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# Crime concerns and the willingness to use autonomous public transportation: a comparative analysis of India, Pakistan, and China

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The adoption of emerging autonomous public transportation, such as buses and ride-pooling services, is critically dependent on public acceptance, which is heavily influenced by perceived interpersonal security (crime-related) concerns. This study aims to examine how perceived crime occurrence, victimization risk, and unwillingness to use autonomous public buses and ride-pooling services differ across three distinct socio-cultural contexts, namely India, Pakistan and China. Data were collected from 2,241 urban respondents using a scenario-based stated-preference questionnaire that presented hypothetical travel situations varying by mode type, time of travel, automation level, and presence of security mechanisms. A multi-method analytical framework was employed, including descriptive analysis, Mann–Whitney U tests, and extended ordered probit models with random parameters to capture both systematic and unobserved heterogeneity in risk perception. Results show that automation significantly increases perceived crime risk and unwillingness to use across all contexts, though the magnitude differs. Respondents in Pakistan reported the highest perceived insecurity and lowest acceptance, followed by India, while Chinese participants showed relatively higher confidence in autonomous systems. Female respondents, lower-income groups, and individuals previously exposed to crime consistently reported elevated fear and avoidance tendencies. The absence of a human driver or security officer emerged as the strongest determinant of perceived insecurity, confirming the critical symbolic role of visible “capable guardianship.” This paper provides the first cross-cultural, quantitative comparison of crime-related AV adoption barriers in an Asian context. Policy implications highlight the necessity of context-sensitive, phased deployment strategies, culturally tailored communication, and visible security mechanisms, to cultivate public trust in autonomous transport.

##### KEYWORDS

autonomous public transportation, crime perception, public acceptance, random parameter models, security concerns, trust in automation

## 1 Introduction

Crime and the fear of crime within public transportation systems are a serious social issue that extends far beyond statistics (Heinen, 2023). These concerns undermine not only the efficiency of transport networks but also broader goals of social equity and sustainable urban mobility (Orozco-Fontalvo et al., 2019). When passengers perceive the transport environment as unsafe, their travel behavior changes, particularly among vulnerable populations such as women, the elderly, and students. Many individuals modify their travel schedules, avoid certain routes, or forgo trips altogether, leading to reduced access to employment, education, and social participation (Heinen, 2023; Orozco-Fontalvo et al., 2019). Thus, perceived insecurity acts as both a social and mobility barrier, eroding public trust and diminishing the inclusiveness of urban transport systems.

This issue is not confined to any single region or level of development but represents a global phenomenon (Soto et al., 2022; Nalla et al., 2011). In high-income countries, public transport crime remains a visible policy concern: in the United States, major offenses in New York's subway system surged by 30% in 2022 (Akinnibi and Korte, 2023), while in the United Kingdom, the London Overground recorded a near threefold increase in its monthly crime rate between 2019 and 2022 (Transport for London, 2022). In developing contexts, however, the situation is often more acute due to weak enforcement mechanisms, inadequate infrastructure, and prevailing gender and social inequalities. In India, for instance, 2,766 transport-related crimes were recorded in 2021 (National Crime Records Bureau, 2022). In Pakistan, public harassment remains endemic, with between 60 and 90% of women reporting experiences of harassment while commuting (Tabassum and Suhail, 2022; Ayaz et al., 2024). Even in China, where urban infrastructure and digital surveillance have expanded rapidly, more than 3,000 incidents of public transport-related crime were reported over the past 5 years, underscoring that rapid modernization does not automatically translate into perceived security (Ministry of Information, 2024).

These security concerns are particularly pronounced in public transportation. Among its main modes, public buses and ride-pooling services form the foundation of urban mobility, offering affordable and accessible transport for millions of people (Heinen, 2023; Lee et al., 2024). However, the shared and often crowded environments of these services make them vulnerable to theft, harassment, and other interpersonal crimes (Jing et al., 2021; Madan and Nalla, 2016). In public buses, overcrowding and limited supervision increase opportunities for such incidents, while in ride-pooling services, the need to share confined spaces with unfamiliar passengers can intensify feelings of insecurity, particularly where regulatory oversight and driver accountability are weak (Gerell, 2021; Dills and Mulholland, 2018). These persistent challenges discourage many users, especially women and other vulnerable groups, from relying on public transport, highlighting the urgent need for safer and more trustworthy mobility solutions.

Amid these enduring security challenges, cities and mobility planners are increasingly turning to technological innovation to restore public confidence in transport systems. Among these innovations, autonomous vehicles (AVs) have emerged as a central pillar of next-generation urban mobility (Benjaafar et al., 2021; Ainsalu et al., 2018). AVs are expected to enhance system-wide performance by reducing crashes, improving traffic flow, and supporting cleaner and more sustainable transport operations (Abe, 2019; Cui et al., 2019; Kim et al.,

2021). Active pilot testing of autonomous public buses and ride-hailing services is already underway in Europe, the United States, and China (Owens et al., 2018; Holt, 2020; Stephen, 2023).

However, the successful integration of this technology depends not only on its technical reliability but also on the public's psychological readiness, how safe and secure passengers feel when using it. Acceptance of AV-based public transport is influenced by trust, familiarity, and perceived risks related not only to technological failures but also to interpersonal threats such as harassment or crime (Cai et al., 2023; Portouli et al., 2017; Greifenstein, 2024). A critical conceptual distinction must therefore be drawn between technical safety, which concerns the probability of collisions or system malfunction, and interpersonal security, which involves exposure to potential crimes or hostile behaviors within the vehicle environment. While automation may effectively reduce crash risks, it can unintentionally heighten concerns over interpersonal safety (Lee et al., 2024; Pervez et al., 2024b; Pervez et al., 2025a). The removal of the human driver, traditionally serving as both an operator and a capable guardian, creates a visible absence of authority within the vehicle (Pervez et al., 2024b). This lack of human oversight may intensify feelings of vulnerability, transferring long-standing fears of theft, harassment, or assault into the autonomous context. In this way, AVs may resolve technical risks while creating a new social and psychological security vacuum, which could critically shape users' willingness to adopt this emerging mode of transport.

Despite the rapid growth of research on AV adoption, the majority of studies have concentrated on issues of technical safety, automation trust, and cybersecurity (Cai et al., 2023; Portouli et al., 2017; Greifenstein, 2024). The equally important dimension of interpersonal crime risk, that is, how perceived risks of crime occurrence and victimization shape public willingness to use AV-based public transport, remains substantially underexplored. Furthermore, existing evidence is largely confined to single, often Western, contexts, leaving critical gaps in understanding how socio-cultural norms, institutional trust, and safety infrastructures influence these perceptions across different societies.

To address this gap, the present study conducts a comparative analysis drawing on empirical evidence from India, Pakistan, and China, three countries that represent different socio-technical contexts of autonomous public transport adoption. Collectively, they offer a unique opportunity to examine how perceived crime risks interact with broader social and mobility environments in shaping acceptance of autonomous public transport. India and Pakistan both represent early-stage, pre-deployment contexts, where public perceptions of AVs are largely anticipatory due to limited real-world exposure. However, the two contexts differ in how such anticipatory perceptions are formed. In India, evaluations of autonomous public transport are more strongly shaped by technology-oriented expectations and future mobility narratives, whereas in Pakistan, perceptions are more closely anchored in prior everyday travel experience and existing security concerns (Shetty, 2024; Shafique et al., 2021). China presents the most technologically advanced case, with extensive AV testing programs and the world's largest driverless vehicle market, where familiarity with automation and confidence in surveillance governance are relatively high (Research and Markets, 2025).

