Competition vs. Cooperation: Do Subsidies with Government-Set Eligibility Threshold Values Produce Lower Battery Electric Vehicle Prices?

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Abstract: The present work is related to a subsidy program, with government-set eligibility threshold values, for Battery Electric Vehicles (BEVs), based on the tender of the Hungarian Ministry of Economics and Technology related to the Climate Action plan. After describing the program, the Hungarian BEV market in this period is presented using aggregate registration data available from 2016 to 2021. The paper has a methodological contribution by showing the relevant breakpoints of illustrated profit functions with imposed threshold values for subsidy eligibility in a monopolistic frame. On this basis, the program's effects on the prices' behavior for three selected BEV models is analyzed and the extent to which the threshold values impact the firms' cooperation in an oligopoly market is evaluated. Results show that the program was inefficient upon its launching since the threshold value was too high, and thus firms could partially capture benefits of the subsidy. On the other hand, it is shown in the third cycle of the program that a threshold value chosen from the optimal price interval gathers prices higher than the threshold to the focal point given by the threshold, and thus it has a price-decreasing effect. In the last cycle of the program, a lower threshold value could have been more effective; however, data on these models show that non-optimum thresholds create competition, and thus prices decrease until a certain level regardless.

Keywords: BEV; battery electric vehicles; government subsidy; focal point; price control; equilibrium price

1 Introduction

The objective of the present work is to analyses a specific subsidy type on the Hungarian battery electric automotive market, where firms have to set their prices below a government-set threshold value in order to be eligible for the subsidy. The aim of the program was to spread the strictly electric vehicles in the country in the time period of 2016 and 2021. The most constraining criteria of product eligibility was a government-imposed threshold value (or values), which acts as a price limitation, very similar to a price ceiling, except that, it is not compulsory for firms to price their products below the imposed value, only if they want them to gain eligibility. Thus, an expected effect of the threshold is the restructuring of the pricing system on the market, so sellers of models with prices exceeding the threshold by a small amount will tend to reduce their sales prices, while those under it will tend to increase them.

The first assumption has already been confirmed, as prices for several models were reduced upon the announcement of the subsidy program. For instance, according to the Portfolio.hu online Hungarian magazine, the price of Peugeot e-2008 was reduced slightly below the threshold from HUF 12.1 M to HUF 11.99 M. Furthermore, price reductions have been implemented for the Kia e-Niro and the Nissan Leaf models as well. Moreover, based on the data, it is obvious that the prices of several models, such as Hyundai Ioniq and Kia EV6, were set just below the threshold of eligibility. There are two interesting questions to be addressed. First, to what extent does the value of the threshold affect the prices of the analyzed models in order to meet the eligibility criteria? Second, will threshold values act as focal points, or will competition force firms to decrease their prices even more below the eligibility threshold?

The present paper uses aggregate data on new BEV registration in Hungary from 2016 to 2022 and adopts the equations included in the methodology suggested by Berry, Levinsohn, and Pakes (1995) [3] to provide a graphical illustration of the results. Expressions derived from the demand and supply theory are used to illustrate profit functions with government-set threshold and subsidy values, assuming the coordination of firms in order to analyses the behavior of these functions. The assumption on the coordination of firms is rather harsh, but it comes with a great advantage since this way a monopolistic frame can be illustrated, and thus the tools for approaching the firms' profit functions are given. The methodology will be presented in more detail in subsections 5.3 and 6.3. Graphical representations are used to show through that the profit functions are not continuous, as their breakpoint locations depend on the threshold values and the subsidy amounts. In the empirical analysis, three BEV models are selected, namely the Kia e-Niro, Hyundai Kona, and Honda-e. In order to represent their profit functions, a total cost value is assumed based on other papers' estimations [1] [8] [13], and further assumptions are made on the value of product characteristics and error terms.

Results show that the program was the most efficient in the third cycle, when analyzed firms priced their products at the focal point that was slightly below the threshold value. In the fourth cycle, due to the higher threshold, competition had more pulling power than cooperation, and thus the analyzed firms priced with roughly 5% below the threshold. This reveals two aspects regarding the fourth cycle: with a lower threshold, prices could have been pushed downwards, but also, in an oligopoly, when the threshold is slightly higher than the optimum, competition will decrease prices until a certain level regardless. This result contributes to the literature on focal points by showing that the higher the threshold value, the lower the probability of tacit collusion [20] and the less likely is the focal point phenomena to happen. The second cycle was quite inefficient due to the very high threshold value, which probably had an undesired effect on firms' pricing strategy.

