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Post hoc, propter hoc? Counterfactuals, placebos, and spillovers in evaluating a local mobility policy

Marco Giuliani
Department of Social and Political Sciences, Università degli studi di Milano, Italy

Abstract

Policy reforms are often unique, in the sense that it is hard to find comparable changes and circumstances that would make it possible to clearly identify their net consequences and thus unambiguously support causality attributions. Without the appropriate counterfactuals, there is no way scholars can avoid the uncertainty of their estimates. However, we should accept the causal complexity that characterizes social science, give up on the idea of a model's precision, and increase the robustness of our empirical evidence through multiple testing. This is the research strategy that we adopted in evaluating a reform in the mobility policy of the municipality of Milan, in Italy, which cannot easily be compared to other policy changes. Overall, we found evidence of the direct and indirect effects of the policy reform. However, the research design helped us refine some of our original expectations and fine-tune the underlying mechanisms. This project uses the proposed case study to emphasize the methodological importance of evaluating any policy change using redundant and robust empirical evidence – even accepting some degree of indeterminacy –rather than relying on isolated positive findings.

Keywords

policy evaluation, causality, counterfactual, robustness, mobility policy

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Online appendix: http://bit.ly/46WJSqL

Introduction

Milan, in Italy, has recently fine-tuned its local mobility policy by raising the entry fee for the city center, the so called "Area C". Unlike other schemes in which access to central urban areas is restricted *tout court* (De Robertis & Tira, 2016), the policy for Area C is primarily designed as a congestion charge. This means that, apart from the most polluting vehicles, which are simply prohibited from entering, anyone who wants to use their own vehicle in the city center needs to pay a fixed toll. Limited exceptions apply only to motorbikes, green vehicles, and service vehicles. Residents of the area are granted a fixed number of free entries and discounted tariffs. Although the policy covers an area of only about eight square kilometers, meaning that the efficiency and magnitude of its environmental impact are somewhat limited, it emulates more extensive areas such as those of London, Stockholm, and Gothenburg (Lehe, 2019; Veitch & Rhodes, 2024).

In autumn 2023, ten years after the policy was first implemented, the Municipality of Milan approved a substantial increase in the toll for entering the city center, which had remained unchanged during the previous decade. This article aims to explore the consequences of the recent policy change and to leverage some of its effects to evaluate the outcomes of the tariff adjustment. The fine-tuning of local mobility policy can generate multiple impacts that vary depending on the proximity of the effects, their intentionality, and the presence of intervening or mediating factors.

Since the measure is primarily framed as a congestion policy, its most direct impact concerns the number of vehicles accessing the city center and, consequently, congestion levels. Indirectly, the policy generates additional revenue for the municipality, which the current administration has pledged to reinvest in more sustainable forms of mobility. Paradoxically, the greater the success of the policy in reducing traffic, the lower the revenue generated through its enforcement—although profits have typically exceeded operational costs.

Environmental quality, particularly the reduction of air pollutants, represents another type of indirect impact. This outcome is sometimes perceived as the primary goal of the policy. However, the relationship is mediated by the composition of the circulating vehicle fleet. This constitutes a third indirect impact of the policy and depends on public awareness of urban areas as shared resources influenced by private choices. Finally, the policy may produce positive spillovers and unintended consequences, such as increased use of public transportation, the adoption of sharing practices, or behavioral adaptations aimed at circumventing road pricing.

Methodologically speaking, although this analysis will primarily focus on traffic levels and vehicle composition, assessing the impact of the policy change is more complex than it might initially appear. A simple comparison of entry numbers before and after the tariff adjustment (*post hoc*) is insufficient to evaluate the policy's actual relevance and impact (*propter hoc*). Such an approach risks conflating correlation with causation and overlooking other contextual factors and temporal dynamics that may influence the observed outcomes.

Since there are no comparable non-treated cases that could assist us in identifying plausible counterfactuals, we experimented several empirical strategies to support the claim for causal attribution. Thus, another aim of this paper is to share the research journey that we have undertaken, highlighting the problems, potential pitfalls, limitations, and lessons learned in evaluating the investigated change. Rather than relying on a single "true" econometric model whose estimates need to be taken as "smoking guns" supporting specific conclusions, we cite a large body of evidence from multiple "imperfect" models and perspectives that mutually reinforce the robustness of our inferences (Neumayer & Plümper, 2017). Thus, our argumentative approach follows the often-quoted aphorism of Hercule Poirot, the famous Agatha Christie character: "One coincidence is just a coincidence, two coincidences are a clue, three coincidences are a proof".

The article is organized as follows. In the next section we reconstruct the origins of the policy limiting private mobility in the city center of Milan and report its first results and the expectations connected to the tariff increase. Thereafter, we introduce the dataset and detail our hypotheses regarding the change in mobility habits for different categories of vehicles. Next, we report the results of our baseline econometric models, highlight some of their limits, and complement them with a first set of robustness tests modelling alternative temporal dynamics. We then extend this approach by using multiple strategies with which to identify counterfactuals and test for indirect effects and placebos. We conclude with some methodological and substantive reflections.

Problems and solutions

Traffic and environmental problems are typical of any metropolis. Milan is certainly no exception, and the first pragmatic discussions and solutions date back to the early 2000s (Lapsley & Giordano, 2010).

The first municipal intervention in this regard, the so called "Ecopass", was implemented in 2008 and was mainly thought to address the almost constant surpassing of the pollution thresholds fixed by the European Directive 1999/30/CE (Mattioli et al., 2012). The policy, which required the payment of a daily toll to enter the city center, was thus framed and communicated as an instrument aimed at reducing air pollution. Consequently, entry fees were differentiated depending on the type of vehicle and its Euro emission standards (Rotaris et al., 2010). The daily charge ranged from free entry, which was granted to the least polluting passenger cars, to ten euros for the most contaminating diesel cars and commercial vehicles. This meant that, during the first year of the policy's implementation, only one fifth of private vehicles actually needed to pay a toll, whereas approximately one in every two commercial vehicles did (AMAT, 2010).

