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# The economics of fleet-wide emission targets and pooling in the EU car market

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# The Economics of Fleet-Wide Emission Targets and Pooling in the EU Car Market *

Markus Dertwinkel-Kalt† Christian Wey‡

July 2025

**Abstract**

To support the green transition in the automotive sector, the EU has introduced $CO_2$ emission performance standards, also known as the excess emissions premium (EEP) regulation, which will tighten until 2035. Manufacturers exceeding their average fleet emission targets must pay a penalty. The regulation also allows pooling of fleets, enabling manufacturers to combine fleets. We analyze how this affects market outcomes. The EEP creates a positive externality of electric on conventional cars. Pooling eases compliance but may weaken competition among existing market players, while simultaneously encouraging the entry of electric-only manufacturers into the EU.

*JEL-Classification*: D04, L11, L50.

*Keywords*: Green regulation, automotive industry, excess emissions premium.

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# 1 Introduction

> "The legacy carmakers [...] effectively have funded the growth of their biggest EV competitor."
>
> *Steve Greenfield, Founder and CEO of Automotive Ventures*[1]

The European Green Deal mandates the largest transformation the automotive industry—often referred to as the 'jewel of the European economy' (Cornet *et al.*, 2023)—has ever experienced. Precisely, it aims for transport-related greenhouse gas emissions to be cut by 90% by 2050, as part of its goal to reach climate neutrality. In the course of the Green Deal and to incentivize car manufacturers to reduce the number of conventional vehicles and—at the same time—increase their electric vehicles sales, the European Union amended the *$CO_2$ emission performance standards*, also referred to as the *excess emissions premium (EEP) regulation*. This regulation establishes carbon dioxide ($CO_2$) emissions performance standards for new passenger cars and vans (European Parliament and Council, 2019). It imposes excess emissions penalties on car manufacturers whose annually registered car fleet exceeds a specified average emissions target per vehicle—a target that becomes progressively stricter over time. The regulation also admits the possibility of *pooling*—a regulatory mechanism that allows car manufacturers to collectively meet emission standards by averaging emissions across their pooled fleets. Instead of each manufacturer having to comply with the emission limits individually, they can form a pool with other manufacturers and have their emissions assessed collectively.[2] Some manufacturers worry about spending billions on excess emissions penalties due to this regulation, while firms like Tesla face the prospect of earning billions by agreeing to pool. Even though automakers are strongly affected by the EEP regulation, its consequences for domestic car manufacturers, consumers, and market outcomes have not been analyzed so far.[3]

We fill this gap by theoretically investigating the effects of the EEP regulation. We begin by analyzing a car manufacturer with monopoly power in electric and conventional vehicle markets. We assume that demand in these markets is downward-sloping and independent. Notably, while independent demand allows us to precisely identify the effects of the EEP regulation, our main results also hold for interdependent demand as we show in Appendices B and C and explain below. The monopolist faces constant marginal costs, which may differ between conventional and electric vehicles. We then introduce the EEP regulation. Electric vehicles have, by definition of the EEP regulation, zero emissions, while conventional vehicles have strictly positive emissions levels. The emission target $t \geq 0$ is set by the regulator and is expected to become progressively stricter until 2035, at which point $t = 0$ will apply. If the target is not met,

[1] See `https://www.cbtnews.com/how-tesla-is-banking-billions-in-regulatory-emissions-credits/`.

[2] The regulation distinguishes between open and closed pools: closed pools refer to linked car manufacturers, such as those within the Volkswagen group, whereas open pools involve independent manufacturers pooling together their car fleets. While we do not explicitly distinguish between the two, our main application concerns open pools. For details on this distinction, see, e.g., `https://circabc.europa.eu/sd/a/f9dce50e-8b82-4771-9f7a-547e11e265be/FAQ%20open%20pools%20May%202018.pdf` (accessed on Feb 10, 2025).

[3] So far, firms like Tesla have already earned billions by selling carbon credits to competitors in other regions with similar regulations, such as China: `https://www.globalfleet.com/en/manufacturers/global/analysis/teslas-dominance-over-carbon-credit-market-explained` and `https://carboncredits.com/teslas-739-million-carbon-credit-revenue-fuels-q3-earnings-surge/` (both accessed on Feb 10, 2025).

an excess emissions premium must be paid, corresponding to the extent by which a manufacturer's average emissions per car in its fleet exceed the target. To characterize the equilibrium, we first denote by $t^* > 0$ the lowest emission target such that the benchmark monopoly profit (i.e., the profit in absence of the EEP regulation) can be obtained. For stricter emission targets $t < t^*$ we distinguish between two solutions: First, the Violated Emission Target (VET) solution, where the manufacturer's average fleet emissions per vehicle exceed the European Union's emission target, leading to the payment of an excess emissions premium, and second the Fulfilled Emission Target (FET) solution, where quantities are adjusted such that the target is just met, avoiding any penalties. Intuitively, for $t < t^*$, selling an electric car exerts a positive externality on the sale of conventional vehicles as it lowers the regulatory costs of conventional cars' excess emissions. The strength of this externality diminishes as regulation becomes stricter, because each electric vehicle provides less emissions leeway for conventional cars when the target is tightened. This allows us to show that for $t$ smaller than but close to $t^*$, we obtain the FET solution and for a strict regulation with $t$ close to zero the VET solution. This also holds for the case of interdependent demands.

We also investigate the emission target expansion path, that is, how the optimal quantities of conventional and electric vehicles change when the regulation becomes progressively stricter. Interestingly, the output of electric vehicles is not monotonic with respect to the strictness of the regulation. When the EEP regulation just starts to be binding, so when $t$ is reduced below $t^*$, then there is a clear incentive to expand the output of electric cars to relax the constraint on conventional cars. However, as the regulation becomes stricter, the positive externality of electric vehicle sales on conventional vehicle sales becomes smaller and ultimately disappears at $t = 0$. Thus, interestingly, a stricter regulation can increase the price and decrease the sales of electric cars. Notably, this effect may not necessarily hold with a more general demand structure.

We next introduce an entrant car manufacturer that, unlike the incumbent manufacturer producing both conventional and electric vehicles, exclusively sells electric cars. The entrant firm is assumed to produce at constant marginal costs that do not exceed those of the incumbent manufacturer. Here, we analyze the case of pooling, which we model as an unconditional lump-sum payment between the two manufacturers. This approach prevents any direct effect of pooling on output, ensuring compliance with regulatory constraints of pooling under Articles 101 and 102 TFEU, which prohibit its use as a cartelization device. We first analyze the case that the two manufacturers do not compete for consumers. Pooling enables the incumbent firm to relax its emissions constraint, thereby expanding its sales of conventional cars. We next assume that the firms compete à la Cournot in the market for electric vehicles. In this setting, pooling softens competition. With pooling, the incumbent manufacturer faces less pressure to sell electric vehicles and therefore reduces its sales. In response, the entrant firm increases its output. As a result, in equilibrium, pooling partially reallocates market shares to the entrant firm. The firms' joint surplus increases, but prices rise, and the overall output of electric vehicles decreases. Furthermore, pooling may incentivize market entry, leading to what we term 'entry for pooling,' where new entrants might only enter the market to take advantage of the potential benefits of pooling. Our core results also hold for interdependent demands (under mild additional assumptions that own-price elasticities dominate cross-price elasticities), namely, that

pooling decreases the output of electric cars and increases the output of conventional cars.

Altogether, we show that pooling softens competition, even though explicit quantity agreements are prohibited by cartel laws. Our analysis suggests that electric car manufacturers are the primary beneficiaries of the pooling option. This is reflected in estimates suggesting that Tesla might earn more than one billion euros in the EU in 2025 solely from pooling arrangements with the conventional manufacturers Stellantis, Toyota, Ford, Mazda and Subaru.[4] Furthermore, pooling could encourage the entry of foreign electric car manufacturers, enabling them to profit from pooling their fleets with conventional car manufacturers and thereby shifting rents from conventional car production to these new entrants. Incumbent car manufacturers then effectively fund their competitors in the market for electric vehicles. Only the payments from pooling their fleets with incumbent carmakers could make entry into the European market profitable for electric vehicle manufacturers, many of whom have not entered the European market yet.[5]

Our results are not restricted to the EEP regulation in Europe but also have implications for related regulations implemented in other regions. California was the first region to implement a related program, the "Zero-Emission Vehicle (ZEV) Program," as early as 1990.[6] In China, a regulation allows car manufacturers to earn carbon credits for selling electric vehicles.[7] Similarly, South Korea mandates that automakers maintain average greenhouse gas (GHG) emissions below a specified standard, with penalties for non-compliance or the option to purchase credits from other companies.[8] Switzerland, for example, has introduced a comparable regulation for importers.[9] For a discussion of the exact regulatory differences in California, China, and the EU see Rokadiya and Yang (2019). Tesla has already earned billions from its emission credits under regulations in countries outside of Europe, as noted in the introductory quote by Steve Greenfield. With EU regulations becoming increasingly stringent, incumbent carmakers' funding of Tesla (and other EV manufacturers) can be expected to become even more important. In 2025, Tesla is projected to generate over 1 billion EUR in revenue from pooling agreements with Stellantis and other partners, while Mercedes is expected to pay approximately 300 million EUR to Volvo for fleet pooling.[10]

**Related Literature.** We contribute to the literature on environmental regulation in the car market (e.g. Axsen *et al.*, 2020; Barahona *et al.*, 2020; Yan and Eskeland, 2018; Leard *et al.*, 2023; Durrmeyer and Samano, 2018; Reynaert and Sallee, 2021; Lin and Linn, 2023), and in particu-

[4] See, e.g., https://www.autonews.com/tesla/ane-tesla-emissions-pool-1-billion-profit/.

[5] For an overview of Chinese electric vehicle manufacturers, see, for instance, https://licarco.com/news/best-chinese-ev-manufacturers (accessed on Feb 10, 2025).

[6] See https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about (accessed on Feb 10, 2025).

[7] See https://electrek.co/2023/07/06/china-revises-ev-credits-automakers-offset-opportunities-production/ (accessed on Feb 10, 2025).

[8] See https://carboncredits.com/tesla-can-trade-carbon-credits-in-south-korea-valued-at-145m/ (accessed on Feb 10, 2025).

[9] See https://www.bfe.admin.ch/bfe/en/home/efficiency/mobility/co2-emission-regulations-for-new-vehicles/passenger-cars/calculation-of-penalties-passenger-cars.html?utm_source=chatgpt.com (accessed on Feb 10, 2025).

[10] See https://www.handelsblatt.com/unternehmen/industrie/co2-ausgleich-konkurrenten-zahlen-tesla-wohl-ueber-eine-milliarde-euro/100099396.html.

lar to the literature on emission standards for cars (Kwoka Jr, 1983; Lin and Linn, 2023; Reynaert, 2021). Kwoka Jr (1983) theoretically analyzed the Corporate Average Fuel Economy (CAFE) regulation, introduced in the US in 1975, which mandated minimum fleet-wide fuel efficiency standards for automakers to reduce fuel consumption and dependence on foreign oil. He showed that to meet these efficiency standards, car manufacturers adjust the mix of their products by raising the prices for large cars and lowering the prices for small cars. As a consequence, the regulation's objective of lowering aggregate fuel consumption may not be achieved, as total car output could increase. Such rebound effects of this regulation have also been empirically documented, for instance, by Goldberg (1998) using a structural model to study the effects of this regulation on the types of conventional cars sold, their sales, prices, and fuel consumption. Extending the work of Kwoka Jr (1983), Holland *et al.* (2009) analyze low-carbon fuel standards and their effects on reducing high-carbon fuel production while increasing low-carbon fuel production, possibly leading to higher net carbon emissions. They showed that this regulation cannot be efficient and run simulations to calculate welfare losses. Regarding the EU, Reynaert (2021) empirically analyzed the extent to which carbon emissions premia led to conventional car models with lower emission levels. Lin and Linn (2023) first demonstrate in a differentiated product market model that standards can impact virtually any product attribute. They show that the European carbon emissions standards for passenger vehicles have not only reduced both fuel consumption and emissions but also unintentionally decreased vehicle quality. Our paper differs from this literature by focusing not on the effects of regulation on different conventional car models, but rather on the interplay between conventional and electric car production, as shaped by the EEP regulation and the pooling option.

# 2 EU regulation on $CO_2$ emission performance standards

We first introduce the EU regulation on $CO_2$ emission performance standards, which has as its core the *excess emissions premium* (Section 2.1), before we discuss it in more detail and derive some of its properties that are important for our subsequent analysis (Section 2.2). Pooling rules are discussed later in the paper, in Section 4.1

## 2.1 The excess emissions premium

Article 8 of EU Regulation 2019/631 defines the *excess emissions premium* (EEP) as the total penalty a car manufacturer must pay to the EU at the end of the year, whenever the average $CO_2$ emissions of a manufacturer's fleet exceeds its specific emission target in a given year. Precisely, the EEP the manufacturer must pay—for each of its new vehicles registered in that year—equals 95 EUR per g of $CO_2$ per km of target exceedance, which gives the following sum in EUR per year (European Parliament and Council, 2019, p. 10):[11]

$$\text{“EEP } = (\text{excess emissions} \times \text{EUR } 95) \times \text{number of newly registered vehicles.”} \qquad (1)$$

[11] The formula applies to all car manufacturer selling passenger cars in the EU. A similar formula applies to light commercial vehicles.

Here, "(...) 'excess emissions' means the positive number of grams per kilometre by which a manufacturer's average specific emissions of $CO_2$ (...) exceeded its specific emission target in the calendar year". Thus, the EEP regulation, and hence, the EEP formula (1) only applies to those manufacturers whose excess emissions are positive, while for any car manufacturer with average emissions below the emission target, the EEP is zero. Throughout the paper, we assume that the total number of cars sold is equal to the "number of newly registered vehicles" of the respective manufacturer per calendar year.[12]

To formalize the EEP, suppose a car manufacturer sells two goods $i = 1, 2$ in quantities $q_1$ and $q_2$, so that $q_1 + q_2$ is the number of newly registered vehicles of the manufacturer. Good 1 represents electric cars with an emissions level $x_1$ being set to zero, and good 2 represents conventional (fossil fuel) cars with an emissions level $x_2 > 0$.[13] The average emissions of the manufacturer's car fleet are given by

$$\overline{x} := \frac{q_2}{q_1 + q_2} \cdot x_2, \tag{2}$$

which is the weighted arithmetic mean of the emissions levels of the cars sold by the manufacturer. Let $t \geq 0$ denote the *emission target*. The excess emissions are given by the difference of the manufacturer's average emissions and the emission target:

$$\overline{x} - t = \frac{-tq_1 + (x_2 - t)q_2}{q_1 + q_2}. \tag{3}$$

The EEP critically depends on whether or not the car manufacturer fulfills the emission target. Formally, this requires

$$\overline{x} - t \leq 0, \tag{4}$$

which can be rewritten as

$$-tq_1 + (x_2 - t)q_2 \leq 0, \tag{5}$$

which we call the *emission target constraint*. If (5) holds, we say that the *emission target is fulfilled*, if it holds with equality, we say that the *emission target is binding*, and if it does not hold, we say that the *emission target is violated*. We also parameterize the multiplier "EUR 95" in (1) by $m > 0$, which we call the *price for excess emissions*.

Taken together, we can now represent the EEP formula (1) via the EEP function

$$S := S(q_1, q_2) = \begin{cases} m\left(-tq_1 + (x_2 - t)q_2\right) & \text{if } -tq_1 + (x_2 - t)q_2 > 0 \\ 0 & \text{if } -tq_1 + (x_2 - t)q_2 \leq 0. \end{cases} \tag{6}$$

**Simplifications.** We have simplified the EEP regulation in two key ways. In the actual regulation: i) a manufacturer's emission target $t$ is adjusted upward when the average weight of

[12] To get the dimensions of the EEP formula right, we here summarize the dimensions of the variables: $\dim$(average emissions) $= \dim$(emissions target) $= \frac{\text{g CO}_2\text{/km}}{\text{car}}$, $\dim$ ("EUR95") $= \frac{\text{euros}}{\text{g CO}_2\text{/km}}$, and $\dim$(number of newly registered vehicles) = (car), which gives $\dim(\text{EEP}) = \frac{\text{euros}}{\text{g CO}_2\text{/km}} \left(\frac{\text{g CO}_2\text{/km}}{\text{car}} - \frac{\text{g CO}_2\text{/km}}{\text{car}}\right)(\text{car}) = (\text{euros})$.

[13] The EEP regulation only refers to emissions "at the tailpipe" and neither considers emissions caused by the production of cars or the generation of electricity. Consequently, electric cars have zero emissions and conventional cars have strictly positive emissions.

its fleet exceeds the EU-wide average; and ii) a manufacturer's average emissions value can be reduced by up to 7 g $CO_2$/km if the manufacturer undertakes eco-innovations (Article 11).

Abstracting from these specificities of the EU regulation, our EEP formula closely mirrors the actual EEP regulation whenever the manufacturer sells only a single type of conventional car with a weight equal to the EU average and does not apply for allowances based on claimed eco-innovations.[14]

**Current calibration.** For the years 2020–2024, the EU-wide fleet targets is 95 g$CO_2$/km (NEDC), equivalent to approximately 115.1 g$CO_2$/km (WLTP), where WLTP is the new certification procedure used to assess the emission levels of car engines. From 2025 onwards, stricter targets will apply: 93.6 g/km until 2029, 49.5 g/km from 2030 to 2034, and 0 g/km from 2035 (all measured with WLTP).

In 2023, 98 out of 101 manufacturers—either individually or as members of a pool—met their binding targets. Only three manufacturers, each responsible for fewer than 1,600 vehicles newly registered in Europe, exceeded their respective emission targets. The electric-only car manufacturers Tesla, BYD, and Polestar were individual manufacturers not part of pooling agreements. This is expected to change, as the pool with the lowest average $CO_2$ emissions was made up of Kia, BMW, and Stellantis, which reported emissions above 100g$CO_2$/km (WLTP), which would also violate the 2025 emission targets.[15]

## 2.2 Properties

We here discuss some straightforward properties of the EEP function $S$ when $S > 0$ holds. We define the (*marginal*) *regulatory costs* of good $i$ as $\partial S/\partial q_i$. These are

$$\frac{\partial S}{\partial q_1} = -mt \text{ and } \frac{\partial S}{\partial q_2} = m(x_2 - t) > 0 \text{ for } t \geq 0. \tag{7}$$

Thus, ceteris paribus, a marginal output increase of electric cars (good 1) reduces the EEP by $-mt$, whereas a marginal increase of sales of conventional cars (good 2) increases the EEP by $m(x_2 - t)$. Put differently, electric vehicle sales exert a positive externality on the production of conventional vehicle as it lowers their regulatory costs.

The emission target $t$ is the critical policy variable. The regulatory costs of both goods depend on $t$ with

$$\left|\frac{\partial^2 S}{\partial q_1 \partial t}\right| = \frac{\partial^2 S}{\partial q_2 \partial t} = m \text{ for } t > 0.$$

Thus, a stricter emission target, that is, a reduction of $t > 0$ affects the marginal reduction of the EEP resulting from an additional electric car sale and the marginal increase of the EEP due to an additional conventional car sale by exactly the same magnitude $m$.