The present enriches the literature on fuel-efficient vehicles that has become very rich in the recent decades, mostly due to the increased popularity of green transportation and climate action programs. Gallagher and Muehlegger's (2008) [14] paper is one of the earliest works that studies the hybrid-electric automobile market in the US, and it concludes that the type of the tax incentive (sales tax, income tax, or non-tax incentive) has the same importance as its value. One year later, Diamond (2009) [6] analyses the impact of government incentives on the adoption of three selected HEV models. Chandra et al. (2010) [5] analyzed a sales tax rebate on HEVs in five provinces in Canada and found that a $1,000 increased in the provincial sales tax rebate increases the market share of hybrid vehicles by 31-38%. Analyzing the incidence of existing subsidies for Toyota Prius, Sallee (2011) [23] determined the benefits from tax incentives for hybrids and concluded that consumers had captured the benefits of the subsidy even though they had had to face long queues because of the high demand. Later, Beresteanu and Li (2011) [2] made another contribution to the literature by adopting a structural method to estimate an equilibrium model for the entire US automobile market, with a focus on gasoline prices and HEV adoption. Jenn et al. (2013) [19] implement a model that is able to neglect the increase in sales as a result of technology adoption and not due to government incentives, and thus it obtains a more realistic result on the effectiveness of the programs. The present work aims to contribute to the presented literature, as it analyses the pricing strategies of three selected BEV models and finds that the value of the eligibility threshold is extremely important for the achievement of price decreases on the targeted BEV market.

Further, the literature on the implementation of focal point hypothesis and on firms' cooperation vs. competition pricing strategies when a price control of some nature is introduced by the government is elaborated. It is known from the theory of focal points that there exists some kind of gathering of prices around certain natural focal points (e.g., $199.99), which may lead to tacit collusion [20]. Let us now introduce a government-set price ceiling. It is expected that prices will be set at the ceiling, and so it is realistic for ceiling values to act as focal points without necessarily involving tacit collusion [20]. Confirming this result, results of the paper at hand show that in certain cycles of the analyzed subsidy, firms decrease the price of their products to the focal point given by the threshold value, which acts like a price ceiling in this case. Another important aspect of the focal point is that, all else being equal, it becomes more difficult to sustain tacit collusion as the focal point rises [20]. The underlying logic is straightforward: the higher the gap between the focal point and the equilibrium point, the higher the place for competition and the more will profits rise with lower prices than with cooperation. Moreover, in this paper it is contended that the higher the threshold value, the lower the probability of the focal point phenomena to occur. This affirms the expectations of Zhang et al. (2020) [25], who argue that a lower price ceiling would result in higher coordination, whilst a higher price ceiling would reduce the probability of reaching a common price at the focal point on the Chinese gasoline station market. Their paper presents an example of tacit collusion, analyzing a price ceiling on the Chinese gasoline station market and outlining some situations in which stations increase prices and coordinate to the focal point at the price ceiling, thus challenging the assumption that price ceilings serve the purpose of preventing firms from monopolizing consumer surplus [24].

The paper signed by Fan and Zhang (2020) [12] is crucial since, to my knowledge, it is the only work that analyses a subsidy program with some type of price control set by the government. The analyzed subsidy form has similar aspects to the one examined in this paper, except that once a firm had gained eligibility for a product, it was constrained to price it below the winning ceiling. Therefore, competition was required for eligibility, and the focal point theory could not hold either since the ceiling values differed both on the firm and product level. The paper at hand paper seeks to find answers to the same fundamental questions but in a slightly different scenario, using a different approach: will threshold values act as focal points and result in decreased prices? Is there an optimal threshold value that generates the lowest prices for the analyzed BEVs, thus increasing the consumer surplus and the spread of BEVs in the country?

2 Background and Data

The Hungarian Ministry of Economics and Technology announced a subsidy within the Climate Action program that aims to stimulate the purchase of fully electric vehicles. The program started in the year 2016 and the last application period was in 2021. Within this time frame, there were four different cycles of the program, all having their specific subsidy benefits and eligibility requirements shown in *Table 1*. The data comes from the private company DATAHOUSE, which collects and processes data on new car registration in Hungary. The provided database contains information on imported and sold automotive vehicles from 2014 to 2022 that covers a wide range of product characteristics and on new BEV registrations from October 2016 to October 2022. In this period a total of 14,112 BEVs were registered.

Unfortunately, we do not have price data on some high-end models such as Tesla, therefore these observations were removed from the database, and thus we end up with 13,676 sold NEVs in this period.

