtr 0.\end{aligned} \tag{A.40}$$

Inserting (A.37) in (A.14) for $\mathrm{d}\overline{e}_{A1} = \mathrm{d}\overline{e}_{A2} = \mathrm{d}\overline{e}_{F1} = \mathrm{d}\underline{e}_{F1} = \mathrm{d}\underline{e}_{F2} = 0$ yields:

$$\begin{aligned}\frac{\mathrm{d}p_{e2}}{\mathrm{d}\overline{e}_{F2}} &= -\frac{\frac{\sigma p_{e2}}{e_{N2}\eta_{N2}}[\widetilde{\Gamma}_0 - p_{e2}[\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}] + p_{x2}\overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{e2}p_{x2}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2}X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] - p_{x2}\widetilde{X}^{E2}_{e_{F1}}X^{E2}_{e_{F2}e_{F2}}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\quad + \frac{p_{e2}\overline{\mu}_2[\widetilde{\Gamma}_0 + p_{x2}\widetilde{X}^{E2}_{e_{F1}}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N1}\eta_{N1}]}{\sigma\widetilde{\Gamma}_0 - p_{x2}\widetilde{X}^{E2}_{e_{F1}}\widetilde{\Theta}e_{N1}\eta_{N1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]} \\ &\gtreqless 0 \quad \Leftarrow \quad \mathrm{d}\overline{e}_{F2} \gtreqless 0 \text{ and } \widetilde{\Theta} \geq \overline{\mu}_2 \cdot \frac{X^{E2}_{e_{F2}e_{F1}}}{X^{E2}_{e_{F2}e_{F2}}} \\ &\qquad \text{and } X^{E2}_{e_{F1}e_{F2}} - \overline{X}^{E2}_{e_{F1}\overline{e}_{F2}} \cdot \frac{p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}}{p_{e2}} \leq 0.\end{aligned} \tag{A.41}$$

A.4 The Gammas

$$
\begin{aligned}
\widetilde{\Gamma}_0 &= [p_{e1} - [X^{E1}_{e_{F1}e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}e_{F1}}]e_{N1}\eta_{N1}][p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] \\
&\quad - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}p_{x2}X^{E2}_{e_{F2}e_{F1}}e_{N2}\eta_{N2} \\
&= \frac{p_{e2}e_{N2}|\eta_{N2}|\,p_{e1}e_{N1}|\eta_{N1}|}{e_{F1}\eta_{F1,2}e_{F2}\widetilde{\eta}_{F2,1}} \cdot \left[\left(\frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{N1}|\eta_{N1}|} + \frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}}\right) \cdot \left(\frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|} + \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}}\right) - 1\right],
\end{aligned} \tag{A.42}
$$

$$
\begin{aligned}
\Gamma_1 &= p_{e2} - [p_{x2}X^{E2}_{e_{F2}e_{F2}} - p_{x2}X^{E2}_{e_{F2}e_{F1}}]e_{N2}\eta_{N2} \\
&= \frac{p_{e2}e_{N2}|\eta_{N2}|}{e_{F1}\eta_{F1,2}} \cdot \left(\frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|} + \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}} - 1\right),
\end{aligned} \tag{A.43}
$$

$$
\begin{aligned}
\Gamma^D_1 &= \Gamma_1 + \frac{1}{\lambda}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] \\
&= \frac{p_{e2}e_{N2}|\eta_{N2}|}{e_{F1}\eta_{F1,2}} \cdot \left(\frac{1+\lambda}{\lambda} \cdot \frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|} + \frac{1+\lambda}{\lambda} \cdot \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}} - 1\right),
\end{aligned} \tag{A.44}
$$

$$
\begin{aligned}
\widetilde{\Gamma}_2 &= p_{e1} - [X^{E1}_{e_{F1}e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}e_{F1}} - p_{x2}X^{E2}_{e_{F1}e_{F2}}]e_{N1}\eta_{N1} \\
&= \frac{p_{e1}e_{N1}|\eta_{N1}|}{e_{F2}\widetilde{\eta}_{F2,1}} \cdot \left(\frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{N1}|\eta_{N1}|} + \frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}} - 1\right),
\end{aligned} \tag{A.45}
$$

$$
\begin{aligned}
\widetilde{\Gamma}^D_2 &= \widetilde{\Gamma}_2 + \frac{1}{\lambda}p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1} \\
&= \frac{p_{e1}e_{N1}|\eta_{N1}|}{e_{F2}\overline{\eta}_{F2,1}} \cdot \left(\frac{e_{F2}\overline{\eta}_{F2,1}}{e_{N1}|\eta_{N1}|} + \frac{e_{F2}\overline{\eta}_{F2,1}}{e_{F1}\overline{\eta}_{F1,1}} - \frac{1+\lambda}{\lambda}\right).
\end{aligned} \tag{A.46}
$$