[14] By assuming just one type of conventional car, the excess emissions premium also incentivizes changes in the composition of conventional car types by making it more attractive to produce and sell cars with lower emissions. However, the effects of such substitution are limited compared to those resulting from electric cars (with the emission value of zero), which is why we abstract from them in this paper.

[15] For details on how car manufacturers' emission levels compare to their targets see `https://www.eea.europa.eu/en/analysis/indicators/co2-performance-of-new-passenger`.

The distinctive feature of the EEP regulation is that it directly affects a manufacturer's incentives to produce both electric and conventional cars, setting it apart from traditional market interventions such as an excise tax on conventional cars, a subsidy for electric cars, or a binding emissions ceiling for newly registered cars.[16]

According to the EEP regulation, the current emission target is 95 g $CO_2$/km, and this value is reduced in 2025 by 15 percent, in 2030 by 55 percent and and finally by 100 percent (i.e., $t = 0$) in 2035. Hence, the EEP function (6) reduces to

$$S(q_1, q_2)|_{t=0} = mx_2q_2. \tag{8}$$

that is, the EEP from 2035 onwards then equals a standard excise tax $mx_2$ per conventional car.

# 3 Monopoly Model

We now analyze the monopoly problem without the EEP regulation (Section 3.1) and with the EEP regulation (Section 3.2) in place. In Section 3.3 we analyze comparative statics of market outcomes regarding the emission target.

Consider a monopolist selling two types of cars, $i = 1, 2$, namely, electric (good $i = 1$) and conventional cars (good $i = 2$). Production cost of good $i$ is given by $C_i(q_i) = c_iq_i$ for $q_i \geq 0$. The inverse market demands are assumed to be independent and are given by $p_i(q_i)$ for $i = 1, 2$. Each inverse demand function is at least twice continuously differentiable and strictly downward sloping with $\frac{\partial p_i}{\partial q_i} < 0$. Let $\overline{p}_i := \lim_{q_i \to 0} p_i(q_i) < \infty$ be the choke price of good $i$, that is, the lowest price at which demand is zero. We assume that the choke price exceeds the sum of marginal production costs and marginal regulatory costs, no matter how strict the EEP regulation is. At $t = 0$ the marginal regulatory costs are maximal for good 2, namely, $mx_2$, whereas the marginal regulatory costs of good 1 are negative (see Eq. (7)). Thus, we assume $\overline{p}_1 > c_1$ and $\overline{p}_2 > c_2 + mx_2$.

## 3.1 Benchmark without EEP

If there is no EEP regulation, the monopolist maximizes his profit $\pi = \pi(q_1, q_2)$ by solving

$$\max_{q_1, q_2} \pi(q_1, q_2) := \sum_{i=1}^{2} q_i(p_i(q_i) - c_i), \tag{9}$$

which yields the first-order conditions

$$\pi_1' := \frac{\partial \pi}{\partial q_1} = 0 \text{ and } \pi_2' := \frac{\partial \pi}{\partial q_2} = 0. \tag{10}$$

We invoke the standard assumption that each product's marginal profit (or, equivalently, marginal revenue) is strictly downward sloping, which implies that the second-order conditions of

[16] Such a regulatory intervention, targeting either only conventional cars or electric cars directly, could also have cross-market effects when a manufacturer's demands and/or costs are interdependent. However, the cross-market effect would then be indirect and absent if demands and costs are independent.

the monopolist's maximization problem hold; i.e., $\pi_i'' := \frac{\partial^2 \pi}{\partial q_i^2} < 0$ for $i = 1, 2$. Thus, Eq. (10) has a unique (interior) solution with the following properties (asterisks indicate optimal values in the benchmark case):

**Lemma 1** (Monopoly Benchmark)**.** *The monopolist's problem* (9) *has a unique solution with* $p_i^* > c_i$, $q_i^* > 0$, *for* $i = 1, 2$ *and* $\pi(q_1^*, q_2^*) > 0$. *Moreover,* $\frac{dp_i^*}{dc_i} > 0$, $\frac{dq_i^*}{dc_i} < 0$, $\frac{dp_i^*}{dc_j} = 0$, $\frac{dq_i^*}{dc_j} = 0$, *and* $\frac{d\pi(q_1^*, q_2^*)}{dc_i} < 0$ *for* $i, j = 1, 2$ *and* $i \neq j$.

**Proof.** See Appendix.

Lemma 1 states that each product's optimal output $q_i^*$ (and price $p_i^*$) only depends on its own marginal costs, $c_i$, and not on the other good's marginal costs, $c_j$ $(i \neq j)$. Clearly, this independence is a direct result of our assumption that the demands for the goods are independent.

Next, we analyze how the EEP regulation affects the monopoly solution. As we will see, the optimal production levels of the goods could then become *interdependent* even though both demands and costs are independent of each other.

### 3.2 Solution with the EEP

With the EEP regulation in place, the monopolist's new profit function, $\Pi$, is the difference of his profits in the absence of an EEP, $\pi$, and the EEP function, $S$, which gives

$$\Pi := \Pi(q_1, q_2) := \pi(q_1, q_2) - S(q_1, q_2). \tag{11}$$

Using (6), the monopolist's problem can then be written as

$$\max_{q_1, q_2} \Pi(q_1, q_2) = \begin{cases} \pi(q_1, q_2) - m\left(-tq_1 + (x_2 - t)q_2\right) & \text{if } -tq_1 + (x_2 - t)q_2 > 0 \\ \pi(q_1, q_2) & \text{if } -tq_1 + (x_2 - t)q_2 \leq 0. \end{cases} \tag{12}$$

To characterize the solution of (12), we proceed in two steps. In Step 1, we solve for the *fulfilled emission target* (*in short: FET*) *solution*, that is, we solve the preceding maximization problem under the assumption that the emission target is fulfilled. In Step 2, we solve for the *violated emission target* (*in short: VET*) *solution*, where we solve the preceding maximization problem under the assumption that the emission target is violated. In Step 3, we determine under which conditions the FET and the VET solution are optimal, respectively.

Before we start, let $t^*$ denote the lowest emissions target such that the benchmark monopoly profit is just obtainable. This means that the emission target (5) is binding in the monopoly solution $(q_1^*, q_2^*)$ so that $t^*$ satisfies $-t^* q_1^* + (x_2^* - t^*)q_2^* = 0$. This yields

$$t^* = \frac{q_2^*}{q_1^* + q_2^*} \cdot x_2. \tag{13}$$

Due to $x_2 > 0$, such a $t^* < x_2$ exists. Then, for $t \geq t^*$, the solution to (12) is given by the benchmark solution $(q_1^*, q_2^*)$. We thus proceed with the analysis of the case where $t < t^*$ holds, so that the maximal profit level $\pi(q_1^*, q_2^*)$ cannot be reached.

**Step 1. Fulfilled emission target (FET).** Assuming that the emission target is fulfilled, we first analyze the case where $0 < t < t^*$. The second-order conditions of the benchmark problem ensure that the profit function $\pi(q_1, q_2)$ is strictly concave, which implies that the emission target (5) must be binding in the FET solution. Thus, the monopolist's constrained maximization problem is given by

$$\max_{q_1,q_2} \pi(q_1, q_2) \text{ s.t. } -tq_1 + (x_2 - t)q_2 = 0. \tag{14}$$

The corresponding Lagrange function is

$$L(q_1, q_2, \lambda) = \pi(q_1, q_2) - \lambda\left(-tq_1 + (x_2 - t)q_2\right), \tag{15}$$

where $\lambda \geq 0$ is the Lagrange multiplier. The solution to (14), that is, $(\widehat{q}_1, \widehat{q}_2, \widehat{\lambda})$—with hats denoting optimal values in the FET case—fulfills the first-order conditions

$$\frac{\partial L}{\partial q_1} = \pi_1' + \lambda t = 0, \tag{16}$$

$$\frac{\partial L}{\partial q_2} = \pi_2' - \lambda(x_2 - t) = 0, \tag{17}$$

$$\frac{\partial L}{\partial \lambda} = tq_1 - (x_2 - t)q_2 = 0. \tag{18}$$

Eliminating $\lambda$, the optimal quantities $(\widehat{q}_1, \widehat{q}_2)$ of the FET solution satisfy[17]

$$-\left.\frac{\pi_1'}{\pi_2'}\right|_{-tq_1+(x_2-t)q_2=0} = \frac{t}{x_2 - t} > 0, \tag{19}$$

so that the ratio of marginal profits obtained from the two goods (in absolute terms) is equal to the ratio of the emission target to the excess emissions per conventional car. Inspecting the first-order conditions (16)-(18), we can rule out $\widehat{\lambda} = 0$, because then the benchmark solution $(q_1^*, q_2^*)$ would follow from (16) and (17), which violates the emission target (or, equivalently, (18)). Thus, we have $\widehat{\lambda} > 0$, which implies that $\pi_1' < 0$ (see (16)) and $\pi_2' > 0$ (see (17)) hold in the FET solution. In the optimum, the manufacturer obtains a negative marginal profit of electric car sales which is achieved by *increasing* the output level above the level of the benchmark solution; that is, we have $\widehat{q}_1 > q_1^*$. Likewise, the marginal profit of conventional car sales is positive since the output level is *decreased* below the level of the benchmark solution; i.e., we have $\widehat{q}_2 < q_2^*$.

We now consider the case $t = 0$. Then the emission target can be only fulfilled if $\widehat{q}_2 = 0$. In this case the EEP is zero and the optimal quantity for good 1 follows from Lemma 1 with $\widehat{q}_1 = q_1^*$.

Finally, the monopolist's profit is always lower in the constrained solutions than in the benchmark solution; that is, $\pi(\widehat{q}_1, \widehat{q}_2) < \pi(q_1^*, q_2^*)$ for all $0 \leq t < t^*$. This follows from the strict concavity of the profit function $\pi(q_1, q_2)$.

[17] From now on we use the following notation for the first and second partial derivatives of the profit function $\pi$ with respect to $q_i$: $\pi_i' := \frac{\partial \pi}{\partial q_i}$ and $\pi_i'' := \frac{\partial^2 \pi}{\partial q_i^2}$ for $i = 1, 2$.

**Interpretation of $\lambda$.** As usual, the Langrage multiplier can be interpreted as the shadow price of the excess emission target. Let $\widehat{\pi}$ stand for the optimal profit level in the FET solution for given values of the parameters $x_2$ and $t$, which is given by

$$\widehat{\pi} := \widehat{\pi}(x_2, t) = \pi(\widehat{q}_1, \widehat{q}_2) - \widehat{\lambda}(-t\widehat{q}_1 + (x_2 - t)\widehat{q}_2) = L(\widehat{q}_1, \widehat{q}_2, \widehat{\lambda}),$$

where $\widehat{q}_1$, $\widehat{q}_2$, and $\widehat{\lambda}$ all depend on $t$. The effect of a small change of the emission target $t$ on the car manufacturer's optimal profit level then follows from

$$\frac{d\widehat{\pi}}{dt} = \underbrace{\left(\pi_1' + \widehat{\lambda}t\right)}_{=0}\frac{\partial \widehat{q}_1}{\partial t} + \underbrace{\left(\pi_2' - \widehat{\lambda}(x_2 - t)\right)}_{=0}\frac{\partial \widehat{q}_2}{\partial t} - \widehat{\lambda}\,(-\widehat{q}_1 - \widehat{q}_2) - \frac{\partial \widehat{\lambda}}{\partial t}\underbrace{(-t\widehat{q}_1 + (x_2 - t)\widehat{q}_2)}_{=0} \tag{20}$$

$$= \widehat{\lambda}\,(\widehat{q}_1 + \widehat{q}_2)\,, \tag{21}$$

where we used (16)-(18). Thus, we have

$$\widehat{\lambda} = \frac{\frac{d\widehat{\pi}}{dt}}{\widehat{q}_1 + \widehat{q}_2}.$$

We see that $\widehat{\lambda}$ mirrors the opportunity costs (per car) induced by a marginal change of the emission target. So, if the excess emission target becomes stricter by a small amount, it reduces the profit of the car manufacturer by $\widehat{\lambda}$ times the total number of cars sold. Using the equation system (16)-(18), it is easily verified that $\frac{d\widehat{\lambda}}{dc_1} > 0$ and $\frac{d\widehat{\lambda}}{dc_2} < 0$, meaning that $\widehat{\lambda}$ increases (decreases) with the marginal production costs of electric (conventional) cars. Intuitively, the lower the marginal costs of conventional cars, the more conventional cars the manufacturer wants to sell, which must—ceteris paribus—increase the shadow price of the excess emissions constraint. Conversely, the lower the marginal costs of electric cars, the easier it is to fulfill the emission target, which must reduce the shadow price of the excess emission target.

**Step 2. Violated emission target (VET).** Assuming that the emission target is violated, we again first analyze the case where $0 < t < t^*$. Then, the first-order conditions

$$\frac{\partial \Pi}{\partial q_1} = \pi_1' + mt = 0 \text{ and} \tag{22}$$

$$\frac{\partial \Pi}{\partial q_2} = \pi_2' - m(x_2 - t) = 0 \tag{23}$$

must hold, where the solution $(\widetilde{q}_1, \widetilde{q}_2)$—with tilde denoting optimal values in the VET case—fulfills $\widetilde{q}_1 > q_1^*$ and $0 < \widetilde{q}_2 < q_2^*$, because $m > 0$. These conditions give rise to the same condition as in (19); namely,

$$-\frac{\pi_1'}{\pi_2'} = \frac{t}{x_2 - t} > 0. \tag{24}$$

We finally analyze the case $t = 0$. The optimal solution follows directly from (22) and (23) evaluated at $t = 0$. It then follows that $\widetilde{q}_1 = q_1^*$ and $0 < \widetilde{q}_2 < q_2^*$, where here $\widetilde{q}_2 > 0$ follows from the assumption $\overline{p}_2 > c_1 + mx_2$. Finally, the monopolist's profit is lower in the VET solution than

in the benchmark solution, because

$$\Pi(\widetilde{q}_1, \widetilde{q}_2) = \pi(\widetilde{q}_1, \widetilde{q}_2) - S(\widetilde{q}_1, \widetilde{q}_2) < \pi(\widetilde{q}_1, \widetilde{q}_2) < \pi(q_1^*, q_2^*). \tag{25}$$

**Step 3. Comparison of FET vs. VET.** Suppose $0 < t < t^*$ and the manufacturer implemented the FET solution $(\widehat{q}_1, \widehat{q}_2)$ with $\widehat{q}_1 > q_1^*$ and $0 < \widehat{q}_2 < q_2^*$. When does the monopolist benefit from switching to the VET solution? Violating the emission target increases the profit if and only if there are $dq_1$ and $dq_2$ so that

$$d\Pi = \left(\pi_1' + mt\right) dq_1 + \left(\pi_2' - m(x_2 - t)\right) dq_2 \quad > \quad 0 \text{ and} \tag{26}$$

$$-t dq_1 + (x_2 - t) dq_2 \quad > \quad 0 \tag{27}$$

hold; that is, there must be small output changes $dq_1$ and $dq_2$ that must strictly increase the firm's profit (26) and that lead to a violation of the emission target (27).

Whether the monopolist prefers VET over FET depends on the relation of $m$ and the Lagrange parameter $\widehat{\lambda}$ in the FET solution. Note that for $m = \widehat{\lambda}$ we have $d\Pi|_{q_1=\widehat{q}_1, q_2=\widehat{q}_2} = 0$, so that in this case $(\widehat{q}_1, \widehat{q}_2)$ solves the first-order conditions (22)-(23) but the emission target is fulfilled. Thus, we have that $(\widehat{q}_1, \widehat{q}_2)$ is the unique profit-maximizing solution whenever $m = \widehat{\lambda}$. Now suppose $m \neq \widehat{\lambda}$, in which case $\frac{\partial \Pi}{\partial q_i} \neq 0$ for $i = 1, 2$. Assume first $m < \widehat{\lambda}$. Then we have

$$d\Pi = \underbrace{\left(\pi_1' + mt\right)}_{(-)} dq_1 + \underbrace{\left(\pi_2' - m(x_2 - t)\right)}_{(+)} dq_2 \text{ and}$$

$$-t dq_1 + (x_2 - t) dq_2 > 0;$$

Here, with $dq_1 < 0$ and $dq_2 > 0$, the profit can be strictly increased and the emission target is violated, so that the VET solution $(\widetilde{q}_1, \widetilde{q}_2)$—as given by (22) and (23)—is the unique solution to (12).

Assume, next, that $m > \widehat{\lambda}$. Then we have

$$d\Pi = \underbrace{\left(\pi_1' + mt\right)}_{(+)} dq_1 + \underbrace{\left(\pi_2' - m(x_2 - t)\right)}_{(-)} dq_2 > 0 \text{ and}$$

$$-t dq_1 + (x_2 - t) dq_2 > 0$$

Here, the profit level cannot be increased in the direction where the emission target is violated. In particular, moving in the direction of $dq_1 > 0$ and $dq_2 < 0$ would increase profits but is not admissable because then the emission target holds strictly. Due to the tangency conditions (19) and (24) being identical, there cannot exist other marginal changes of the output levels $dq_1$ and $dq_2$ that both violate the emission target and where $d\Pi|_{q_1=\widehat{q}_1, q_2=\widehat{q}_2} > 0$. Thus, the FET solution $(\widehat{q}_1, \widehat{q}_2)$ is the unique solution to (12) for $m > \widehat{\lambda}$.

For $t = 0$ electric cars cannot cross-subsidize conventional cars anymore. It then follows that the output level of electric cars is equal to the benchmark level (i.e., we have $\widehat{q}_1 = \widetilde{q}_1 = q_1^*$), whereas the output of conventional cars is only strictly positive in the VET solution (i.e., we

have $\widetilde{q}_2 > \widehat{q}_2 = 0$). By assumption on the choke price, it follows that the VET solution is optimal at $t = 0$.

Writing $\widehat{\Pi} = \widehat{\pi} = \Pi(\widehat{q}_1, \widehat{q}_2)$, $\widetilde{\Pi} = \Pi(\widetilde{q}_1, \widetilde{q}_2)$, $\widehat{S} = S(\widehat{q}_1, \widehat{q}_2)$, and $\widetilde{S} = S(\widetilde{q}_1, \widetilde{q}_2)$, we can summarize those results as follows.

**Proposition 1.** *The monopolist's problem under the EEP regulation* (12) *has a unique solution depending on* $t$ *and* $m$.

*i) If* $t \geq t^*$, *the benchmark monopoly solution* (*Lemma 1*) *applies and the EEP regulation does not affect the solution.*

*ii) If* $0 < t < t^*$, *the solution depends on* $m$ *and the Lagrangian parameter* $\widehat{\lambda}$ *under the FET solution:*

*a) FET solution: If* $m \geq \widehat{\lambda}$, *then the solution follows from* (16)-(18) *and is given by* $(\widehat{q}_1, \widehat{q}_2)$, *with* $\widehat{q}_1 > q_1^*$, $0 < \widehat{q}_2 < q_2^*$. *Moreover,* $\widehat{\Pi} = \widehat{\pi} < \pi^*$ *and* $\widehat{S} = 0$.