By comparing these three settings, this study investigates whether the influence of perceived crime risk on AV acceptance is universal or context-dependent. Specifically, we explore how socio-demographic attributes, situational factors, and security design features, such as the

presence of drivers or security officers, CCTV or emergency buttons, time of travel, and trip duration, affect perceived crime risk and unwillingness to use autonomous transport. To achieve this, we employ a multi-method analytical framework combining descriptive statistics, nonparametric tests, and random-parameters ordered probit models, which capture both systematic and unobserved heterogeneity in behavioral responses.

This study contributes in three key ways. First, it integrates the underexamined dimension of interpersonal crime risk into AV acceptance research through a comparative, scenario-based approach across three culturally and developmentally distinct contexts. Second, it quantifies how specific design and situational factors shape perceived security and willingness to adopt AV-based transport, thereby linking social cognition to technology design. Third, the cross-national comparison yields policy-relevant insights for governments, operators, and manufacturers seeking to enhance public confidence and ensure the equitable, secure, and culturally responsive integration of autonomous public transportation.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature; Section 3 presents the common methodology and data framework; Section 4 reports the comparative modeling results; Section 5 discusses key findings and policy implications; and Section 6 concludes the paper.

## 2 Literature review

### 2.1 Distinguishing perceptions: safety, security, and interpersonal crime risk in autonomous mobility

Public acceptance remains one of the most persistent challenges to the widespread deployment of AVs (Wu et al., 2021; Nordhoff et al., 2018). This acceptance is shaped by a constellation of user perceptions that can be broadly categorized into three interrelated domains: safety, cybersecurity, and interpersonal security, which collectively form the foundation of trust in automation.

Perceived safety refers to an individual's subjective evaluation of a vehicle's reliability and the likelihood of harm resulting from mechanical or software malfunction. This dimension has dominated AV research, with numerous studies showing that trust in system reliability and predictability strongly predicts willingness to adopt (Nordhoff et al., 2019; Passerone et al., 2019; Mueller et al., 2020). Early reluctance toward automation often reflected anxieties over sensor or software failures during dynamic or unpredictable traffic scenarios (Haboucha et al., 2017; Yeong et al., 2021).

Perceived cybersecurity risk encompasses concerns about intentional digital interference, such as hacking, data theft, or remote vehicle manipulation (Kenesei et al., 2022). Since AVs depend heavily on vehicle-to-everything connectivity and continuous data exchange, users' trust in data protection and system integrity becomes a critical determinant of acceptance (George et al., 2025). These concerns extend beyond privacy to fears of physical endangerment through cyberattacks, making cybersecurity an integral component of perceived safety.

Perceived interpersonal crime risk, the focus of this study, captures users' assessment of the likelihood of being victimized by another person while using AV-based transport. These risks include

theft, assault, robbery, or harassment, all of which are already prevalent in conventional public transport systems (Loukaitou-Sideris, 2014; Ceccato et al., 2022). This dimension draws from criminological and mobility-safety literature, which emphasizes that users' sense of security is deeply shaped by the social context of travel. In traditional public transport, the driver or conductor serves as a "capable guardian," both a deterrent and a source of reassurance (Carter, 2005; Paes-Machado and Viodres-Inoue, 2017). In autonomous contexts, the removal of this visible authority figure fundamentally changes the social ecology of travel. The absence of human oversight may heighten passengers' perceived exposure to interpersonal threats, even if objective crime risks remain unchanged (Lee et al., 2024; Pervez et al., 2024b).

These fears are particularly salient in shared or semi-private environments. In autonomous public buses, the larger, more open space allows for collective visibility but may still evoke uncertainty about accountability in emergencies (Schuß et al., 2023). In autonomous ride-pooling services, confined spaces shared with unfamiliar passengers amplify feelings of vulnerability and interpersonal risk (Sanguinetti et al., 2019). Hence, while automation promises greater operational safety, it simultaneously introduces new psychological insecurities by replacing embodied social guardianship with technological mediation.

### 2.2 Determinants of fear of crime in conventional public transport

Research on conventional public transport provides valuable context for understanding how interpersonal crime risks might translate to autonomous settings. Empirical evidence consistently shows that fear of crime is socially differentiated, with gender, age, income, and education shaping perceived vulnerability (Nalla et al., 2011; Madan and Nalla, 2016; Ceccato et al., 2022).

Gender remains the most salient predictor of insecurity in public transport. Women typically report higher levels of fear, particularly of sexual harassment, reflecting broader gendered patterns of spatial vulnerability and restricted access to public space (Loukaitou-Sideris, 2014; Ceccato and Loukaitou-Sideris, 2022). These gendered mobility constraints are particularly severe in South Asia: surveys indicate that 60–90% of women in Pakistan (Tabassum and Suhail, 2022), and 70% of women in India (Madan and Nalla, 2016), have experienced some form of harassment while commuting. Similarly, age also shapes fear of crime. Older passengers often express greater insecurity due to physical vulnerability, lower confidence in responding to threats, and dependency on public transport for essential mobility (Ceccato et al., 2022).

Socioeconomic and educational background also influence fear of crime. Lower-income passengers, more dependent on public buses and shared services, often experience higher insecurity due to exposure to poorly maintained or inadequately supervised environments (Pantazis, 2000; Yavuz et al., 2007). Conversely, higher educational attainment is associated with reduced fear of crime, as educated individuals tend to possess greater awareness of safety measures and institutional resources, enhancing their perceived sense of control (Noble and Jardin, 2020; Levine and Wachs, 1986).

Beyond personal characteristics, situational factors play a similarly critical role. The presence of transport personnel such as drivers, conductors, or security officers acts as a "capable guardian," deterring deviance and enhancing passengers' psychological comfort (Liu et al.,

2020; Cozens et al., 2005). Likewise, technological safeguards, including CCTV cameras, panic buttons, and improved lighting, have become common safety measures (Lorenc et al., 2013; Gekoski et al., 2017). Yet their effectiveness is strongly influenced by context: in environments with high institutional trust (e.g., China), surveillance may increase reassurance, whereas in low-trust environments (e.g., Pakistan and India), it may be perceived as insufficient or unreliable (Welsh and Farrington, 2009).

Finally, travel-related characteristics, including time, duration, and mode, consistently influence perceived insecurity. Traveling at night or on longer routes heightens perceived risk due to reduced social visibility and limited opportunities for assistance (Soto et al., 2022; Tabassum and Suhail, 2022; Madan and Nalla, 2016). Public buses are generally seen as less risky than ride-pooling services because their open environment facilitates collective monitoring, whereas ride-pooling confines users in semi-private spaces with strangers, amplifying perceived interpersonal threats (Wallace et al., 1999; Nguyen-Phuoc et al., 2020). These behavioral patterns highlight how personal, social, and situational cues collectively shape perceptions of transport security, and how these same cues are likely to influence acceptance of autonomous buses and ride-pooling services in emerging mobility ecosystems.

### 3 Methodology

#### 3.1 Methodological framework and underlying assumptions

The present study adopts a perception–behavior framework in which perceived likelihood of crime occurrence and perceived victimization risk are modeled as key determinants of respondents’ unwillingness to use autonomous public transport. The approach rests on four main assumptions. First, the three outcomes, perceived likelihood of crime occurrence, perceived victimization risk, and unwillingness to use autonomous public transport, are collected using five-point Likert scales and are therefore treated as ordered responses

reflecting an underlying latent propensity. Second, perceptions of interpersonal security are expected to vary systematically with socio-demographic characteristics, prior crime exposure, and travel/situational attributes embedded in the stated scenarios. Third, because attitudes toward crime and automation are not homogeneous, unobserved heterogeneity is anticipated; accordingly, random-parameters ordered probit models are employed to allow selected effects to vary across observations. Fourth, cross-country comparability is supported by applying a common stated-preference scenario structure and harmonized data screening criteria across India, Pakistan, and China. Consistent with this framework, the analysis proceeds sequentially from survey/scenario design and data screening to descriptive and nonparametric comparisons, and finally to random-parameters ordered probit estimation with heterogeneity extensions.