Table 1
Benefits and requirements of the government subsidy program between 2016 and 2021 (prices and values in HUF)

	I	II	III	IV
Application Period	09.2016 — 08.2018	10.2018 — 02.2020	15.06.2020	06.2021
Value	21% (max. 1.5 M)	21% (max. 1.5 M)	2.5 M / 0.5 M	2.5 M / 1.5 M
Threshold	15 M	20 M	11 M / 15 M	12 M / 15 M
Budget	2.3 B	3 B	2 B	3 B

Table 2 presents the central tendency and variability measures of the gross prices of registered BEVs with dealer discounts other than the subsidy in each cycle of the program. Note that due to slow administrative procedures some of the BEVs subsidized in the first cycle were actually registered in 2019 and 2020. Similarly, registrations from the second cycle were dragged on at least until 2021. Having information on actual purchases in almost each year from official statements [9] [10] [11] [16-18], the data company delimited the cycle periods when BEVs were actually registered, accumulating linearly in time the subsidized registrations in each cycle. In this sense, the first cycle includes all BEV registrations from 2016 to 2018 and the remaining subsidized registrations from January 2019 and 2020 respectively. The second, the third, and the fourth cycle include all registrations from February 2019 to May 2020, from June 2020 to July 2021, and from August 2021 to October 2022 respectively.

Firstly, it is to be observed that contrary to the maximum values, the minimum values of BEVs did not increase remarkably; the most expensive electric vehicle in the last cycle being almost 5 times higher than in the first one. This increase in prices on the high-end comes along with the worldwide spread of BEVs and thus the appearance of luxury electric vehicles that are usually SUV models and are more expensive to produce. For instance, in *Table 2*, the maximum values for 2020 and 2021 correspond to the Audi E-tron GT and Mercedes EQS sports cars respectively, both having a kW power value greater than 400. It is interesting to note that in the first cycle even the price of the most expensive car was non-binding and more than that, it appears from import data that 100% of the list prices were non-binding in the second cycle until the end of the application period. This brings up an interesting question about the meaning of the threshold value in these years. In the third cycle, the mode value is HUF 10.99 M, which is slightly below the eligibility threshold. This suggests that there might be a gathering of prices around a focal point defined by the threshold value in the third cycle.

The median price is rising, however its value in the fourth cycle is only 1.43 times as high as in the first one, while the maximum price increased to a 4,83 times higher value in the same period.

Table 2
Descriptive statistics measures of gross prices with dealer discounts of BEVs registered in Hungary during the four cycles of the analyzed subsidy program (prices in million HUF)

	I. Cycle	II. Cycle	III. Cycle	IV. Cycle
Total Obs.	2119	2421	3129	5460
Minimum	6.91	6.55	6.50	6.57
Maximum	13.88	33.01	53.25	67.09
Mean	9.71	12.03	12.42	15.92
Mode	7.15	11.25	10.99	8.49
Median	9.89	11.29	11.97	14.19
Std. dev.	2.10	4.10	4.30	8.20

Further, the mean price increased by 64% during the four cycles, which is again higher than the increase of the median value (43%), showing that even though the BEVs' scale of diversity and price value has risen, the majority of the vehicles are priced lower than the average and probably target the low- and middle-class of consumers. Finally, the standard deviation measures of prices increased significantly, which was expected taking into account the above-mentioned widening of the price range.

3 Illustration of Profit Functions with Thresholds Required for Subsidy Eligibility Following a Cooperative Strategy

This paper makes use of the equations from the mentioned BLP approach that builds on a random-coefficients logit model. After shortly presenting the demand and supply sides of this model, several scenarios will be presented to show the potential equilibrium prices of cooperating firms considering a subsidy with government-imposed threshold values set for eligibility. As it is assumed that firms cooperate, we can implement a monopoly market that simplifies the model that implements several advantages to be presented later on. The assumption of a monopolistic market structure may seem harsh at first sight, but considering the subsidy eligibility as carrying a higher market power than competition, thus encouraging firms to set prices at the focal point, the monopolistic approach might be a realistic one.

3.1 Demand

The utility that consumer i obtains from consuming product j is given by equation (1):

$$u_{ijm} = \alpha_i p_{jm} + x_{jm}\beta_i + \xi_{jm} + \varepsilon_{ijm} \quad (1)$$

where α_i is the individual-specific coefficient of price, p_{jm} is the price of product *j* in market m, x_{jm} is a vector of non-price attributes of product *j* in market m, β_i is an individual-specific vector of the coefficients, ξ_{jm} is the product-specific utility in market *m* that is unobserved by the researcher and correlated with p_{jm}. The product- and individual-specific idiosyncratic error term, ε_{ijm}, is assumed to be an iid type I extreme value random variable.