$\widetilde{\Gamma}_0 > 0$ because $\frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}} \cdot \frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}} > 1$, see note on page 9. For the same reason, $\Gamma_1 \leq 0$ implies $\widetilde{\Gamma}_2 > 0$ and $\widetilde{\Gamma}_2 \leq 0$ implies $\Gamma_1 > 0$. Furthermore,

$$
\begin{aligned}
&\widetilde{\Gamma}_0 > p_{e1}[p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}] = \frac{p_{e1}p_{e2}e_{N2}|\eta_{N2}|}{e_{F1}\eta_{F1,2}} \cdot \left(\frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|} + \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}}\right) \\
\Leftrightarrow\quad &\frac{p_{e2}e_{N2}|\eta_{N2}|\,p_{e1}e_{N1}|\eta_{N1}|}{e_{F1}\eta_{F1,2}e_{F2}\widetilde{\eta}_{F2,1}} \cdot \left[\frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}} \cdot \left(\frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|} + \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}}\right) - 1\right] > 0, \\
&\widetilde{\Gamma}_0 > p_{e2}[p_{e1} - [X^{E1}_{e_{F1}e_{F1}} + p_{x2}\widetilde{X}^{E2}_{e_{F1}e_{F1}}]e_{N1}\eta_{N1}] = \frac{p_{e1}p_{e2}e_{N1}|\eta_{N1}|}{e_{F2}\widetilde{\eta}_{F2,1}} \cdot \left(\frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{N1}|\eta_{N1}|} + \frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}}\right) \\
\Leftrightarrow\quad &\frac{p_{e2}e_{N2}|\eta_{N2}|\,p_{e1}e_{N1}|\eta_{N1}|}{e_{F1}\eta_{F1,2}e_{F2}\widetilde{\eta}_{F2,1}} \cdot \left[\left(\frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{N1}|\eta_{N1}|} + \frac{e_{F2}\widetilde{\eta}_{F2,1}}{e_{F1}\widetilde{\eta}_{F1,1}}\right) \cdot \frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}} - 1\right] > 0,
\end{aligned}
$$

which holds for the same reason as above so that $\widetilde{\Gamma}_0 > p_{e1}\Gamma_1$ and $\widetilde{\Gamma}_0 > p_{e2}\widetilde{\Gamma}_2$. Finally,

$$
\widetilde{\Gamma}_0 = [p_{e2} - p_{x2}X^{E2}_{e_{F2}e_{F2}}e_{N2}\eta_{N2}]\widetilde{\Gamma}_2 - p_{x2}X^{E2}_{e_{F1}e_{F2}}e_{N1}\eta_{N1}\Gamma_1.
$$

A.5 The Sigmas

$$\overline{\sigma}_{\widetilde{1}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}}\right), \tag{A.47}$$

$$\frac{\partial\overline{\sigma}_{\widetilde{1}}}{\partial\widetilde{X}^{E2}_{e_{F1}}} = \frac{p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left[\left(1+\frac{\widetilde{X}^{E2}_{e_{F1}}}{p_{e1}-\overline{X}^{E1}_{\overline{e}_{F1}}}\right) \cdot \overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} - 2\widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}}\right] \tag{A.48}$$

$$\leq 0 \quad \Leftarrow \quad \overline{\sigma}_{\widetilde{1}} \leq 0,$$

$$\frac{\partial\overline{\sigma}_{\widetilde{1}}}{\partial\widetilde{X}^{E2}_{e_{F1}e_{F1}}} = -\frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|\, p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}^2} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{1}}}\right) \tag{A.49}$$

$$\gtreqless 0 \quad \Leftrightarrow \quad \overline{\sigma}_{\widetilde{1}} \lesseqgtr 0,$$

$$\overline{\sigma}_{\widetilde{D}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{1-\overline{\gamma}_{\widetilde{D}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}}\right), \tag{A.50}$$

$$\frac{\partial\overline{\sigma}_{\widetilde{D}}}{\partial\widetilde{X}^{E2}_{e_{F1}}} = \frac{p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left[\left(1+\frac{\widetilde{X}^{E2}_{e_{F1}}}{p_{e1}-\overline{X}^{E1}_{\overline{e}_{F1}}}\right) \cdot \overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{1-\overline{\gamma}_{\widetilde{D}}} - 2\widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}}\right] \tag{A.51}$$

$$- \frac{\lambda p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|\, p_{x2}}{[1+\lambda]p_{e1}^2\left(\frac{e_{F1}\eta_{F1,2}}{e_{N2}|\eta_{N2}|}+\frac{e_{F1}\eta_{F1,2}}{e_{F2}\eta_{F2,2}}\right)} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{1-\overline{\gamma}_{\widetilde{D}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}}\right)$$

$$\leq 0 \quad \Leftarrow \quad \overline{\sigma}_{\widetilde{D}} \leq 0,$$

$$\frac{\partial\overline{\sigma}_{\widetilde{D}}}{\partial\widetilde{X}^{E2}_{e_{F1}e_{F1}}} = -\frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|\, p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}^2} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}} \cdot \left(\overline{\mu}_1 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{1-\overline{\gamma}_{\widetilde{D}}} - \widetilde{\Theta} \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{1-\overline{\gamma}_{\widetilde{D}}}\right) \tag{A.52}$$