Figure 1 summarizes the sequential research process, from scenario-based survey design and harmonized data screening across India, Pakistan, and China to descriptive/nonparametric comparisons and random-parameters ordered probit estimation with heterogeneity extensions, culminating in cross-country interpretation and policy implications.

#### 3.2 Questionnaire survey design

In the present study, a structured questionnaire survey (illustrated in Appendix 1) was employed to collect empirical data on user perceptions of autonomous public buses and ride-pooling services, with a particular focus on crime-related concerns. The questionnaire was carefully developed through an extensive review of prior research on perceived transport security and behavioral intentions (Orozco-Fontalvo et al., 2019; Soto et al., 2022; Orozco-Fontalvo et al., 2019) complemented by consultations with experts in transport security and behavioral modeling. These preparatory steps ensured that the instrument captured the multidimensional nature of perceived insecurity while reflecting both global and local mobility contexts.

A common experimental framework was applied across all three countries, India, Pakistan, and China, to facilitate conceptual and analytical comparability. Minor linguistic and contextual adaptations were introduced to improve clarity and cultural relevance in each national

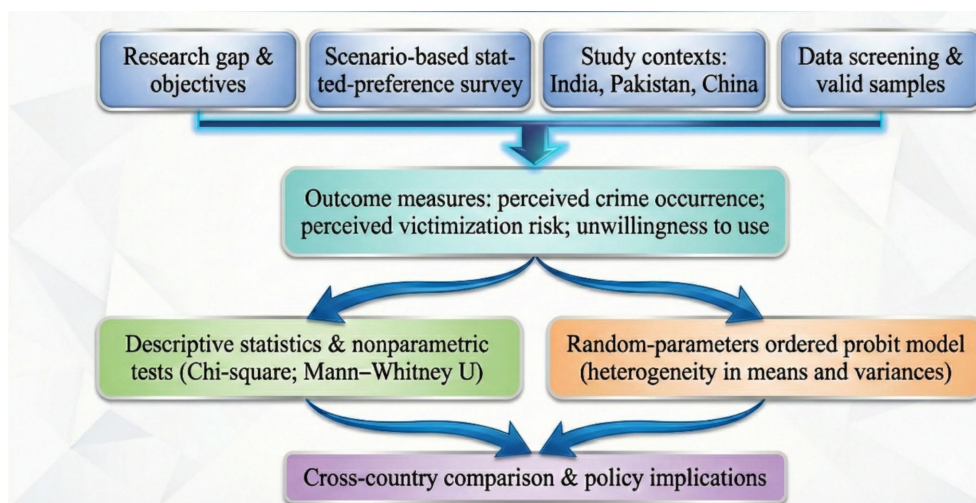


FIGURE 1 Methodological framework and analytical workflow of the study.

context. The questionnaire was administered in Hindi in India, in Urdu in Pakistan, and in Chinese in China. A harmonized instrument was used across all settings, with language-specific translation and reconciliation procedures to ensure consistent interpretation and semantic equivalence across countries.

The questionnaire comprised two main sections. The first section collected socio-demographic and behavioral information, including gender, age, education, income level, and primary travel mode. It also recorded prior experience or observation of transport-related crimes (e.g., theft, harassment, assault, or verbal abuse), as these experiences were expected to shape respondents' sensitivity to risk perception. The second section implemented a stated-preference experimental design, a widely used method for assessing behavioral intentions toward emerging technologies under limited real-world exposure. Each participant was presented with a series of hypothetical travel scenarios that systematically varied across four key operational and security-related attributes: type of security mechanism (no supervision, CCTV with emergency button, or the presence of a security officer), mode of travel (autonomous public bus or autonomous ride-pooling services), time of travel (daytime or nighttime), and trip duration (short  $\leq 30$  min or long  $> 30$  min). A fractional factorial design was used to generate eight unique combinations of these attributes, allowing efficient estimation of attribute effects while minimizing respondent fatigue.

Each scenario was accompanied by a concise, neutrally worded description and an illustrative image to enhance realism and comprehension. To minimize ordering effects, the presentation of scenarios was randomized across respondents. For every scenario, participants were asked to rate three statements on a five-point Likert scale (1 = "extremely unlikely" to 5 = "extremely likely"): "A crime could occur during this trip" (perceived likelihood of crime occurrence), "I might become a victim of a crime" (perceived victimization risk), and "I would choose to travel in this vehicle" (willingness to use). To ensure conceptual consistency with the negative framing of the first two items, the willingness-to-use item was reverse-coded so that higher values reflect greater unwillingness to use autonomous services.

Prior to the main data collection, pilot testing was conducted separately in each country to evaluate translation accuracy, question clarity, and scenario realism. Feedback from pilot participants informed several refinements to ensure contextual appropriateness, particularly regarding the description of crime types. For instance, terms were adjusted to reflect common incidents such as harassment in Pakistan, pickpocketing in China, and overcrowding-related theft in India. These revisions strengthened the instrument's validity and cross-cultural robustness.

### 3.3 Sample collection

All data in this study were collected through online dissemination across India, Pakistan, and China using structured digital questionnaires hosted on widely accessible survey platforms. This web-based approach ensured consistency in administration, enabled efficient targeting of urban commuter populations, and facilitated the inclusion of respondents who are most likely to engage with autonomous transport technologies.

To ensure data quality and internal consistency, a consistent filtering criterion was applied across all three national datasets. Responses were excluded if participants completed the survey in unrealistically short durations, defined as less than 100 s per item (Huang et al., 2012)

or if their answers showed repetitive or invariant patterns across a substantial portion of the questionnaire (Curran, 2016). This standardized cleaning procedure minimized the likelihood of inattentive or automated responses and enhanced cross-country comparability.

In India, the survey was administered via Google Forms between July and October 2022 through social media platforms (e.g., WhatsApp, Facebook, Twitter, and LinkedIn). A total of 819 responses were collected, of which 732 valid cases remained after cleaning, yielding an effective response rate of 89.4%. In Pakistan, data collection was conducted via Microsoft Forms from August to October 2022. Out of 724 responses, 667 valid cases were retained after validation, resulting in an effective response rate of 92.1%. In China, the survey was conducted in June and July 2022 via the Wenjuanxing platform, complemented by limited in-person recruitment. Of 1,006 total responses, 842 valid cases were retained, producing an effective response rate of 83.7%.

Across the three countries, respondents' dominant travel modes reflected national commuting structures: urban rail and metro in China, buses and two-wheelers in India, and buses and motorcycles in Pakistan. Notably, prior exposure to crime while commuting varied substantially: 42% of respondents in China, 80% in Pakistan, and 84% in India reported witnessing or experiencing transport-related offenses. These cross-national differences highlight contrasting baseline perceptions of security and provide a meaningful foundation for comparative analysis.

## 3.4 Statistical analysis

### 3.4.1 Descriptive and nonparametric analysis

Descriptive statistics were first computed to summarize socio-demographic profiles and identify general trends in perceived crime occurrence, victimization risk, and unwillingness to use autonomous public transport.