We can decompose the term α_i from equation (1) as $\alpha_i = \alpha + \sigma v_{i\alpha_i}$ random variable, with the expected value of α and variance σ, $v_i \sim N(0,1)$. In this model specification, the probability that a randomly chosen consumer chooses product *j* in market *m* is given by equation (2):

$$s_{jm} = \int_{R^K} \frac{exp\left(\left(\alpha+\sigma v_{i\alpha_i}\right)p_{jm}+x_{jm}(\beta+\Lambda v_i)+\xi_{jm}\right)}{1+\sum_{r=1}^{J} exp\left(\left(\alpha+\sigma v_{i\alpha_i}\right)p_{rm}+x_{rm}(\beta+\Lambda v_i)+\xi_{rm}\right)} \phi\left(v_{i\alpha_i} v_i\right) dv_{i\alpha_i}\, dv_i \tag{2}$$

The probability that a randomly chosen consumer chooses none of the products in market *m* is given by equation (3):

$$s_0 = \int_{R} \frac{1}{1+\sum_{r=1}^{J} exp\left(\left(\alpha+\sigma v_{i\alpha_i}\right)p_{rm}+x_{rm}(\beta+\Lambda v_i)+\xi_{rm}\right)} \phi\left(v_{i\alpha_i} v_i\right) dv_{i\alpha_i}\, dv_i \tag{3}$$

Since the integral in equation (2) cannot be calculated exactly, it is usually approximated by the Monte Carlo simulation given by equation (4):

$$\widetilde{s_{jm}} = \frac{1}{N}\sum_{i=1}^{N} \frac{exp\left(\left(\alpha+\sigma v_{i\alpha_i}\right)p_{jm}+x_{jm}(\beta+\Lambda v_i)+\xi_{jm}\right)}{1+\sum_{r=1}^{J} exp\left(\left(\alpha+\sigma v_{i\alpha_i}\right)p_{rm}+x_{rm}(\beta+\Lambda v_i)+\xi_{rm}\right)} \tag{4}$$

3.2 Supply

We assume that firms engage in a pricing game. There are F firms, $f \in \{1, \dots, F\}$, and we suppose they solve a standard Bertrand price competition – thus, one firm sets its prices given other firms' retail prices, so we denote the prices of competitor firms' products by p_{-fm} and the marginal cost of product *j* in market *m* by mc_{jm}. We denote the product set of firm *f* in market *m* by $\mathcal{J}_{fm}$. The profit of firm *f* is defined as:

$$\Pi_f(p) = M \sum_{j\in\mathcal{J}_{fm}} \left(p_{jm} - mc_{jm}\right) s_{jm}(p_{fm}, p_{-fm})$$

where p_{jm} is the vector of all prices in market m and M is the number of consumers in market m. For notation purposes, we denote the market share function in equation (2) as $s_{jm}(p_{fm}, p_{-fm})$. The Nash equilibrium is given by the solution of the non-linear system of equations:

$$\frac{\partial \Pi_{fm}}{\partial p_{jm}}(p) = 0, f = 1, \dots, F$$

which is equivalent to:

$$s_{jm}(p) + \sum(p_{rm} - mc_{rm})\frac{\partial s_{rm}}{\partial p_{jm}}(p) = 0$$

This equation stands for the standard case where firms are not constrained by a threshold value for eligibility. However, not being free to set any price and also benefiting from the subsidy changes this equation. The case of threshold constraints will be elaborated in the next section by discussing several scenarios that lead to different equilibrium prices on the market.

3.3 Illustration of Equilibrium Prices with Government-Set Threshold Values for Subsidy Eligibility in Cooperation

Assuming that firms cooperate, we consider a market of monopoly for analyzing the behavior of the profit functions with imposed threshold values above which products are not eligible for the subsidy. The analysis is performed with the help of a graphical representation of the profit functions in four scenarios that have distinct profit-maximizing price outcomes due to the differently defined set-ups of threshold and subsidy amount values. For illustration purposes, we will use a simpler version of equation (4), where we define the market share as being dependent on price *p* and gather all other variables in a parameter *d*:

$$s(p) = \frac{\exp(-p+d)}{1+\exp(-p+d)}$$

In the standard case when there is no government-set subsidy available, the profit function takes the following form:

$$\pi(p) = (p - c)s(p)$$

and the firm wants to maximize its profit:

$$\max_p\left((p - c)\frac{\exp(-p+d)}{1+\exp(-p+d)}\right)$$

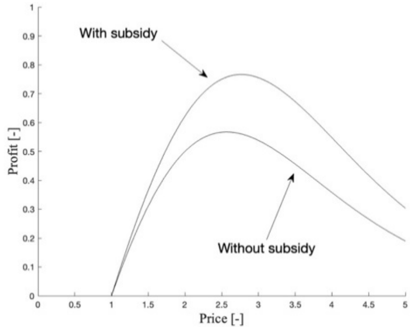
In order to illustrate the profit function, we have to assume the values of marginal cost, product characteristics, and error term, so let $c = 1$ and $d = 2$. Further, we introduce a government subsidy, $q = 0.5$; however, for now, we assume there is no threshold for eligibility. Thus, the profit function takes the following form:

$$\pi(p) = (p - c)s(p - q)$$

and the firm wants to maximize its profit:

$$\max_p\left((p - c)\frac{\exp(-(p-q)+d)}{1+\exp(-(p-q)+d)}\right), \text{such that } c = 1, d = 2, q = 0.5$$

Figure 1 contains the graphical representation of the profit functions with and without subsidy, which, as expected, are concave and continuous respectively.