In spite of these limitations, the regulation immediately reduced the amount of traffic and emissions both within and outside the city center, thus contributing to improving the air quality, decreasing the number of accidents, and increasing the use of public transport (AMAT, 2008). A comprehensive cost-benefit analysis confirmed the new policy's many advantages (Danielis et al., 2012). However, these initial results were short-lived and were not sustained beyond the first year of implementation. While the number of highly polluting vehicles entering the downtown area also decreased in 2009, this reduction was more than offset by the increased number of private cars and commercial vehicles that were exempted from the toll because of their relatively lower emissions. The overall effect was a 5% increase in the number of vehicles circulating in the center of Milan. The replacement of older (paying) vehicles with newer (exempt) ones, along with the slight increase in traffic volume, soon led to a plateau, if not a regression, of the initial environmental benefits, and to a decrease in the municipality's revenues (Commissione Ecopass, 2011).

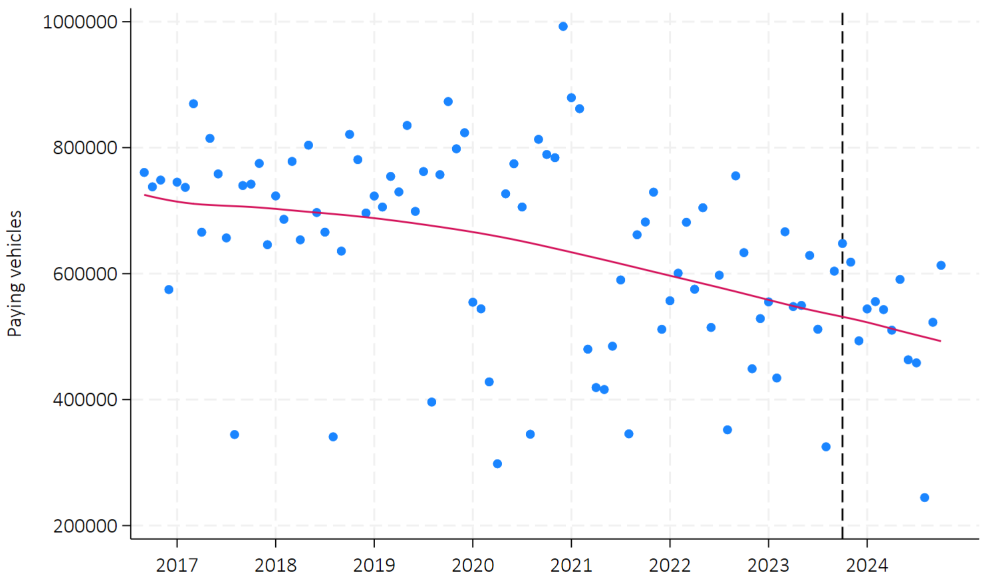
The shortcomings of the Ecopass scheme fostered debate within the municipal council and, most importantly, mobilized activists and associations who acted as policy entrepreneurs, reframing the overall approach to the policy. Among other things, they managed to promote consultative *referenda* on five local environmental issues, including one that proposed extending the toll for entering the city center to all vehicles and progressively expanding it to a larger area.

The referendum, which took place in 2011, saw a large majority in favor of the proposed reforms (Boggio & Beria, 2019; Percoco, 2017). This level of support was not entirely anticipated, considering the contrasting outcomes of similar initiatives and the status quo bias typically associated with such referenda (Hensher & Li, 2013). It prompted Milan's municipality to take immediate action. The administration launched an 18-month experimentation of a new fixed 5-euro congestion charge for every type of private or commercial vehicle entering the city ring that became known as "Area C" (Comune di Milano, 2011; Mattioli et al., 2012).

After just 12 months, the new policy was permanently implemented in 2013 with the direct aim of reducing traffic, promoting more sustainable public or shared means of transport, and indirectly contributing to the improvement of the air quality (Comune di Milano, 2013). Forty checkpoints equipped with cameras controlled access to Area C, with payment required on weekdays and between 7:30 am and 7:30 pm. Access restrictions were fine-tuned over time to adjust to stricter emission standards, and differentiated fees remained for residents and special transport vehicles.

The previous trial had achieved significant reductions in traffic and accidents in the city center, increased commercial circulation, improved regularity of public transportation, and considerable decreases in traffic-related pollutants and their concentrations near areas with stronger health impacts, such as schools and hospitals (AMAT, 2013). Ten years after the policy's introduction, these initial results seem to have been confirmed in the long run (AMAT, 2022, 2023).

Figure 1. Monthly entries of paying vehicles during weekdays between 7.30 and 19.30 with lowess smoothed values



Source: The authors

Figure 1 provides a synthetic representation of the continuous improvements to which the policy likely contributed. The points represent monthly access of paying vehicles in Milan's city center, the solid red line represents the fit of a lowess regression, while the dashed vertical line identifies the point at which the entry fee was increased. In spite of the evident seasonality of the traffic and the exceptional nature of the pandemic period – first characterized by lockdowns and then by the suspension of the policy – the smoothed trend highlights the steady decline of paying vehicles. This could be due to the persistent consequences of the municipal regulations or to some exogenous change in mobility habits. This is something that we will need to consider in our empirical research strategy.

For the first ten years of Area C, the daily ticket cost five euros, yielding about 30 million euros in revenue annually – not counting fines for non-compliance, the total amount of which has been estimated to be even larger (Spaccini, 2023). While revenues can be thought of as resources to be invested in favor of citizens' welfare, they can also be considered the proof that the tariff was insufficient to discourage polluting behaviors and that there was room for stricter regulations. During those ten years, the local administration seemed to have adhered more to the first position, while environmentalists, even within the city council, advocated for the second. To further persuade citizens to adopt more sustainable mobility habits, they requested a substantial tariff increase and the extension of its enforcement to all days of the week. Eventually, in October 2023, the municipality approved a 50% tariff increase, raising the cost of entering the city center to 7.50 euros, which is approximately 1.50 euros more than the simple revaluation due to inflation.