To test for group-level differences in perceptions across key socio-demographic and situational factors, nonparametric statistical tests were employed due to the ordinal nature of the dependent variables and the lack of normal distribution. The Pearson Chi-square test was first used to examine associations between categorical variables, such as gender, education level, prior experience of crime, and the likelihood of perceiving a high crime risk. This test also assessed differences in response proportions across travel scenarios (e.g., autonomous versus conventional, day versus night; Washington et al., 2020).

In addition, the Mann-Whitney U test was applied to compare two independent groups (e.g., male vs. female, younger vs. older respondents) across ordinal variables such as perceived crime occurrence, victimization risk, and unwillingness to use. This test was particularly suitable given its robustness to non-normality and unequal group sizes, providing a reliable means of assessing distributional differences in median response levels (Washington et al., 2020).

### 3.4.2 Ordered probit modeling and extensions

The three outcome variables in this study, perceived probability of crime occurrence, perceived probability of being a victim, and unwillingness to use autonomous public transport, were measured as ordered responses on a five-point Likert scale (1 = extremely unlikely, ..., 5 = extremely likely). Since the dependent variables are ordinal, an ordered probit specification is an appropriate starting point

(Washington et al., 2020). The ordered probit model assumes that the respondent's ordinal choice  $Y_n$  is driven by an unobserved (latent) continuous utility  $U_n$ :

$$U_n = \beta' X_n + \varepsilon_n$$

where,  $X_n$  is the vector of observed explanatory variables (e.g., gender, "No Driver," "Night"),  $\beta'$  is the vector of estimable parameters, and  $\varepsilon_n$  is the error term assumed to follow a standard normal distribution. The observed ordinal outcome  $Y_n$  is determined by threshold (cut-point) parameters  $\{u_1, u_2, u_3, u_4\}$  such that  $Y_n = j$  if  $u_{j-1} < U_n \leq u_j$  (with  $u_0 = -\infty$  and  $u_5 = +\infty$ ).

To capture individual differences in perception, a random-parameters ordered probit model was further estimated, relaxing the assumption of fixed coefficients:

$$\beta_{ni} = \beta_i + \sigma_i v_{ni}$$

where  $\beta_i$  is the mean parameter estimate (the average effect across the entire sample),  $v_{ni}$  is a randomly distributed term, and  $\sigma_i$  is the standard deviation that is estimated by the model. A statistically significant standard deviation  $\sigma_i$  confirms that the parameter's effect is not fixed in the population and that significant heterogeneity exists.

To further relax the model and explicitly model sources of heterogeneity, we allow both the mean and the standard deviation of random parameters to be functions of observed respondent characteristics. Concretely, for respondent  $n$  the random parameter can be written as (Seraneeprakarn et al., 2017; Pervez et al., 2022b):

$$\beta_{ni} = \beta_i + \delta_i Z_{ni} + \sigma_i \text{EXP}(\phi_i \psi_{ni}) \omega_{ni}$$

where,  $Z_{ni}$  accounts for the heterogeneity in means of the random parameters with parameter vector  $\delta_i$ ,  $\psi_{ni}$  captures the heterogeneity in the standard deviation ( $\sigma_i$ ) of random parameters with estimable parameters in vector  $\phi_i$  and  $\omega_{ni}$  is the disturbance term. It should be noted that if the vector  $\psi_{ni}$  does not have statistically significant variables, the model will be reduced to a random parameters model focusing solely on heterogeneity in the means. Similarly, when both  $\psi_{ni}$  and  $Z_{ni}$  lack significant variables, the model simplifies to a standard random parameter model (Pervez et al., 2022a; Pervez et al., 2025c).

All estimations were conducted using simulated maximum likelihood with 1,000 Halton draws in NLOGIT 6.0 to ensure stable parameter convergence.

## 4 Results

### 4.1 Respondent characteristics

A total of 2,241 valid responses were analyzed across the three study countries: India ( $N = 732$ ), Pakistan ( $N = 667$ ), and China ( $N = 842$ ), as illustrated in Table 1. Across all samples, respondents were predominantly young and well-educated. Individuals aged 30 years or below constituted the majority in each country (India: 80.7%; Pakistan: 67.6%; China: 72.3%), while those holding at least an undergraduate qualification represented substantial shares (India: 40.4%; Pakistan: 36.4%; China: 43.3%). Gender distribution was

generally balanced, with females comprising 49.3% in India, 54.1% in Pakistan, and 55.3% in China.

Travel behavior reflected distinct national modal structures. In India, motorcycles or two-wheelers (25.4%) and public buses (22.8%) were the most commonly used modes, followed by private cars (14.7%). In Pakistan, motorcycles (29.2%) and public buses (21.8%) similarly dominated urban mobility, while private cars accounted for 24.2% of trips. In China, urban rail and metro systems were the most frequently used mode (35.5%), followed by private cars (17.3%) and public buses (14.7%). These variations mirror broader structural differences in national transport systems, with two-wheelers and buses serving as the primary mass mobility options in India and Pakistan, and rail transit playing a central role in China (Pervez et al., 2021; Pervez et al., 2025b; Pervez et al., 2024a; Seum et al., 2020). Notably, 17.8% of Indian, 10.6% of Pakistani, and 18.5% of Chinese respondents reported using other modes (e.g., walking, bicycle, or taxi), accounting for the remaining modal share.

Exposure to crime while commuting revealed sharp cross-country contrasts. In India, 84.1% of respondents reported witnessing at least one criminal incident while traveling, most commonly verbal harassment (79.5%), theft or robbery (71.3%), and physical harassment (69.9%). In Pakistan, 80.5% reported similar experiences, with verbal harassment (60.5%) and theft or robbery (38.0%) as the most frequent offenses. In China, crime exposure was substantially lower, with 42.2% of respondents indicating at least one such experience, most commonly verbal harassment (31.3%), physical harassment (23.4%), and theft or robbery (14.6%). Prior exposure to autonomous transport was negligible in India and Pakistan but notably higher in China, where 25.9% of respondents reported some familiarity, reflecting greater technological diffusion.

### 4.2 Perceptions of crime, victimization, and unwillingness across modes and automation scenarios

To examine how automation influences perceived crime risk and willingness to use, respondents in India, Pakistan, and China evaluated two transport modes, public buses and ride-pooling services, under both autonomous (driverless) and conventional (driver-present) conditions. For analytical clarity, responses rated as extremely unlikely, unlikely, or neutral were grouped as non-affirmative, while likely and extremely likely were grouped as affirmative. This classification was an analytical choice intended to distinguish affirmative perceptions from non-affirmative or uncertain responses, rather than to imply substantive disagreement. Grouping neutral responses with the non-affirmative category helped avoid overestimating perceived risk or willingness to use among respondents who had not formed a clear judgment at the time of the survey (Lee et al., 2024; McCarthy et al., 2021). In addition, the presentation order of scenarios was randomized across respondents to reduce potential ordering or assignment effects.

As shown in Table 2, results from India indicate that automation markedly heightened perceived crime risk and unwillingness to use across both transport modes. About 62.2% of respondents believed that a crime could occur on driverless public buses compared with 28.6% on human-driven ones. For ride-pooling services, the corresponding figures were 66.5% for driverless and 32.9% for driver-present conditions. A similar pattern was observed for victimization: 55.4% anticipated being a victim on

TABLE 1 Summary of respondent socio-demographic characteristics and travel behaviors across the three countries.