Profit functions for monopoly with and without subsidy (q = 0.5) and without eligibility threshold

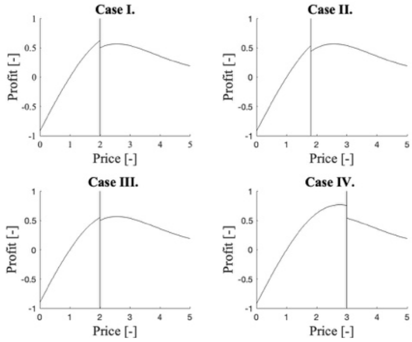
We can easily observe in *Figure 1* the pricing strategy mechanism when a subsidy without any price limitation is "freely" given by the government. For any price that generates a positive profit, the profit function with subsidy is above the one without subsidy, and thus we can see that the value of profit is higher for any price greater than one. Moreover, the profit function with subsidy reaches its maximum at a higher price, and thus the monopolist will raise the price of the product in order to increase the producer surplus and partially capture benefits of the subsidy. Obviously, the aim of such incentives is the spread of subsidized products, and thus producers increasing prices and benefiting from the subsidy is highly counterproductive.

A solution to this issue is the application of a threshold price above which products do not benefit from the subsidy. We denote the threshold by $\bar{p}$ and let $\bar{p} = 2$, and thus the profit function takes the following form:

$$\begin{cases} (p - c)s(p - q) & \text{if } p < \bar{p} \\ (p - c)s(p) & \text{if } p \geq \bar{p} \end{cases}$$

Depending on the threshold value and the subsidy amount, there are four important scenarios that must be distinguished. *Figure 2* illustrates these four cases using different threshold values and subsidy amounts in order to analyses their effect on the profit-maximizing prices. Firstly, it is to be noted that the profit functions are not continuous, their breakpoints being at the threshold. Secondly, observe that there are cases in which the profit-maximizing price is higher than the threshold. Furthermore, in the last case, the profit-maximizing price is below the threshold, but note that this scenario generates the highest price.

The first case is the only one in which the profit-maximizing price is at the threshold. In the second case, the threshold value is lower, $\bar{p} = 1.8$, and thus the value of profit at the profit-maximizing price without subsidy is higher than any other value of profit with subsidy. The outcome of the third case is similar, but here the difference is in the subsidy amount, which is reduced to $\bar{q} = 0.2$.



Graphical illustration of monopolist profit functions facing different eligibility threshold values and subsidy amounts

Again, due to the low subsidy amount, the profit-maximizing price is higher than the threshold value. Lastly, in the fourth case, the threshold value is increased to $\bar{p} = 3$. In this case, there is no point using the threshold value as a limitation since the profit-maximizing point is below it. To conclude, the second and the third case is the same as if there had not been any subsidy available, while the fourth case is as if there had not been any price limitation for eligibility. In this sense, the most efficient scenario is the first one, where the price was reduced compared to the one without subsidy. This structure shows that if the price chosen by a monopolist is not equal to the threshold, then a better setting of the threshold value or subsidy amount probably exists. In addition, if the profit-maximizing price is below the threshold, the firm is partially benefiting from the subsidy, and a lower threshold would generate a lower price.

4 Illustration of Profit Functions with Thresholds Required for Subsidy Eligibility following a Cooperative Strategy

Considering the illustrations presented in Section 4.3, I analyses three selected BEV models and observe if the data correspond to any of the cases in a monopolistic frame. Thus, we can confirm whether the assumption on pricing at the focal point is stronger than that of competition among firms. Three BEV models are selected, specifically Kia e-Niro, Hyundai Kona, and Honda-e. These models were selected for several reasons. First of all, these are among the few that directly indicated the price decreases made in the interest of subsidy eligibility for each vehicle sold. This is a crucial advantage since this way it is known that these models were indeed priced and sold in the framework of the program. Secondly, the selection was made so that analyzed models belong to manufacturers from different countries. Lastly, by opting for this selection, examples of every program cycle and most threshold variations can be examined. In the following section, I will analyses the gross list prices of the mentioned BEVs with discounts other than the subsidy and then illustrate their profit functions based on the presented theory.

4.1 Evolution of BEV Sales and Prices of the Analyzed Models

The first analyzed model is the Kia e-Niro with 100 kW power. It can be seen in *Table 3* that the highest price of this model was in the second cycle, when the threshold value was very high compared to the equilibrium price; thus, firms engaged in an unconstrained price competition and probably even monopolized part of the consumer surplus due to the subsidy.

Table 3
Price and number of Kia e-Niro (100 kW) BEVs registered in Hungary (prices in thousand HUF)

	II. Cycle		**III. Cycle**		**IV. Cycle**
Sales Price	11,799	12,499	10,999	10,899	11,499
Sold no.	2	29	150	3	151

In the third cycle, the highest number of sales was made with almost all of the Kia e-Niro models priced at the threshold. Then in the fourth cycle we can observe the second highest number of sales combined with the second lowest price, which is below the threshold value of HUF 12 M.