Research design: variables, data, and model specification

According to basic micro-economic principles, an increase in the real price of a good or service should correspond to a reduction in demand for that good or service. In other words, it was expected that there would be a decrease in the number of people accessing the center of Milan after the tariff's increase. However, the extent to which traffic decreases depends on the price elasticity of demand for the good in question, and drivers could be relatively indifferent to the approved tariff increase. This may occur for a variety of reasons.

First, the difficulty in finding feasible alternatives: for example, people who reside in Area C and use a vehicle cannot avoid being filmed by the cameras whenever they return home. Likewise, this could also apply to other non-optional mobility behaviors, such as delivering to the city center or reaching services and hospitals located in that area. Second, inelasticity could depend on the fact that those segments of the population that are more sensitive to the additional fee because of its higher marginal cost had already stopped using their cars at the time when the policy was first introduced, while the marginal cost of a 50% increase is insufficient to modify the behavior of the richer segments. Third, instead of the traditional downward slope, the demand curve could be characterized by a step function. For different tariffs, traffic could remain fairly constant before diminishing abruptly and significantly when the fee exceeded certain thresholds. Finally, mobility behaviors could be relatively indifferent to tariff changes in the short run because decisions such as finding new workplaces or replacing older cars with newer eco-friendly ones take some time. In this case, the effects can only be tested in the long term because immediate changes are too small to be appreciated or are simply non-existent.

If the effectiveness of the change in tariff cannot be taken for granted, assessing the actual impact of the new policy is not straightforward and presents methodological challenges. A seemingly intuitive approach, such as comparing the number of entries in the week preceding and following the implementation of the new tariff, oversimplifies the complexities involved and fails to account for confounding variables. Although this approach implements the logic of regression discontinuity over time, a methodology which has often been applied in the field of environmental and mobility policies (Davis, 2008; Hausman & Rapson, 2018), it presents some shortcomings.

First, it assumes that the best comparability is obtained "locally", in the immediate vicinity of the discontinuity. However, this did not happen in our case because of feast days and long weekends which altered both the standard mobility behaviors and the working of the policy. Second, it presumes that policy-takers can adapt their conduct immediately, but we have seen that changes in mobility practices may require time and are not without cost. Third, drivers may have anticipated the need to change their habits, resulting in no observable change before and after the introduction of the new fee. Lastly, exogeneous conditions affecting mobility behaviors may vary even in the very short term, and not considering them alters the *ceteris paribus* assumption of a simple time discontinuity comparison.

What conditions need to be equalized under both a short- and longer-term perspective? As already observed, fewer entries in the city center are expected on holidays, and this also holds for different days of the week and for different months. The online appendix clearly shows the effect on traffic of both types of seasonality. Furthermore, it is well known that weather conditions influence mobility practices (Böcker et al., 2019; Crotti et al., 2022; Nogueira et al., 2023), although their effect on entry into Area C remains unclear (Moulin & Urbano, 2025). In principle, rainy days could incentivize the use of private vehicles rather than public transport, but they could also prioritize the use of cars rather than bicycles and motorbikes. In addition to weather conditions, the availability of public alternatives could affect the preference for private mobility. During strikes in urban transport or rail connections to the metropolis, we can expect an increase in the use of private vehicles that contributes to traffic congestion in the city center (Anderson, 2014). Conversely, the extension of the underground network, with the recent opening of new subway stations within Area C, should help reduce the number of vehicles (Chen & Whalley, 2012). Finally, following technological improvements, the most polluting vehicles have been gradually prohibited from entering the city center, thus reducing the potential fleet to which the tariff could be applied and forcing some citizens to modify their mobility practices. All of these conditions need to be kept constant in a counterfactual comparison.

There are other aspects of our research design that need to be clarified. Detailed open data about access to the center of Milan are available since September 2016 and were used in the previous Figure 1. However, maintaining this long temporal perspective would have required us to also model the confounding effects of the Covid-19 pandemic, national and local restriction policies, and the municipality's fine-tuning of the mobility policy, which included suspensions and shortened daily enforcement of the tariffs. We employ this approach in the online appendix to demonstrate the robustness of our findings with longer time coverage. However, to respect the fundamental principle of "control(ling) for extraneous variance", which suggests selecting appropriate cases and time periods (Lijphart, 1971; Peters, 2020), we chose to limit the analysis to a shorter and more homogeneous period without any other policy fine-tuning.

We thus decided to focus on the interval between mid-June 2021 and the end of October 2024: slightly more than two years before the implementation of the new charge and exactly one year of its enforcement. This period is sufficiently long to allow for a large experimental variance but short enough to avoid unnecessary confounding effects due to unknown or unmeasurable factors that contribute to relevant behavioral changes. We collected the overall daily entries further differentiated by category, focusing on ecological vehicles, motorbikes, residents, and ordinary paying vehicles. For some replications, we also aggregated the daily entries into weekly periods.

The hypotheses tested the standard economic expectation that the consumption of a good decreases due to an increase in its price. This negative effect, against the null hypothesis, applies to ordinary paying vehicles and, to a certain extent, to residents within the area as well. One could also expect a transformation of other mobility practices with an intensified use of (non-paying) motorbikes and the gradual substitution of the polluting fleet with more ecological vehicles exempted from paying the Area C charge.[1] As a result of these opposing tendencies, the overall effect of the policy reform on the total number of vehicles could be null or a less systematic decrease.