Variable	Category	India (%)	Pakistan (%)	China (%)
Sample size (N)	—	732	667	842
Gender	Female	49.30	54.12	55.34
	Male	50.70	45.88	44.66
Age group	> 30 years	19.30	32.38	27.67
	≤ 30 years	80.70	67.62	72.33
Annual household income	China: < 50,000 CNY	—	—	17.93
	China: 50,000–100,000 CNY	—	—	26.48
	China: 100,001–150,000 CNY	—	—	23.52
	China: 150,001–200,000 CNY	—	—	13.06
	China: 200,001–250,000 CNY	—	—	5.94
	China: > 250,000 CNY	—	—	13.06
	India: < 100,000 INR	8.88	—	—
	India: 100,000–250,000 INR	12.70	—	—
	India: 250,001–500,000 INR	47.00	—	—
	India: 500,001–750,000 INR	14.75	—	—
	India: 750,001–1,000,000 INR	10.25	—	—
	India: > 1,000,000 INR	6.42	—	—
	Pakistan: up to 240 k PKR	—	35.08	—
	Pakistan: 240 k–360 k PKR	—	13.64	—
	Pakistan: 360 k–480 k PKR	—	10.49	—
	Pakistan: 480 k–720 k PKR	—	13.79	—
	Pakistan: 720 k–1,000 k PKR	—	13.79	—
Pakistan: > 1,000 k PKR	—	13.19	—	
Highest education level	High school or lower	9.70	2.70	9.50
	Professional college / College	35.80	13.34	9.74
	Undergraduate (bachelor's)	40.40	36.43	43.35
	Master's or higher	14.10	47.53	37.41
Most frequently used mode	Motorcycle	25.41	29.24	4.27
	Rail transit / Subway	11.50	9.15	35.51
	Public bus	22.83	21.89	14.73
	Ride-hailing / Ride-pooling	7.70	4.80	9.62
	Private car	14.70	24.29	17.34
	Other (calculated remainder)	17.86	10.63	18.53
Observed crime while traveling	Verbal harassment	79.50	60.57	31.35
	Physical harassment	69.90	33.43	23.40
	Theft / Robbery	71.30	38.08	14.61
	Sexual assault	—	3.15	3.44
	None reported	15.85	19.49	57.72
Reported witnessing any crime	Yes	84.15	80.51	42.28

autonomous buses and 59.7% on autonomous ride-pooling, compared with 25.82 and 30.41%, respectively, in conventional scenarios. Unwillingness to use also rose sharply under automation, 63.2% for driverless buses and 67.6% for driverless ride-pooling, relative to 27.1 and 31.3% for their driver-present counterparts. Pearson's chi-square tests confirmed all differences as statistically significant ( $p < 0.01$ ), indicating that the removal of the driver

consistently elevated perceived insecurity and reduced acceptance in India.

In Pakistan, respondents reported substantially higher perceived crime and victimization risk in autonomous settings. As shown in Table 2, 70.3% of participants agreed that a crime might occur on driverless public buses compared with 29.7% on human-driven ones, while for ride-pooling services the proportions were 77.2 and 22.8%,

TABLE 2 Comparison of respondents' perceptions regarding automation and mode.

Country	Description	Mode	Automation	Agree (%)	Disagree (%)	$\chi^2$	p-value
India	Crime may occur	Public bus	Driverless	62.18	37.82	22.47	< 0.01
			Driver present	28.64	71.36		
		Ride-pooling service	Driverless	66.47	33.53	21.83	< 0.01
			Driver present	32.58	67.42		
	Being a victim of crime	Public bus	Driverless	55.36	44.64	17.63	< 0.01
			Driver present	25.82	74.18		
		Ride-pooling service	Driverless	59.74	40.26	16.94	< 0.01
			Driver present	30.41	69.59		
	Unwillingness to use	Public bus	Driverless	63.25	36.75	24.82	< 0.01
			Driver present	27.13	72.87		
		Ride-pooling service	Driverless	67.58	32.42	24.49	< 0.01
			Driver present	31.32	68.68		
Pakistan	Crime may occur	Public bus	Driverless	70.30	29.70	61.75	< 0.01
			Driver present	29.70	70.30		
		Ride-pooling service	Driverless	77.20	22.80	14.16	< 0.01
			Driver present	22.80	77.20		
	Being a victim of crime	Public bus	Driverless	70.30	29.70	97.41	< 0.01
			Driver present	29.70	70.30		
		Ride-pooling service	Driverless	76.70	23.30	11.61	< 0.01
			Driver present	23.30	76.70		
	Unwillingness to use	Public bus	Driverless	80.10	19.90	45.37	< 0.01
			Driver present	19.90	80.10		
		Ride-pooling service	Driverless	72.60	27.40	5.98	0.02
			Driver present	27.40	72.60		
China	Crime may occur	Public bus	Driverless	42.00	58.00	62.29	< 0.01
			Driver present	32.90	67.10		
		Ride-pooling service	Driverless	42.00	58.00	120.65	< 0.01
			Driver present	27.00	73.00		
	Being a victim of crime	Public bus	Driverless	31.20	68.80	69.91	< 0.01
			Driver present	20.60	79.40		
		Ride-pooling service	Driverless	29.00	71.00	66.72	< 0.01
			Driver present	18.80	81.20		
	Unwillingness to use	Public bus	Driverless	38.80	61.20	137.45	< 0.01
			Driver present	23.00	77.00		
		Ride-pooling service	Driverless	35.40	64.60	149.29	< 0.01
			Driver present	19.40	80.60		

respectively. Perceived victimization followed the same pattern, 70.3% for autonomous buses and 76.70% for autonomous ride-pooling, versus 29.7 and 23.3% under conventional conditions. Unwillingness to use was also much higher, at 80.1% for driverless buses and 72.6% for driverless ride-pooling, compared with 19.9 and 27.4% for conventional options. All differences were statistically significant ( $p < 0.01$ ), revealing strong sensitivity to automation and widespread apprehension about crime risk among Pakistani participants.

In China, the magnitude of difference between autonomous and conventional scenarios was smaller but directionally

consistent. Approximately 42.0% of respondents believed crimes were likely to occur on driverless public buses compared with 32.9% on human-driven ones, while 42.0% viewed driverless ride-pooling as risky versus 27.0% for conventional operation. Regarding victimization, 31.2% expressed fear of being a victim on driverless buses and 29.0% on driverless ride-pooling, compared to 20.6 and 18.8%, respectively, when a driver was present. Unwillingness to use rose from 23.0 to 38.8% for public buses and from 19.4 to 35.4% for ride-pooling services when the driver was removed. Pearson's chi-square results confirmed all differences as

statistically significant ( $p < 0.01$ ), showing that even in a technologically advanced and surveillance-equipped environment, automation still increased perceived insecurity among Chinese respondents.

### 4.3 Group differences in perceived crime risk and unwillingness to use autonomous public transport

To explore how perceptions of crime and behavioral intentions toward autonomous public transport differ across socio-demographic groups, a series of Mann–Whitney U tests were conducted for three dependent variables: (i) perceived likelihood of crime occurrence, (ii) perceived likelihood of victimization, and (iii) unwillingness to use autonomous public transport. The tests were performed separately for India, Pakistan, and China, across categories of gender, age, education, income, and prior exposure to crime (Table 3). In the table, the standardized test statistic ( $Z$ ) and the corresponding two-tailed  $p$ -value are reported to assess whether group differences are statistically significant.

