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Evaluating public sentiment towards transport policies: A causal analysis of the motorbike ban in Hanoi

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ABSTRACT

Controversial transport policies, such as the proposed ban on non-electric motorbikes in Hanoi, Vietnam, often challenge the status quo and spur resistance among road users. This paper aims to unpack the causal implications of the motorbike ban, with an emphasis on elucidating potential transformations in urban mobility patterns and public sentiment in Hanoi. The research methodology is rooted in an mixed-methods approach. It begins by applying Spatial Propensity Score Matching (SPSM) to a bespoke transport survey to mitigate geographical confounding in the identification of the ban's causal effects on societal attitudes and behaviours. Subsequently, it applies Ordinal Logistic Regression to quantify the causal influences of diverse socio-economic and demographic factors on public opinion towards the motorbike ban. Together, these methods yield a robust analysis of the policy's prospective impacts.

Through this framework, the study provides insights into the key factors influencing individual's opinion on controversial transport policies, such as the motorbike ban in Hanoi. Specifically, the approach reveals 4 key geographical insights into socioeconomic status, public transport perception, motorbike dependency, and automobile affinity among people in Hanoi.

1. Introduction

As a result of recent increases in wealth, many developing countries are experiencing a significant increase in traffic congestion and pollution, often driven by the proliferation of petrol-powered motorbikes. Major cities such as Hanoi, the capital city of Vietnam, have thus been transformed from "tranquil" places filled with bicycles to metropolises that are now characterised by "constant buzzing and honking" from motorbikes (Hansen, 2022).

The transformation of the automobile landscape in Hanoi is inextricably linked to the political climate of the city. Economic reforms (Doi Moi) in 1986 opened Vietnam to regional and global capitalism, ultimately transforming urban mobility (Hansen, 2017; Hansen, 2017). The transformation into a market economy and freedom of private acquisition saw a shift away from bicycle-dominated streetscapes to those dominated by motorbikes (Truitt, 2008). Doi Moi brought rapid urbanisation, new leisure activities, new employment, and housing, which increased the demand for intra-urban and urban–rural mobility (Drummond, 2012; Hansen, 2017). The Hanoi streetscape was a complex network of alleyways and narrow roads, thus, motorbikes were the perfect vehicle to meet the rapidly growing demand for mobility. This allowed convenient spatial linkages between activities associated with post-Doi Moi society, especially with poor public transport infrastructure and services (Hansen, 2017). In 1996, Vietnam was home to 4 million motorbikes (Turner, 2020). The current number in Hanoi alone is 5.6 million vehicles in 2022 (VnExpress, 2021), or the equivalent of around 2 and a half motorbikes per household.

The prolific use of motorbikes in Hanoi has led to increased congestion, dust, and pollution. Additionally, the lack of physical protection around the driver has raised concerns about accidents and injuries (Gillen, 2016; Nguyen et al., 2020; Tung, 2019). Non-motorised transport is squeezed out of the busy streets. In many ways, the motorbike's affordability, flexibility and convenience are making active travel less tempting, even over short distances. Combined with limited public transport, Hanoians are left with a lack of alternative choices and are "locked in" to motorbike use (Hansen, 2017).

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In an effort to curb reliance on motorcycles, the central and Hanoi government has enacted several legislative initiatives, such as a 2003 campaign called one motorcycle per person" (Tung, 2019). Hanoi officials are taking this further by introducing a stepwise ban on non-electric motorcycles from inner-city streets by 2030 as part of the Hanoi Capital Construction Master Plan to 2030 and Vision to 2050 campaign to make Hanoi the world's first sustainable city (Turner, 2020; Tung, 2019) and increase the share of public transport modes to 65% (Hanoi People's Council, 2017). The city officials actively endorse modern mobilities such as the implementation of rapid bus transit systems and metro systems while prioritising the phase-out of slow" mobilities such as motorbikes which are considered to negatively impact the smooth and sustainable traffic flows (Turner, 2020).

The resistance among Hanoians, accustomed to the flexibility and convenience of motorbikes, highlights the necessity for a thorough analysis of societal attitudes and behaviours in light of this proposed ban (Hansen, 2017; Turner, 2020). While it is relatively easy to survey individuals about their views on transport policies, it is challenging to quantify how the factors that are uncovered in surveys cause these views. Traditional statistical methodologies that prioritise correlation can be insufficient and, at times, misleading. They can be prone to the conundrum of spurious correlation, where variables may appear to be related but are either unrelated (the correlation arises by chance) or they are influenced by unseen confounding factors (Angrist and Pischke, 2008).

This paper employs causal inference techniques to provide rigorous insights into the key factors shaping public opinion regarding the controversial motorbike ban in Hanoi. Causal inference moves beyond correlational analysis to identify causal relationships from observational data. Specifically, we utilise Propensity Score Matching (PSM) methods (Rosenbaum and Rubin, 1983) that emulate randomised controlled trials by balancing confounding factors between different populations. This allows us to estimate the causal effects of individual characteristics like age, vehicle ownership status, etc. on individuals' acceptance or resistance towards the proposed policy change (Austin, 2011). However, traditional PSM methods do not account for spatial autocorrelation, which is the phenomenon where individuals living in close proximity are more likely to have similar attitudes and behaviours.

To address this, we apply Spatial Propensity Score Matching (SPSM), which incorporates geographic location into the propensity score model. By matching treated and untreated groups based on both observed covariates and spatial proximity, SPSM allows us to isolate the causal effect of the proposed policy changes while controlling for potential spatial confounding (Gonzales et al., 2016; Zhai et al., 2022; Kim and Bell, 2022). In this way, SPSM emulates a randomised controlled trial to quantify the causal effect of a "treatment" variable (e.g. car ownership) on an "outcome" variable (e.g. opinion of the ban), while controlling for confounding influences. By matching treated and untreated groups based on a range of observed characteristics, SPSM allows us to isolate the causal effect of the proposed policy changes on Hanoians' attitudes and behaviours towards transportation modes (Rosenbaum and Rubin, 1983).

The application of SPSM in this study enhances our understanding of the potential social impacts of a motorbike ban, informing the development of strategies to facilitate a smooth transition towards sustainable transportation in Hanoi. We further apply ordinal logistic regression on the matched sample from SPSM. This enables analysis of how individual characteristics, such as age, vehicle ownership and travel behaviours, impact the opinion on the motorbike ban. Together, SPSM and logistic regression provide a rigorous and nuanced estimate of the causal effects influencing public sentiment towards the controversial motorbike ban, generating actionable insights to guide policymaking. This causal analysis is fuelled by a large-scale dataset of over 26,000 respondents on their perceptions of transport in Hanoi, as well as state-of-the-art causal inference algorithms, in particular a Spatial PSM method.

The remainder of this paper includes a Literature review (Section 2), Data and Methodology sections (Sections 3 and 4, respectively), a Results section (Section 5), and finally a Discussion and Conclusion.