In what follows, while the focus will be mostly on traffic during the 12 hours in which the tariff applies – from 7.30 am to 7.30 pm during weekdays – we will also explore the possibility of eluding the policy by slightly anticipating or postponing entry into the city center. We shall do so by considering the volume of traffic in the 30 minutes before and after the aforementioned time slot, which is also presumed to increase as a consequence of the new tariff. Furthermore, basic models will be applied to the overall number of vehicles over 24 hours and to the use of shared mobility (cars and bikes) and public transport in order to determine spillovers, side-effects, and more widespread changes in mobility practices.

Consequently, the dependent variables will be: (i) the daily or weekly number of vehicles belonging to the various categories, and (ii), for the spillover effects, the corresponding amount of car and bike sharing usage and of passengers in Milan's underground train network. The independent variable is simply represented by the time discontinuity in the Area C tariff, with a dummy variable taking the value of zero before 30 October 2023, and one afterwards.

The control variables to capture the aforementioned confounding effects are as follows:

- Days of the week are represented by a categorical variable measuring their effects relative to a reference value from Monday's entries;
- Months of the year are also represented by a categorical variable and their effects are measured relative to entries in August – the month with the least traffic;
- Weather conditions are operationalized with the number of millimeters of rainfall;
- Strikes in urban and/or railway transportation are measured with a cumulative dummy variable;
- Progressively stricter rules prohibiting entry to the city center by the more polluting vehicles are coded with an ordinal variable;
- Finally, the arrival of the new underground line MM4 within Area C, representing an effective and economical alternative to private transport, is coded with a dummy variable.[2]

In terms of specification, given the large number of observations, we opted for least squares regressions with robust standard errors which effectively cope with potential violations of the homoskedasticity assumption (Angrist & Pischke, 2009). Although the outcome was discrete and non-negative, we decided not to use count regressions considering the large counts and after inspecting the distribution of the dependent variables and of the models' residuals. Nev-

1 — For the Area C regulations, electric vehicles and hybrid cars with CO_2 emissions below 100 g/km are considered ecological.

2 — Models using weekly data also include the presence of holidays within the week. However, this is unnecessary when using daily data, which is restricted to days on which the tariff is active. The main variables, together with some descriptive statistics, are described in detail in the online appendix.

ertheless, negative binomial models are presented in the online appendix, and their outputs confirm the basic results presented in the text. In that context, panel models with observations for each gate in Area C are also presented.

Empirical results

This section first presents the results of our baseline models for all categories of vehicles. It then challenges those empirical findings by introducing alternative temporal dynamics due to exogeneous factors into our equations.

Baseline models

Table 1 presents a series of baseline models including all the variables listed above for the different types of vehicles during the days and hours in which the Area C tariff operates.

Starting with the control variables, the discomfort caused by rainy days increases the traffic of ordinary paying vehicles, but also that of residents and ecological vehicles, while it understandably reduces the circulation of motorbikes. The overall result concerning the total number of vehicles, which also includes the categories not reported in the table, is also negative, probably driven by the strong effect on bikers' mobility choices. Strikes in the local transport network systematically increase the traffic of all types of vehicles, while stricter regulations that prevent the most polluting vehicles from entering the city center lead to a reduction in ordinary traffic and trigger a substitution of the circulating fleet, favoring more ecological cars. Finally, the arrival in the city center of the new underground line in July 2023 seems not to have influenced the mobility practices of most citizens.

Table 1. Baseline models of mobility in Area C (weekdays, 7.30 am - 7.30 pm)

	(1)	(2)	(3)	(4)	(5)
	Total	Residents	Ecological	Motorbikes	Ordinary
Day of the week	✓	✓	✓	✓	✓
Month	✓	✓	✓	✓	✓
Rain	-194.9***	11.5***	33.2***	-275.5***	31.5**
	(37.3)	(2.9)	(9.4)	(23.9)	(14.5)
Strikes	6346.6***	271.2***	1047.6***	1133.7**	2446.5***
	(1388.4)	(75.7)	(273.0)	(458.1)	(445.4)
Ban (ref: Euro 1)					
Euro 2	-2269.2**	-705.0***	2765.0***	1288.9***	-1177.1***
	(975.0)	(62.9)	(185.7)	(331.1)	(333.9)
Euro 3	-5111.1***	-876.8***	5914.0***	-558.9	-1435.0**
	(1575.5)	(129.9)	(440.2)	(916.7)	(656.8)

MM4	141.5	84.1	2054.1***	1796.2***	-568.6
	(1477.8)	(86.0)	(328.2)	(553.9)	(475.9)
New fee	-3291.6**	-426.8***	947.7***	-1487.3***	-3463.6***
	(1439.5)	(77.1)	(307.4)	(547.4)	(436.7)
Constant	45900.4***	2679.2***	2586.4***	6762.6***	14401.1***
	(1877.8)	(103.0)	(346.5)	(577.3)	(545.5)
Observations	825	825	825	825	825
R-squared	0.76	0.79	0.76	0.68	0.72
Robust standard errors are in parentheses: *** p<.01, ** p<.05, * p<.10					

Source: The authors

The coefficient of the "New fee" variable represents the difference, all other things being equal, in the expected average number of vehicles before and after the increase in the tariff introduced by the reformed mobility policy. The new charge is associated with a 12% reduction in the daily number of ordinary paying vehicles that entered the city center before its implementation (-3464). Likewise, residents modified their behavior, with an 8% reduction of the previous circulation (-427). However, this reduction is off-set by a similar percentage increase in ecological vehicles (+948). Unexpectedly, even bikers seem to have avoided Area C, contributing to the overall reduction of almost 3300 vehicles per day (-3%). The explained variance of all models is sufficiently high, ranging from 68% to 79%. Residential mobility is the type that is best explained, while motorbikes and ordinary traffic are the types that are comparatively the least explained.