*b) VET solution: If* $m < \widehat{\lambda}$, *then the solution follows from* (22)-(23) *and is given by* $(\widetilde{q}_1, \widetilde{q}_2)$, *with* $\widehat{q}_1 > \widetilde{q}_1 > q_1^*$ *and* $\widehat{q}_2 < \widetilde{q}_2 < q_2^*$. *Moreover,* $\widetilde{\Pi} < \pi^*$ *and* $\widetilde{S} = m(-t\widetilde{q}_1 + (x_2 - t)\widetilde{q}_2) > 0$.

*iii) If* $t = 0$, *then the solution follows from* (22)-(23) *and is given by* $(\widetilde{q}_1, \widetilde{q}_2)$, *with* $\widetilde{q}_1 = q_1^*$ *and* $0 < \widetilde{q}_2 < q_2^*$. *Moreover,* $\widetilde{\Pi} < \pi^*$ *and* $\widetilde{S} = mx_2\widetilde{q}_2 > 0$.

If the EEP regulation is sufficiently strict, either the FET or VET solution will apply. When the price for excess emissions, $m$, is relatively high, the FET solution applies. In this case, the car manufacturer avoids paying the EEP penalty by strongly increasing the production of electric cars and reducing the production of conventional cars. Conversely, if the price for excess emissions is relatively low, the VET solution applies. The latter case holds for $m < \widehat{\lambda}$ and is illustrated in Figure 1. Relative to the benchmark solution, sales of electric vehicles are increased and conventional car sales decreased, but both quantity distortions are smaller in the VET solution than in the FET solution. Notably, distortions in both the FET and VET solutions can be so large that electric vehicles are sold below cost, depending on the profitability of conventional cars and the price of excess emissions.

### 3.3 The emission target expansion path

How does the monopoly solution change when the emission target $t$ becomes successively stricter, that is, $t$ becomes lower as stipulated in the EEP regulation? For $t \geq t^*$, we obtain the benchmark solution $q_1^* > 0$ and $q_2^* > 0$. As soon as $t$ falls below $t^*$, we have, no matter whether the FET or the VET solution applies, that the output of conventional cars is reduced and the output of electric cars is increased relative to the benchmark solution. A stricter emission target reduces the car manufacturer's profit in the FET solution (see (21)) as well as in the VET solution (see (25)). In the following, we analyze how a stricter regulation affects the FET and the VET solution, respectively.

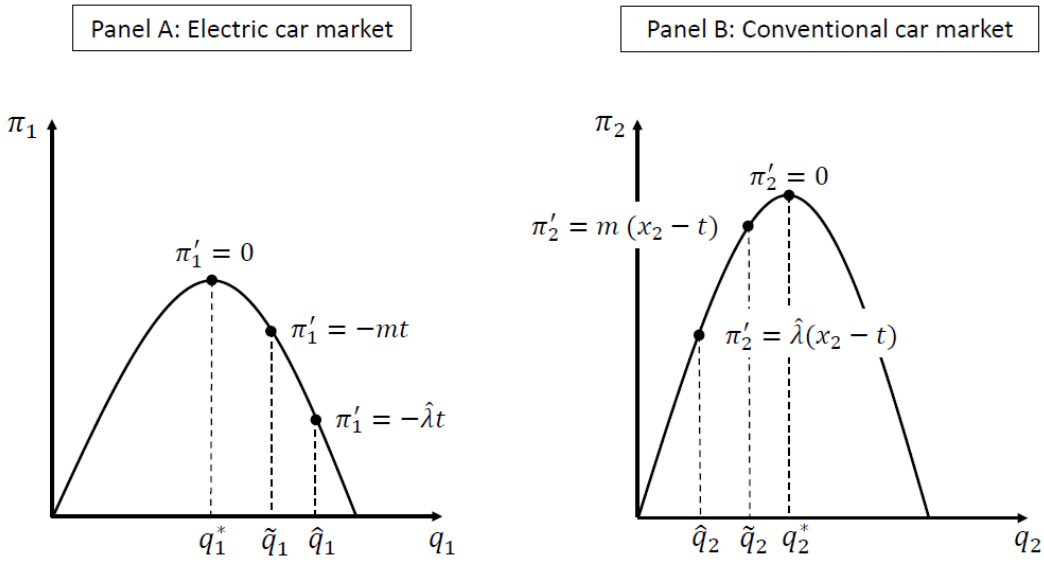


Figure 1: *The figure shows the profit in the electric car market, $\pi_1 := (p_1 - c_1)q_1$, in Panel A and the profit in the conventional car market, $\pi_2 := (p_2 - c_2)q_2$, in Panel B. It illustrates part ii.b) of Proposition 1 when $m < \widehat{\lambda}$ holds and the VET solution $(\widetilde{q}_1, \widetilde{q}_2)$ is optimal. In the electric car market (Panel A) the VET solution implies an output level, $\widetilde{q}_1$, above the benchmark solution, $q_1^*$, but below the FET solution, $\widehat{q}_1$. In the conventional car market (Panel B) the VET solution, $\widetilde{q}_2$, implies an output level above the FET solution, $\widehat{q}_2$, but still below the benchmark level, $q_2^*$.*

**FET solution with a stricter regulation.** The FET solution $(\widehat{q}_1, \widehat{q}_2)$ solves (18) and (19) from which we get $\frac{d\widehat{q}_2}{dt} > 0$ for $t \in (0, t^*)$, whereas the corresponding derivative for good 1, $\frac{d\widehat{q}_1}{dt}$, can be positive, negative or zero over $t \in (0, t^*)$. Consequently, a stricter emission target, $t$, always reduces the number of conventional cars produced but could lead to an increase or decrease in the production of electric cars. Yet, the latter ambiguity is resolved at the boundaries of the interval $(0, t^*)$ over which the emission target constraint is binding. To see this note first that the unconstrained output level of good 1, $q_1^*$, is optimal at $t = t^*$ and $t = 0$ with $\pi_1' = 0$ holding. A small reduction of $t$ below $t = t^*$ and a small increase of $t$ above $t = 0$ must then both increase the optimal output of electric cars beyond the unconstrained monopoly level (i.e., $\widehat{q}_1 > q_1^*$ for $t \in (0, t^*)$). This follows directly from the optimality condition (19), which requires a strictly negative marginal profit for electric cars because the marginal profit of conventional cars is strictly positive.

Another feature of the FET solution is that the monopolist's optimal production quantities and his profit function are all continuous at $t = t^*$. Lemma 2 summarizes our results.

**Lemma 2.** *Suppose the FET solution over $(0, t^*)$. The firm's optimal outputs and maximal profit then depend on t as follows:*

*i) Output of good 1: $\frac{d\widehat{q}_1}{dt}|_{t=t^*} < 0$ and $\frac{d\widehat{q}_1}{dt}|_{t=0} > 0$, and $\frac{d\widehat{q}_1}{dt} \gtreqless 0$ otherwise, with $\lim_{t \nearrow t^*} \widehat{q}_1 = \lim_{t \searrow 0} \widehat{q}_1 = q_1^*$.*

*ii) Output of good 2: $\frac{d\widehat{q}_2}{dt} > 0$, with $\lim_{t \nearrow t^*} \widehat{q}_2 = q_2^*$, and $\lim_{t \searrow 0} \widehat{q}_2 = 0$.*

*iii) Profit:* $\frac{d\widehat{\pi}}{dt} > 0$ *with* $\lim_{t \nearrow t^*} \widehat{\pi} = \pi^*$.

**Proof.** See Appendix.

**VET solution with a stricter regulation.** Let us next turn to the VET solution, $(\widetilde{q}_1, \widetilde{q}_2)$, as given by (22) and (23), which yields

$$\frac{d\widetilde{q}_1}{dt} = -\frac{m}{\pi_1''} > 0 \text{ and } \frac{d\widetilde{q}_2}{dt} = -\frac{m}{\pi_2''} > 0 \text{ for all } t \in (0, t^*).$$

Thus, when the emission target becomes stricter, both the output of electric and conventional cars must decrease. As we know that the output of electric cars is always larger in the VET solution than in the benchmark solution (i.e., $\widetilde{q}_1 > q_1^*$ for all $0 < t < t^*$), this result clearly points at a discontinuity at $t = t^*$. In fact, there must be a jump in the firm's profit function at $t = t^*$ when approaching $t^*$ from below. This follows from noticing that the firm's marginal costs of good 1 and good 2 change from $c_1$ and $c_2$ to $c_1 - mt$ and $c_2 + m(x_2 - t)$, respectively, when $t$ is reduced slightly below $t^*$. Thus, we have $\lim_{t \nearrow t^*} \widetilde{q}_1(t) > q_1^*$ and $\lim_{t \nearrow t^*} \widetilde{q}_2(t) < q_2^*$. The induced (discrete) change of the marginal costs when $t$ is reduced slightly below $t^*$ leads to a (discrete) change of the output levels which in turn must reduce the firm's profit by a non-marginal amount.

But how does the firm's maximal profit level change over $(0, t^*)$ when the VET solution applies? We get

$$\frac{d\Pi(\widetilde{q}_1, \widetilde{q}_2, t)}{dt} = \frac{\partial \Pi(\widetilde{q}_1, \widetilde{q}_2, t)}{\partial t} = m(\widetilde{q}_1 + \widetilde{q}_2) > 0, \tag{28}$$

where we used (22) and (23). Thus, a more restrictive emission target always reduces the maximal profit of the firm in the VET solution. We summarize those results for the VET solution as follows.

**Lemma 3.** *Suppose the VET solution holds over* $(0, t^*)$*. The firm's optimal outputs and maximal profit then depend on* $t$ *as follows:*

*i) Output of good 1:* $\frac{d\widetilde{q}_1}{dt} > 0$*, with* $\lim_{t \nearrow t^*} \widetilde{q}_1 > q_1^*$ *and* $\lim_{t \searrow 0} \widetilde{q}_1 = q_1^*$.

*ii) Output of good 2:* $\frac{d\widetilde{q}_2}{dt} > 0$*, with* $\lim_{t \nearrow t^*} \widetilde{q}_2 < q_2^*$.

*iii) Profit:* $\frac{d\Pi(\widetilde{q}_1, \widetilde{q}_2, t)}{dt} > 0$*, with* $\lim_{t \nearrow t^*} \Pi(\widetilde{q}_1, \widetilde{q}_2, t) < \pi^*$.

From Lemmas 1 and 2 it follows that a slight reduction of $t$ below $t^*$ must always induce the FET solution because here the firm's maximal profit is continuous at $t = t^*$, whereas the maximal profit level in the VET solution is strictly below $\pi^*$ when $t$ approach $t^*$ from below. Conversely, for $t$ close to zero, the VET solution must apply because at $t = 0$ we have $\widetilde{\pi} > \widehat{\pi}$ and $\widetilde{\pi}$ and $\widehat{\pi}$ are continuous at $t = 0$. Taken those results together, we can describe the emission target expansion path as follows.

**Proposition 2** (Emission Target Expansion Path)**.** *When $t$ is reduced below $t^*$, the firm first applies the FET solution. As $t$ approaches zero, the firm applies the VET solution, as it does at $t = 0$. As $t$ becomes stricter, the firm's profit decreases. The output of electric cars increases when $t$ is reduced below $t^*$ and decreases as $t$ approaches $0$.*

Proposition 2 builds on the insight gained in Proposition 1 that the type of the optimal solution (either FET or VET) critically depends on the comparison of the Lagrange multiplier, $\widehat{\lambda}$, and the value of $m$. It demonstrates that the output of electric vehicles is not monotonic with respect to the strictness of the regulation. When the EEP regulation starts to become binding (i.e., $\widehat{\lambda}$ is small and the FET solution is optimal), there is a clear incentive to expand the output of electric cars to relax the constraints on conventional cars. However, as the regulation becomes stricter, the positive externality of electric vehicle sales on conventional vehicle sales becomes smaller and ultimately disappears at $t = 0$. Thus, a reduction of the emission target must reduce electric car sales when it becomes sufficiently restrictive.

While so far we have assumed independent demand functions to clearly show the effects of the EEP regulation and disentangle them from standard substitution effects, interdependent demand functions are clearly more realistic. In Appendix B, we thus analyze this case. Here, we derive an analogue of Proposition 1 for interdependent demands. We also investigate the emission target expansion path for the case of interdependent demands and find one difference: that the output of electric cars may decrease for a strict regulation with $t$ close to zero, which must not hold true with this more general demand structure.

# 4 The Pooling Problem for Two Car Manufacturers

So far we have analyzed how the EEP affects a monopoly producing both conventional and electric cars. In this section we analyze the pooling option as stipulated in the EEP regulation. As in the monopoly version of our model, we assume an *incumbent* car manufacturer $I$, which produces both conventional and electric cars. In addition we suppose a second *entrant* firm $E$, which only produces electric cars. In the European context we can interpret firm $I$ as a *conventional* car manufacturer, as for instance, Volkswagen or BMW, and firm $E$ as a new electric car manufacturer, as for instance, Tesla or BYD. To proceed parsimoniously, we use the same notation for firm $I$ as in the monopoly part of our model. For instance, $q_1$ and $q_2$ stand for the production quantities of electric and conventional cars of firm $I$, respectively, and $\pi$ for firm $I$'s profit from selling electric and conventional cars. Variables belonging to firm $E$ are indexed by the subscript $E$; for instance, $q_E$ and $\pi_E$ stand for the production quantity and the profit of firm $E$, respectively.

We start our analysis with a formalization of the pooling option as put forward in the EEP regulation. We then analyze pooling for the case where firms $I$ and $E$ do not compete in the electric car market (we call this the *no-competition* case) and for the case where they compete in the electric car market (we call this the *competition case*). Assuming an EEP regulation in place, we compare the equilibrium outcomes with and without pooling. We show that pooling is valuable for the firms whenever the excess emission target is binding for the incumbent firm. In the

no-competition case, pooling relaxes the EEP constraint of the conventional manufacturer and thus creates a joint surplus, meaning that joint profits are higher with than without pooling. In the competition case, an additional incentive to pool is caused by the fact that the EEP regulation tends to intensify competition in the electric car market because of the conventional car manufacturer's incentive to "cross-subsidize" his conventional car sales by expanding electric car sales. In this setting, pooling not only relaxes the emissions constraint of the conventional car manufacturer but also induces a less competitive equilibrium outcome in the electric car market.

### 4.1 Formalization of Pooling

The EEP regulation allows car manufacturers to pool their fleets. If the firms do not pool their fleets under an EEP regulation, then firm $I$'s emissions constraint is given by (5) as in the monopoly version of our model. Firm $E$'s emissions constraint can be written as

$$-tq_E \leq 0, \tag{29}$$

which is never binding because firm $E$ only produces electric cars which have zero $CO_2$ emissions at the tailpipe.

By the EEP regulation, a firm that strictly meets its own emissions target is not only exempted from any EEP obligations but it also becomes the owner of emissions credits. Thus, if firm $E$ sells $q_E > 0$ cars in the EU and if an EEP is in place with $t > 0$, then firm $E$ becomes the holder of "emissions credits" amounting to $tq_E > 0$, which can be pooled with the conventional car manufacturer $I$. While the EEP regulation allows for either full pooling or no pooling of emission credits, our formal analysis benefits from also including the concept of *partial pooling*, where only a fraction of the obtained emission credits is pooled. Let $\alpha \in [0, 1]$ be the share of $E$'s total sales quantity which the firms agree to pool with firm $I$'s total car sales $q_1 + q_2$. Given such a pooling agreement, the *joint emission target constraint* of firms $I$ and $E$ is given by

$$-tq_1 + (x_2 - t)q_2 - \alpha tq_E \leq 0. \tag{30}$$

The EEP regulation stipulates the following pooling rules.

**Assumption 1** (Pooling Rules of the EEP Regulation)**.** *Suppose firms $I$ and $E$ agree to pool firm $I$'s total car sales $q_1 + q_2$ with the share $\alpha$ of firm $E$'s electric car output $q_E$. The EEP is then as follows:*

*i) Firm $E$ is always exempted from the EEP regulation.*

*ii) If the joint emission target is fulfilled, firm $I$ pays no EEP.*

*iii) If the joint emission target is violated, then the EEP firm $I$ has to pay is given by $S(q_1, q_2, \alpha q_E) = m\left(-tq_1 + (x_2 - t)q_2 - \alpha tq_E\right)$.*

Because of the pooling option, firm $E$'s emissions credits allow to relax the emission target for the incumbent firm when it is constrained by the EEP regulation. We now consider $I$'s profit

maximization problem under a pooling agreement with firm $E$, when firm $E$ holds emissions credits $tq_E > 0$ and shares $\alpha$ of it with firm $I$. In this case, firm $I$ solves

$$\max_{q_1,q_2} \Pi = \begin{cases} \pi - m\left(-tq_1 + (x_2 - t)q_2 - \alpha t q_E\right) & \text{if } -tq_1 + (x_2 - t)q_2 - \alpha t q_E > 0 \\ \pi & \text{if } -tq_1 + (x_2 - t)q_2 - \alpha t q_E \leq 0. \end{cases} \tag{31}$$

For any $\alpha > 0$, pooling relaxes firm $I$'s emissions constraint because the joint emissions constraint (30) is less restrictive than his own excess emissions constraint (5). In addition, pooling reduces firm $I$'s EEP in case of a violation of the joint emissions constraint by the amount of $m\alpha t q_E$. Thus, if firm $I$ is constrained by the EEP regulation, then —*ceteris paribus*— pooling must increase firm $I$'s profit, $\Pi$.

In the following, we assume $\alpha = 1$ if the firms agree to pool their fleets; that is, firm $E$ pools its entire electric car output with firm $I$'s total sales quantity. If no pooling agreement is reached, we have $\alpha = 0$.

We analyze a pooling agreement under two assumptions. *First*, the pooling agreement has to be concluded before the sales period starts, and *second*, it only specifies a lump-sum payment from one firm to the other that cannot be conditioned on any payoff-relevant variable. The *joint surplus of pooling*, $JSP(\alpha = 1)$, of firms $I$ and $E$ is given by the sum of the parties' profit gains from pooling:

$$JSP(\alpha = 1) := \Pi(\alpha = 1) - \Pi(\alpha = 0) + \pi_E(\alpha = 1) - \pi_E(\alpha = 0), \tag{32}$$

where $\Pi(\alpha = 1)$ and $\pi_E(\alpha = 1)$ are firm $I$'s and firm $E$'s profits in case of pooling and $\Pi(\alpha = 0)$ and $\pi_E(\alpha = 0)$ are the firms profits if they do not pool their fleets. Here all profits represent anticipated values that the firms expect to realize at the end of the sales period. In accordance with the Nash bargaining solution, we posit that if the joint surplus of pooling (32) is strictly positive, then the firms agree to pool their fleets and they split the surplus with the use of an unconditional lump-sum payment, $T$, such that each party is strictly better off with than without pooling. If $T > 0$, then firm $I$ makes a payment to firm $E$, and if $T < 0$, then $E$ makes a payment to $I$.