2. Literature review

2.1. Public perceptions on transportation modes

Globally, many countries are explicitly pushing for robust agendas to ban gasoline vehicles to achieve sustainable development of the transportation industry (Xenias and Whitmarsh, 2013; Zhang and Dong, 2023). The rationale behind these programs is linked to reducing environmental impacts from transport vehicles and increasing the safety of cities (Zhang and Dong, 2023). However, it is crucial to address that vehicles are an important means of mobility for many citizens and helps to increase autonomy within cityscapes. To this end, existing studies often focused on new technology, low-carbon vehicles, emission assessments and vehicle energy consumption (Zhang and Dong, 2023). There is a lack of focus on user habits, perceptions, impacts and attitudes of the public towards the ban and the characteristics behind differing opinions, despite earlier studies emphasising the need for public acceptance for bans to be successful (Cherry and Cervero, 2007; Skinner et al., 2010; Anable et al., 2012; Xenias and Whitmarsh, 2013; Puhe and Schippl, 2014). Here, we draw on literature that highlights user habits, perceptions and attitudes towards various proposed or realised vehicle bans. It is important to note that the Hanoi motorbike ban is not a complete ban on gasoline vehicles and only directly targets two-wheeled vehicles within the inner city. This is in contrast with many of the proposed bans globally which propose a broader ban on all vehicles with an internal combustion engine. Nonetheless, the relevance of this study is not overemphasised and although it is difficult to sort out the literature that is completely consistent with a motorbike-specific ban, the findings and methodologies from these studies will undoubtedly be useful.

Household income and education level are significant drivers of varying transport modal usage with many users of gasoline vehicles citing speed and convenience as their main reason for modal choice (Cherry and Cervero, 2007; Bennett and Vijaygopal, 2018; Zhang and Dong, 2023). A study in China found that with a higher education level, individuals were more likely to reflect on their environmental footprint and pay attention to the environmental benefits that the policy could bring (Zhang and Dong, 2023). This is in contrast to a questionnaire study conducted in Copenhagen, Budapest and Karlsruhe on young adults which found that environmental benefits did not significantly influence their transport options and instead, the quality of local transport systems for non-automobile mobility was a key factor (Puhe and Schippl, 2014). This difference could be a direct demonstration of how the quality of alternative modes of transport contrast between the countries. In China, bicycle infrastructure has been annexed and national policies actively promote car growth and ownership whereas, young adults in all three countries cited being satisfied with their respective countries' public transport systems and cycling/walking infrastructure demonstrated in the dropping car ownership rates. Several studies in China using regression and principle component analysis also found an overwhelming number of respondents said that in the absence of bikes, they would shift to taxis/cars citing faster speeds as the primary reason as well, to show elevated status or a better driving experience despite an expensive price-tag (Cherry and Cervero, 2007; Zhang and Dong, 2023). This is a complete deviation from findings in Copenhagen, Budapest and Karlsruhe where young adults responded that cars were losing status and are becoming an unimportant factor for the quality of urban life (Puhe and Schippl, 2014). These studies have demonstrated the importance of context, especially cultural and geographical nuances associated with the location where such policies of banning vehicles are being implemented or proposed and the need for such behavioural, contextual and habitual factors to be acknowledged and taken into account when making transport-related decisions.

Controversial transportation policies like bike bans on a certain mobility mode can impact commuter behaviors and mobility mode choices, underscoring the need to consider resulting shifts in travel patterns when evaluating such interventions. A study by Zheng et al. (2022) investigated the impact of changing urban landscapes on the mobility of commuters using different transport modes and found that, as a city has expanded, people have become more car-dependent and this may lead to a reduction of non-car transportation facilities (e.g., sidewalks, non-motorised vehicle lanes). Cherry and Cervero (2007) explores the transport modes that would be relied upon by the public in the absence of bikes using questionnaire data and a fixed effect logit model, a popular discrete choice model in statistics. This is an important point of study as without understanding this, there is difficulty in recognising whether a ban will reap positive or negative effects on the transportation system. The authors found that although banning bikes would increase public transport usage, namely bus services, without proper investment and expansion of these services, there could be a severe oversaturation of already over-subscribed bus services (Cherry and Cervero, 2007). Further, this could lead to an already increasing population of automobile (i.e., car) users and negate any benefit associated with a bike ban (Cherry and Cervero, 2007). Findings from this paper appear to be especially relevant to the Hanoi context as the proposed ban is limited to two-wheeled vehicles within the inner-city and not on gasoline vehicles as a whole.

A ban is associated with high financial cost and income may sacrifice with many individuals not having the financial freedom to purchase a car or a low-carbon vehicle (Bennett and Vijaygopal, 2018). A study on public opinion on the forthcoming ban on gasoline vehicles in the United Kingdom using a structural equation model found that higher-income individuals are able to absorb this income sacrifice easily thus, are more likely to support the ban in contrast to lower-income individuals (Bennett and Vijaygopal, 2018). This is an important demographical discussion to be had as a case study of a motorbike ban in Nigeria found that the recent ban has left many, especially former motorbike operators, roaming the streets with increased insecurity, crime and unemployment (Ikot et al., 2011). Within the city of Hanoi where many rely on motorbikes for their livelihood, namely motorcycle taxis (called Xe Om), the proposed ban must address potential negative ramifications on the livelihood of these operators and alternative income sources to avoid a situation such that (Ikot et al., 2011) witnessed.

2.2. Propensity score matching methods in transportation

Causal inference methods have become increasingly prevalent in transportation research to robustly evaluate the impacts of policies, programs, and infrastructure investments. Observational regression analysis can establish correlation and partial out some confounding, but may still fall short of fully isolating causal effects due to potential unmeasured confounding. Causal analysis provides a rigorous framework to quantify the changes directly attributable to a treatment or intervention.

PSM methods are among the most popular causal analysis techniques in transportation research (Li, 2013; Cao, 2010). By matching treated and control groups on covariates, propensity scores balance confounders to emulate random assignment used in experimental studies. Applications include assessing the causal effects of transportation equity policies (Shao et al., 2022), the relationship between the built environment and travel behavior (Zhong et al., 2021), congestion pricing (Zhang et al., 2017), impacts of urban transit lines (Dai et al., 2020; Dai et al., 2022) and traffic safety interventions (Zhai et al., 2022).

Geo-spatial variables have increasingly been important in causal analysis studies, as people in different areas of cities experience different transport services and even different transport policies. Cao (2010) investigates the causal effect of neighborhood type on walking behavior and the extent to which self-selection influences this relationship. Propensity score stratification is used to reduce selection bias and the results suggest that the causal influences of neighborhood type on walking behavior are likely to be overstated by 64% for utilitarian walking. Recent advances extend propensity scores to spatial settings through distance-based matching (Papadogeorgou et al., 2019). In the face of growing car dependency, especially in emerging economies, several PSM studies have found that increasing public transport accessibility reduces car dependency and spatial segregation (Pathak et al., 2017; Shao et al., 2022). Although this correlation is not consistent in all cities, a study by Nilsson and Delmelle (2020) showed little evidence of decreasing spatial segregation and neighbourhood income diversity with the implementation of a new rail transit system in the United States. This is likely explained by seldom studied habitual and behavioural patterns of transport usage that may need to be studied over time to fully understand. However, the potential of the PSM methodology and its ability to balance comparison groups and incorporate spatial relationships to assess the impact of a given treatment/program cannot be understated, especially with many countries proposing vehicle bans, it will undoubtedly become an important tool in transport research.

This study contributes to urban mobility research by integrating SPSM with Ordinal Logistic Regression, offering a nuanced perspective on policy impacts and the variables influencing societal attitudes. It provides unique insights into the complexities of transitioning towards sustainable transport in developing cities like Hanoi, enriching both academic discourse and practical policymaking worldwide.