The second analyzed model is the Hyundai Kona with 100 kW power, which is very similar to the previous one considering its pricing strategy. We can calculate from *Table 4* that 92.18% of the total sales for this model were registered in the third cycle and priced slightly below the threshold of HUF 11 M.

Table 4
Price and number of Hyundai Kona (100 kW) BEVs registered in Hungary (prices in thousand HUF)

	II. Cycle	**III. Cycle**	**IV. Cycle**		
Sales Price	12,049	10,999	13,299	14,469	10,699
Sold no.	15	271	4	3	1

Also, we can see that within this cycle period 100% of the BEVs were priced at the threshold value. Note that in the second cycle the price of this model is approximately HUF 1 M (9.55%) higher than in the third cycle. Also, note that in the fourth cycle the sales of these models were relatively low and the prices were above the threshold value that increased to HUF 12 M. However, it is to be mentioned that these models were all registered in 2022, and thus probably this dramatic price increase is not only due to the fact that there was no subsidy in 2022 but also to increased production costs caused by the high inflation in the energy and raw material sectors. More than that, we know from the import data that the original list price value for six of these models was HUF 11,650 K, but they were eventually sold for a higher price.

The third analyzed BEV model, the Honda-e, was not a very popular choice among consumers, as it can be seen in *Table 5* that the total number of registered models was 26.

Table 5
Price and number of Honda-e (100 kW) BEVs registered in Hungary (prices in thousand HUF)

	II. Cycle	III. Cycle
Sales Price	10,999	11,555
Sold no.	16	10

However, regarding the pricing strategy, it follows the path of the Kia e-Niro, and Hyundai Kona models since 16 vehicles were priced exactly below the threshold value of HUF 11 M in the third cycle. Moreover, just like in the case of the previous models, the price is set with roughly HUF 500 K below the threshold of HUF 12 M in the fourth cycle.

4.2 Assumption of BEV Production Total Cost and Consumer Valuation of Product Characteristics

In order to implement the theory presented, the values for cost and product characteristics had to be assumed. The cost of producing a BEV is higher than for an internal combustion (IC) vehicle, mainly due to the high battery costs [7]. In order to become competitive with IC vehicles, the battery pack cost of a BEV must be less than roughly $150 per kWh [13] [22]. In the same paper, the authors calculate with a cost of $250 per kWh for the Li-ion batteries in the optimum scenario [13]; based on this paper, the estimated cost of a Li-ion battery weighting 451 kg is $16,125 [8]. However, technology has advanced, and thus the cost of Li-ion battery production has decreased since the year 2000. Based on other publications of future cost estimations, the cost in 2020 is expected to reach $200 per kWh. This is in line with the battery pack cost assumption of $190–$210 per kWh made in 2019 [1], but it is still higher than the competitive price estimated by [15]. Calculating with a price of $200 per kWh, *Table 6* shows the estimated costs based on the battery types of the analyzed models in the year 2019. The costs are converted to HUF on the average exchange rate in 2019, which was HUF 290.6518/ $1.

Table 6
Estimated battery costs of the analyzed BEVs in 2019

Model	**Type**	**Capacity (kWh)**	**Cost (US$)**	**Cost (HUF)**
Kia e-Niro, Hyundai Kona	Li-Poly	42	8,400	2,441,475
Honda-e	Li-ion	35.5	7,100	2,063,628

Knowing that the total cost of a base IC automotive vehicle is about \$22.5 K, subtracting the IC-related content and adding the BEV-related content but the battery-pack, the total cost of a base BEV is \$24.5 K [1]. Adding the battery pack costs, we get a total cost of \$32.9 K for Kia e-Niro and Hyundai Kona, while for Honda-e the total cost is \$31.6 K. Converting USD to HUF, we get that in 2019 the estimated total cost of Kia e-Niro and Hyundai Kona is HUF 9,562,444 and for Honda-e is HUF 9,184,597. Thus, we assume the cost parameter c from equation (9) to be HUF 9.6 M and HUF 9.2 M respectively. The consumer valuation of BEVs is captured through the product characteristics and unobserved terms measured by parameter d from equation (8). For all analyzed models, except for Honda-e, this parameter is assumed to be HUF 12 M, so roughly the average between the amounts payable with and without subsidy. As Honda-e has a smaller battery capacity and a smaller size, the assumed consumer valuation of the product will also be lower.

4.3 Simulation of the Profit Functions for the Analyzed Models

In the second cycle of the subsidy, the profit functions of the Kia e-Niro and Hyundai Kona models are illustrated in *Figure 3* based on the monopolistic frame described in Section 4.3 and the assumption on cost and product valuation parameters. The two curves represent the profit functions with and without subsidy deduction, and the vertical line stands for the threshold value.