**Assumption 2** (Pooling Agreement)**.** *If $JSP(\alpha = 1) > 0$, then firms $I$ and $E$ conclude a pooling agreement with $\alpha = 1$, which specifies a lump-sum payment $T$ such that each party is strictly better off with pooling than without pooling.*

As a consequence, the lump-sum payment of a pooling agreement itself cannot affect each of the firms' optimal output decisions because it leaves all first-order conditions and the excess emissions constraints untouched. Assumption 2 thus guarantees that the pooling agreement cannot be abused as a cartelization device, which is explicitly required in Article 6, Paragraph 5, of the EEP regulation (EC 2019): *"Manufacturers may enter into pooling arrangements provided that their agreements comply with Articles 101 and 102 TFEU (...)."*

We begin our analysis with the *no-competition case*, where the demands of the firms' cars in the electric car market are independent and then turn to the *competition case* where firms compete in the electric cars market.

### 4.2 No-Competition Case

Suppose that the demands of the electric cars of firms $I$ and $E$ are independent of each other. Firm $I$'s inverse demand of its electric cars is given by $p_1 = p_1(q_1)$, and let $p_E = p_E(q_E)$ stand for the inverse demand of firm $E$'s electric cars. Firm $E$'s cost function is $C_E(q_E) = c_E q_E$, where $c_E \geq 0$ stands for the marginal production costs of electric cars of firm $E$. In the absence of an EEP regulation, firm $I$'s optimal production plan $(q_1^*, q_2^*)$ is given by Lemma 1 and firm $E$'s optimal output $q_E^*$ is given by

$$q_E^* = \arg\max_{q_E \geq 0} \pi_E = (p_E(q_E) - c_E)\, q_E, \tag{33}$$

where we assume that the second-order condition, $\frac{\partial^2 \pi_E}{\partial q_E^2} < 0$ holds and that $q_E^* > 0$. As demands are independent, firms' optimization problems are also independent of each other in the absence of an EEP regulation.

**Lemma 4** (No-Competition Case without EEP)**.** *In the no-competition case without an EEP, the optimal production quantities of firm $I$, $(q_1^*, q_2^*)$, are given by Lemma 1, and the optimal production quantity of firm $E$, $q_E^*$, is given by (33).*

Now suppose an EEP is in place and assume that $t < t^*$, where $t^*$ is given by (13). Thus, firm $I$'s benchmark solution $(q_1^*, q_2^*)$ is effectively constrained by the EEP regulation if there is no pooling. Firm $I$ then realizes either the FET solution $(\widehat{q}_1, \widehat{q}_2)$ or the VET solution $(\widetilde{q}_1, \widetilde{q}_2)$ (see Proposition 1). As firm $E$ produces only electric cars, it is exempted from the EEP regulation.

**Lemma 5** (No-Competition Case with EEP)**.** *Suppose $t < t^*$. In the no-competition case with an EEP, the optimal production quantities of firm $I$ are either given by the FET solution $(\widehat{q}_1, \widehat{q}_2)$ or the VET solution $(\widetilde{q}_1, \widetilde{q}_2)$, as stated in Proposition 1. The optimal production quantity of firm $E$, $q_E^*$, is given by (33).*

Now, suppose that the two firms agree to pool their fleets. Note that such an arrangement does not affect firm $E$'s optimal production plan, $q_E^*$, because we assumed that such an agreement only specifies a lump-sum payment. If both firms pool their fleets, then the joint emissions constraint is given by (30) with $\alpha = 1$. Let $t^{PN}$ be the target value such that the joint emissions constraint is binding in the unconstrained solution (Lemma 5); that is,

$$-tq_1^* + (x_2 - t)q_2^* - tq_E^* = 0 \text{ at } t = t^{PN},$$

where the superscript $PN$ indicates a pooling agreement in the no-competition case. Clearly, we have $t^{PN} < t^*$ because $q_E^* > 0$ and $t > 0$.[18]

In the following, we analyze two cases depending on whether or not pooling allows the incumbent firm $I$ to realizes the unconstrained monopoly solution (Lemma 1). In Case 1, we suppose a relatively high value of the emission target $t$ such that pooling allows firm $I$ to realize the unconstrained monopoly solution; that is, we assume $t^{PN} \leq t < t^*$. In Case 2 we consider stricter values of the emission target $t$ so that firm $I$ could not realize the unconstrained

[18] Here and in the following, we ignore the case $t = 0$ where pooling is useless.

monopoly solution even though pooling relaxes the emissions constraint; that is, we assume $0 < t < t^{PN}$.

**Case 1** ($t^{PN} \leq t < t^*$)**.** If pooling allows firm $I$ to realize the unconstrained monopoly solution, the effects of pooling are as follows.

**Proposition 3** (Pooling in the No-Competition Case for $t^{PN} \leq t < t^*$)**.** *Suppose an EEP regulation is in place that allows for pooling, and assume $t^{PN} \leq t < t^*$. In the equilibrium of the no-competition case, firms $I$ and $E$ reach a pooling agreement with $\alpha = 1$, which has the following effects:*

*i) Firm $I$'s output of electric cars is reduced from either $\widehat{q}_1$ or $\widetilde{q}_1$ to $q_1^*$.*

*ii) Firm $I$'s output of conventional cars is increased from either $\widehat{q}_2$ or $\widetilde{q}_2$ to $q_2^*$.*

*iii) Firm $I$'s profit is increased from either $\widehat{\pi}$ or $\widetilde{\Pi}$ to $\pi^*$.*

*iv) Firm $E$'s output and profit are not affected and remain at $q_E^*$ and $\pi_E^*$, respectively.*

*v) The joint surplus of pooling is strictly positive, $JSP(\alpha = 1) > 0$, and firm $I$ makes a strictly positive payment to $E$ with $T > 0$.*

From Proposition 1, we know that firm $I$ always distorts the output of good 1 (good 2) upward (downward) in the EEP-constrained solution when compared with the unconstrained solution (Lemma 1). The results stated in Proposition 3 then follow directly from the fact that pooling relaxes firm $I$'s excess emissions constraint such that it is not binding anymore (i.e, it restores the unconstrained solution according to Lemma 1), whereas firm $E$'s optimal output is not affected by the pooling agreement. It is then also immediate that firm $I$'s profit must increase and that firm $E$'s profit is not affected by pooling. Thus, pooling creates a strictly positive joint surplus and firm $E$ gets a strictly positive payment $T$ from firm $I$. Notably, if the VET solution holds without pooling, then pooling reduces the EEP penalty to zero.

**Case 2** ($0 < t < t^{PN}$)**.** In this case, pooling does not allow firm $I$ to realize the unconstrained benchmark solution $(q_1^*, q_2^*)$ but, instead, firm $I$ will remain in an EEP-constrained solution, which is either FET or VET according to Proposition 1. Still, the effects of pooling are qualitatively similar to the results stated in Proposition 3. To see this, note first that a pooling agreement does not affect firm $I$'s production plan if the VET solution is optimal with and without pooling. This follows directly from inspecting the first-order conditions (22) and (23). As pooling also does not affect the optimal output of firm $E$, we get that all output levels $(\widetilde{q}_1, \widetilde{q}_2, q_E^*)$ remain untouched by pooling. Yet, pooling still creates a strictly positive joint surplus by reducing the EEP the incumbent has to pay by the amount of $mtq_E^*$.

Next, suppose that firm $I$ is in the FET solution when there is no pooling. Then, firm $I$ solves (14), so that the optimal quantities $(\widehat{q}_1, \widehat{q}_2)$ follow from (16)-(18). With a pooling agreement in place, firm $I$ solves again (14) with the only difference that the less restrictive joint emissions constraint (30) applies. This is true for both a pooling agreement with $\alpha = 1$ and any partial pooling agreement with $\alpha < 1$. Thus, under any pooling agreement with $\alpha \leq 1$, firm $I$'s

optimal quantities of good 1 and good 2 and the value of the Lagrange multiplier in the FET solution—which we denote by $(\widehat{q}_1(\alpha), \widehat{q}_2(\alpha), \widehat{\lambda}(\alpha))$—fulfill (16), (17), and the joint emissions constraint (30) holds with equality. Totally differentiating this equation system with respect to $\alpha$ and applying Cramer's rule, we get

$$\frac{d\widehat{q}_1(\alpha)}{d\alpha} < 0, \frac{d\widehat{q}_2(\alpha)}{d\alpha} > 0, \text{ and } \frac{d\widehat{\lambda}(\alpha)}{d\alpha} < 0. \tag{34}$$

Thus, if the FET solution holds with and without pooling, then a pooling agreement with $\alpha = 1$ can only reduce the output of good 1 and increase the output of good 2, while it strictly increases firm $I$'s profits. Notably, the Lagrange multiplier is monotonically decreasing in $\alpha$ and becomes minimal at $\alpha = 1$; namely, when a pooling agreement is concluded. Using Proposition 1, we know that the VET (FET) solution applies if and only if $m < \widehat{\lambda}(\alpha)$ ($m \geq \widehat{\lambda}(\alpha)$). Thus, if $m < \widehat{\lambda}(\alpha = 1)$, the VET solution holds with and without pooling. However, if $m < \widehat{\lambda}(\alpha = 0)$ and $m > \widehat{\lambda}(\alpha = 1)$, then the VET solution holds without pooling, whereas the FET solution holds with pooling. In the former case, pooling has no effect on firm $I$'s optimal output levels, whereas it must decrease the output of good 1 and increase the output of good 2 in the latter case. We thus have established the following result.

**Proposition 4** (Pooling in the No-Competition Case for $0 < t < t^{PN}$)**.** *Suppose an EEP regulation is in place that allows for pooling, and assume $0 < t < t^{PN}$. In the equilibrium of the no-competition case, firms $I$ and $E$ reach a pooling agreement with $\alpha = 1$, which has the following effects:*

*i) If $m > \widehat{\lambda}(\alpha = 1)$, firm $I$'s output of electric cars is reduced from either $\widehat{q}_1$ or $\widetilde{q}_1$ to $\widehat{q}_1(\alpha = 1)$, whereas it is not affected and stays at $\widetilde{q}_1$ if $m \leq \widehat{\lambda}(\alpha = 1)$.*

*ii) If $m > \widehat{\lambda}(\alpha = 1)$, firm $I$'s output of conventional cars is increased from either $\widehat{q}_2$ or $\widetilde{q}_2$ to $\widehat{q}_2(\alpha = 1)$, whereas it is not affected and stays at $\widetilde{q}_2$ if $m \leq \widehat{\lambda}(\alpha = 1)$.*

*iii) Firm $I$'s profit is increased from either $\widehat{\pi}$ or $\widetilde{\Pi}$ to $\Pi(\alpha = 1)$.*

*iv) Firm $E$'s output and profit are not affected and remain at $q_E^*$ and $\pi_E^*$, respectively.*

*v) The joint surplus of pooling is strictly positive, $JSP(\alpha = 1) > 0$, and firm $I$ makes a strictly positive payment to $E$ with $T > 0$.*

**Proof.** See Appendix.

### 4.3 Competition Case

Suppose consumers regard the electric cars of firm $I$ and firm $E$ as perfectly substitutable. Let the inverse market demand for electric cars be the same as in the monopoly version of our model. Thus, the inverse market demand for electric cars is given by $p_1(Q_1)$, which depends on the total supply of electric cars $Q_1 := q_1 + q_E$. We suppose Cournot competition so that the firms set their supply quantities simultaneously. In the absence of an EEP regulation, firm $I$'s problem is given by

$$\max_{q_1, q_2 \geq 0} \pi := \pi(q_1, q_2, q_E) := (p_1(Q_1) - c_1)q_1 + (p_2(q_2) - c_2)q_2 \tag{35}$$

and firm $E$'s problem by

$$\max_{q_E \geq 0} \pi_E := \pi_E(q_1, q_2) := (p_1(Q_1) - c_E)q_E. \tag{36}$$

We assume that firm $E$'s marginal production costs $c_E$ do not exceed $I$'s marginal production costs, $c_1$, of producing electric cars; i.e., $c_E \leq c_1$. This assumption can be justified by the fact that Tesla (or more recently BYD) has much higher electric car sales volumes than incumbent conventional car producers such as Volkswagen or BMW.[19]

If no EEP regulation is in place, the Cournot Nash equilibrium $(q_1^{**}, q_E^{**}, q_2^{**})$ solves the first-order conditions following from (35) and (36), which are given by

$$\pi_1' := \frac{\partial \pi(q_1, q_E)}{\partial q_1} = p_1 + q_1 \frac{\partial p_1}{\partial Q_1} - c_1 = 0, \tag{37}$$

$$\pi_2' := \frac{\partial \pi(q_2)}{\partial q_2} = p_2 + q_2 \frac{\partial p_2}{\partial q_2} - c_2 = 0, \text{ and} \tag{38}$$

$$\pi_E' := \frac{\partial \pi_E(q_1, q_E)}{\partial q_E} = p_1 + q_E \frac{\partial p_1}{\partial Q_1} - c_E = 0. \tag{39}$$

We assume that the equation system (37)-(39) has a unique and interior solution $(q_1^{**}, q_E^{**}, q_2^{**})$. Uniqueness is guaranteed by assuming that (in addition to second-order conditions) each firm's marginal profit (or, equivalently, marginal revenue) is decreasing in the other firm's output and that it reacts stronger to its own output than to the other firm's output (see Vives, 1999).

**Assumption 3** (Unique Equilibrium)**.** *In addition to standard second-order conditions,* $\pi_1'' := \frac{\partial^2 \pi}{\partial q_1^2} < 0$ *and* $\pi_E'' := \frac{\partial^2 \pi_E}{\partial q_E^2} < 0$*, the following holds:*

*i)* $\pi_{1E}'' := \frac{\partial^2 \pi}{\partial q_1 \partial q_E} < 0$ *and* $\pi_{E1}'' := \frac{\partial^2 \pi_E}{\partial q_E \partial q_1} < 0$.

*ii)* $\pi_1'' - \pi_{1E}'' < 0$ *and* $\pi_E'' - \pi_{E1}'' < 0$.

Note that part ii) of Assumption 3 also ensures that firms' best-response functions in the electric market are strictly downward sloping with a slope between $-1$ and $0$. In addition to Assumption 3, we also rule out a "corner" equilibrium outcome, where only the more efficient firm (here, firm $E$) is active in the electric car market. This holds if firm $E$'s marginal profit (39) is strictly negative at the "limit quantity", $q_E'$, where $p_1(q_E') = c_1$ holds. This is ensured by assuming that the difference between the firms' marginal costs $c_1 - c_E$ is not too large. We thus formulate the following lemma.

**Lemma 6** (Competition Case Without EEP)**.** *The benchmark duopoly without an EEP has a unique (interior) equilibrium* $(q_1^{**}, q_E^{**}, q_2^{**})$*, which satisfies (37)-(39).*

[19] In our analysis below this assumption ensures a pooling outcome when the incumbent and the entrant firm compete in the electric car market. We regard it as realistic because electric car manufacturers such as Tesla or BYD benefit from their technological leadership and scale economies in the production of electric cars. However, this competitive advantage could disappear if the EU imposes significant import tariffs which raise marginal supply costs of firms like BYD that export their cars into the EU.

We thus have a standard Cournot equilibrium in the electric car market $(q_1^{**}, q_E^{**})$. In the conventional car market, firm $I$ realizes the monopoly solution, $q_2^{**} = q_2^*$, as stated in Lemma 1, because the demand and production costs of fuel cars are independent of the electric car market.

Now suppose an EEP is in place. Firm $I$'s excess emissions constraint is given by (5). Let $t^{**}$ such that firm $I$'s excess emission target is binding in the benchmark duopoly solution $(q_1^{**}, q_2^{**})$; i.e., we have

$$-tq_1^{**} + (x_2 - t)q_2^{**} = 0 \text{ at } t = t^{**}.$$

In the following we assume $t < t^{**}$, so that the benchmark solution $(q_1^{**}, q_2^{**})$ violates firm $I$'s excess emission target. Firm $E$'s excess emission target is given by (29), which is never binding. Thus, if there is no pooling, then firm $I$'s benchmark solution $(q_1^{**}, q_2^{**})$ is effectively constrained by the EEP regulation. In analogy to the monopoly version of our model, we get either a FET equilibrium $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$ or a VET equilibrium $(\widetilde{q}_1, \widetilde{q}_E, \widetilde{q}_2)$.

**FET equilibrium with EEP (no pooling).** If the incumbent finds the FET solution optimal, then the unique Cournot Nash equilibrium $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$ (in short: FET equilibrium) follows from

$$(\widehat{q}_1, \widehat{q}_2) = \arg\max_{q_1, q_2} \pi \text{ s.t. (5) and} \tag{40}$$

$$\widehat{q}_E = \arg\max_{q_E} \pi_E. \tag{41}$$

Using the Lagrange function, $L := L(q_1, q_2, \lambda)$, to solve firm $I$'s problem, we get the first-order conditions

$$\frac{\partial L}{\partial q_1} = \pi_1' + \lambda t = 0, \tag{42}$$

$$\frac{\partial L}{\partial q_2} = \pi_2' - \lambda(x_2 - t) = 0, \tag{43}$$

$$\frac{\partial L}{\partial \lambda} = tq_1 - (x_2 - t)q_2 = 0, \tag{44}$$

while firm $E$'s first-order condition (39) is not affected by the EEP regulation. Note that the output levels in the FET equilibrium, $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$, fulfill the equations (39) and (42)-(44), and that the optimal value of the Lagrange multiplier $\widehat{\lambda}$ is part of the FET equilibrium outcome. Comparing (42)-(44) with firm $I$'s first-order conditions in the duopoly benchmark (37)-(38), it is obvious that the output of good 1 is increased and the output of good 2 is reduced under an EEP regulation. This follows directly from (42) and (43), respectively, and noticing that the optimal value of the Lagrange multiplier, $\widehat{\lambda}$, must be strictly positive for $t < t^{**}$. As the incumbent distorts the output level of its electric cars above the benchmark duopoly level, it must also be that the entrant reduces the output of its electric cars below the benchmark level $q_E^{**}$, because its best-response function slopes downward.

**VET equilibrium with EEP (no pooling).** If the incumbent finds the VET solution optimal, then the unique Cournot Nash equilibrium $(\widetilde{q}_1, \widetilde{q}_2, \widetilde{q}_E)$ (in short: VET equilibrium) follows from

$$\begin{aligned}(\widetilde{q}_1, \widetilde{q}_2) &= \arg\max_{q_1,q_2} \Pi := \pi - S = \pi - m(-tq_1 + (x_2 - t)q_2), \\ \widetilde{q}_E &= \arg\max_{q_E} \pi_E,\end{aligned}$$

and thus fulfills firm $I$'s first-order conditions

$$\frac{\partial \Pi}{\partial q_1} = \pi_1' + mt = 0, \tag{45}$$

$$\frac{\partial \Pi}{\partial q_2} = \pi_2' - m(x_2 - t) = 0, \tag{46}$$

and firm $E$'s first-order condition (39), which is not affected by the EEP-regulation. The quantity distortions induced by the EEP in the VET equilibrium point in the same direction as in the FET equilibrium. Comparing (45)-(46) with (37)-(38), it is straightforward that firm $I$ increases the output of good 1 and reduces the output of good 2, while firm $E$'s output of electric cars must be reduced because its best-response function slopes downward.