Across all three countries, gender emerged as the strongest and most consistent differentiator. In India, females reported significantly higher perceived risks of both crime occurrence ( $Z = 2.3$ ,  $p = 0.02$ ) and victimization ( $Z = 6.0$ ,  $p < 0.01$ ), whereas males exhibited slightly greater unwillingness to use autonomous transport ( $Z = -4.9$ ,  $p < 0.01$ ). In Pakistan, females expressed substantially higher perceived likelihood of crime ( $Z = 5.6$ ,  $p < 0.01$ ) and victimization ( $Z = 9.5$ ,  $p < 0.01$ ), as well as greater unwillingness to use ( $Z = 2.4$ ,  $p = 0.02$ ). In China, the gender gap was particularly pronounced, female respondents rated higher perceptions of crime occurrence ( $Z = 22.5$ ,  $p < 0.01$ ), victimization ( $Z = 35.3$ ,  $p < 0.01$ ), and unwillingness to use ( $Z = 16.7$ ,  $p < 0.01$ ). These consistent patterns reaffirm the gendered nature of perceived insecurity in public transport contexts.

Age differences were less consistent but still notable. In India, younger respondents ( $\leq 30$  years) perceived similar or slightly lower crime risks than older ones but demonstrated higher willingness to use, with unwillingness significantly higher among older individuals ( $Z = 2.1$ ,  $p = 0.03$ ). In Pakistan, younger participants reported significantly lower perceived risks of crime occurrence ( $Z = -3.1$ ,  $p < 0.01$ ) and victimization ( $Z = -2.4$ ,  $p = 0.02$ ), as well as lower unwillingness to use ( $Z = -3.7$ ,  $p < 0.01$ ). In China, younger respondents also perceived lower victimization risk ( $Z = -6.8$ ,  $p < 0.01$ ), consistent with greater technological optimism among younger age groups.

Education level showed country-specific effects. In India, higher education (undergraduate and above) was associated with significantly lower unwillingness to use ( $Z = -10.5$ ,  $p < 0.01$ ), indicating greater confidence in autonomous technologies. In Pakistan, participants with higher education expressed significantly higher perceived crime risk ( $Z = -11.3$ ,  $p < 0.01$ ) and stronger unwillingness to use ( $Z = -4.9$ ,  $p < 0.01$ ), suggesting that awareness of safety limitations may amplify caution. In China, higher education correlated with lower perceived victimization ( $Z = -4.8$ ,  $p < 0.01$ ) and lower unwillingness to use ( $Z = 2.9$ ,  $p < 0.01$ ).

Income effects were significant primarily in India and China. In India, lower-income respondents perceived higher risks of crime occurrence ( $Z = 4.8$ ,  $p < 0.01$ ) and victimization ( $Z = -12.9$ ,  $p < 0.01$ ), reflecting their greater exposure to insecure public environments. In China, higher-income respondents showed greater unwillingness to use autonomous transport ( $Z = -3.2$ ,  $p < 0.01$ ).

Finally, prior exposure to crime strongly intensified perceived insecurity across all contexts. Respondents who were female and had witnessed crime during travel exhibited the highest perceived risks and unwillingness levels (India: all  $p < 0.01$ ; Pakistan: all  $p < 0.01$ ; China: all  $p < 0.01$ ). This interaction effect highlights that experiential conditioning, particularly among women, had a powerful influence on both perceived vulnerability and behavioral resistance to automation.

### 4.4 Modeling results

The extended ordered probit model results (Table 4) reveal that socio-demographic, experiential, and situational factors significantly shape perceptions of crime occurrence, perceived victimization, and unwillingness to use autonomous public transport across India, Pakistan, and China. The findings demonstrate substantial cross-national variation, though consistent directional trends in key variables. Table 4 also reports model fit statistics, including the log-likelihood of the null model, the log-likelihood of the estimated model, and McFadden's pseudo- $R^2$ . Across all three countries and outcomes, the estimated models show improvement over the null specification, and the McFadden  $R^2$  values (0.075–0.278) indicate acceptable to strong model performance for ordered probit models, suggesting that the included explanatory variables contribute meaningfully to explaining perceived crime occurrence, victimization risk, and unwillingness to use autonomous public transport.

Age exhibited mixed but notable effects on perceived crime and adoption attitudes. In India, younger respondents ( $\leq 30$  years) perceived a higher likelihood of crime occurrence but were less likely to feel personally victimized and less unwilling to use autonomous public transport compared with older respondents. In Pakistan, younger individuals consistently showed lower perceived crime risk, lower victimization, and greater willingness to adopt AVs, indicating greater technological openness. In China, age did not influence perceived crime or victimization but younger respondents showed slightly higher willingness to use autonomous transport.

Gender emerged as one of the strongest and most consistent predictors of perceived insecurity across all three countries. Female respondents reported significantly higher perceived risks of crime occurrence and victimization, as well as stronger reluctance to use autonomous transport. This gendered pattern was evident in India, Pakistan, and China, with the largest effects observed in China, followed by Pakistan and India, underscoring the persistent gendered dimensions of safety perceptions in automated public transport environments.

Education level also influenced perceived risk and adoption attitudes, though in different directions across the three contexts. In India, respondents with lower education levels (below undergraduate) perceived higher crime occurrence but lower victimization risk and were less willing to use autonomous transport. In Pakistan, lower-educated respondents showed higher perceived crime occurrence, greater perceived victimization, and increased unwillingness to adopt autonomous modes. In China, lower-educated respondents were slightly more willing to use AVs, whereas education effects on perceived crime and victimization were not significant.

Household income influenced perceptions of safety and willingness differently across the three countries. In India, lower-income respondents perceived higher crime occurrence but lower victimization risk and were less unwilling to use autonomous transport. In Pakistan, lower-income respondents consistently reported higher perceived crime occurrence, greater victimization concerns, and stronger

TABLE 3 Results for group differences in perceived crime risk and unwillingness to use autonomous public transport.

Variables	Categories	India			Pakistan			China		
		Possibility of crime occurrence	Possibility of being a victim of crimes	Unwillingness to use	Possibility of crime occurrence	Possibility of being a victim of crimes	Unwillingness to use	Possibility of crime occurrence	Possibility of being a victim of crimes	Unwillingness to use
Age	Younger ( $\leq$ 30 years old)	5839.25	5886.39	5887.56	5275.55	5288.79	5262.14	6641.52	6600.61	6,704
	Older ( $>$ 30 years old)	5928.79	5731.2	5726.3	5463.77	5436.11	5491.77	6984.74	7091.68	6821.46
	Z †	-1.18	2.05	2.12	-3.05	-2.41	-3.73	-4.74	-6.79	-1.62
	Asymp. Sig. (2-tailed) ††	0.24	0.04	0.03	0.002	0.02	< 0.01	< 0.01	< 0.01	0.11
Gender	Male	5787.41	5681.04	6002.24	5159.6	5042.17	5260.15	5926.25	5465.14	6131.43
	Female	5927.5	6036.82	5706.72	5486.45	5585.98	5401.22	7390.27	7762.32	7224.71
	Z	2.34	5.95	-4.94	5.64	9.48	2.44	22.49	35.31	16.74
	Asymp. Sig. (2-tailed)	0.02	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01
Level of education	Lower education (Lower than undergraduate)	5848.09	5729.62	5861.47	4592.21	5045.95	5011.86	6644.88	6416.45	6927.54
	Higher education (Undergraduate and higher)	5907.83	6631.35	5826.14	5478.71	5392.02	5398.53	6758.33	6812.75	6690.99
	Z	-0.69	-10.49	0.41	-11.27	-4.44	-4.92	-1.38	-4.83	2.87
	Asymp. Sig. (2-tailed)	0.48	< 0.01	0.68	< 0.01	< 0.01	< 0.01	0.16	< 0.01	< 0.01
Income <sup>a</sup>	Low income	5643.11	6427.98	6066.93	5326.18	5357.92	5371.15	6760.94	6780.33	6686.09
	High income	5954.23	5594.77	5760.13	5346.31	5316.15	5303.57	6632.32	6549.65	6951.37
	Z	4.83	-12.94	-4.76	-0.34	0.73	1.17	1.56	2.79	-3.20
	Asymp. Sig. (2-tailed)	< 0.01	< 0.01	< 0.01	0.73	0.46	0.24	0.12	< 0.01	< 0.01