Temporal dynamics

As stated by Angrist and Pischke (2009, p. 64), "control for covariates can increase the likelihood that regression estimates have a causal interpretation". However, in our case, the possibility of underlying, unmodelled temporal dynamics limits this expectation. The difference in traffic between the two time periods, even when the effect of known and measurable confounding factors is kept constant, may depend on unmeasurable change in preferences, habits, and behaviors that have nothing to do with the policy change. Remote working practices, post-pandemic fears, e-commerce preferences, and environmental lifestyles are all significant social dynamics that may have interfered with our covariate of interest, preventing a causal interpretation of its coefficient. In fact, the data in the online appendix clearly show that these temporal dynamics predate the change in tariff and evidence a widespread reduction in the circulation of most types of vehicles, with a significant counter-cyclical increase in ecological motor vehicles. In this context, even after all due controls have been performed, the months before the introduction of the new tariff cannot be considered good counterfactuals of those that followed it.

However, it is possible to improve our baseline models by including different time effects representing those latent and unmeasurable dynamics on the right-hand side of the equation. In so doing, not only would we increase the fit of our estimates, but we would also strengthen the causal interpretation of the coefficient of the tariff increase. We have devised three different ways to include unobserved temporal dynamics in our models. The first one simply adds year dummies to the list of control variables. The second one includes a linear temporal effect measured by a continuous variable represented by the daily fraction of a year. Finally, the third strategy reflects a more flexible approach to temporal patterns by including in the equation the most fitting fractional polynomial that models continuous time dynamics.[3] We report, in the online appendix, the complete models for these alternative options applied to each type of vehicle and summarize their results for the covariate of interest in Table 2.

Table 2. Baseline models with alternative temporal dynamics (weekdays, 7.30 am - 7.30 pm)

	(1)	(2)	(3)	(4)	(5)
	Total	Residents	Ecological	Motorbikes	Ordinary
Year dummies	✓	✓	✓	✓	✓
New fee	-3921.3	-344.8**	508.9	-271.7	-3052.5***
	(3009.8)	(172.9)	(514.5)	(998.3)	(908.1)
R-squared	0.76	0.79	0.80	0.69	0.72
AIC	17576.0	12925.9	14947.2	15851.4	15759.1
BIC	17693.8	13043.8	15065.1	15969.2	15877.0
Time (linear)	✓	✓	✓	✓	✓
New fee	-3174.8*	-417.3***	-1192.1***	-2366.8***	-4532.0***
	(1678.2)	(97.1)	(331.2)	(630.6)	(540.8)
R-squared	0.76	0.79	0.79	0.68	0.72
AIC	17572.2	12925.2	14960.6	15860.0	15761.7
BIC	17680.7	13033.6	15069.0	15968.5	15870.2
Time (frac. poly)	✓	✓	✓	✓	✓
New fee	-2141.1	-287.3*	1045.2**	1568.5*	-1536.2*
	(2588.9)	(149.2)	(506.6)	(919.5)	(784.6)
R-squared	0.76	0.79	0.81	0.70	0.73
AIC	17573.9	12925.5	14913.0	15817.3	15733.8
BIC	17687.0	13038.7	15026.1	15930.4	15487.0

3 — More specifically, we followed the default option suggested for the corresponding Stata command, which looks for the best-fitting fractional polynomial of grade 2 among the 44 possible combinations of powers.

Robust standard errors in parentheses: *** p<.01, ** p<.05, * p<.10
Note: The coefficients of the complete models, with the other control variables are in the Appendix

Source: The authors

While the introduction of these temporal dynamics does not change the sign and significance of the control variables (see online appendix), they do partially alter the behavior of our treatment – the dummy variable related to the new tariff. Indeed, it would have been odd if they did not, since our running variable is in fact a time threshold whose effects are somewhat internalized by the new temporal dynamics. More explicitly, since the new tariff was introduced in October 2023, it is clear that the year 2024 dummy variable included in the first row of models in Table 2 already incorporates some of its effects, which subtracts from the explanatory power shown by the treatment in the baseline models.

Nonetheless, we see from that same first row that the negative association between the introduction of the new fee and the number of ordinary paying vehicles remains significant, and the same applies to residential traffic. However, there is a null effect on overall traffic. Contrary to the baseline model in Table 1, the circulation of non-paying vehicles, such as ecological cars and motorbikes, also seems to be unaffected by the policy reform.

The second row of models includes a temporal linear effect to discount potentially proportional changes in habits. In these models, the treatment variable is always statistically significant, though sometimes in an unexpected direction. As expected, overall traffic and residential and ordinary traffic decreased after the introduction of the new fee. Surprisingly, the same reduction applied to motorbikes and ecological vehicles, whose use should have been incentivized by the increased tariff.

Nevertheless, there is a way to make sense of these paradoxical results. In this part of the table, unmeasurable latent behavioral changes are thought to vary linearly with constant increases or decreases over time. For example, the ecological fleet is estimated to grow by over 3, 000 vehicles each year, and the number of bikers is expected to increase by 1, 000 each year (see Table A.7 in the appendix). However, a linear trend is not always the best approximation. For instance, if the number of ecological vehicles is increasing – but at a decreasing rate – then incorporating a linear trend in an additive model may lead to negative residuals for the most recent observations, as the model overestimates the actual values. Since these are also the points in time after the policy change, our treatment variable consequently takes a negative coefficient to account for those residuals.