For any given value of $q_E$, firm $I$ chooses the solution which gives the highest profit. Comparing the first-order conditions in the FET and the VET solution (that is, (42)-(43) and (45)-(46)), it is obvious that the FET solution is optimal when $m \geq \widehat{\lambda}$, because then the VET solution is not admissible. In this case, the VET solution would imply a higher output of electric cars and a lower output of conventional cars when compared with the FET solution, implying that firm $I$'s emissions constraint (5) is not violated. Thus, if $m \geq \widehat{\lambda}$, then the FET solution must be optimal because of the strict concavity of $I$'s profit function. If, to the contrary, $m < \widehat{\lambda}$, then the VET solution is optimal because now the distortions of firm $I$'s outputs of good 1 and good 2 away from the unconstrained levels are minimal. We summarize these results as follows.

**Lemma 7** (Competition Case with EEP)**.** *In the competition case with an EEP in place, the equilibrium is either a FET equilibrium* $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$ *if* $m \geq \widehat{\lambda}$*, which satisfies* (42)-(44) *and* (39)*, or a VET equilibrium* $(\widetilde{q}_1, \widetilde{q}_2, \widetilde{q}_E)$ *if* $m < \widehat{\lambda}$*, which satisfies* (45)-(46) *and* (39)*.*

Now suppose that the two firms agree to pool their fleets. Note that such an agreement does not affects firm $E$'s first-order condition (39), because we assumed that it only specifies a lump-sum payment that cannot be conditioned on any market variable. If both firms pool their fleets, then the joint emissions constraint is given by (30) with $\alpha = 1$. Let $t^{PC}$ such that the joint emissions constraint of firms $I$ and $E$ (see (30)) holds as an equality in the benchmark duopoly equilibrium $(q_1^{**}, q_2^{**}, q_E^{**})$ when the firms pool their entire fleets (with $\alpha = 1$); i.e., we have

$$-tq_1^{**} + (x_2 - t)q_2^{**} - tq_E^{**} = 0 \text{ at } t = t^{PC}.$$

In the following, we distinguish two cases depending on whether or not pooling allows to realize the unconstrained duopoly equilibrium $(q_1^{**}, q_2^{**}, q_E^{**})$. The unconstrained outcome is feasible whenever $t^{PC} \leq t < t^{**}$ holds, and it is not feasible if $t < t^{PC}$ holds.

**Case 1** ($t^{PC} \leq t < t^{**}$)**.** If pooling makes the unconstrained duopoly equilibrium feasible, then this is the unique equilibrium and we get the following results, which follow directly from comparing the unconstrained equilibrium (Lemma 6) and the EEP-constrained equilibrium (Lemma 7).

**Proposition 5** (Pooling in the Competition Case)**.** *Suppose an EEP regulation is in place that allows for pooling, and assume $t^{PC} \leq t < t^{**}$. In the equilibrium of the competition case, firms $I$ and $E$ reach a pooling agreement with $\alpha = 1$, which has the following effects:*

*i) Firm $I$'s output of electric cars is reduced from either $\widehat{q}_1$ or $\widetilde{q}_1$ to $q_1^{**}$.*

*ii) Firm $I$'s output of conventional cars is increased from either $\widehat{q}_2$ or $\widetilde{q}_2$ to $q_2^{**}$.*

*iii) Firm $I$'s profit is increased from either $\widehat{\pi}_1$ or $\widetilde{\Pi}_1$ to $\pi_1^{**}$.*

*iv) Firm $E$'s output (profit) is increased from either $\widehat{q}_E$ ($\widehat{\pi}_E$) or $\widetilde{q}_E$ ($\widetilde{\pi}_E$) to $q_E^{**}$ ($\pi_E^{**}$).*

*v) The joint surplus of pooling is strictly positive, $JSP(\alpha = 1) > 0$, and either firm $I$ or firm $E$ makes a strictly positive payment to the other pooling partner.*

*vi) The total output in the electric car market is reduced, and the market price for electric cars is increased.*

In the competition case, pooling induces firm $E$ to expand its output of electric cars because firm $I$ reduces its electric car output. This leads to a positive profit effect of pooling on $E$'s side which is absent in the no-competition case. Note also that the output expansion of firm $E$ could lead to a reduction of firm $I$'s profits from selling electric cars even though the market price for electric cars increases under pooling. Taking both effects together, the gain from pooling could be larger for $E$ than for $I$, in which case firm $E$ makes a payment to firm $I$ to conclude the pooling agreement (i.e., we have $T < 0$).

**Case 2** ($0 < t < t^{PC}$)**.** We now analyze the case where pooling does not allow firm $I$ and firm $E$ to realize the unconstrained benchmark solution (Lemma 6). In this case firm $I$ will remain in an EEP-constrained solution which is either FET or VET according to Lemma 7. Still, the effects of pooling are qualitatively similar to the results stated in Proposition 5. To see this, note first that a pooling agreement does not affect firm $I$'s production plan if the VET solution is optimal with and without pooling, which follows directly from inspecting the first-order conditions (45) and (46). As pooling also does not affect the optimal output of firm $E$, we get that all output levels $(\widetilde{q}_1, \widetilde{q}_2, \widetilde{q}_E)$ (Lemma 7) remain untouched by pooling. Yet, pooling still creates a strictly positive joint surplus by reducing the EEP the incumbent has to pay by the amount of $mt\widetilde{q}_E$.

Next, suppose that the firms $I$ and $E$ are in the FET equilibrium without pooling. Here firm $I$ solves (40) so that the optimal quantities $(\widehat{q}_1, \widehat{q}_2)$ and the optimal value of the Lagrange multiplier $\widehat{\lambda}$ follow from (42)-(44). With a pooling agreement in place, firm $I$ solves again (40) with the only difference that now the less restrictive joint emissions constraint (30) applies. Note that the joint emissions constraint (30) is relaxed not only under a pooling agreement with $\alpha = 1$

but also for pooling agreements with $0 < \alpha < 1$, where firm $E$ only pools a share of its total output with firm $I$'s total car sales. In all those cases, firm $I$'s optimal quantities of good 1 and good 2 together with the Lagrange multiplier, and firm $E$'s output fulfill the equation system (42)-(44) and (39) in the FET equilibrium. By the implicit function theorem, this equation system defines the values of $(q_1, q_2, \lambda, q_E)$ in the FET equilibrium as implicit functions of $\alpha$, which gives $\widehat{q}_1(\alpha)$, $\widehat{q}_2(\alpha)$, $\widehat{\lambda}(\alpha)$, and $\widehat{q}_E(\alpha)$. Totally differentiating this equation system with respect to $\alpha$ (i.e., the share of firm $E$'s electric car output $q_E$ pooled with firm $I$'s total car output) and applying Cramer's rule, we get

$$\frac{d\widehat{q}_1(\alpha)}{d\alpha} < 0, \frac{d\widehat{q}_2(\alpha)}{d\alpha} > 0, \frac{d\widehat{\lambda}(\alpha)}{d\alpha} < 0, \text{ and } \frac{d\widehat{q}_E(\alpha)}{d\alpha} > 0. \tag{47}$$

Thus, if the FET solution holds with and without pooling, then a pooling agreement with $\alpha = 1$ can only reduce the output of good 1 and increase the output of good 2. Notably, the Lagrange multiplier is monotonically decreasing in $\alpha$ and becomes minimal at $\alpha = 1$; namely, when a pooling agreement is concluded. Using Lemma 7, we know that the VET (FET) solution applies if and only if $m < \widehat{\lambda}(\alpha)$ ($m \geq \widehat{\lambda}(\alpha)$). Thus, if $m < \widehat{\lambda}(\alpha = 1)$, the VET solution holds with and without pooling, because $\widehat{\lambda}(\alpha)$ is monotonically decreasing in $\alpha$. However, if $m < \widehat{\lambda}(\alpha = 0)$ and $m \geq \widehat{\lambda}(\alpha = 1)$, then the VET solution holds without pooling, whereas the FET solution holds with pooling. In the former case, pooling does not affect firm $I$'s optimal output levels, whereas it must decrease the output of good 1 and increase the output of good 2 in the latter case.

Firm $E$'s output must increase if the FET equilibrium holds under pooling (i.e., if $m > \widehat{\lambda}(\alpha = 1)$, because its best-response function is downward sloping (Assumption 3). Moreover, the market price for electric cars increases through pooling because a reduction of firm $I$'s output by one unit induces an expansion of firm $E$'s output by less than one unit (see part ii) of Assumption 3). If, however, the VET equilibrium holds before and after pooling, then not only firm $I$'s outputs but also firm $E$'s output is unaffected by pooling. Consequently, the market price for electric cars then also remains the same before and after pooling.

The joint surplus of pooling (with $\alpha = 1$) is strictly positive if the VET equilibrium holds with and without pooling because it reduces firm $I$'s EEP payment by the amount of $mt\widetilde{q}_E$ and leaves all production quantities unchanged. If the FET equilibrium holds with and without pooling, then the joint surplus also increases through pooling because we assumed that $E$'s marginal production costs are not strictly larger than firm $I$'s marginal production costs of electric cars; i.e., we have

$$c_E \leq c_1 \Rightarrow \widehat{JSP}(\alpha = 1) > 0. \tag{48}$$

The reason for this result is that pooling shifts parts of the production of electric cars from the less efficient firm $I$ to the more efficient firm $E$, while at the same time the market price for electric cars is increased because total output falls under pooling. If the VET equilibrium holds without pooling and the FET equilibrium with pooling, then the increase of the joint surplus is a combination of the surplus generated in the VET equilibrium (by reducing the EPP payment of firm $I$) and in the FET equilibrium. We summarize those results as follows.

**Proposition 6** (Pooling in the Competition Case for $0 < t < t^{PC}$)**.** *Suppose an EEP regulation is*

*in place that allows for pooling, and assume $0 < t < t^{PC}$. In the equilibrium of the no-competition case, firms $I$ and $E$ reach a pooling agreement with $\alpha = 1$, which has the following effects:*

*i) If $m > \widehat{\lambda}(\alpha = 1)$, firm $I$'s (firm $E$'s) output of electric cars is reduced (increased) from either $\widehat{q}_1$ ($\widehat{q}_E$) or $\widetilde{q}_1$ ($\widetilde{q}_E$) to $\widehat{q}_1(\alpha = 1)$ ($\widehat{q}_E(\alpha = 1)$), whereas the output of electric cars of firm $I$ and firm $E$ is not affected and stays at $\widetilde{q}_1$ and $\widetilde{q}_1$ if $m \leq \widehat{\lambda}(\alpha = 1)$.*

*ii) If $m > \widehat{\lambda}(\alpha = 1)$, firm $I$'s output of conventional cars is increased from either $\widehat{q}_2$ or $\widetilde{q}_2$ to $\widehat{q}_2(\alpha = 1)$, whereas it is not affected and stays at $\widetilde{q}_2$ if $m \leq \widehat{\lambda}(\alpha = 1)$.*

*iii) If $m > \widehat{\lambda}(\alpha = 1)$, firm $E$'s profit is increased from either $\widehat{\pi}_E$ or $\widetilde{\Pi}_E$ to $\Pi_E(\alpha = 1)$, whereas it is not affected and stays at $\widetilde{\pi}_E$ if $m \leq \widehat{\lambda}(\alpha = 1)$.*

*iv) The joint surplus of pooling is strictly positive, $JSP(\alpha = 1) > 0$, and either firm $I$ or firm $E$ makes a strictly positive payment to the other firm.*

**Proof.** See Appendix.

Altogether, pooling is strictly profitable for the two firms. For all cases but the case where before and after pooling the VET case applies, pooling increases the output of conventional vehicles and softens competition in the market for electric vehicles, reducing the output of the incumbent firm and increasing the sales of the entrant firm.

**Entry for Pooling.** Now suppose that firm $E$ must cover fixed costs $F > 0$ to enter the market. Thus, we introduce a preliminary stage in which $E$ decides whether to enter or not. It only enters when entry is strictly profitable. As we have shown in Section 3, the incumbent firm expands its output due to the EEP regulation. Hence, one might think that this reduces the incentive for entry. However, as pooling creates a joint surplus that the entrant strictly benefits from, the incentives for entry are higher than in the absence of the EEP regulation. Specifically, then, the pooling option can induce entry by expanding the range of fixed costs for which entry is profitable.

Denote by $F^{\text{NO-EEP}}$ the minimal fixed costs that prohibits entry of $E$ when there is no EEP regulation, by $F^{\text{NO-POOL}}$ the minimal fixed costs that prohibits entry of $E$ when there is the EEP regulation but no pooling option, and by $F^{\text{POOL}}$ minimal fixed costs that prohibits entry of $E$ when there is the EEP regulation and the pooling option.

**Corollary 1.** *The minimal fixed costs that prohibit entry satisfy $0 < F^{\text{NO-POOL}} < F^{\text{NO-EEP}} < F^{\text{POOL}}$.*

Thus, entry is least likely when the EEP is in place, but pooling is not feasible. This is because the incumbent firm becomes more competitive in the presence of the EEP, expanding its output of electric vehicles in response to the regulation. Without the EEP, the incumbent firm is less competitive, making entry more profitable. When pooling is feasible, the duopoly outcomes (as in the absence of the EEP regulation) are realized, but in addition, the entrant earns a strictly positive share of the joint surplus generated through pooling. Consequently, pooling shifts part of the rents earned from conventional vehicles to the entrant firm, increasing the likelihood of its entry.

This analysis applies especially to Chinese manufacturers of electric vehicles, which are numerous, and of which many have yet to enter the European market (e.g., Li Auto).[20] The opportunity to increase profits under the EEP regulation could incentivize their market entry—unless countered by import tariffs, which are also under discussion.

# 5 Conclusion

In this paper, we analyzed the effects of the EEP on the automotive market. The EEP incentivizes manufacturers that produce both conventional and electric cars to increase their electric car sales in order to meet emission targets. We distinguish between two solutions: one in which the emission target is violated (VET) and one in which it is fulfilled (FET). The EEP induces an expansion of electric car sales and a reduction in conventional car sales. These effects are stronger in the FET than in the VET solution. The effect of a stricter emission target is non-monotonic: when it just becomes binding, electric car sales are incentivized. However, when it becomes more restrictive, the positive externality of electric car sales on the regulatory costs of conventional car sales is reduced, and thus electric car sales might decrease.

When considering more than one car manufacturer, the EEP regulation creates a market for emissions credits through the pooling option, with electric car manufacturers as the primary beneficiaries. Even though explicit quantity agreements are prohibited by cartel laws, we have shown that pooling—which only specifies an unconditional lump-sum payment between manufacturers—softens competition. Furthermore, pooling could encourage the entry of foreign electric car manufacturers, enabling them to profit from pooling their fleets with conventional car manufacturers and thereby shifting rents from conventional car production to these new entrants. While our main analysis builds on independent demands for conventional and electric cars, we demonstrate in Appendices B and C that the main results remain valid even when demands are interdependent—for example, pooling decreases the output of electric cars and increases the output of conventional cars.

Our analysis shows that the regulation may not necessarily achieve the benefits it is supposed to deliver (European Parliament and Council, 2019). Specifically, we find that the effect of a stricter emission target is non-monotonic: tightening the regulation does not necessarily lead to an expansion of electric vehicle sales. Instead, due to pooling, conventional car sales may increase while electric vehicle sales decline due to weakened competition. This outcome runs counter to the regulation's intended goal of promoting the "wider deployment of [...] zero-emission vehicles" and could contradict its broader objective of "achieving climate neutrality."

Our analysis could be extended in several directions. For instance, we have only analyzed the case of two car manufacturers. In a more general oligopoly setting, the crucial question, then, is who pools fleets with whom and how pooling partners are selected. Moreover, we have assumed that pooling involves a lump-sum payment. While the pooling regulation prohibits contract schemes involving quantity agreements, it is possible that car manufacturers might agree on more complex contracts than simple unconditional payments for pooling. All more

[20] For an overview of Chinese electric vehicle manufacturers, see, for instance, `https://licarco.com/news/best-chinese-ev-manufacturers`.

complicated contract schemes, however, could induce coordinated effects regarding sold quantities, at the extreme this would mean a monopolization of the electric car market. This would reinforce and amplify our central finding that pooling weakens competition in the electric car market and facilitates an expansion of conventional car sales.

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# Appendix

In Appendix A, we present the missing proofs. In Appendix B, we generalize our monopoly analysis toward interdependent demands. In Appendix C, we generalize our duopoly and pooling results toward interdependent demands.

## Appendix A: Missing Proofs

**Proof of Lemma 1 (Monopoly Benchmark).** The monopolist solves (9). The unique solution $(q_1^*, q_1^*)$ follows from the first-order conditions

$$\frac{\partial \pi}{\partial q_i} = 0 \Leftrightarrow q_i \frac{\partial p_i(q_i)}{\partial q_i} + p_i(q_i) - c_i = 0 \text{ for } i = 1, 2. \tag{49}$$

For each good $i = 1, 2$ the first-order condition gives a unique solution $q_i^* > 0$ because we assumed marginal revenue, i.e., $q_i \frac{\partial p_i(q_i)}{\partial q_i} + p_i(q_i)$, to be strictly decreasing in $q_i$ and the choke price $\overline{p}_i$ to be sufficiently large. The optimal prices are then given by $p_i^* = p_i(q_i^*)$ for $i = 1, 2$.