3. Data

The data used in this study were collected through a two-phase process consisting of a pilot survey in 2020 followed by a full-scale survey in 2021 in Hanoi, Vietnam. The pilot survey aimed to validate the integrity of the survey questions. It was initially implemented as face-to-face interviews by personnel and students from Vietnam National University's (VNU) University of Science using Kobo Toolbox. The pilot garnered approximately 1,500 responses before being halted due to the COVID-19 pandemic. Insights from the preliminary round contributed to refining the survey questions.

Upon relaxation of pandemic containment measures in 2021, the full-scale survey was conducted via telephone interviews by the Vietnam General Statistics Office, Ministry of Planning and Investment. Leveraging their experience with the national census, they secured a representative sample of households in Hanoi. The survey targeted a random 2.5% of households in four central districts of Hanoi (Hoan Kiem, Ba Dinh, Hai Ba Trung, and Dong Da) most affected by a prospective motorbike ban. Alternative households were selected when a target household was unreachable. The final dataset achieved a 2.51% coverage of the population in the four districts, with 26,106 responses. Samples from the pilot and incomplete surveys were excluded. For more details on the dataset, including the validity of its records and to access the data, please refer to Kieu et al. (2024).

The survey is divided into several sections, as listed in Table 1. The first section gathers information about the respondent's demographics and home location. The next section, "living conditions", aims to understand the individual's quality of life and access to necessities such as open space, school, and hospital. The "household composition and vehicle ownership" section aims to gather information about the respondent's family structure and the number of vehicles owned by the household. The "primary trip" section asks about a single, regular trip that the respondent often makes, while the "mode choice" section collects information about the individual's frequency of usage and perceptions of different modes of transportation. Lastly, the "motorbike ban" section explores the individual's awareness of the ban, their agreement/disagreement with the ban, and their plans for alternative vehicles if the motorbike ban is implemented.

Table 1
Main survey questions.

Group	Questions (selected)
General	Age, gender, home location, occupation
Living conditions	Living duration, property type, status, home ownership, water quality, open space, noise, school access, market access, hospital access, bank access, security, leisure access
Household composition and vehicle ownership	Household car ownership, household motorbike ownership, household e-bike ownership, household bike ownership
Primary trip	Origin, destination, travel purpose, mode choice, the reason for mode choice, travel time, frequency per day, frequency per week, frequency per month
Mode choice	Frequency usage of a car, motorbike, e-bike, bike, bus; future purchase; reason not to buy a certain vehicle; distance to public transport; opinion of of a certain transport mode
Motorbike ban	Awareness of the potential motorbike ban, opinion, alternative vehicle: car, e-bike, bike, taxi, bus, light rail, taxi, walk; reason for vehicle ban: convenience, cost, parking, other

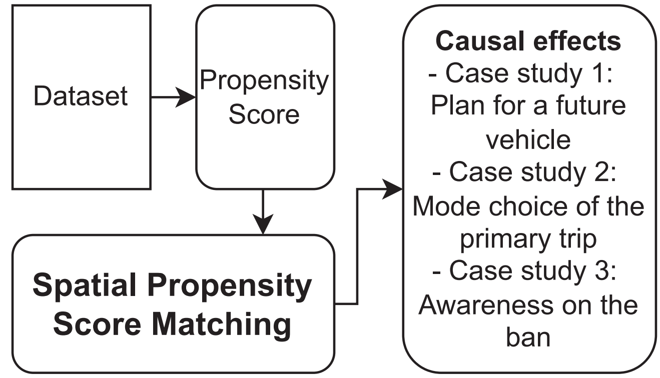


Fig. 1. Flow chart of the methodology.

4. Methodology

The greatest challenge for any evaluation program in experimental studies lies in defining the counterfactual group – the group in which researchers plan to explore an "outcome", or the question of what would happen in the absence of treatment. Without this comparison group, it is not possible to determine whether the effect on participants was due to the program. In experimental studies, the counterfactual group is randomly assigned to the treatment group to assure that the only differing factor between these two groups is whether they were subject to the intervention or not. This random assignment embedded into the design of the study ensures that the distribution of background and personal characteristics (i.e., covariates) are balanced between treatment and control groups (Stuart, 2010).

We adopted the same principle for causal inference analysis in this study. An important outcome for transport and urban planning is the individual perception of a potential policy. Our 'treatment' is not as obvious as taking a new medicine, but there are variables that are of interest to policymakers in transportation that can be used to explore the causal impacts on the policy outcomes, e.g. whether access to public transport or car ownership impacts individual perceptions of a potential policy. The group of individuals that are receiving the treatment is called the 'treatment' group, whereas the remainder is called the 'control' group. However, it is not feasible to select random individuals for the 'treatment' group in our case, because we could not force people to have access to public transport or to buy a car. This results in treatment and control individuals having systematic differences in personal characteristics that could subsequently influence treatment assignment, as well as study outcome (Heckman et al., 1997). Many methods have arisen to address this problem, but this study will focus on one method in particular: matching.

Matching methods aim to pair a treatment individual – for example in this case, someone who owns a car – to a control individual who shares the same or similar observed characteristics, where the causal effect of a treatment can be isolated and the average treatment effect can be estimated by subtracting the mean outcomes (Heckman et al., 1997; Stuart, 2010). This comparison is valid on the condition that matched pairs must be statistically equivalent to avoid the injection of selection bias in the study (Rubin, 1976; Heinrich et al., 2010). The interested reader can refer to Heinrich et al. (2010) for a detailed, worked example.

This study employed a robust causal inference framework integrating SPSM and ordinal logistic regression modelling to provide causal insights into key factors influencing individual's opinion on Hanoi's proposed motorbike ban. Fig. 1 illustrates the study work flow. First, propensity score, or the probability of an individual belonging to a particular group of interests in the data was estimated for each sample in the dataset. Second, SPSM is central to balancing confounders between treatment and control groups based on demographics, spatial proximity, and other covariates. This technique emulates randomised experiments to isolate the effect of variables of interest. Key considerations in implementing SPSM include defining appropriate distance metrics between observations and selecting algorithms to optimize matched sets. Finally, the causal effects are analysed in 3 case studies related to impacts of the plan for a future vehicle, the mode choice of the primary trip and the awareness on the ban to the actual opinion on the ban. The quality of matches must be thoroughly assessed before proceeding to causal effect estimation using regression modeling, where ordinal logistic regression is applied on the matched sample to estimate treatment effects across multiple levels of agreement with the ban. Interpretation of the fitted model's conditional effects and odds ratios provides nuanced, causally valid insights into the factors driving public attitudes towards this controversial transportation policy reform.

4.1. Propensity score

The propensity score is the probability of an individual belonging to a particular group of interests in our dataset, e.g. the group of future car owners, given observed covariates, X. It aims to shrink the multidimensional observed characteristics into a single value between 0 and 1 (Rosenbaum and Rubin, 1983). The propensity score is expressed as:

$$e(X) = pr(z = 1|X) \quad (1)$$

where z is the treatment, and X is a vector of observed characteristics. The propensity score is estimated for each observation through a logistic regression in which a binary treatment indicator (1/0; Yes/No) is regressed on a vector of observed characteristics (Austin, 2011). The resulting propensity score is the probability of participating in a treatment given X.