The third approach, which relies on fractional polynomials, is more flexible in this regard. Instead of assuming linear trends in the supposed data-generating process, this approach allows each category of vehicles to display its own latent temporal dynamics. The large variety of functions granted by fractional polynomials reduces the likelihood of paradoxes like the one described in the preceding paragraph. At the same time, precisely because these functions can smoothly approximate any temporal trend, they risk also explaining the variations actually produced by the policy change, absorbing the variance originally explained by our treatment variable. In Table 2, the third row contains these types of models applied to the different types of traffic. This time, all the variables have the expected signs – negative for ordinary, residential, and overall number of vehicles, and positive for motorbikes and ecological vehicles – though, as anticipated, the relationship is less systematic, and the magnitude of the coefficients is smaller. All other things being equal, the number of paying vehicles – residential and ordinary – decreased after the introduction of the new Area C tariff: the relationship is only weakly significant and entails a reduction of approximately 5% in traffic generated by both categories. Conversely, there was an increase in traffic caused by non-paying vehicles – motorbikes and ecological cars – of respectively 8% and 9%, compared to the pre-treatment period.

While we cannot know the exact latent temporal dynamics, we can infer some indirect information about their shapes from the fit of our models. The explained variance is always rather high, but tends to be slightly higher – at least in models regarding ecological vehicles, motorbikes and ordinary vehicles – if we include fractional polynomials. Akaike information criteria, which are normally used to evaluate the quality of alternative models, result in the same preference. As expected, the new tariff increased the circulation of the first two categories and reduced standard payments. There are no significant differences amongst the three approaches for residential and total number of vehicles, and incidentally, they also yield similar results. As conjectured, there is a weak or insignificant reduction in overall traffic and a more systematic reduction for residents.

Placebos, counterfactuals, and spillovers

In this section, we test the robustness of our previous findings using a series of alternative models. First, we examine whether assuming a different timing for the new policy yields the same results despite clear theoretical and methodological reasons to expect otherwise. Next, we apply alternative research designs to isolate potential counterfactuals. Finally, we assess whether the policy produced external effects consistent with the observed reduction in private traffic during Area C's operating hours, such as shifts in entry timing or increased use of public transportation.

Placebos

The inclusion of these temporal dynamics may be suspected of artificially producing the expected results through excessive manipulation of our equations. However, another argument can be made that indirectly increases the robustness of the results presented in Table 2. If the significance of the variable connected to the new fee was the result of statistical manipulation, then altering that variable, for example by supposing that the tariff's increase occurred one year earlier, would produce the same results (Gallego et al., 2013).

In other words, what would happen if, instead of having a treatment modifying mobility behaviors after October 2023, we introduced into our equations a placebo in October 2022? We replicated all the models in Table 2, replacing the dummy for the new tariff with the placebo variable, and the results changed entirely. As shown in the online appendix, the placebo is virtually never significant. On the few occasions when the association turns out to be systematic, as with the circulation of motorbikes, it goes against any expectation or plausible mechanism. These placebo simulations not only confirm the associations in Table 2, but they also reinforce the claim that it was really the new tariff enforced on the 30th of October 2023 that triggered the observed change in mobility practices.

Counterfactuals

One problem with supporting causal attributions in contexts like ours is the absence of clear counterfactuals, as there are no other sufficiently similar cases that would favor a comparison. To get around this limitation, we adopted a series of alternative strategies.

A first option is to leverage the difference between weekdays and weekends within the time window in which the Area C policy is usually active. Since Area C operates only between Monday and Friday, the former should have been affected by the change in tariff, whereas the latter should not.[4] In other words, although weekend mobility has a different intensity, its trend can be considered counterfactual for the actual weekday traffic. If this is true, the gap in mobility levels between weekdays and weekends should have decreased after the enforcement of the new tariff for paying vehicles and remained constant or increased for the others.

Table 3. Gap between the traffic during weekdays and weekends (7.30 am - 7.30 pm)

	(1)	(2)	(3)	(4)	(5)
	Total	Residents	Ecological	Motorbikes	Ordinary
New fee	-11647.7	-1299.9**	2890.0	-5498.6	-11519.8***
	(10952.8)	(564.1)	(2372.9)	(4471.3)	(3360.8)
Constant	65017.3	-3786.1	-6575.0	22097.9	12649.3
	(171912.8)	(10465.9)	(24375.6)	(34954.4)	(70562.1)
Observations	170	170	170	170	170
R-squared	0.83	0.76	0.78	0.79	0.69

Robust standard errors in parentheses: *** p<.01, ** p<.05, * p<.10
Note: The coefficients of the complete models, with the other control variables are in the Appendix

Source: The authors

Table 3 confirms these expectations. The gap in residential mobility shows a systematic reduction of 1, 300 vehicles per week after the enforcement of the new fee, while the highly significant decrease in ordinary paying vehicles is around 11, 500 per week. As hypothesized, there are no significant increases or decreases in mobility for non-paying vehicles or for overall traffic flow. Interestingly, these analyses do not require modeling temporal dynamics because they are already internalized in the actual and counterfactual trends. Computing their difference cancels out their influence.

A second option is to focus on within-year trends to check for differential tendencies after the introduction of the new fee. Difference-in-differences (DID) models usually require other non-treated cases with parallel pre-intervention trends to compute the average treatment effect on the treated (ATET). However, instead of looking for unavailable data on other comparable cities, we could concentrate on 2023, when the new tariff was introduced in late October, and use the preceding years as counterfactuals without treatment. Using this approach, we can fit a two-period, two-group DID model to determine if the change in policy made a difference, at least in the first months of its enforcement.[5]

The short-term effects investigated by this approach, detailed in the appendix, are less reassuring than those reported thus far. Overall traffic seems to have diminished, but the assumption

4 — In the online appendix, we present a series of models that mostly confirm these assumptions and support the subsequent analyses.
5 — Since the year 2024 is entirely "treated", it cannot be included in this type of DID analysis. Consequently, longer-term effects are disregarded.

of a parallel pre-treatment trend is not confirmed, which invalidates that result. This assumption is proven for single vehicle categories, but the ATET is null for residents, motorbikes, and ordinary vehicles. However, it is (weakly) positive for ecological vehicles, confirming their increase after the change in policy.