(Continued)

TABLE 3 (Continued)

Variables	Categories			India			Pakistan			China		
	Possibility of crime occurrence	Unwillingness to use	Possibility of being a victim of crimes	Possibility of crime occurrence	Unwillingness to use	Possibility of being a victim of crimes	Possibility of crime occurrence	Unwillingness to use	Possibility of being a victim of crimes	Possibility of crime occurrence	Unwillingness to use	Possibility of being a victim of crimes
Gender*Observed crime (Gender = female = 1; Observed crime = Yes = 1)	Yes interaction	6180.93	5978.97	5531.7	5541.21	5694.78	5550.22	7909.32	8247.82	7264.04		
	No interaction	5676.72	5788.64	6036.49	5151.09	5012.01	5124.08	6341.84	6227.93	6558.98		
	Z	8.08	3.05	-8.07	6.75	11.92	6.66	21.03	27.11	9.42		
	Asymp. Sig. (2-tailed)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		

\*Income: Higher (China: Income more than 360 k Pakistani rupees; India: Income more than 500 k Indian rupees); Lower (China: Income less than 360 k Pakistani rupees; India: Income less than 500 k Indian rupees).

† Z denotes the standardized Mann-Whitney U test statistic; †† Asymp. Sig. (2-tailed) denotes the two-tailed p-value (asymptotic significance).

reluctance to adopt AVs. In China, the income effect was limited, only the perceived victimization risk was lower among low-income respondents, while other differences were statistically insignificant.

Prior exposure to or observation of crime while traveling was a significant determinant of perceived insecurity. In Pakistan, those who had experienced or witnessed transport-related crimes reported higher perceived crime occurrence, higher victimization risk, and greater unwillingness to use autonomous transport. In China, crime exposure increased both perceived crime occurrence and unwillingness to use. In contrast, in India, the variable did not yield statistically significant results.

The presence or absence of a driver had a major influence on safety perceptions and willingness to adopt autonomous public transport. Across all three countries, removing the human driver increased perceived crime occurrence and reluctance to use. The effect was especially strong in Pakistan and China, where the absence of a driver also heightened perceived victimization risk. In addition, the absence of a security officer similarly elevated perceived insecurity across all three countries. In India, Pakistan, and China alike, respondents reported higher perceived crime occurrence, greater victimization risk, and increased unwillingness to use when no security officer was present. This pattern reinforces the critical symbolic and deterrent role of visible authority in maintaining passenger confidence during automated transport.

Technological security measures such as CCTV and emergency buttons also shaped perceptions but to a lesser degree than human supervision. In all three countries, the absence of CCTV or an emergency button led to higher perceived crime occurrence, increased victimization concerns, and greater unwillingness to use autonomous modes. The effect was particularly pronounced in Pakistan and China, suggesting stronger sensitivity to visible technological safeguards in these contexts.

Mode-specific differences were observed in all three countries. Respondents generally viewed autonomous ride-pooling as more vulnerable to interpersonal crime than autonomous buses. In India and Pakistan, ride-pooling was associated with higher perceived crime and victimization risks and greater unwillingness to use, likely reflecting concerns over smaller passenger groups and reduced social visibility. In China, differences between autonomous buses and ride-pooling were smaller but directionally consistent.

Trip duration was a significant situational factor influencing safety perceptions. Across all three countries, nighttime travel increased perceived likelihood of crime occurrence, perceived victimization, and unwillingness to use autonomous transport. The nighttime effect was strongest in Pakistan and India, reflecting heightened safety concerns in lower-surveillance environments. Moreover, trip duration also affected safety perceptions. Longer trips (exceeding 30 min) increased perceived crime occurrence, perceived victimization, and unwillingness to use autonomous transport in India, Pakistan, and China. The consistent positive association between trip length and insecurity reflects discomfort with prolonged exposure in unsupervised or semi-autonomous environments.

## 5 Discussion

### 5.1 Comparative patterns across national contexts

The comparative results in Table 2 indicate that perceived crime risks had a substantial influence on public willingness to adopt

TABLE 4 Model estimation results for perceived risk of crime occurrence, perceived risk of being victim of crime and unwillingness to use.

Category	Variable	India			Pakistan			China		
		Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use
		Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
-	Constant	2.76***	3.82***	3.79***	0.16**	-0.29***	1.39***	-0.77***	-0.12**	-0.75***
-	<i>St. dev.</i> †	—	—	—	—	0.83***	0.67***	—	—	—
Age	Older (Over 30 years old)	Reference								
	Younger (Less than or equal to 30 years old)	0.08***	-0.90***	-0.39***	-0.12***	-0.26***	-0.10***	—	—	-0.10***
	<i>Std. dev.</i>	—	—	—	-0.11***	—	—	—	—	1.12***
Gender	Male	Reference								
	Female	0.28***	0.27***	0.27***	0.24***	0.12***	0.15***	0.62***	0.30***	0.87***
—	<i>Std. dev.</i>	—	—	—	—	0.24***	0.25***	0.19***	—	0.68***
Highest education level	Higher education (Undergraduate and higher)	Reference								
	Lower education (Lower than undergraduate)	0.12**	-0.09***	-0.96***	0.42***	0.14***	0.05**	—	—	-0.41***
	<i>Std. dev.</i>	—	—	—	0.30***	—	—	—	—	0.83***
Annual household income <sup>a</sup>	Higher income	Reference								
	Lower income	—	—	—	0.30***	—	—	—	-0.25***	—
—	<i>Std. dev.</i>	—	—	—	0.24***	—	—	—	0.85***	—
If observed crime type while traveling	No	Reference								

(Continued)

TABLE 4 (Continued)

Category	Variable	India			Pakistan			China		
		Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use
		Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
—	Yes (crimes include theft/ robbery, verbal, physical, or sexual harassment)	—	—	—	0.05***	0.63***	0.25***	0.25***	—	0.50***
	<i>Std. dev.</i>	—	—	—	,	0.47***	0.18***	0.23***	—	0.39***
Driving automation	Driver is present	Reference								
	No driver	0.88***	0.07*	0.07*	0.44***	0.30***	0.29***	1.01***	1.30***	0.93***
	<i>Std. dev.</i>	—	—	—	0.51***	0.28***	0.44***	0.63***	0.78***	0.87***
Security officer is present	Security officer is present	Reference								
	No security officer	0.93***	0.25***	0.25***	1.01***	0.72***	0.50***	0.99***	0.85***	0.90***
	<i>Std. dev.</i>	—	—	—	0.60***	0.64***	0.59***	0.46***	0.50***	0.65***
Security measure: CCTV/ emergency button	CCTV/ emergency button is present	Reference								
	No CCTV/ emergency button	0.48***	0.10***	0.10***	0.63***	0.63***	0.43***	0.69***	0.72***	0.60***
	<i>Std. dev.</i>	—	—	—	0.94***	0.60***	0.62***	0.60***	0.64***	0.67***
Travel mode	Ride-pooling service	Reference								
	Bus	0.16**	0.23***	0.24***	0.04**	0.05**	0.02**	0.04**	-0.03**	0.08***
	<i>Std. dev.</i>	—	—	—	0.03**	—	—	0.36***	0.41***	0.45***

(Continued)

TABLE 4 (Continued)