Eq. (49) defines for each good $i$ an implicit function $q_i^*(c_i)$. Using the Implicit function theorem, we then get

$$\frac{dq_i^*}{dc_i} = -\frac{\frac{\partial^2 \pi}{\partial q_i \partial c_i}}{\frac{\partial^2 \pi}{\partial q_i^2}} = -\frac{-1}{2 \cdot \frac{\partial p_i(q_i)}{\partial q_i} + q_i \frac{\partial^2 p_i(q_i)}{\partial q_i^2}} < 0 \text{ for } i = 1, 2,$$

and

$$\frac{dq_i^*}{dc_j} = 0 \text{ for } i, j = 1, 2 \text{ and } j \neq i,$$

as stated in the lemma. Accordingly, the price effects of a small change of marginal costs are given by

$$\frac{dp_i^*}{dc_i} = \frac{\partial p_i}{\partial q_i} \frac{dq_i^*}{dc_i} > 0 \text{ and } \frac{dp_i^*}{dc_j} = 0 \text{ for } i, j = 1, 2 \text{ and } i \neq j.$$

Using (49), the effect of a marginal change of $c_i$ on the optimal monopoly profit, $\pi(q_1^*, q_2^*)$, is given by the partial derivative of the profit function; this gives

$$\frac{d\pi(q_1^*, q_2^*)}{dc_i} = \frac{\partial \pi(q_1^*, q_2^*)}{\partial c_i} = -q_i^* < 0 \text{ for } i = 1, 2.$$

This proves Lemma 1. **Q.E.D.**

**Proof of Lemma 2.** The FET solution $(\widehat{q}_1, \widehat{q}_2)$ solves (18) and

$$-(x_2 - t)\pi_1' - t\pi_2' = 0, \tag{50}$$

where (50) follows from the optimality condition (19). Both equations together define the implicit functions $\widehat{q}_1(t)$ and $\widehat{q}_2(t)$. Taking the total derivative of both equations with respect to $t$, we get

$$\begin{pmatrix} -t & x_2 - t \\ -(x_2 - t)\pi_1'' & -t\pi_2'' \end{pmatrix} \begin{pmatrix} \frac{dq_1}{dt} \\ \frac{dq_2}{dt} \end{pmatrix} = \begin{pmatrix} q_1 + q_2 \\ -\pi_1' + \pi_2' \end{pmatrix}. \tag{51}$$

The $2 \times 2$ matrix on the left-hand side of (51) we denote by $A$. Define the matrix $A_i$, $i = 1, 2$, by matrix $A$, where the $i^{\text{th}}$ column vector is substituted by the column vector on the right-hand side of (51). By Cramer's rule, we then get

$$\frac{d\widehat{q}_1}{dt} = \frac{|A_1|}{|A|} = \frac{-(q_1 + q_2)\, t\pi_2'' - (-\pi_1' + \pi_2')(x_2 - t)}{t^2\pi_2'' + (x_2 - t)^2\pi_1''} \tag{52}$$

and

$$\frac{d\widehat{q}_2}{dt} = \frac{|A_2|}{|A|} = \frac{-t(-\pi_1' + \pi_2') + (x_2 - t)\pi_1''(q_1 + q_2)}{t^2\pi_2'' + (x_2 - t)^2\pi_1''} > 0. \tag{53}$$

To determine the signs of equations (52) and (53) notice that $\pi_i'' < 0$, for $i = 1, 2$ (second-order conditions), and that $\pi_1' < 0$ and $\pi_2' > 0$ follow directly from (16) and (17), respectively. It then follows that $|A|, |A_2| < 0$ and thus $\frac{d\widehat{q}_2}{dt} > 0$, whereas $\frac{d\widehat{q}_1}{dt} \overset{sgn}{=} -|A_1|$ can be positive, negative, or zero. Consequently, a stricter emission target, $t$, always reduces the number of conventional cars produced but could lead to an increase or decrease in the production of electric cars. To understand the latter ambiguity, we examine the optimal adjustment of $q_1$ in a small neighborhood of the boundaries over $(0, t^*)$.

First take $t = t^*$, in which case the optimal production plan is $(q_1^*, q_2^*)$ with $\pi_i' = 0$ for $i = 1, 2$. Suppose the emission target is reduced slightly below $t^*$ by $dt < 0$. Then, at $(q_1^*, q_2^*)$, the emission target constraint (5) is violated by the amount of $(q_1^* + q_2^*)dt > 0$. By (53) we know that the manufacturer reduces the output of conventional cars, $q_2$. Now suppose that the firm *only* reduces the output of good 2 to make the emission target binding again. Reducing the output of good 2 from $q_2^*$ by $d\overline{q}_2$ to $\overline{q}_2$ with $d\overline{q}_2 = -\frac{q_1^* + \overline{q}_2}{x_2 - t}dt < 0$ restores equality of the excess emissions constraint (5). By this, we have reached the point $(q_1^*, \overline{q}_2)$ with $\overline{q}_2 < q_2^*$, where

$$-tq_1^* + (x_2 - t)\overline{q}_2 = 0 \tag{54}$$

holds and the firm's profit is reduced by $d\pi = \pi_2' d\overline{q}_2 = -\pi_2' \frac{q_1^* + \overline{q}_2}{x_2 - t} dt < 0$. However in any such point, the firm can increase its profit by increasing the output of electric cars beyond $q_1^*$ and at the same time increase the output of conventional cars so that the total derivative of the excess emissions constraint (holding as an equality) is just zero; i.e., according to $\frac{dq_2}{dq_1} = \frac{t}{x_2 - t} > 0$. This follows from totally differentiating the firm's profit $\pi(q_1, q_2(q_1))$ with respect to $q_1$ and evaluating it at $(q_1^*, \overline{q}_2)$. We then get

$$\left. \frac{d\pi}{dq_1} \right|_{q_1 = q_1^*, q_2 = \overline{q}_2} = \pi_1' \big|_{q_1 = q_1^*} + \pi_2' \big|_{q_2 = \overline{q}_2} \cdot \frac{dq_2}{dq_1} = \pi_2' \big|_{q_2 = \overline{q}_2} \cdot \frac{t}{x_2 - t} > 0, \tag{55}$$

where we used that $\pi_1'|_{q_1 = q_1^*} = 0$ and where the positive sign follows from $\overline{q}_2 < q_2^*$ which implies $\pi_2'|_{q_2 = \overline{q}_2} > 0$. Note that (55) holds for any point $(q_1^*, \overline{q}_2)$, where $\overline{q}_2$ follows from (54) so that $\overline{q}_2 < q_2^*$ holds for all $t \in [0, 1)$. Thus, starting from $(q_1^*, \overline{q}_2)$, the firm can strictly increase its profit by increasing the output of electric cars above $q_1^*$ by one unit and by simultaneously increasing the output of conventional cars by $\frac{t}{x_2 - t}$ units, so the emissions target (5) is binding. The firm follows this adjustment path until the tangency condition (19) holds, where it reaches the FET solution $(\widehat{q}_1, \widehat{q}_2)$ as stated in Proposition 1. Thus, a reduction of $t$ below $t^*$ not only reduces the output of conventional cars below $q_2^*$ but at the same time increases the output of electric cars beyond $q_1^*$. Due to continuity arguments, there exists $\varepsilon > 0$ so that (55) also holds for $t < t^*$, with $t^* - t < \varepsilon$. Let $d\widehat{q}_1/dt|_{t=t^*}$ be the left-derivative of the optimal output of good 1 in the FET solution with respect to $t$. We then have that $d\widehat{q}_1/dt|_{t=t^*} < 0$.

Moreover, from the above analysis, we also get that the monopolist's maximal profit, $\Pi^{FET}$, as a function of $t$ is continuous at $t = t^*$, whenever the FET solution holds over $(0, t^*)$ with

$$\Pi^{\text{FET}} := \begin{cases} \pi^* & \text{if } t \geq t^* \\ \widehat{\pi} & \text{if } t < t^*, \end{cases}$$

because $\lim_{t \nearrow t^*} \widehat{q}_1 = q_1^*$ and $\lim_{t \nearrow t^*} \widehat{q}_2 = q_2^*$.

We next analyze the case $t = 0$, where $\widehat{q}_1 = q_1^*$ and $\widehat{q}_2 = 0$. How does a slight increase of the excess emissions target above $t = 0$ affect the firm's optimal production plan here? We know that the firm now wants to increase the output of conventional cars, $q_2$ (see (53)). Suppose the firm does so until the emission target is binding while it keeps the output of electric cars at $\widehat{q}_1 = q_1^*$. This gives $\overline{q}_2$ according to (54). But then we know from (55) that the firm wants to raise also $q_1$ above $q_1^*$. Notably, in this case a decrease of $t$ *increases* the output of electric cars, which in turn makes it possible for the firm also to increase the output of conventional cars beyond $\overline{q}_2$, which restores equality of the excess emissions condition without changing the output of electric cars $q_1$. These arguments also hold in a small neighborhood to the right of $t = 0$, and we have thus established that $\frac{d\widehat{q}_1}{dt}|_{t=0} > 0$, where Let $d\widehat{q}_1/dt|_{t=0}$ is the right-derivative of the optimal output of good 1 in the FET solution with respect to $t$.

Moreover, the firm's maximal profit, $\Pi^{FET}$, as a function of $t$ whenever the FET solution applies over $(0, t^*)$ is continuous at $t = 0$, because $\lim_{t \searrow 0} \widehat{q}_1 = q_1^*$ and $\lim_{t \searrow 0} \widehat{q}_2 = 0$. The next lemma summarizes those results for the FET solution. **Q.E.D.**

**Proof of Proposition 4 (Pooling in the No-Competition Case for $0 < t < t^{PN}$).** Suppose a pooling agreement with $\alpha \in (0, 1]$, so that we treat $\alpha$ now as a continuous variable. Assume that the FET solution holds with and without pooling. We show that any such pooling agreement reduces the output of electric cars and increases the output of conventional cars of firm $I$. At the same time, it reduces the value of the Lagrange multiplier and increases the profit of firm $I$ for all $t < t^{PN}$. The FET solution $(\widehat{q}_1(\alpha), \widehat{q}_2(\alpha), \widehat{\lambda}(\alpha))$ solves (31) in the case where the joint emission target is binding. The corresponding Lagrange function is $L = \pi - \lambda(-tq_1 + (x_2 - t)q_2 - t\alpha q_E^*)$, from which we get the first-order conditions (16)-(17) and the condition $tq_1 - (x_2 - t)q_2 + t\alpha q_E^* = 0$. These equations define the FET solution for $q_1$, $q_2$, and $\lambda$ as functions of $\alpha$. Totally differentiating the equation system with respect to $\alpha$, we get

$$\frac{d\widehat{q}_1(\alpha)}{d\alpha} = \frac{t^2 q_E^* \pi_2''}{-(x_2 - t)^2 \pi_1'' - t^2 \pi_2''} < 0 \text{ and } \frac{d\widehat{q}_2(\alpha)}{d\alpha} = \frac{-t(x_2 - t) q_E^* \pi_1''}{-(x_2 - t)^2 \pi_1'' - t^2 \pi_2''} > 0, \tag{56}$$

which give the signs as stated in (47).

**Proof of Proposition 6 (Pooling in the Competition Case for $0 < t < t^{PC}$).** If $t < t^{PC}$, then the unconstrained duopoly equilibrium (Lemma 6) is not feasible. In this case, the equilibrium under pooling is either FET or VET (Lemma 7). We start with the FET equilibrium and then turn to the VET equilibrium.

*FET Equilibrium.* The effects of a pooling agreement (with $\alpha = 1$) can be analyzed via the comparative statics of the equation system (42)-(44) and (39) with respect to $\alpha$, which is the share of firm $E$'s output of electric cars pooled with the total car sales of firm $I$. Note that the equations (42)-(44) and (39) pin down the quantities $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$ and the optimal value of the Lagrange multiplier $\widehat{\lambda}$ in the FET equilibrium for any value of $0 \leq \alpha \leq 1$. By the implicit function theorem, those equations define the implicit functions $(\widehat{q}_1(\alpha), \widehat{q}_2(\alpha), \widehat{q}_E(\alpha), \widehat{\lambda}(\alpha))$, and totally differentiating the equation system (42), (43), (39), and (44) (in that order) with respect to $\alpha$ and rearranging, we get[21]

$$\underbrace{\begin{pmatrix} \pi_1'' & 0 & \pi_{1E}'' & t \\ 0 & \pi_2'' & 0 & -(x_2 - t) \\ \pi_{1E}'' & 0 & \pi_E'' & 0 \\ t & -(x_2 - t) & \alpha t & 0 \end{pmatrix}}_{=A} \begin{pmatrix} \frac{d\widehat{q}_1}{d\alpha} \\ \frac{d\widehat{q}_2}{d\alpha} \\ \frac{d\widehat{q}_E}{d\alpha} \\ \frac{d\widehat{\lambda}}{d\alpha} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ -t\widehat{q}_E \end{pmatrix}. \tag{57}$$

Define the $4 \times 4$ matrix on the left-hand side of (57) by $A$ and the matrix $A_k$, with $k = 1, 2, 3, 4$, by matrix $A$ with the $k$'s column vector of $A$ replaced by the vector on the right-hand side of (57). Calculating the determinants of those matrices, we get the following expressions and signs for

[21] Note that all values of the second derivatives of the profit functions stated below are evaluated in a small neighborhood of the FET equilibrium $(\widehat{q}_1, \widehat{q}_2, \widehat{q}_E)$ and the optimal value of the Lagrange multiplier $\widehat{\lambda}$, where all those values depend on $\alpha$.

all $t > 0$ and $\alpha \in [0,1]$:

$$\begin{aligned}
|A| &= -(x_2 - t)^2 \left(\pi_1'' \pi_E'' - \pi_{E1}'' \pi_{1E}''\right) - t^2 \pi_2'' \left(\pi_E'' - \pi_{E1}'' \alpha\right) < 0, \\
|A_1| &= t^2 \widehat{q}_E \pi_2'' \pi_E'' > 0, \\
|A_2| &= -t \widehat{q}_E (x_2 - t) \left(\pi_1'' \pi_E'' - \pi_{E1}'' \pi_{1E}''\right) < 0, \\
|A_3| &= -t \widehat{q}_E \pi_2'' \left(\pi_1'' \pi_E'' - \pi_{E1}'' \pi_{1E}''\right) > 0, \text{ and} \\
|A_4| &= -t^2 \widehat{q}_E \pi_{E1}'' \pi_2'' < 0.
\end{aligned}$$

By Cramer's rule, we then get

$$\frac{d\widehat{q}_1(\alpha)}{d\alpha} = \frac{|A_1|}{|A|} < 0, \frac{d\widehat{q}_2(\alpha)}{d\alpha} = \frac{|A_2|}{|A|} > 0, \frac{d\widehat{\lambda}(\alpha)}{d\alpha} = \frac{|A_3|}{|A|} < 0, \text{ and } \frac{d\widehat{q}_E(\alpha)}{d\alpha} = \frac{|A_4|}{|A|} > 0. \tag{58}$$

which gives the signs of the comparative statics of the FET equilibrium with respect to $\alpha$ as stated in (47).

We next analyze the price effect of pooling in the electric car market and the joint surplus of pooling when the FET equilibrium applies.

The equilibrium price in the electric car market is given by $\widehat{p}_1 := p_1(\widehat{q}_1 + \widehat{q}_E)$ and we get

$$\frac{d\widehat{p}_1}{d\alpha} = \frac{\partial p_1}{\partial Q_1}\left(\frac{d\widehat{q}_1}{d\alpha} + \frac{d\widehat{q}_E}{d\alpha}\right) = \frac{\partial p_1}{\partial Q_1} \frac{t^2 \widehat{q}_E \pi_2'' \left(\pi_E'' - \pi_{E1}''\right)}{|A|} > 0, \tag{59}$$

so that any marginal increase of $\alpha$ unambiguously reduces total output and increases the market price for electric cars in the FET equilibrium.

We next show that our assumption on the firms' marginal costs of electric cars (that is, $c_E \leq c_1$) ensures that the joint surplus of pooling is always strictly positive. Define the joint surplus of pooling in the FET equilibrium for any value of $\alpha > 0$ by

$$\widehat{JSP}(\alpha) := \widehat{\pi}(\alpha) - \widehat{\pi}(0) + \widehat{\pi}_E(\alpha) - \widehat{\pi}_E(0), \tag{60}$$

where $\widehat{\pi}(\alpha)$ ($\widehat{\pi}_E(\alpha)$) and $\widehat{\pi}(0)$ ($\widehat{\pi}_C(0)$) are the incumbent's (entrant's) equilibrium profits for $\alpha > 0$ and $\alpha = 0$, respectively. Now note that $I$'s profit from selling conventional cars can only increase through pooling because pooling increases $I$'s output of conventional cars while $I$'s marginal profits are strictly positive in the FET equilibrium. Ignoring $I$'s conventional car gains, a sufficient condition for a strictly positive joint surplus from pooling is that the firms' sum of profits in the electric car market, $\pi_1 + \pi_E$, increases through pooling. Taking the total differential of both firms' profits in the electric car market gives

$$d[\pi_1 + \pi_E] = \left(\pi_1' + \frac{\partial p_1}{\partial Q_1} q_E\right) dq_1 + \left(\pi_E' + \frac{\partial p_1}{\partial Q_1} q_1\right) dq_E \tag{61}$$

Note first that the terms in brackets on the right-hand side of (61) are strictly negative in the unconstrained benchmark duopoly equilibrium (that is at $(q_1^{**}, q_E^{**})$), where $\pi_1' = \pi_E' = 0$ holds. It then follows that any reduction of the firms' outputs must increase the sum of firm profits,

which is intuitive because competition induces the firms to produce too many electric cars when compared with the quantity a monopolist would choose. Next note that both terms remain strictly negative in the FET equilibrium (that is, at $(\widehat{q}_1, \widehat{q}_1)$), where $\pi_1' < 0$ and $\pi_E' = 0$ hold. From (58) and (59) we know that any marginal increase of $\alpha$ reduces $I$'s electric car output and increases $E$'s output and that the former change is larger than the total value of the latter change. Rewriting (61) as

$$d[\pi_1 + \pi_E] = \left(\frac{\partial p_1}{\partial Q_1} Q_1 + p_1 - c_1\right) dq_1 + \left(\frac{\partial p_1}{\partial Q_1} Q_1 + p_1 - c_E\right) dq_E \tag{62}$$

shows that $c_1 \geq c_E$ is sufficient to ensure that the firms' sum of profits in the electric car market must increase with a marginal increase of $\alpha$. The terms in brackets on the right-hand side of (62) are equal except for the marginal cost terms. If $c_1 \geq c_E$ then the term in brackets in front of $dq_1$ is strictly smaller than the term in brackets in front of $dq_2$ (while both are negative). A reduction of $q_1$ by an amount larger than the total value of the increase of $q_E$ must then increase the sum of firm profits. Above we showed that any marginal increase of $\alpha$ results in such an adjustment of the outputs in the FET equilibrium. It follows that a pooling agreement with $\alpha = 1$ must increase the sum of the firm profits in the electric car market so that the joint surplus from pooling is also strictly positive, i.e., we have the result as stated in (48).