Finally, if there are almost no short-term effects but preceding analyses confirm average changes in traffic, this could imply that the new tariff, instead of abruptly modifying the mobility behaviors of citizens, has gradually changed them, potentially accelerating the already existing change in attitudes that we have modelled in Table 2. One way to keep both aspects together could be to employ Interrupted Time-Series Analysis, ITSA. "By design, a single-group ITSA has no comparable control group; rather, the preintervention trend projected into the treatment period serves as the counterfactual" (Linden, 2015, p. 482). The basic logic of this approach relies on interacting the time variable with the dummy representing the treatment – in our case the new fee. After the appropriate autocorrelation structure has been accounted for, the coefficient of the treatment reflects the immediate change after the policy, and the coefficient of the interaction term represents the corresponding change in slope relative to the trend before the treatment.

As we show in the appendix, the results obtained by adopting this approach cast doubt on the impact of the new policy on most categories. First, there are no effects in the first week after the introduction of the new tariff. However, and in spite of the mostly appropriate signs of the interaction coefficients, there are also null results concerning the longer-term effects on overall traffic, residential mobility, and the circulation of ecological vehicles and motorbikes. Nevertheless, and perhaps most importantly, the only systematic effect of the new tariff is the change in the mobility habits of ordinary paying citizens, demonstrating an acceleration of the decline of the previously slow decline in traffic.[6]

Spillovers

The multiple analyses above mostly agree that the new tariff triggered the expected effect on paying vehicles, although they also partially disagree on the impact on overall mobility and other specific categories. One way to further increase the robustness of this finding could be to investigate the existence of side-effects and spillovers. For example, do (some) of the paying citizens react to the change by simply anticipating or delaying, when possible, their entry into the city center? Do they prefer some form of shared mobility, or do they directly opt for the public transport system?

We tested these hypotheses using our preferred model specification, which included fractional polynomials as trend variables. The dependent variables included the traffic entering Area C in the 30 minutes before and after the enforcement of the tariff, the number of bicycles and car sharing usages during the 12 hours in which the tariff operates, and the number of citizens using the various metro lines in the same time period.[7]

6 — On the other hand, simply including an interaction between treatment and time in our baseline equations yield a systematic reduction in the circulation of most vehicles' categories, though not in the overall traffic.

7 — It is not possible to restrict the analysis to the use of bike- and car-sharing in the city-center, or discriminate the use of the metro depending on the specific itinerary. Additionally, reliable data on the use of surface public transport is unavailable. For these reasons, our tests provide conservative estimates of public and shared transportation usage.

Table 4. Spillover effects (OLS models with fractional polynomial trend)

	(1)	(2)	(3)	(4)	(5)
	Residents pre-post	Ordinary pre-post	Bike sharing	Car sharing	Metro passengers
Time (frac. poly)	✓	✓	✓	✓	✓
New fee	3.3	222.1**	771.1	81.9	65972.0***
	(18.2)	(103.2)	(764.2)	(135.1)	(22063.4)
Observations	825	825	825	825	825
R-squared	0.73	0.67	0.70	0.64	0.84

Robust standard errors in parentheses: *** p<.01, ** p<.05, * p<.10
Note: The coefficients of the complete models, with the other control variables are in the Appendix

Source: The authors

As shown in Table 4, while residents do not seem to have modified their habits, the number of ordinary paying vehicles, which diminished after the introduction of the new fee during the operating hours of the Area C policy, actually increased in the 30 minutes before and after its activation. In so doing, citizens managed to bypass the policy and reduce its positive environmental effects. This type of spillover provides indirect confirmation that it was indeed the new tariff that triggered the change in mobility proven by the preceding models and had some unexpected consequences that limited the effectiveness of the regulation.

Another potential spillover, devoid of these unintended outcomes, could be represented by the choice of some form of shared mobility. Car sharing does not reduce the amount of traffic in the city center, but it still represents a more efficient use of motor vehicles, while bike sharing is an even more environmentally friendly behavior. However, perhaps due to the large and still changing variability of sharing practices after the pandemic period, there has been no systematic change in car and bike sharing since the increased fee of the Area C policy. The coefficients are positive but not statistically significant.

Finally, the clearest alternative to private transport is public transport. The modelling challenge here again consists of capturing the dynamics of post-pandemic trends, with the use of underground lines that, even now, hardly reach the pre-2020 levels. Nevertheless, our fractional polynomial approach should adequately accomplish this task, while controlling for the opening of a new metro line with a more fine-grained ordinal variable. After all these controls, the introduction of the new fee is positively associated with increased use of Milan's five metro lines at a high level of statistical significance, which would certainly represent a positive and coherent side-effect of the policy.

Discussion and conclusion

This paper has investigated one of the situations that scholars evaluating a policy reform often encounter: the absence of adequate untreated cases that can be employed as counterfactuals or similar data for comparison. In these circumstances, "post hoc" is certainly insufficient to advocate “propter hoc”, and there is no observational information that can unambiguously support the claim of causality. While there is no “smoking gun” to rule out the risks of misspecification and spurious association, there are ways in which our expectations of a causal relationship can be tested and supported.

This is not a matter of statistical sophistication and precision; rather, it is a matter of robustness. “No empirical model can ever capture the true data generating process. (…) Rather than trying to specify models correctly, (…) by providing additional evidence from plausible alternative models, robustness tests potentially increase the validity of inferences compared to inferences based only on the baseline model” (Neumayer & Plümper, 2017, p. 11). The multiple points of view and econometric models presented in the paper serve this purpose.