Once calculated, propensity scores were used to match individuals – i.e. those who are part of the treatment group with those who are not – under the assumption that by matching those that have the same or similar propensity score, their observed characteristics will be the same or similar. Recall that in this study we defined the 'treatment' group as the individuals who have particular characteristics (e.g. owning a car) and the 'control' group as everyone else. The similarity between individual propensity scores was calculated by the difference in the logit transformations of their propensity scores:

$$\delta_{ij} = |logit(e(X_i)) - logit(e(X_j))| \quad (2)$$

where $e(X_k)$ is the estimated propensity score of individual k. Small difference values are indicative of a better matching pair. A threshold called a 'calliper' is often introduced to prevent the matching of two individuals that differ by too large of a degree, especially in cases where there are an insufficient number of individuals with similar propensity scores (Papadogeorgou et al., 2019). Following previous work in the literature (Li, 2013; Lunt, 2014), the calliper in this study was set to 0.25; matching does not occur where propensity scores differed by more than 0.25 standard deviations of the propensity score distribution.

Full matching is a method of PSM that can help reduce bias and balance covariates between treated and control groups. In full matching, all individuals are matched, rather than discarding untreated individuals who do not have suitable matches as done in other methods like nearest neighbor or caliper matching. This avoids the loss of data and maximizes the use of available information (Stuart and Green, 2008), especially where there is a desire to use data on all individuals (Hansen, 2004; Ming and Rosenbaum, 2001; Stuart, 2010).

However, as Stuart and Green (2008) outlined in their study, full matching ratios of control to treatment can significantly vary, leading to large discrepancies and reduced precision in matching. To address this issue, a method called the constrained full matching procedure (Hansen, 2004) limits the ratio in each matched set, with no less than half and no more than double the sample size in the treatment group. This study utilised constrained full matching.

4.2. Spatial Propensity Score Matching (SPSM)

A drawback with traditional PSM is that it is inefficient in capturing spatial heterogeneity and dependency, assuming independent and identically distributed errors. This is often unrealistic as spatial autocorrelation often exists. It also assumes that there are no hidden biases due to unmeasured variables, an assumption often violated in observational studies (Heckman and Robb, 1985; Heinrich et al., 2010).

Papadogeorgou et al. (2019) argued that in spatially-indexed data, geographical location (i.e., coordinates) can serve as a proxy for unmeasured covariates that are likely to vary spatially and closer observations may exhibit similar spatialities of such patterns. Thus, in the presence of such unobservables and the potential presence of geographic confounding in both observed and unobserved variables, incorporating spatial proximity into the PSM methodology has become a critical point of discussion (Davis et al., 2019; Kim and Bell, 2022). The incorporation of spatial coordinates within the PSM framework prioritises spatial proximity of matches and takes on the same notion of a “bandwidth” in geographic regression frameworks where only observations that are in a certain spatial proximity to each other are comparable (Papadogeorgou et al., 2019).

To this end, we adopted a recent method developed called distance-adjusted PSM (DAPSM) (Papadogeorgou et al., 2019), a method that includes spatial information while also preserving the most salient benefits of PSM. The quantification of policy effects on a population is difficult due to the inherent qualitative nature of survey questions and urban experiences. Further, a ban in the inner city will impact people differently depending on how they utilise the city, thus, DAPSM provides an opportunity to tackle both of these challenges and simulate a randomised experiment to control for confounding factors to extract opinions of the public on the ban. It is important to note that unlike a traditional PSM, DAPSM is defined for every pair (i,j) of treated i unit and control j unit, incorporating the geographical distance between these two units (Papadogeorgou et al., 2019).

Formally, DAPSM is calculated as Papadogeorgou et al. (2019):

$$DAPS_{ij} = W_s \times |logit(e(X_i)) - logit(e(X_j)| + (1 - W_s) \times Dist_{ij} \tag{3}$$

where the $Dist_{ij}$ is the spatial proximity between the two units and W_s is the weight which defines the degree of spatial or covariate weighting. This matches pairs of treatment and control units i and j based on a weighted combination of their propensity score difference ($logit(e(X_i)) - logit(e(X_j))$) and spatial distance $Dist_{ij}$. The weight W_s controls the tradeoff between covariate balance (propensity score difference) and geographic proximity. W_s=1 corresponds to traditional PSM, while W_s=0 matches purely on spatial distance (Papadogeorgou et al., 2019). To determine Ws we performed matching across a range of possible W_s values, and selects the smallest W_s value where the absolute standardised difference of means (ASDM) is below a threshold (usually 0.1 Papadogeorgou et al., 2019).

4.3. Assessing the quality of matching

In order to reveal the causal effect of a given treatment from PSM, an estimand must be chosen. The most commonly used estimands in the literature are: the average treatment effect on the entire population (ATE) and the average treatment effect on the treated population (ATT) (Grilli and Rampichini, 2011; Pirracchio et al., 2016). Here, the ATE is more appropriate because our goal concerns the impact of a policy on the entire population of Hanoi, not just the impact on particular groups. The equation for the ATE is:

$$ATE = \mathbb{E}[Y(1) - Y(0)] \tag{4}$$

where, for each binary treatment, each subject has a pair of possible observed outcomes: $Y(0)$ and $Y(1)$. For each subject, the effect of treatment is the difference in outcomes between treatment scenarios. The ATE takes the average of this difference for the entire population.

Along with the ATE, to assess the quality of matches, the balance of SPSM scores between treatment and control groups are analysed using three statistics discussed by Rubin (2001): the difference in means of propensity scores (PS) between treatment and control; the ratio of variances of PS; and the ratio of variances of the residuals of the covariates after matching. Here, balance refers to similarity of PS distribution between treatment and control groups thus, the quality of matching is considered good if the means of difference and variance ratios are close to zero and one, respectively. According to Rubin (2001), variance ratio values between 0.8 and 1.2 are considered best. In this paper, instead of difference of means and following (Stuart, 2010; Woo et al., 2021), absolute standardised means difference (ASMD) between treatment and control groups was used. ASMD, also known as the Cohen's d or Standardized Mean Difference, is a measure of effect size commonly used to quantify the difference between two groups. In the context of PSM, ASMD was employed in this paper to assess the balance of covariates between treatment and control groups before and after matching. ASMD can be calculated as follows:

$$\text{ASMD} = \frac{X_{\text{treatment}} - X_{\text{control}}}{S_p} \tag{5}$$

where $X_{\text{treatment}}$ and X_{control} are the means of a covariate in the treatment and control groups, respectively, and S_p is the pooled standard deviation of the covariate across both groups. Here, the difference in propensity score is standardised by the standard deviation for continuous variables and the average difference in proportions for categorical (Stuart, 2010). For ASMD, Cohen (2013) suggested a value below 0.2 is indicative of adequate balance, values between 0.2 and 0.4 are moderately balanced and any value above 0.4 is indicative of large imbalance.

4.4. Causal effects of variables to the opinion on the motorbike ban

While SPSM allows us to mimic the conditions of a randomised experiment, it primarily facilitates our estimation of average treatment effects, with limited insight into differential treatment effects across various categories of our outcome variable. In the presence of an ordinal outcome variable (e.g. frequency of travel and opinion on the motorbike ban), understanding how the treatment impacts across different levels of the outcome becomes crucial.

This leads us to the next step in our causal inference analysis of individual perceptions on transportation policies: an ordinal logistic regression, also known as ordinal logit modelling. It extends our analysis by allowing for a nuanced exploration of the average treatment effect

(ATE) across the multiple ordered categories of our outcome variable. This analysis estimates the change in odds of being in a higher category of the outcome variable for the treatment group compared to the control group, controlling for other predictors in the model. By using the matched dataset from our PSM in the ordinal logit model, we maintained the balance in observed covariates that was achieved through matching, thereby addressing the confounding bias. This approach does not only help us in obtaining a more comprehensive understanding of the treatment effect but also allows us to discern and compare the potential impacts of the treatment across the various stages of our ordinal outcome.