*VET Equilibrium.* Suppose a pooling agreement with $\alpha > 0$. If the VET equilibrium holds with and without the pooling agreement then the production quantities are not affected and the joint surplus from pooling is given

$$\widetilde{JSP}(\alpha) := \widetilde{\Pi}(\alpha) - \widetilde{\Pi}(0) + \widetilde{\pi}_E(\alpha) - \widetilde{\pi}_E(0) = m\alpha t \widetilde{q}_E > 0. \tag{63}$$

This completes the proof of the proposition. **Q.E.D.**

## Appendix B: Monopoly with Interdependent demands

**Analogue of Proposition 1.** Here, we analyze the monopoly version of our model (Section 3) for the case where the demands for goods $i = 1, 2$ are interdependent. Let $p_i = p_i(q_1, q_2)$ stand for the inverse demand of good $i = 1, 2$ with the following three properties: i) $\frac{\partial p_i}{\partial q_i} < 0$ and ii) $\frac{\partial p_i}{\partial q_i} - \frac{\partial p_1}{\partial q_2} < 0$ with $i = 1, 2$. Thus, the demands are strictly downward sloping in their own and the other good's price, and the own price effect dominates the cross-price effect. In the benchmark case (without an EEP regulation), the monopolist solves

$$\max_{q_1, q_2} \pi := (p_1(q_1, q_2) - c_1)q_1 + (p_2(q_1, q_2) - c_2)q_2, \tag{64}$$

which gives the first-order conditions

$$\pi_1' := \frac{\partial \pi}{\partial q_1} = \frac{\partial p_1}{\partial q_1} q_1 + p_1 - c_1 + \frac{\partial p_2}{\partial q_1} q_2 = 0, \tag{65}$$

$$\pi_2' := \frac{\partial \pi}{\partial q_2} = \frac{\partial p_2}{\partial q_2} q_2 + p_2 - c_2 + \frac{\partial p_1}{\partial q_2} q_1 = 0. \tag{66}$$

Denote the second derivatives of $\pi$ by $\pi_i'' := \frac{\partial^2 \pi}{\partial q_i^2}$ and $\pi_{ij}'' := \frac{\partial^2 \pi}{\partial q_i \partial q_j}$ for $i, j = 1, 2$ and $i \neq j$. The matrix, $M$, of the second derivatives of $\pi$ is then given by

$$M := \begin{pmatrix} \pi_1'' & \pi_{12}'' \\ \pi_{21}'' & \pi_2'' \end{pmatrix} \tag{67}$$

$$= \begin{pmatrix} 2\frac{\partial p_1}{\partial q_1} + \frac{\partial^2 p_1}{\partial q_1^2} q_1 + \frac{\partial^2 p_2}{\partial q_1^2} q_2 & \frac{\partial^2 p_1}{\partial q_1 \partial q_2} q_1 + \frac{\partial p_1}{\partial q_2} + \frac{\partial p_2}{\partial q_1} + \frac{\partial^2 p_2}{\partial q_1 \partial q_2} q_2 \\ \frac{\partial^2 p_1}{\partial q_1 \partial q_2} q_1 + \frac{\partial p_1}{\partial q_2} + \frac{\partial p_2}{\partial q_1} + \frac{\partial^2 p_2}{\partial q_1 \partial q_2} q_2 & 2\frac{\partial p_2}{\partial q_2} + \frac{\partial^2 p_2}{\partial q_2^2} q_2 + \frac{\partial^2 p_1}{\partial q_2^2} q_1 \end{pmatrix}. \tag{68}$$

Note that the cross-derivatives $\pi_{12}''$ and $\pi_{21}''$ are equal. We assume that marginal profits $\pi_1'$ and $\pi_2'$ are strictly decreasing in $q_1$ and $q_2$ and that own-quantity effects dominate cross-quantity effects; that is, we assume

$$\pi_1'', \pi_2'', \pi_{12}'' < 0 \text{ and } \pi_i'' - \pi_{12}'' < 0, \text{ for } i = 1, 2. \tag{69}$$

As a consequence of this, the second-order conditions of the monopolist's problem (64) are fulfilled; namely, we have $\pi_1'' < 0$ and $|M| > 0$. Throughout our analysis, we assume the existence of an interior solution with strictly positive quantities $q_1, q_2 > 0$. Let $q_1^*, q_1^*$ denote the unique and interior solution of the monopolist's problem (64) which fulfills (65) and (66). We then get the same result as stated in Lemma 1 with the only difference that a change of good $i$'s marginal costs not only affects the output of good $i$ but also the output of the other good $j$, with $i, j = 1, 2$ and $i \neq j$. Precisely, for a small change of $c_i$, we get

$$\frac{dq_i}{dc_i} = \frac{\pi_j''}{|M|} < 0 \text{ and } \frac{dq_j}{dc_i} = \frac{-\pi_{ji}''}{|M|} > 0, \text{ for } i, j = 1, 2 \text{ and } i \neq j. \tag{70}$$

With interdependent demands, a small increase of the marginal costs of good $i$ reduces the output of good $i$ (as stated in Lemma 1) and increases the output of the other good $j$. When goods are substitutable, the induced output reduction of good 1 drives some consumers to good 2, which must increase the consumption of the other good in the optimal monopoly solution. Thus, in contrast to the case of independent demands as analyzed in Section 3, a tax on conventional cars would lead to an output expansion of electric cars when goods are substitutable.

Suppose now an EEP regulation in place, which gives rise to the EEP function (6), so that the monopolist's problem is given by (12). Define $t^*$ as in (13) with the only difference that the optimal quantities $(q_1^*, q_2^*)$ now follow from (65) and (66). We then get the same first-order conditions for the FET solution (see (16)-(18)) and for the VET solution (see (22)-(23)) as stated in Section 3, with the only difference that the marginal profits $\pi_1'$ and $\pi_2'$ are now given by (65) and (66), respectively. If we redefine $(\widehat{q}_1, \widehat{q}_2, \widehat{\lambda})$ and $(\widetilde{q}_1, \widetilde{q}_2)$ as solutions of (16)-(18) and (22)-(23), respectively, then Proposition 1 also holds for the interdependent demands case.

**Analogue/Qualification of Proposition 2.** We note that the incentive to expand the production of electric cars beyond the benchmark monopoly solution, $q_1^*$, is now reinforced because of the interdependence of the demands. Under an EEP with $t < t^*$ the output of conventional cars must be reduced below the benchmark monopoly level $q_2^*$ both in the FET and the VET

solution. A reduction of $q_2$ below $q_2^*$ —ceteris paribus— increases the marginal profit of good 1, which in turn directly creates an incentive to raise the output of good 1 (see (65)). That effect is absent when demands are independent. A consequence of this is that the electric car output is larger in the FET solution even for $t = 0$ when demands are interdependent. In contrast, for independent demands, we got that the output of electric cars in the FET solution for $t = 0$ is the same as in the benchmark solution. Formally, we can prove the quantity distortions induced by the EEP both in the FET and the VET solution by examining the comparative statics of the system of first-order conditions (either in case of the FET solution (16)-(17) or of the VET solution (22)-(23)) with respect to $t$. For the VET solution we then get

$$\frac{dq_1}{dt} = -m\frac{\pi_2'' + \pi_{12}''}{|M|} > 0 \text{ and } \frac{d\widetilde{q}_2}{dt} = m\frac{\pi_1'' + \pi_{21}''}{|M|} < 0, \tag{71}$$

where the signs follow from (69). We get the same expressions for the FET solution when we substitute $m$ by $\widehat{\lambda}$. Thus, an EEP with $t < t^*$ always increases (decreases) the output of good 1 (good 2) when compared with the benchmark solution without an EEP. Note also that the monopolist chooses the FET solution (VET solution) when $\widehat{\lambda} \leq m$ ($\widehat{\lambda} > m$) holds. This follows again from noticing that the optimality conditions in the FET solution (24) and the VET solution (24) are parallel while the profit function $\pi(q_1, q_2)$ is strictly concave.

Next, we analyze the emissions target expansion path. Note first that the result stated in Lemma 3 for the VET solution stays valid. This follows directly from the first-order conditions for the VET solution (see (22)-(23)) and using (65) and (66). This gives rise to the comparative statics results stated in (71), which are the same as stated in Lemma 3. Likewise, the discontinuity at $t = t^*$ also stays valid because the products' regulatory marginal costs change abruptly at the point where the emissions target is violated.

The FET solution fulfills (16)-(18), where $\pi_1'$ and $\pi_2'$ are given by (65) and (66), respectively. Taking the total derivative with respect to $t$, we get

$$\begin{pmatrix} \pi_1'' & \pi_{12}'' & t \\ \pi_{21}'' & \pi_2'' & -(x_2 - t) \\ t & -(x_2 - t) & 0 \end{pmatrix} \begin{pmatrix} \frac{d\widehat{q}_1}{dt} \\ \frac{d\widehat{q}_2}{dt} \\ \frac{d\widehat{\lambda}}{dt} \end{pmatrix} = \begin{pmatrix} -\widehat{\lambda} \\ -\widehat{\lambda} \\ -(\widehat{q}_1 + \widehat{q}_2) \end{pmatrix}. \tag{72}$$

Note that (72) gives the total derivatives of $\widehat{q}_1$, $\widehat{q}_2$, and $\widehat{\lambda}$ for all values of $0 \leq t \leq t^*$ with respect to $t$, where the derivatives evaluated at the boundaries $t = 0$ and $t = t^*$ are the left-sided and right-sided derivatives, respectively. Note also that $\widehat{\lambda} = 0$ at $t = t^*$ and that $\widehat{\lambda} > 0$ and $\widehat{q}_2 = 0$ at $t = 0$. Denote the $3 \times 3$ matrix on the left-hand side of (72) by $B$. Let $B_i$, with $i = 1, 2, 3$, be matrix $B$, where the $i$'s column of $B$ is replaced by the vector on the right-hand side of (72).

The determinants of those matrices are

$$
\begin{aligned}
|B| &= -\left[(x_2-t)^2\pi_1'' + t^2\pi_2'' + (x_2-t)t\pi_{12}''\right] > 0 && (73)\\
|B_1| &= (x_2-t)\left[\widehat{\lambda}(x_2-t) + \pi_{12}''(\widehat{q}_1+\widehat{q}_2)\right] + t\left[\widehat{\lambda}(x_2-t) + \pi_2''(\widehat{q}_1+\widehat{q}_2)\right] && (74)\\
|B_2| &= -\left[(x_2-t)\left(\pi_1''(\widehat{q}_1+\widehat{q}_2) - t\widehat{\lambda}\right) + t\left(\pi_{21}''(\widehat{q}_1+\widehat{q}_2) - t\widehat{\lambda}\right)\right] > 0 && (75)\\
|B_3| &= -\widehat{\lambda}\left[-(x_2-t)\left(\pi_{21}'' - \pi_1''\right) - t\left(\pi_2'' - \pi_{12}''\right)\right]. && (76)
\end{aligned}
$$

We thus have $|B| > 0$ and $|B_2| >$ for all $0 \leq t \leq t^*$, whereas the signs of $|B_1|$ and $|B_3|$ can be positive or negative over $0 \leq t \leq t^*$. By Cramer's rule, we then get that a stricter emission target always reduces the number of conventional cars produced; i.e., we have

$$\frac{\widehat{q}_2}{dt} = \frac{|B_2|}{|B|} > 0, \text{ for all } 0 \leq t \leq t^*.$$

Evaluating the effect of $t$ on $\widehat{q}_1$ at the upper boundary $t = t^*$, where $\widehat{\lambda} = 0$ holds, and thus $|B_1|$ reduces to the expression

$$(x_2-t)\left[\pi_{12}''(\widehat{q}_1+\widehat{q}_2)\right] + t\left[\pi_2''(\widehat{q}_1+\widehat{q}_2)\right] < 0,$$

we consequentially get

$$\frac{\widehat{q}_1}{dt} = \frac{|B_1|}{|B|} < 0 \text{ at } t = t^*.$$

Thus, reducing the emission target by a small amount below $t^*$ must increase the number of electric cars produced. Turning to the lower end of values of $t$, we get that $|B_1|$ reduces to the expression

$$|B_1| = x_2\left[\widehat{\lambda}x_2 + \pi_{12}''\widehat{q}_1\right] \text{ at } t = 0,$$

because $\widehat{q}_2 = 0$ must hold at this point. Using (66) and the first-order condition (17), we then get that

$$|B_1| \gtreqless 0 \Leftrightarrow x_2\pi_1'|_{\widehat{q}_2=0} \gtreqless -\widehat{q}_1\pi_{12}''|_{\widehat{q}_2=0} \text{ at } t = 0, \tag{77}$$

with $x_2\pi_1'|_{\widehat{q}_2=0} > 0$. We then get the result stated in Proposition 1 that $\frac{d\widehat{q}_1}{dt} = \frac{|B_1|}{|B|} > 0$ holds at $t = 0$, if the choke price —and with that $\pi_1'|_{\widehat{q}_2=0}$— is sufficiently large. However, in contrast to Proposition 1, condition (77) also shows that there could be instances, where a small increase of $t$ above $t = 0$ could reduce the output of electric cars. If the inverse demands are linear in $q_1$ and $q_2$, the condition (77) can be rewritten as

$$|B_1| \gtreqless 0 \Leftrightarrow p_2 - c_2 \gtreqless -\frac{\partial p_2}{\partial q_1}\widehat{q}_1, \tag{78}$$

where we used (66) and (68). Thus, a small increase of $t$ above $t = 0$ could induce a reduction of electric cars produced whenever the profit margin of conventional cars, $p_2 - c_2$ is small at the choke price and the products are close substitutes such that $-\frac{\partial p_2}{\partial q_1}$ gives a large positive number.

## Appendix C: Pooling with Interdependent demands

We now show that our main results of pooling (see Proposition 6) concerning its allocative effects stay valid when the electric and the conventional car demands are interdependent. Accordingly, assume the inverse demand for electric cars is given by

$$p_1 = p_1(Q_1, q_2) \text{ with } \frac{\partial p_1}{\partial Q_1} < \frac{\partial p_1}{\partial q_2} < 0, \tag{79}$$

and the inverse demand for conventional cars is given by

$$p_2 = p_2(Q_1, q_2) \text{ with } \frac{\partial p_2}{\partial q_2} < \frac{\partial p_2}{\partial Q_1} < 0; \tag{80}$$

that is, we assume that the products are (imperfect) substitutes. We assume that the inverse demand functions are at least twice continuously differentiable and that the mixed partial derivatives are equal (i.e., Young's Theorem holds). The profits $\pi$ and $\pi_E$ and the marginal profits $\pi_1'$, $\pi_2'$, and $\pi_E'$ are defined as before with the only difference that the inverse demands are now given by (79) and (80).

Our analysis from now on proceeds in four steps. In step 1, we analyze the benchmark case without an EEP and here we introduce our main assumption for the entire duopoly analysis with interdependent demands. In step 2, we analyze the effects of pooling when the FET equilibrium holds with and without pooling. In step 3, the effect of pooling is examined when the VET equilibrium holds without pooling. In step 4, we show that the allocative consequences of pooling remain qualitatively valid when pooling allows to realize the benchmark equilibrium without an EEP regulation. Finally, we recapitulate all results in a summary statement.

**Step 1 (Benchmark case without an EEP).** Given the demands (79) and (80), we get the following expressions for the marginal profits and the first-order conditions:

$$\pi_1' = \frac{\partial p_1}{\partial Q_1} q_1 + p_1 - c_1 + \frac{\partial p_2}{\partial Q_1} q_2 = 0, \tag{81}$$

$$\pi_2' = \frac{\partial p_2}{\partial q_2} q_2 + p_2 - c_2 + \frac{\partial p_1}{\partial q_2} q_1 = 0, \text{ and} \tag{82}$$

$$\pi_E' = \frac{\partial p_1}{\partial Q_1} q_E + p_1 - c_E = 0. \tag{83}$$

The second derivatives of firms' profits are given by

$$G := \begin{pmatrix} \pi_1'' & \pi_{12}'' & \pi_{1E}'' \\ \pi_{21}'' & \pi_2'' & \pi_{2E}'' \\ \pi_{E1}'' & \pi_{E2}'' & \pi_E'' \end{pmatrix} =$$

$$\begin{pmatrix} \frac{\partial^2 p_1}{\partial Q_1^2} q_1 + 2\frac{\partial p_1}{\partial Q_1} + \frac{\partial^2 p_2}{\partial Q_1^2} q_2 & \frac{\partial^2 p_1}{\partial Q_1 \partial q_2} q_1 + \frac{\partial p_1}{\partial q_2} + \frac{\partial p_2}{\partial Q_1} + \frac{\partial^2 p_2}{\partial Q_1 \partial q_2} q_2 & \frac{\partial^2 p_1}{\partial Q_1^2} q_1 + \frac{\partial p_1}{\partial Q_1} + \frac{\partial^2 p_2}{\partial Q_1^2} q_2 \\ \frac{\partial^2 p_1}{\partial q_2 \partial Q_1} q_1 + \frac{\partial p_1}{\partial q_2} + \frac{\partial p_2}{\partial Q_1} + \frac{\partial^2 p_2}{\partial q_2 \partial Q_1} q_2 & \frac{\partial^2 p_2}{\partial q_2^2} q_2 + 2\frac{\partial p_2}{\partial q_2} + \frac{\partial^2 p_1}{\partial q_2^2} q_1 & \frac{\partial^2 p_2}{\partial q_2 \partial Q_1} q_2 + \frac{\partial p_2}{\partial Q_1} + \frac{\partial^2 p_1}{\partial q_2 \partial Q_1} q_1 \\ \frac{\partial^2 p_1}{\partial Q_1^2} q_E + \frac{\partial p_1}{\partial Q_1} & \frac{\partial^2 p_1}{\partial Q_1 \partial q_2} q_E + \frac{\partial p_1}{\partial q_2} & \frac{\partial^2 p_1}{\partial Q_1^2} q_E + 2\frac{\partial p_1}{\partial Q_1} \end{pmatrix}. \tag{84}$$

Let $J := \{1, 2, E\}$ denote the set of the considered products with $j \in J$. We impose the standard assumption that all marginal profits (or, equivalently, all marginal revenues) are strictly decreasing in any of the products' quantities. In addition, we suppose that the matrix of the second derivatives of the firms' profits, $G$, is row-wise diagonally dominant.

**Assumption A.1.** *Let*

$$\pi''_j - \pi''_{jj'} - \pi''_{jj''} < 0 \text{ with } \pi''_{jj'}, \pi''_{jj''} < 0 \text{ for all } j \in J \text{ and } j \neq j' \neq j''. \tag{85}$$

As $\pi''_{12} = \pi''_{21}$ holds (see (84)), Assumption A1 implies

$$\pi''_{12} = \pi''_{21} < \pi''_{2E}, \tag{86}$$

which follows from noticing that $\pi''_{12} = \pi''_{21} = \pi''_{2E} + \frac{\partial p_1}{\partial q_2}$ (see (84)). Thus firm $I$'s marginal profit of good 2 reacts stronger to the sales of its own electric cars $q_1$ than to the sales of firm $E$'s electric cars $q_E$. This is a consequence of the multiproduct problem firm $I$ faces. By results presented in McKenzie (1960), the diagonally dominance of $G$ implies that the system of first-order conditions (81)-(83) has a unique and stable Nash equilibrium which we denote by $(q_1^{**}, q_2^{**}, q_E^{**})$.

Let us next analyze the comparative statics of the Nash equilibrium in the absence of an EEP regulation with respect to $c_1$ and $c_2$. Totally differentiating the system of first-order conditions (81)-(83) and rearranging gives

$$\underbrace{\begin{pmatrix} \pi''_1 & \pi''_{12} & \pi''_{1E} \\ \pi''_{21} & \pi''_2 & \pi''_{2E} \\ \pi''_{E1} & \pi''_{E2} & \pi''_E \end{pmatrix}}_{=:G} \begin{pmatrix} \frac{dq_1}{dc_1} & \frac{dq_1}{dc_2} \\ \frac{dq_2}{dc_1} & \frac{dq_2}{dc_2} \\ \frac{dq_E}{dc_1} & \frac{dq_E}{dc_2} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{pmatrix}. \tag{87}$$

By (85) $G$ is a diagonally dominant matrix, which implies that the sign of the determinant of each principal minor of $G$ is given by the product of the respective diagonal entries. Thus, we get $|G| < 0$ which we prove in the following lemma.