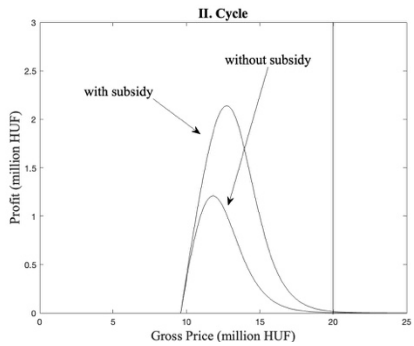


Figure 3
Illustration of the profit functions with and without subsidy of the Kia e-Niro and Hyundai Kona models in the second cycle

We can observe in *Figure 3* that in the second cycle the threshold value for eligibility was very high compared to the profit-maximizing point. Therefore, it basically did not have any direct effect on the pricing strategy[1]. This scenario can be associated with the fourth case of the presented monopoly structure. As the threshold is very high, the firm increases the price and chooses the profit-maximizing point benefiting from the subsidy, thus transforming potential consumer surplus into producer surplus. This supports the first focal point hypothesis, as the gap between the focal point and the market equilibrium is too high and firms refuse to cooperate [20]. We can graphically observe that if the vertical line representing the threshold value would shift to the left to any point in the price interval of the profit-maximum values with and without subsidy, the price would be equal to the threshold. Also, note that the profit-maximizing point with subsidy is roughly at the true price value of the models presented in Tables 3 and 4.

As the production costs of BEVs have become cheaper over time, mainly due to reduction of battery production costs [4], we also gradually reduce the value of the total cost estimation. Whereas by mid-2020, the total base cost of a BEV had reached \$27.4 K – \$28.8 K, this is expected to decrease to \$21.2 K – \$22.6 K by 2025 due to improvements in battery efficiency, reduction in battery pack cost, increase in volume and material substitution [4] [21] [25]. This means a cost reduction of 18.55% on average, and thus parameter c is reduced from \$32.9 K to \$26.8 K for the Kia e-Niro, and Hyundai Kona models and from \$31.6 K to \$25.7 K for the Honda-e model. On the other hand, the exchange rate of Hungarian forint continued to decline compared to the US dollar, and thus the costs increased indirectly. Converted to HUF at the average 2020 exchange rate before the subsidy program was available (HUF 312.986/ \$1), the cost parameter c is HUF 8.4 M and HUF 8 M respectively. Moreover, there were minor improvements performed on the same models over the years (e.g., design), and consumers' valuation of BEVs grew as well due to high popularity and marketing effects. Thus, the parameter d is increased from HUF 12 M to HUF 12.5 M for the Kia e-Niro and Hyundai Kona models. However, Honda-e having lower battery capacity and a smaller size, it was necessary to assign a lower parameter value of product valuation, thus d being HUF 12 M for this model. The subsidy amount q takes the real value of HUF 2.5 M in the third cycle. In *Figure 4*, we can see the illustrations of the profit functions of the Kia e-Niro, Hyundai Kona, and Honda-e BEVs with and without the government subsidy.

[1] It may have had some psychological marketing effects on consumers, as they must have perceived the real price as a good deal being almost twice as low as the threshold.

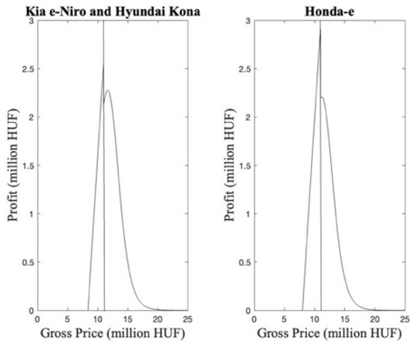


Figure 4
Illustration of profit functions of the analyzed BEVs with imposed eligibility thresholds in the third cycle

In the third cycle, the government lowered the eligibility threshold to HUF 11 M, and we can see in *Figure 4* that the profit-maximizing price for all models is at the threshold. Since Honda-e has a lower total cost and a lower assumed product characteristics value, when comparing the profit-maximizing points with and without subsidy, the absolute difference in the profit values is higher for Honda-e than for the other analyzed models. Perhaps, had it lowered the price, Honda could have sold more models but with a lower profit margin. However, in this period, 100% of the analyzed models were priced slightly below the threshold. This reflects the first case of the monopolistic frame and shows a gathering of these products' prices at the focal point that is at the threshold. This indicates that the threshold value was set to optimum for these models, as a higher value might have resulted in tacit collusion at a higher price [20], whereas a lower value would have been probably ignored by Kia and Hyundai, as the profit without subsidy almost equals that with subsidy for $\bar{p}$ = HUF 11 M.