5. Numerical experiments

Three case studies were carefully chosen to uncover public attitudes towards the controversial motorbike ban proposal in Hanoi. As discussed in the introduction, motorbikes now dominate transportation and cause congestion, accidents, and pollution in Hanoi. The government has proposed banning motorbikes from inner city streets by 2030 to make Hanoi more sustainable. However, resistance is expected given Hanoians' reliance on motorbikes.

The case studies provide causal insights into key factors influencing this resistance. Table 2 summaries the three chosen case studies in their definition of "treatment" and "control" groups, as well as their policy hypothesis. Quantifying these effects enhances comprehension of the social impacts of limiting motorbike usage in Hanoi. The case studies deliver targeted causal insights essential for developing balanced transportation reforms that avoid unanticipated public opposition.

They were purposefully chosen through exploratory analysis to highlight attitudes central to the motorbike ban debate and facilitate an equitable transition to sustainability. Fig. 2 visualises the 3 chosen case studies.

The first case study looks into the future to see if a person agrees with the motorbike ban simply because they are intending to purchase a car. If someone agrees with limiting motorbike usage because they plan for a car, the ban would even lead to more congestion in Hanoi. Fig. 2(a) shows that future car owners seem to be more likely to "agree" and "strongly agree" with the ban, but SPSM will enable us to eliminate other factors (e.g. social demographics, travel profiles, etc) to investigate the causal effect of the plan for purchasing a car to the opinion on the motorbike ban.

The second case study focuses again on motorbike users to see if those using motorbikes for the 'primary' trip (e.g. commuting) would cause someone to depend on the vehicle and disagree with the motorbike ban. This causal inference analysis is important to judge the level of motorbike dependency in Hanoi. Fig. 2(b) shows that motorbike users are less likely to agree with the ban, but SPSM will enable to confirm this causal relationship.

Table 2
Summary of case studies.

Case	Treatment group	Control group
1	Individuals intending to purchase a car	Individuals not intending to purchase a car
	Objective: Assessing intentions to purchase cars reveals potential unintended consequences of inducing more car usage	
	Hypothesis: Intending to purchase a car causes increased agreement with the motorbike ban	
2	Individuals using motorbikes for their primary trip	Individuals not using motorbikes for their primary trip
	Objective: Examining motorbike dependence evaluates reliance levels and the need for alternative options	
	Hypothesis: Using motorbikes for primary trips causes disagreement with the motorbike ban	
3	Individuals aware of the potential motorbike ban	Individuals unaware of the potential motorbike ban
	Objective: Analysing ban awareness guides strategies to build acceptance through public consultation	
	Hypothesis: Being aware of the potential ban causes increased agreement with the ban	

The final case study aims to find out whether being more aware of the motorbike ban would cause someone to agree with it. This is important to see if more public consultation would lead to public acceptance of controversial transport policies, such as the motorbike ban. Fig. 2(c) shows a much higher proportion of "agree" and "strongly agree" on those who are aware of the ban. We will use SPSM to confirm this relationship.

Fig. 3 shows the spatial nature of opinions regarding the motorbike ban. Here we assign a value from -2 to $+2$ for each individual opinion on the ban from "strongly disagree" to "strongly agree". The mean value for each cell in the grid is then calculated to show the spatial dimension of public opinion on the potential motorbike ban. The empty cells have no respondents located in. There are areas in Hanoi (e.g. north east) where people seems to disagree with the ban more, while people in the centre and south west seems to be in favour of the ban. Fig. 3 shows that a spatial-based method is indeed needed to analyse the public sentiment on the ban.

5.1. Quality of matching and its implications

This section shows the actual matching of individuals in the "treatment" and "control" groups for each of the case study. The aim is to evaluate the quality of the proposed SPSM matching and to understand its parameters, such as the spatial weight W_s. Fig. 4 shows the matching results for a section of the study area for each of the case study.

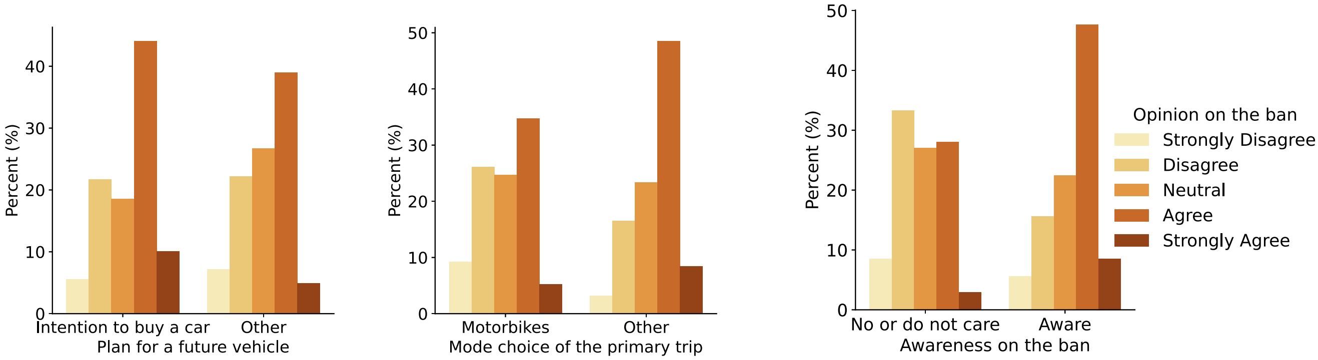
Fig. 4 shows examples of the SPSM results between treatment and control groups for the three case studies. Each subfigure visualises matched pairs of observations, with one individual from the "treatment" group and one from the "control" group. For instance, in Case study 1 the "treatment" group are individuals planning to purchase a car, while the "control" group are those not planning to buy a car. The link between them shows the spatial matching. The larger value of W_s (in Fig. 4(a) and (c)) shows that spatial element play a more important role in the matching.

After matching, ASMD index is used to evaluate the balance of covariates between the two groups in Fig. 5. The ASMD values are calculated by taking the absolute difference in means or proportions of a covariate in the treatment and control group divided by the standard deviation of that covariate in the control groups. ASMD values range from 0 to 1, with 0 indicating perfect balance (i.e., no difference in means or proportions) and 1 indicating complete imbalance. As a rule of thumb, an ASMD value less than 0.1 suggests that the covariate is similarly distributed in both groups.

For Fig. 4(a) on future vehicle ownership, the hypothesis was that intending to buy a car causes increased agreement with the motorbike ban. The covariates included demographics, vehicle ownership, trip characteristics, and opinions on transport modes. Its pairing Fig. 5(a) demonstrates that most covariates were well balanced, with absolute standardized mean differences below 0.1. This indicates the matching procedure successfully balanced the distribution of covariates between future car owners and non-car owners.

The same interpretation can be applied to Fig. 4(b) on using motorbikes for the primary trip and Fig. 4(c) on awareness of the ban. In Case study 1 and 3, SPSM shows its impact by matching individuals of close proximity. This means that people in different areas of Hanoi are significantly different in the plan for a future vehicle, and the awareness of the ban. Case study 2 is closely related to motorbikes, as it is about people who choose motorbike as the primary travel mode. It requires a large value of W_s, which shows that spatial elements have little impact on the matching. This is expected as motorbike ownership and usage are universal across Hanoi.