$$\gtreqless 0 \quad \Leftrightarrow \quad \overline{\sigma}_{\widetilde{D}} \lesseqgtr 0,$$

$$\widetilde{\sigma}_{\widetilde{1}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{\widetilde{\gamma}_{\widetilde{1}} - \delta\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}, \tag{A.53}$$

$$\frac{\partial\widetilde{\sigma}_{\widetilde{1}}}{\partial\widetilde{X}^{E2}_{e_{F1}}} = \frac{p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{1}}}{\widetilde{\gamma}_{\widetilde{1}} - \delta\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}} \tag{A.54}$$

$$\gtreqless 0 \quad \Leftrightarrow \quad \widetilde{\sigma}_{\widetilde{1}} \gtreqless 0,$$

$$\frac{\partial\widetilde{\sigma}_{\widetilde{1}}}{\partial\widetilde{X}^{E2}_{e_{F1}e_{F1}}} = 0, \tag{A.55}$$

$$\widetilde{\sigma}_{\widetilde{D}} = \frac{p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}} + \frac{\lambda\widetilde{\Theta}}{1+\lambda} \cdot \frac{\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N2}|\eta_{N2}|}{e_{N2}|\eta_{N2}|+e_{F2}\eta_{F2,2}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\right), \tag{A.56}$$

$$\frac{\partial\widetilde{\sigma}_{\widetilde{D}}}{\partial\widetilde{X}^{E2}_{e_{F1}}} = \frac{p_{x2}e_{N1}|\eta_{N1}|}{p_{e1}} \cdot \left(\overline{\mu}_2 \cdot \frac{\overline{\gamma}_{\widetilde{D}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}} + \frac{\lambda 2\widetilde{\Theta}}{1+\lambda} \cdot \frac{\overline{\gamma}_{\widetilde{1}} \cdot \frac{e_{N2}|\eta_{N2}|}{e_{N2}|\eta_{N2}|+e_{F2}\eta_{F2,2}}}{\widetilde{\gamma}_{\widetilde{D}} - \delta\overline{\gamma}_{\widetilde{D}} \cdot \frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\right) \tag{A.57}$$

$$
\begin{aligned}
&+\frac{\lambda p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|\,p_{x2}}{[1+\lambda]p_{e1}^2\left(1+\frac{e_{F2}\eta_{F2,2}}{e_{N2}|\eta_{N2}|}\right)}\cdot\frac{\overline{\gamma}_{\widetilde{1}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\\
&\cdot\left(\overline{\mu}_2\cdot\frac{\overline{\gamma}_{\widetilde{D}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}+\frac{\lambda\widetilde{\Theta}}{1+\lambda}\cdot\frac{\overline{\gamma}_{\widetilde{1}}\cdot\frac{e_{N2}|\eta_{N2}|}{e_{N2}|\eta_{N2}|+e_{F2}\eta_{F2,2}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\right)\\
&>0\quad\Leftarrow\quad\overline{\gamma}_{\widetilde{D}}>0\text{ and }\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}>0\\
&\qquad\qquad\text{or }\overline{\gamma}_{\widetilde{D}}<0\text{ and }\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}>0\text{ and }\widetilde{\sigma}_{\widetilde{D}}>0,
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial\widetilde{\sigma}_{\widetilde{D}}}{\partial\widetilde{X}^{E2}_{e_{F1}e_{F1}}}&=\frac{\lambda p_{x2}\widetilde{X}^{E2}_{e_{F1}}e_{N1}|\eta_{N1}|\,p_{x2}e_{N1}|\eta_{N1}|}{[1+\lambda]p_{e1}^2\left(1+\frac{e_{F2}\eta_{F2,2}}{e_{N2}|\eta_{N2}|}\right)}\cdot\frac{\overline{\gamma}_{\widetilde{1}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\\
&\cdot\left(\overline{\mu}_2\cdot\frac{\overline{\gamma}_{\widetilde{D}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}+\frac{\lambda\widetilde{\Theta}}{1+\lambda}\cdot\frac{\overline{\gamma}_{\widetilde{1}}\cdot\frac{e_{N2}|\eta_{N2}|}{e_{N2}|\eta_{N2}|+e_{F2}\eta_{F2,2}}}{\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}}\right)\\
&>0\quad\Leftarrow\quad\overline{\gamma}_{\widetilde{D}}>0\\
&\gtreqless 0\quad\Leftrightarrow\quad\overline{\gamma}_{\widetilde{D}}<0\text{ and }\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}>0\text{ and }\widetilde{\sigma}_{\widetilde{D}}\gtreqless 0\\
&\qquad\qquad\text{or }\overline{\gamma}_{\widetilde{D}}<0\text{ and }\widetilde{\gamma}_{\widetilde{D}}-\delta\overline{\gamma}_{\widetilde{D}}\cdot\frac{e_{N1}|\eta_{N1}|}{e_{F2}\eta_{F2,2}}<0\text{ and }\widetilde{\sigma}_{\widetilde{D}}\lesseqgtr 0.
\end{aligned}
\tag{A.58}
$$

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