**Lemma A.1.** *Assumption A1 implies* $|G| < 0$.

**Proof.** We apply Gaussian elimination to the first column of $G$. Dividing each row of $G$ by the row's first entry, then substracting the first row from the second and the third row, respectively, yields

$$G' := \begin{pmatrix} 1 & \frac{\pi''_{12}}{\pi''_1} & \frac{\pi''_{1E}}{\pi''_1} \\ 0 & \frac{\pi''_2}{\pi''_{21}} - \frac{\pi''_{12}}{\pi''_1} & \frac{\pi''_{2E}}{\pi''_{21}} - \frac{\pi''_{1E}}{\pi''_1} \\ 0 & \frac{\pi''_{E2}}{\pi''_{E1}} - \frac{\pi''_{12}}{\pi''_1} & \frac{\pi''_E}{\pi''_{E1}} - \frac{\pi''_{1E}}{\pi''_1} \end{pmatrix}.$$

Next, we multiply the second (third) row of $G'$ by $\pi''_1$ and $\pi''_{21}$ ($\pi''_1$ and $\pi''_{E1}$), respectively, which

gives

$$G'' := \begin{pmatrix} 1 & \frac{\pi''_{12}}{\pi''_1} & \frac{\pi''_{1E}}{\pi''_1} \\ 0 & \pi''_2\pi''_1 - \pi''_{21}\pi''_{12} & \pi''_1\pi''_{2E} - \pi''_{21}\pi''_{1E} \\ 0 & \pi''_1\pi''_{E2} - \pi''_{E1}\pi''_{12} & \pi''_1\pi''_E - \pi''_{E1}\pi''_{1E} \end{pmatrix}.$$

The sign of the determinant of $G''$ is positive if

$$\pi''_2\pi''_1 - \pi''_{21}\pi''_{12} > \pi''_1\pi''_{2E} - \pi''_{21}\pi''_{1E} \text{ and} \tag{88}$$

$$\pi''_1\pi''_E - \pi''_{E1}\pi''_{1E} > \pi''_1\pi''_{E2} - \pi''_{E1}\pi''_{12} \tag{89}$$

hold. Rewriting the first inequality (88), we get

$$\begin{aligned} \pi''_2\pi''_1 - \pi''_{21}\pi''_{12} - \pi''_1\pi''_{2E} + \pi''_{21}\pi''_{1E} &> \pi''_1\pi''_{21} + \pi''_1\pi''_{2E} - \pi''_{21}\pi''_{12} - \pi''_1\pi''_{2E} + \pi''_{21}\pi''_{1E} \\ = \pi''_1\pi''_{21} - \pi''_{21}\pi''_{12} + \pi''_{21}\pi''_{1E} &= \pi''_{21}(\pi''_1 - \pi''_{12}) + \pi''_{21}\pi''_{1E} > 0. \end{aligned}$$

Proceeding likewise for the second inequality (89), we get

$$\begin{aligned} \pi''_1\pi''_E - \pi''_{E1}\pi''_{1E} - \pi''_1\pi''_{E2} + \pi''_{E1}\pi''_{12} &> \pi''_1(\pi''_{E1} + \pi''_{E2}) - \pi''_{E1}\pi''_{1E} - \pi''_1\pi''_{E2} + \pi''_{E1}\pi''_{12} \\ = \pi''_1\pi''_{E1} - \pi''_{E1}\pi''_{1E} + \pi''_{E1}\pi''_{12} &= \pi''_{E1}(\pi''_1 - \pi''_{1E}) + \pi''_{E1}\pi''_{12} > 0. \end{aligned}$$

Thus, both inequalities (88) and (89) are fulfilled, which implies $|G''| > 0$, and hence, $|G| < 0$ because we multiplied seven times a row of $G$ by a negative expression to obtain $G''$. This proves the lemma. **Q.E.D.**

Let $G_{jk}$ be matrix $G$ where the $j^{\text{th}}$ column vector $(j = 1, 2, E)$ is replaced by the $k^{\text{th}}$ column vector $(k = 1, 2)$ of the matrix on the right-hand side of (87). Using Cramer's rule and calculating the determinants of the matrices $G_{jk}$, we get the following comparative statics results:

$$\begin{aligned} \frac{dq_1}{dc_1} &= \frac{|G_{11}|}{|G|} = \frac{\pi''_2\pi''_E - \pi''_{E2}\pi''_{2E}}{|G|} < 0 \\ \frac{dq_2}{dc_1} &= \frac{|G_{21}|}{|G|} = -\frac{\pi''_{21}\pi''_E - \pi''_{E1}\pi''_{2E}}{|G|} > 0 \\ \frac{dq_E}{dc_1} &= \frac{|G_{E1}|}{|G|} = \frac{\pi''_{21}\pi''_{E2} - \pi''_{E1}\pi''_2}{|G|} \end{aligned} \tag{90}$$

$$\begin{aligned} \frac{dq_1}{dc_2} &= \frac{|G_{12}|}{|G|} = -\frac{\pi''_{12}\pi''_E - \pi''_{E2}\pi''_{1E}}{|G|} \\ \frac{dq_2}{dc_2} &= \frac{|G_{22}|}{|G|} = \frac{\pi''_1\pi''_E - \pi''_{E1}\pi''_{1E}}{|G|} < 0 \\ \frac{dq_E}{dc_2} &= \frac{|G_{E2}|}{|G|} = -\frac{\pi''_1\pi''_{E2} - \pi''_{E1}\pi''_{12}}{|G|}. \end{aligned} \tag{91}$$

Given Assumption A1 and noticing (86), we can sign all derivatives except $\frac{dq_E}{dc_1}$, $\frac{dq_1}{dc_2}$, and $\frac{dq_E}{dc_2}$.

However, for the total electric car sales $Q_1$, we get clear cut effects; namely, we have

$$\begin{aligned}\frac{dQ_1}{dc_1} &= \frac{dq_1}{dc_1}+\frac{dq_E}{dc_1}\\ &= \frac{\pi_2''(\pi_E''-\pi_{E1}'')+\pi_{E2}''(\pi_{21}''-\pi_{2E}'')}{|G|}<0 \text{ and} \qquad (92)\\ \frac{dQ_1}{dc_2} &= \frac{dq_1}{dc_2}+\frac{dq_E}{dc_2}\\ &= -\frac{\pi_{12}''(\pi_E''-\pi_{E1}'')+\pi_{E2}''(\pi_1''-\pi_{1E}'')}{|G|}>0. \qquad (93)\end{aligned}$$

Those results are intuitive. Total electric car output is reduced by a small increase of $c_1$ (see (92)) because this induces firm $I$ to reduce its electric car sales and to increase its conventional car sales. Both reactions together tend to lower total electric car sales, and this direction cannot be compensated by the countervailing adjustment of $q_E$. In contrast, a small increase of $c_2$ increases total electric car sales (see (93)) because this induces firm $I$ to reduce its conventional car sales which drives consumers into the electric market which must expand accordingly.

**Step 2 (The effect of pooling in the FET equilibrium).** We are now in a position to analyze the effect of a pooling agreement if the FET equilibrium holds with and without pooling. The FET equilibrium $(\widehat{q}_1,\widehat{q}_2,\widehat{q}_E,\widehat{\lambda})$ fulfills

$$\begin{aligned}\pi_1'+\lambda t &= 0, \qquad (94)\\ \pi_2'-\lambda(x_2-t) &= 0, \qquad (95)\\ \pi_E' &= 0, \text{ and} \qquad (96)\\ tq_1-(x_2-t)q_2+\alpha t q_E &= 0. \qquad (97)\end{aligned}$$

As explained in Section 4, $\alpha=0$ stands for the no-pooling case, and $\alpha=1$ stands for the case that firms $I$ and $E$ pool their entire fleets. In the former case, (97) stands for firm $I$'s emission target constraint, and in the latter case, (97) stands for the joint emission target constraint of firms $I$ and $E$. To compare the FET equilibria of both cases, we treat $\alpha$ as a continuous variable over $[0,1]$.

Totally differentiating the equation system (94)-(97) with respect to $\alpha$, we get

$$\underbrace{\begin{pmatrix}\pi_1'' & \pi_{12}'' & \pi_{1E}'' & t\\ \pi_{21}'' & \pi_2'' & \pi_{2E}'' & -(x_2-t)\\ \pi_{E1}'' & \pi_{E2}'' & \pi_E'' & 0\\ t & -(x_2-t) & \alpha t & 0\end{pmatrix}}_{=:L}\begin{pmatrix}\frac{d\widehat{q}_1}{d\alpha}\\ \frac{d\widehat{q}_2}{d\alpha}\\ \frac{d\widehat{q}_E}{d\alpha}\\ \frac{d\widehat{\lambda}}{d\alpha}\end{pmatrix}=\begin{pmatrix}0\\0\\0\\-tq_E\end{pmatrix}. \qquad (98)$$

Denote the $4\times 4$ matrix on the left-hand side of (98) by $L$ and by $L_i$ the matrix $L$ where the $i^{\text{th}}$ column is replaced by the column vector on the right-hand side of (98). We first analyze the determinant of $L$, which turns out to be strictly negative.

**Lemma A.2.** *Assumption A1 implies* $|L|<0$.

**Proof.** Using the Laplace expansion along the fourth row of $L$, we get

$$|L| = -t \begin{vmatrix} \pi''_{12} & \pi''_{1E} & t \\ \pi''_{2} & \pi''_{2E} & -(x_2-t) \\ \pi''_{E2} & \pi''_{E} & 0 \end{vmatrix} - (x_2 - t) \begin{vmatrix} \pi''_{1} & \pi''_{1E} & t \\ \pi''_{21} & \pi''_{2E} & -(x_2-t) \\ \pi''_{E1} & \pi''_{E} & 0 \end{vmatrix} - \alpha t \begin{vmatrix} \pi''_{1} & \pi''_{12} & t \\ \pi''_{21} & \pi''_{2} & -(x_2-t) \\ \pi''_{E1} & \pi''_{E2} & 0 \end{vmatrix}.$$

Using next for the remaining three $3 \times 3$ matrices the Laplace expansion along the third column, we get

$$\begin{aligned} |L| &= -\left[t^2\phi_1 + t(x_2-t)\phi_2 + (x_2-t)^2\phi_3\right], \text{ with} \qquad (99) \\ \phi_1 &:= \pi''_2\pi''_E - \pi''_{E2}\pi''_{2E} + \alpha\pi''_{21}\pi''_{E2} - \alpha\pi''_{E1}\pi''_2, \\ \phi_2 &:= \pi''_{12}\pi''_E - \pi''_{E2}\pi''_{1E} + \pi''_{21}\pi''_E - \pi''_{E1}\pi''_{E2} + \alpha\pi''_1\pi''_{E2} - \alpha\pi''_{E1}\pi''_{12}, \text{ and} \\ \phi_3 &:= \pi''_1\pi''_E - \pi''_{E1}\pi''_{1E}. \end{aligned}$$

Inspecting the expressions of $\phi_1$ and $\phi_3$, we get that both are strictly positive, which follows from

$$\begin{aligned} \phi_1 &> \pi''_2\pi''_{E1}(1-\alpha) + \pi''_{E2}\pi''_{21}(1+\alpha) > 0 \text{ and} \\ \phi_3 &> \pi''_{12}\pi''_{E1} + \pi''_{12}\pi''_{E2} + \pi''_{1E}\pi''_{E2} > 0, \end{aligned}$$

whereas the sign of $\phi_2$ remains ambiguous. Now note that the sum of the terms in the rectangular brackets on the right-hand side of (99) is positive if the following two inequalities are fulfilled:

$$\phi_1 + \phi_2 > 0 \text{ and } \phi_2 + \phi_3 > 0. \qquad (100)$$

For the first inequality of (100), we get

$$\begin{aligned} \phi_1 + \phi_2 &> (1-\alpha)(\pi''_2\pi''_1 + \pi''_{12}\pi''_{E1} - \pi''_{E2}\pi''_{1E}) + (1+\alpha)(\pi''_{E2}\pi''_{21} + \pi''_{E2}\pi''_{12}) + \pi''_{E1}(\pi''_{21} - \pi''_{E2}) \\ &> (1-\alpha)(\pi''_2\pi''_1 - \pi''_{E2}\pi''_{1E}) \\ &\geq (1-\alpha)\left[\pi''_{21}\pi''_{12} + \pi''_{1E}(\pi''_{21} - \pi''_{E2}) + \pi''_{2E}\pi''_{12} + \pi''_{2E}\pi''_{1E}\right] \geq 0, \end{aligned}$$

where the last inequality follows from (86). And for the second inequality of (100), we get

$$\begin{aligned} \phi_2 + \phi_3 &> (1-\alpha)(\pi''_{12}\pi''_{E1} - \pi''_{E2}\pi''_{1E}) + \pi''_{E1}(\pi''_{21} - \pi''_{E2}) + \pi''_{E2}\pi''_{12}(1+\alpha) + \pi''_{12}(\pi''_{E1} + \pi''_{E2}) + \pi''_{1E}\pi''_{E2} \\ &> -\pi''_{E2}\pi''_{1E}(1-\alpha) + \pi''_{1E}\pi''_{E2} \\ &= \alpha\pi''_{1E}\pi''_{E2} \geq 0. \end{aligned}$$

Thus, the term in rectangular brackets on the right-hand side of (99) is strictly positive, and we get the result stated in the lemma. **Q.E.D.**

It is immediate that $|L_4| = -tq_E|G| > 0$, which implies

$$\frac{d\widehat{\lambda}}{d\alpha} = \frac{|L_4|}{|L|} < 0.$$

Thus, a pooling agreement unambiguously relaxes the incumbent firm's emission constraint. This in turn implies that —for a fixed value of $q_E$— the output of electric cars must be reduced whereas the output of conventional cars must increase. Taking into account the optimal response of $E$ this result stays valid as we show next. For the determinant of $L_1$, we get

$$\begin{aligned} |L_1| &= tq_E \begin{vmatrix} \pi''_{12} & \pi''_{1E} & t \\ \pi''_{2} & \pi''_{2E} & -(x_2-t) \\ \pi''_{E2} & \pi''_{E} & 0 \end{vmatrix} \\ &= tq_E \left[ t(\pi''_2\pi''_E - \pi''_{E2}\pi''_{2E}) + (x_2-t)(\pi''_{12}\pi''_E - \pi''_{E2}\pi''_{1E}) \right] \end{aligned}$$

and for the determinant of $L_E$, we get

$$\begin{aligned} |L_E| &= tq_E \begin{vmatrix} \pi''_{1} & \pi''_{12} & t \\ \pi''_{21} & \pi''_{2} & -(x_2-t) \\ \pi''_{E1} & \pi''_{E2} & 0 \end{vmatrix} \\ &= tq_E \left[ t(\pi''_{21}\pi''_{E2} - \pi''_{E1}\pi''_2) + (x_2-t)(\pi''_1\pi''_{E2} - \pi''_{E1}\pi''_{12}) \right]. \end{aligned}$$

It then follows that

$$\begin{aligned} \frac{dQ_1}{d\alpha} &= \frac{dq_1}{d\alpha} + \frac{dq_E}{d\alpha} = \frac{|L_1| + |L_E|}{|L|} \\ &= tq_E \frac{t(\pi''_2(\pi''_E - \pi''_{E1}) + \pi''_{E2}(\pi''_{21} - \pi''_{2E})) + (x_2-t)(\pi''_{12}(\pi''_E - \pi''_{E1}) + \pi''_{E2}(\pi''_1 - \pi''_{1E}))}{|L|} < 0, \end{aligned}$$

so pooling must reduce total electric car sales. For firm $I$'s conventional car sales, we get the opposite outcome because

$$\begin{aligned} \frac{dq_2}{d\alpha} &= \frac{|L_2|}{|L|} = \frac{-tq_E}{|L|} \begin{vmatrix} \pi''_{1} & \pi''_{1E} & t \\ \pi''_{21} & \pi''_{2E} & -(x_2-t) \\ \pi''_{E1} & \pi''_{E} & 0 \end{vmatrix} \\ &= -tq_E \frac{t(\pi''_{21}\pi''_E - \pi''_{E1}\pi''_{2E}) + (x_2-t)(\pi''_1\pi''_E - \pi''_{E1}\pi''_{1E})}{|L|} > 0. \end{aligned}$$

We thus have established the following result.

**Proposition A.1.** *Assume the demands for electric and conventional cars are given by* (79) *and* (80)*, respectively, and that assumption* (85) *holds. If the FET equilibrium holds with and without pooling, then pooling with* $\alpha = 1$ *has the following effects:*

*i*) *Pooling reduces the total output of electric cars* $Q_1$*.*

*ii*) *Pooling increases the output of conventional cars* $q_2$*.*

*iii*) *Pooling reduces the value of the Lagrange multiplier* $\lambda$*.*

**Step 3 (The effect of pooling in the VET equilibrium).** The VET equilibrium $(\widetilde{q}_1, \widetilde{q}_2, \widetilde{q}_E)$ fulfills (94)-(96) if we replace $\lambda$ by $m$ in (94) and (95). This equation system is independent of $\alpha$, so

that pooling has not allocative effects if the VET equilibrium holds with and without pooling. From Proposition A1, we know that the Lagrange multiplier in the FET equilibrium decreases monotonically in $\alpha$. Thus, if the VET equilibrium holds without pooling, then pooling can induce a switch to the FET equilibrium if $\widehat{\lambda}(\alpha = 0) > m \geq \widehat{\lambda}(\alpha = 1)$ holds. If this is the case, then pooling leads to the same effects are stated in Proposition A1.

**Step 4.** Suppose that pooling allows to realize the benchmark equilibrium $(q_1^{**}, q_2^{**}, q_E^{**})$, which is the case if the joint emission target constraint is not binding at this point; i.e., if

$$-tq_1^{**} + (x_2 - t)q_2^{**} - tq_E^{**} < 0$$

holds. If the FET solution holds without pooling, then the effect of pooling follows from noticing that pooling reduces the Lagrange multiplier in (94) and (95) from a strictly positive value to zero. The effect of pooling is then analogous to an increase of $c_1$ and a reduction of $c_2$. Using our above comparative static results for $Q_1$ (see (92) and (93)) and $q_2$ (see (90) and (91)) it follows that pooling must reduce $Q_1$ and increase $q_2$. Finally, assume that the VET solution holds without pooling. As noted above the VET solution also fulfills (94) and (96) if we replace $\lambda$ by $m$. The effect of pooling then follows from reducing $m$ from a strictly positive value to zero. It is then obvious that the effect of pooling is to reduce $Q_1$ and to increase $q_2$.

We summarize those results as follows.

**Proposition A.2.** *Assume the demands for electric and conventional cars are given by (79) and (80), respectively, and that assumption (85) holds. A pooling agreement between I and E then has the following allocative effects depending on the value of $m$ and the value of $\widehat{\lambda}$ at $\alpha = 0$ and $\alpha = 1$:*

*i) If $\widehat{\lambda}(\alpha = 0) \leq m$, then the FET equilibrium holds without pooling and pooling reduces the total output of electric cars and increases the output of conventional cars.*

*ii) If $\widehat{\lambda}(\alpha = 1) \leq m < \widehat{\lambda}(\alpha = 0)$, then the VET equilibrium holds without pooling and pooling reduces the total output of electric cars, increases the output of conventional cars, and reduces the EEP firm I has to pay to the government.*

*iii) If $m < \widehat{\lambda}(\alpha = 1)$, then the VET equilibrium holds with and without pooling and pooling only reduces the EEP firm I has to pay to the government.*

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