In each case, SPSM balanced the covariates, as seen in Fig. 5, enabling unbiased estimation of the treatment effects in the final regression model. The figures and results together showcase how SPSM



(a) Case study 1 (b) Case study 2 (c) Case study 3

Fig. 2. The 3 chosen case studies analyse the relationship between peoples' perception of the ban and: (a) whether they were intending to purchase a car; (b) whether they regularly use motorbikes for their primary trips; (c) whether they are already aware of the potential ban.

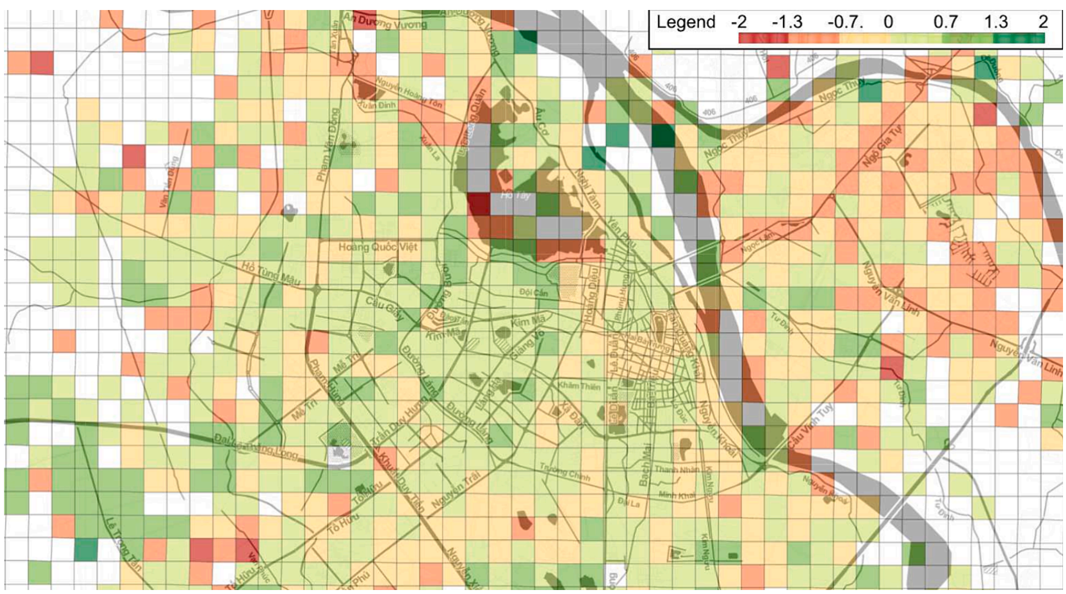


Fig. 3. Spatial distribution of average opinion on the ban in Hanoi.

helps isolate the impact of key variables of interest on attitudes towards the motorbike ban.

5.2. Results and discussion

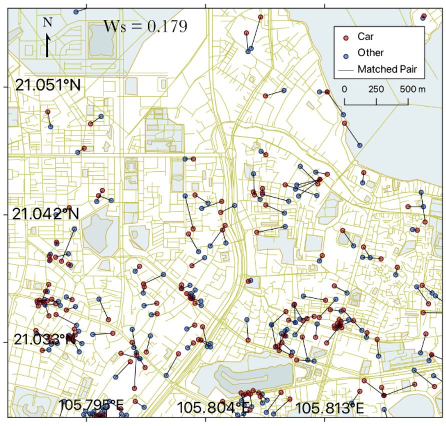
The core of this study is a causal inference analysis using Ordinal Logistic Regression. This analysis enables us to estimate an average treatment effect (ATE) across the multiple ordered categories of our outcome variable, and compare the potential impact of treatments across the various stages of our ordinal outcome.

Table 3 presents the modelling results. The 'odds ratio' represents the odds of a particular outcome (e.g., agreeing with a motorbike ban) occurring in the treatment group compared to the odds of it occurring in the control group, after adjusting for the confounding variables through PSM. In other words, it represents the odds that an outcome will occur given a particular predictor, compared to the odds of the outcome occurring in the absence of that predictor. An odds ratio of larger than 1 means that a variable has a positive causal impact to the outcome (opinion on motorbike ban), and vice versa. We identify 4 major insights from the impacts of: socioeconomic status, public transport perception, motorbike dependency, and automobile affinity.

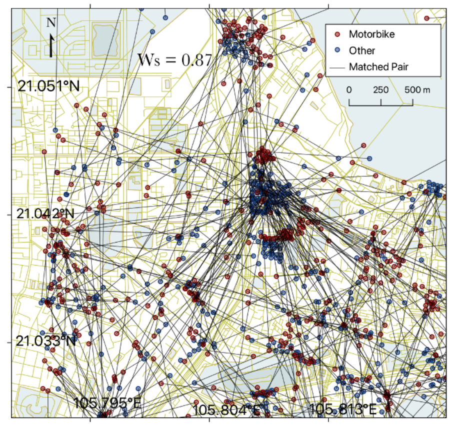
5.2.1. Socioeconomic status

Our analysis underscores a causal relationship between socioeconomic status and attitudes towards the proposed motorbike ban in Hanoi. Throughout the case studies, we found that homeowners were 15–34 percent more likely to support the ban compared to those who mortgage, rent, or live in their parents' houses. We can see this by looking at the Odds ratio of variable *own_house* in Table 3, where a value of 1.34 in the first case study means that if an individual is a home owner, the odd for them to agree with the ban is 1.34 times more likely.

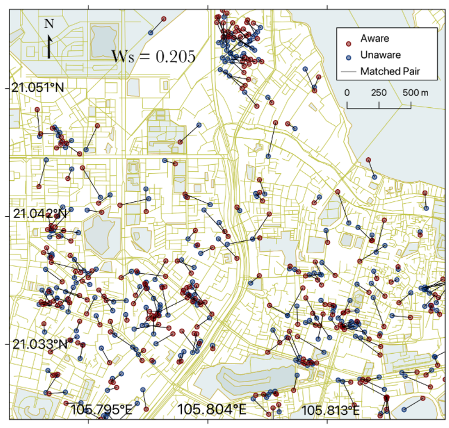
This discrepancy might be attributed to homeowners representing a group that can bear increased out-of-pocket costs associated with alternatives to motorbike travel. According to a range of studies, migrant motorcyclists may experience increased out-of-pocket costs due to motorcycle restrictions (Ye and Wang, 2011; Xu, 2014; Wen-hua and Dong, 2013; Xingdong et al., 2009). It has been noted that Vietnam, similar to China, operates a household registration system (Ho Khau), which regulates city residency and related benefits (Karis, 2013; Haughton et al., 2018). Benefits such as access to subsidised health care, property purchase, labour contract security, public school enrolment for children, and bank loans are tied to the possession of an official residence permit (Haughton et al., 2018; Anh et al., 2016; Cameron, 2012; Dang, 2010). Migrant workers without this permit tend to earn less than



(a) Case study 1: Future vehicle vs Opinion on the ban



(b) Case study 2: Mode choice vs Opinion on the ban



(c) Case study 3: Awareness vs Opinion on the ban

Fig. 4. SPSM result.

their resident counterparts (Haughton et al., 2018) and often accept jobs with less favourable conditions. Within Hanoi's urban landscape, homeowners, permanent residents, and employed individuals may face fewer challenges regarding a potential motorcycle ban. Many of migrant works, who are often young (Haughton et al., 2018), rely on their motorbikes for livelihood activities. The survey results suggest that groups with a higher socio-economic status (e.g., residents, males) show more agreement with the ban, while marginalised groups tend to disagree. These differences may be tied to the ability to handle out-of-pocket costs and opportunity cost of travel time that result from the ban. Therefore, addressing these disparities is vital when considering the implementation of such transportation policies.