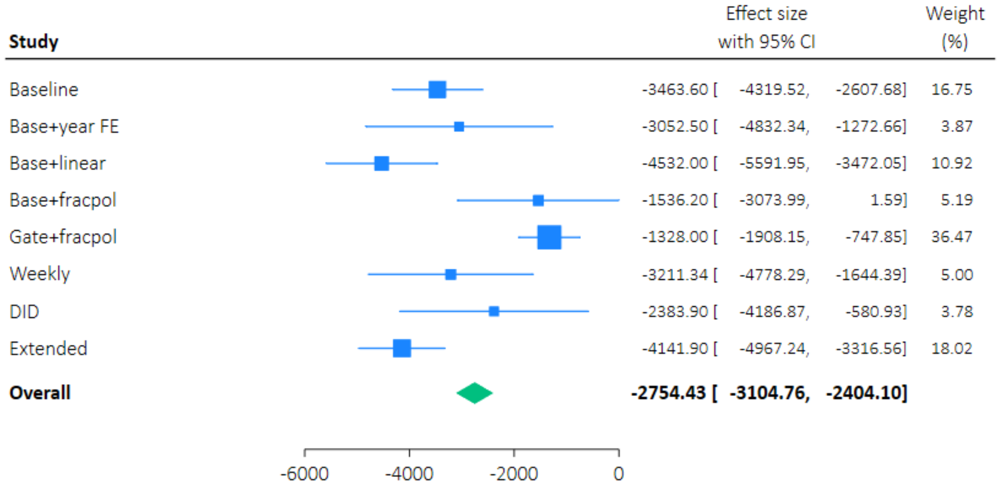
The appropriate sign and significance of the treatment variable in parallel regressions on different categories of vehicles – e.g. ecological versus ordinary paying vehicles – is in itself an element of robustness. But then we have also shown how similar results are obtained by employing gate data in a panel setting, as well as daily and weekly data in more traditional cross-section analyses. This was done using a standard linear approach, running count models, and three diverse models of unmeasurable latent trends. Further robustness is provided by the null results of placebo tests and the construction of plausible counterfactuals, such as the test on the gaps between weekdays and weekends. With some limitations, robustness is also provided by the incomplete evidence from difference-in-differences testing and by applying the logic of interrupted time series.

Finally, indirect evidence has also been provided by a series of models investigating the external spillovers of change in mobility that yield results in line with our main hypotheses. Assuming that the need to enter the city center is not affected by the change in tariff, how can those citizens that no longer access Area C satisfy that need? The fact that we are able to trace alternative behaviors, such as anticipating or postponing access or choosing public transportation, provides further indirect support for our expectations.

All these results can be conceived as stemming from single studies constituting a sort of meta-analysis in which the overall effect is determined by the predominance and significance of positive, rather than negative or null, coefficients. The heterogeneity of the results may also represent a piece of the puzzle which helps highlight the underlying mechanism. In our case, the absence of immediate effects following the introduction of the new tariff, combined with the acceleration of pre-existing changes in mobility habits, provides insight into how the policy change influenced traffic flow throughout the day. This perspective also contributes to a more comprehensive evaluation of the policy’s effectiveness.

In fact, shifting from a methodological to a substantive perspective reveals that the increased tariff has indeed contributed to a change in mobility habits, mostly by reducing the number of ordinary paying vehicles during the hours in which the policy is in effect. Figure 2 proposes a formal, quantitative meta-analysis of this effect, based on the main coefficients presented in the article and the appendix.

Figure 2. Meta-analysis of the daily impact of the new tariff on ordinary paying traffic across models



Source: The authors

With the sole exception of the baseline model featuring a fractional polynomial trend, all model specifications confirm the negative effect of the new tariff on ordinary traffic at conventional levels of statistical significance. Even the exception supports this finding, albeit at the weaker 10% significance level. The estimated impacts range from a minimum reduction of 1, 328 vehicles per day to a maximum reduction of 4, 532 per day. The meta-analysis indicates an overall statistically significant decrease of approximately 2, 750 ordinary paying vehicles per day.[8] These results confirm the previous evidence regarding the overall effectiveness of Area C policy in reducing traffic congestion (Lehe, 2019; Moulin & Urbano, 2025).

In spite of this good news, the new tariff has also triggered some less desirable effects, such as eluding the controls by anticipating or delaying access to Area C. This allows free circulation in the city center, without any reduction in traffic or emissions. The gradual replacement of polluting vehicles – with hybrids and electric ones – is a positive environmental development, but it also means a null or limited effect in terms of overall traffic reduction, while the free access of motorbikes risks limiting the benefits obtained by the regulation of other vehicles (Percoco, 2014). Indeed, the most recent monthly data collected by the local mobility monitoring agency indicate that the combined effect of these two dynamics – avoiding the hours when the tariff is active and replacing the vehicle fleet – has led to stable, if not increased, congestion indices when measured across the entire day (AMAT, 2024).

If this is true, then part of the original aim of the policy remains unfulfilled, if not betrayed, despite the reduced number of paying vehicles accessing the city center in the busiest hours of the day. However, the perspective should be enlarged further to encompass the ways in which the resources obtained from the policy – which are expected to increase to 40 million euros in

8 — Since we are conducting a meta-analysis on the same population, we opted for a common-effects model. However, substantively similar results are confirmed using fixed-effects and random-effects models. Similar meta-analyses are reported for the remaining categories in the Online appendix.

2026 – could be reinvested to consolidate the public transport system and favor environment-friendly mobility practices (Beria, 2016; Veitch & Rhodes, 2024). The municipality has already announced its intention to introduce a much more significant change to urban mobility policy, namely extending the tariff to weekends as well. This reform has already sparked intense debates and strong opposition. Evaluating the effects of a policy such as this one is not only relevant *per se*. It also feeds back into the "seamless web" representing the overall policy process (Pressman & Wildavsky, 1979), becoming an essential ingredient for understanding the politics of policy-making. For these reasons, we must take the apparently technical task of assessing the impact of the policies we are studying as seriously as possible. Finding counterfactuals is more difficult than it is often believed to be, and the search for robustness in causality attribution requires some degree of creativity. However, this should not discourage political scientists from devoting more attention to policy evaluation.

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