The fourth cycle is the one in which the monopolistic frame partially contradicts the reality. In the illustration presented in *Figure 5*, we can see that the equilibrium price should be at the threshold, but in reality, it is by approx. HUF 500 K below it for all analyzed models[2].

[2] Note that the cost parameter c was further reduced to \$23 K for the Kia e-Niro and Hyundai Kona models, while parameter d was increased to HUF 13.5 M. In 2021,the average USD/ HUF exchange rate was HUF 296.85/ \$1, so parameter c is HUF 6.8 M.

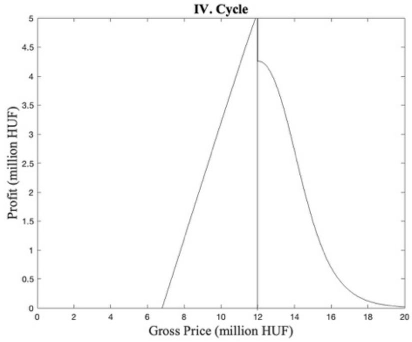


Figure 5
Illustration of the profit functions with and without subsidy of the Kia e-Niro and Hyundai Kona models

This result is consistent with the finding of Zhang et al. (2020) [25], showing that the higher the price ceiling, the lower the probability of coordination. A speculative reason in this typical case, supported by the large number of sales in the case of Kia e-Niro, would be a higher gap between the cooperation at the focal point and the initial market equilibrium with no subsidy, and thus the reduction of prices in hope of higher sales in an oligopoly market. We should also observe that Honda-e did not decrease its prices in the third cycle despite the large gap between the focal point and the initial equilibrium and thus ended up with a low number of sales. In addition, note that, as a rule, profit values show an upward tendency year by year for all BEVs, an observation that might justify the competitive strategy.

In *Figure 6*, we can observe a counterfactual simulation of the fourth cycle, where all values remain unchanged except for the threshold value, which is reduced to HUF 11 M. We can see that in this situation the new equilibrium price might be the original one due to the lower threshold value, representing the second case in the monopolistic frame. According to this counterfactual illustration, it is probable that in reality the threshold would be the equilibrium since the profit values are almost the same for the two functions, and the lower price would attract more consumers in an oligopoly. However, it was rational from the government to increase the threshold value and avoid a scenario in which firms refuse to take the subsidy eligibility into account. More than that, we find that even though the threshold value was slightly higher than the optimum, tacit collusion did not occur at the higher threshold since prices were reduced in the hope of higher profits in an oligopoly market.

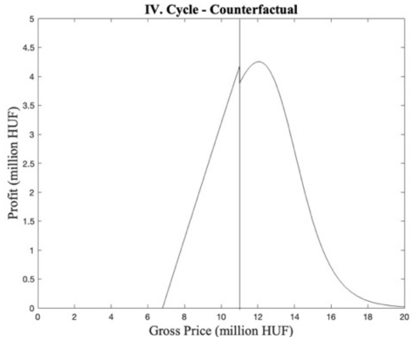


Figure 6
Counterfactual illustration of the profit functions with and without subsidy, when $\bar{p} = 11$

Conclusions

We can conclude that the analyzed subsidy program for BEVs, launched by the Hungarian Ministry of Economics and Technology, was overall effective, considering both the increase in sales and decrease in prices of BEVs, during the program period. The sales of the Kia e-Niro model were 5.76 times higher in 2020 compared to 2019, and the price of the model decreased by 12%, reaching the threshold, in the same period. Furthermore, the sales of the same model increased from January 2021, when no subsidy was available, to May 2021, when the fourth cycle was announced, by 61.97%, while the price decreased by 9.45%. Moreover, 91.03% of all Hyundai Kona models were sold in the third subsidy cycle (in the period of 2019–2022) and at the lowest price. On top of that, all models sold in the third cycle, were priced at the threshold for eligibility, and an increase in prices could be observed subsequently. Also, the highest prices and the lowest sales of the analyzed models were in periods when no subsidy cycle was available.

In the second cycle, the program was inefficient, as the threshold value was too high considering the profit-maximizing prices of the BEVs on the market. This resulted in increased MSRPs and producer surplus. However, it could have had a positive marketing effect on the perception of sales prices by consumers. On the other hand, the choice of the threshold value was highly appropriate in the third cycle, confirmed by both the raw data and the similarity to the theoretical monopolistic frame. Concerning this cycle, it can be concluded that cooperation at the focal point was stronger than competition, and thus the monopolistic pricing strategy could be applied. In the fourth cycle, the increase of the threshold value was rational, as – according to the graphical counter-simulation – without this decision there would have been a risk of firms opting for the profit-maximizing price without the subsidy.

Although here the monopolistic frame could not be applied, we have come to understand that whenever the threshold value is slightly higher than the optimum, firms will engage in a competition and still lower their prices until reaching a new equilibrium point.

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