5.2.2. *Public transport perception*

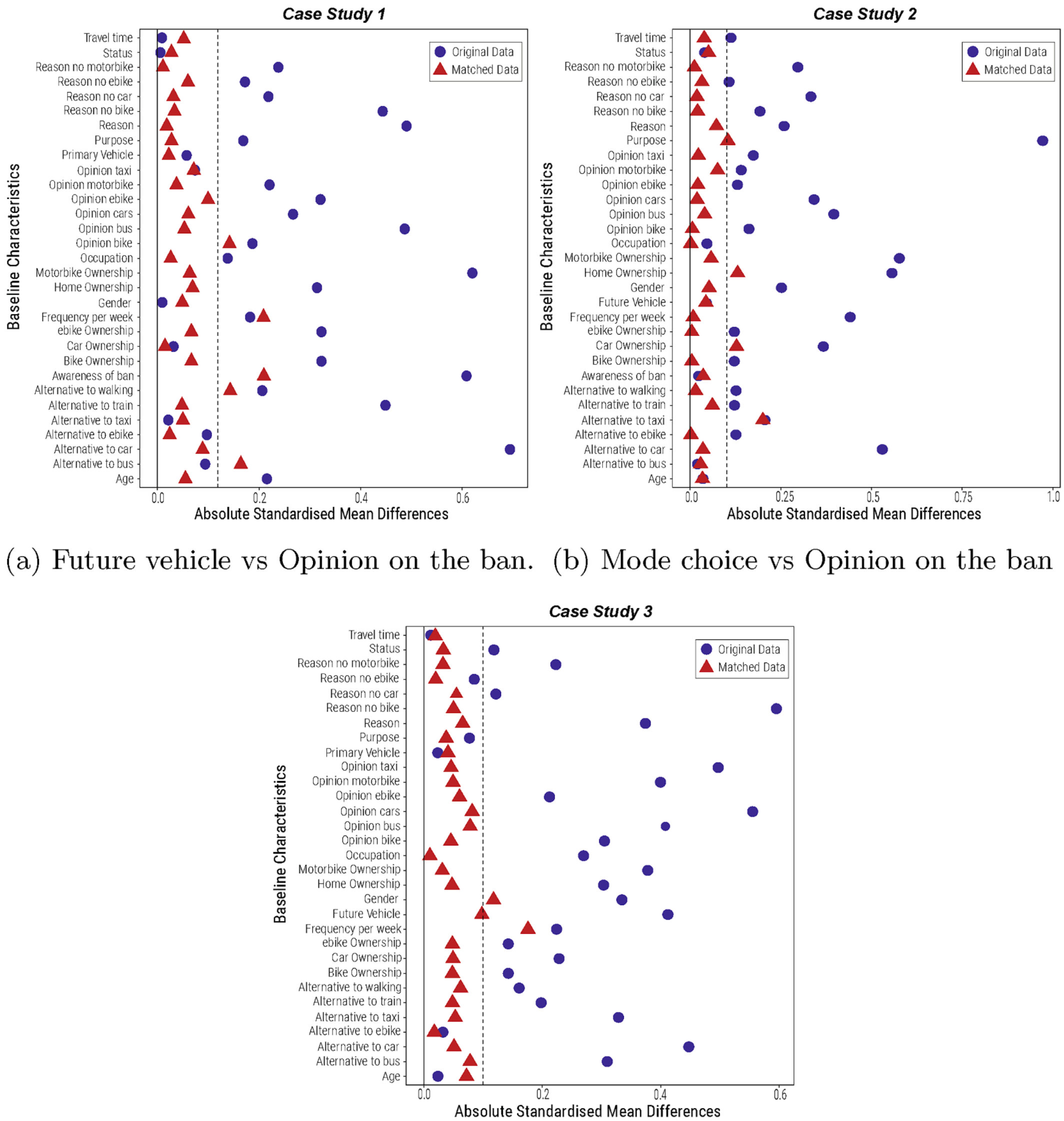
An individual's perception of public transport systems significantly influences their stance towards the proposed motorbike ban. Our survey results demonstrated that respondents who held positive views of buses (*opinion_busverygood*) were more likely to support the ban. Interestingly, those who considered buses a suitable alternative to motorbikes were 45–64% more likely to be in agreement with the ban compared to those who disagreed with this perspective.

However, despite the optimistic projections, the Bus Rapid Transit (BRT) system, which aimed to reduce the number of motorcycles by five million, has been met with lukewarm reception and a low adoption rate; primarily being used by retirees and students (Nguyen et al., 2017; Nguyen-Phuoc et al., 2020; Ng and Phung, 2021). It has also been observed that the BRT system primarily attracts former bus passengers, while its appeal to motorists remains marginal (Nguyen et al., 2020). Moreover, the slow progress in construction and testing of urban rail lines further fuels the uncertainty regarding the effectiveness of these alternative transportation modes (Nguyen and Pojani, 2023). These findings underscore the challenges in shifting the transportation mode preference from motorcycles to public transit.

5.2.3. *Motorbike dependency*

Motorcycle ownership and usage patterns play a crucial role in shaping attitudes towards a potential motorbike ban in Hanoi. According to our survey, a positive correlation was observed between the number of motorbikes owned and disagreement with the ban. Specifically, respondents who owns motorbikes are only 0.23 to 0.38 times the odds (or 62% to 77% lower odds) to accept the ban in the three case studies, compared to those who do not own motorbikes. Similarly, those who cited motorbikes as their primary mode of transportation were also around 30% more likely to oppose the ban, compared to those who chose other modes of transport.

Although it has been proposed that replacing motorbikes with cars and buses could alleviate congestion, such a transition seems unlikely to bring immediate relief (Turner, 2020). Nguyen Tien Minh, the People's Council Deputy, noted that motorbikes were involved in approximately 70 percent of traffic accidents, suggesting high-risk conditions for motorbike drivers (Vietnam News, 2017b cited in Turner, 2020). However, given the 10:1 ratio of motorbikes to cars in Hanoi, this degree



(a) Future vehicle vs Opinion on the ban. (b) Mode choice vs Opinion on the ban

(c) Awareness vs Opinion on the ban

Fig. 5. Absolute standardised means difference (ASMD) between treatment and control groups.

of accident involvement appears to be proportionate, thereby weakening the argument for an outright ban (Turner, 2020). Interestingly, while most road traffic crashes (73.4%) involve motorcycles (Phong, 2010), serious injuries are often linked with car crashes (Department, 2006; Phong, 2010). The versatility and maneuverability of motorcycles, specifically their ability to navigate small alleys and provide door-to-door mobility, also contribute to their popularity and convenience (Truong et al., 2021).

Vehicle ownership, seen partly as a proxy for accessibility, reveals another key advantage of motorcycles. Compared to automobile users, motorbike users tend to cover shorter distances, often using smaller alleyways for quicker commutes (Truong et al., 2021). Interestingly, it seems that as people own more motorbikes, it is more unlikely for them to accept the motorbike ban. This shows that limiting motorbike ownership may lead to more acceptance of policies like the motorbike ban. However, these factors further illustrate the deep-rooted reliance on motorbikes and explain the resistance to a potential ban among a significant portion of Hanoi's population. The resistance from motorbike enthusiasts raises an essential question regarding the inclusivity of policymaking processes, specifically, are the voices of these individuals adequately represented?.

5.2.4. *Automobile affinity*

The study highlights that car owners, or individuals who aspire to own cars (variable *fut_veh_car*), and who regard cars favourably (variable *opinion_carverygood*), tend to agree more with the ban compared to others. Table 3 shows that apart from one case study, all other odd ratios are larger than one for these two variables, showing that they tend to cause more agreement with the ban, especially for the opinion on cars (*opinion_carverygood*).

Their acceptance may stem from a perceived benefit – by eliminating motorbikes, they anticipate reduced traffic congestion, leading to enhanced road mobility. Table 3 shows that people who own cars or believe that cars are a good alternative to motorbikes are more than 2 times more likely to accept the ban. This means encouraging car usage and ownership would easily lead to acceptance of the motorbike ban policy, but even without a further analysis we can see that if a significant proportion of the population shifts from motorcycles to cars, this could potentially lead to additional societal challenges (Guo et al., 2020). Such a transition may exacerbate social inequality and contribute to the exclusion of migrant motorcyclists, particularly given the existing household registration policy. It could also create a scenario where decreases in motorcycle-related traffic congestion, pollution, and safety

Table 3
Results from the logistic regression model.

Case	Variable	Odds ratio	lower	upper	p	Findings
Future vehicle	*age*	0.99	0.98	0.99	0.00	Status
	own_house	1.34	1.15	1.57	0.00	
	occupstudent	0.77	0.63	0.95	0.01	
	aware_banyes	1.40	1.22	1.62	0.00	
	opinion_busverygood	1.59	1.41	1.78	0.00	Public transport
	alt_ltrain	1.31	1.11	1.53	0.00	
	alt_bus	1.44	1.23	1.68	0.00	
	own_motob	0.38	0.23	0.63	0.00	
	vehic_motob	0.68	0.58	0.79	0.00	
	own_car	2.46	2.08	2.91	0.00	Cars lovers
	travel time	1.01	1.01	1.02	0.00	
	opinion_carverygood	1.56	1.40	1.72	0.00	
Mode choice	*own_house*	1.15	1.03	1.29	0.01	
	occupstudent	0.64	0.55	0.74	0.00	
	aware_banyes	1.97	1.77	2.20	0.00	
	opinion_busverygood	1.64	1.51	1.79	0.00	Public transport
	alt_ltrain	1.15	1.01	1.30	0.03	
	alt_bus	1.49	1.32	1.67	0.00	
	freq_week	0.98	0.96	0.99	0.00	Motorbike lovers
	own_motob	0.23	0.17	0.30	0.00	
	vehic_motob	0.71	0.64	0.79	0.00	
	own_car	1.90	1.66	2.17	0.00	Cars lovers
	travel time	1.01	1.00	1.01	0.00	
	fut_veh_car	1.23	1.08	1.39	0.00	
	opinion_carverygood	1.41	1.28	1.55	0.00	
Awareness of ban	*own_house*	1.25	1.10	1.44	0.00	
	occupstudent	0.77	0.65	0.92	0.00	
	aware_banyes	1.74	1.56	1.94	0.00	
	opinion_busverygood	1.45	1.31	1.61	0.00	Public transport
	alt_bus	1.31	1.16	1.48	0.00	
	freq_week	0.97	0.96	0.98	0.00	Motorbike lovers
	own_motob	0.37	0.27	0.50	0.00	
	vehic_motob	0.78	0.68	0.90	0.00	
	own_car	2.42	2.10	2.80	0.00	Cars lovers
	travel time	1.01	1.00	1.01	0.00	
	opinion_carverygood	1.41	1.28	1.55	0.00	

issues are offset by an increase in problems associated with automobiles (Guo et al., 2020). Lastly, given that travel time and cost can be significant, particularly during peak hours, people who travel longer distances are more likely to own and use a private vehicle (Truong et al., 2021). As we continue to navigate the complexities of urban planning, striking a balance between sustainable transportation and individual needs remains a persistent challenge that merits further exploration.

6. Conclusion

This paper has presented a data-driven causal analysis on the transformation of the urban mobility landscape in Hanoi, driven largely by the rapid increase in motorbike usage following Vietnam's transition to a market economy in 1986. This shift has led to heightened congestion and pollution in the city, but the ubiquitous presence of motorbikes has become a significant part of daily life for the city's residents.

We examined the proposed ban on non-electric motorbikes in Hanoi by 2030, a radical policy that presents numerous challenges due to the ingrained societal behaviours and attitudes towards motorbike usage. Using a large-scale dataset on Hanoians' perceptions of transport and SPSM method, we were able to robustly evaluate the potential social impacts of this ban and provide valuable insights for policymaking.

The main scientific contributions of this paper are twofold:

1. Development of a mixed-spatial-method approach in causal analysis. This study contributes to geographic and urban mobility research through its mixed-methods approach; integrating SPSM with Ordinal Logistic Regression. By applying SPSM to a large-scale travel survey dataset, the research offers a nuanced estimation of a proposed policy's causal effects on societal attitudes and behaviours. The subsequent application of Ordinal Logistic Regression further provides an understanding of socio-economic and demographic influences on public opinion towards the proposed motorbike ban.
2. Insights into urban mobility and policy impact in developing contexts. This study offers insights into the societal response to transformative urban mobility policies in a developing city context, which is often less understood in literature (Hansen, 2022). By focusing on Hanoi's proposed non-electric motorbike ban, the research sheds light on the complexities of shifting societal behaviour towards more sustainable transport modes. It reveals the factors influencing public attitudes towards such changes and highlights the potential implications for policy-making and implementation. As such, the study contributes to the academic discourse on sustainable urban mobility and offers practical insights that could guide policy-making in similar urban contexts worldwide.

Our findings underscore the complex intertwining of transportation modes, societal culture, and political climate in the evolution of urban mobility in Hanoi. Our methodological approach, combining traditional PSM with spatial information, provides a promising avenue for future research on urban transport policy, particularly in developing countries where such topics are currently understudied.

Ultimately, the transition towards sustainable transportation systems is a complex process that involves not only technical and infrastructural changes but also significant shifts in societal norms and behaviours. The results of this study should help to inform a nuanced and empathetic approach to policymaking, one that respects the cultural significance of existing modes of transport while also addressing the pressing environmental and public health issues associated with them.

While this study provides valuable insights into factors influencing public attitudes towards the motorbike ban, the limitations of cross-sectional data must be acknowledged. Specifically, there is potential for reverse causation between the key variables explored in the case studies and opinion on the controversial policy. For instance, while motorcycle usage is assumed to cause disagreement with the ban in Case Study 2, it is plausible the reverse is true as well. However, opinion on the proposed reform can arguably be considered a more reactive variable shaped by external forces, while variables like vehicle purchase plans reflect more active decisions of individuals. Nonetheless, with observational data it remains difficult to definitively determine the direction of causality. This is an inherent limitation in analysing cross-sectional data. Access to longitudinal or experimental data could help strengthen the analysis to better isolate the causal mechanisms at play.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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