Category	Variable	India			Pakistan			China		
		Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use	Crime occurrence	Victimization	Unwillingness to use
		Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Time of day	Day	Reference								
	Night	0.88***	0.06**	0.06**	0.45***	0.37***	0.27***	0.26***	0.32***	0.15***
	<i>Std. dev.</i>	—	—	—	0.47***	0.46***	0.48***	0.61***	0.66***	0.55***
Trip duration	Short travel (≤ 30 min)	Reference								
	Long travel (> 30 min)	0.16***	0.17***	0.17**	0.25***	0.30***	0.23***	0.39***	0.23***	0.30***
	<i>Std. dev.</i>	—	—	—	0.20***	0.22***	—	—	—	—
Model Fit	Log-likelihood of the null model	-17,635.65	-17,132.64	-18,192.41	-16,307.37	-15,544.19	-15,886.93	-19,352.27	-19,236.21	-18,632.69
	Log-likelihood of the estimated model	-13,695.95	-12,821.62	-13,141.75	-12,856.07	-13,624.86	-14,070.06	-16,610.47	-14,515.40	-17,236.54
	McFadden R <sup>2</sup>	0.224	0.252	0.278	0.211	0.124	0.114	0.142	0.245	0.075

\*Income: Higher (China: Income more than 100 k CNY; Pakistan: Income more than 360 k Pakistani rupees; India: Income more than 500 k Indian rupees); Lower (China: Income less than 100 k CNY; Pakistan: Income less than 360 k Pakistani rupees; India: Income less than 500 k Indian rupees).

Significance: \* $p \leq 0.1$ ; \*\* $p \leq 0.05$ ; \*\*\* $p \leq 0.01$ . †St. dev. Reflects standard deviations of the random parameters.

autonomous public buses and ride-pooling services. Consistent with descriptive findings, Chinese respondents reported the lowest perceived interpersonal crime risks and the highest willingness to use autonomous public transport. This pattern can be understood within China's broader "trust ecology," where citizens associate automation with institutional stability, predictability, and state-managed safety. Previous studies (Tsai et al., 2024; He et al., 2025) similarly note that China's large-scale investment in surveillance infrastructure, real-time monitoring, and controlled AV trials reinforces public confidence that advanced transport technologies will be safely governed in practice.

In contrast, respondents in India and Pakistan perceived substantially higher risks of crime and expressed lower willingness to adopt autonomous systems. These responses mirror social realities where harassment, petty theft, and limited institutional enforcement remain prevalent in everyday commuting (Tabassum and Suhail, 2022; Madan and Nalla, 2016; Haroon, 2015). For many commuters, especially women, the perception of safety is not derived from abstract technical reliability but from visible forms of social control, such as the presence of drivers, conductors, or security officers (Ceccato et al., 2022; Ceccato and Loukaitou-Sideris, 2022). When automation removes these human guardians, it symbolically removes a critical element of reassurance. The resulting apprehension is not purely technological but deeply experiential, reflecting what may be termed experience-driven risk perception, where fear and trust are constructed through daily interactions with public safety rather than through conceptual understanding of automation.

From a comparative standpoint, these findings imply that trust in technology is socially produced rather than universally transferable. In China, trust is largely institutional, anchored in confidence in the state's regulatory and surveillance capacity. In India and Pakistan, trust is more relational and situational, dependent on interpersonal accountability and visible authority. The removal of human supervision therefore generates a "trust vacuum," where individuals substitute institutional assurance with personal heuristics and prior experience. Consequently, even when the physical technologies of automation are identical, their social reception diverges sharply depending on the prevailing trust infrastructure, exposure to crime, and lived realities of safety.

## 5.2 Cross-country differences in model coefficients

As shown in Table 4, the estimated coefficients of the random-parameters ordered probit models differ across India, Pakistan, and China. These cross-country variations are consistent with the view that perceived security and trust in autonomous public transport are shaped by national security environments, institutional capacity, and everyday exposure to interpersonal risks (Currie et al., 2013; Sundling and Ceccato, 2022).

In India, the relatively large and positive constant terms across the three outcomes suggest higher baseline perceptions of crime occurrence and victimization risk, together with stronger reluctance to use autonomous public transport. This pattern is plausible in contexts where harassment and theft are salient features of daily commuting and where perceived safety is often anchored in visible guardianship (e.g., drivers, conductors, or staff presence) rather than in the technology itself (Ceccato et al., 2022).

In contrast, the negative constants estimated for China indicate lower baseline perceived crime risk and lower baseline reluctance to

use autonomous public transport. This aligns with evidence that safety perceptions in Chinese urban transport are closely linked to institutional oversight and extensive surveillance capacity, which can reduce reliance on interpersonal reassurance when forming security judgments (Liang et al., 2025).

Pakistan shows a more heterogeneous pattern: baseline constants are lower, but several parameters exhibit statistically significant standard deviations, indicating meaningful unobserved heterogeneity. This suggests that perceived crime risk and adoption reluctance vary more strongly across individuals and may be more sensitive to personal crime exposure and local travel conditions (Pervez et al., 2025a).

## 5.3 Gendered vulnerability and cultural context

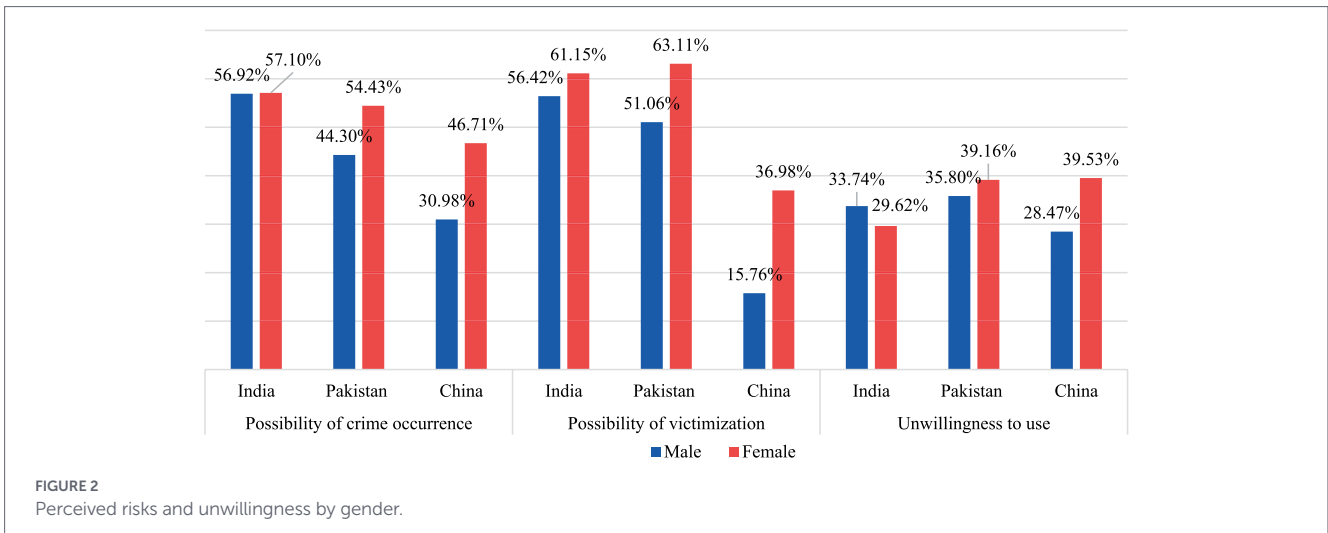
As shown in Figure 2 and Tables 2, 3, gender emerged as one of the strongest and most consistent predictors of perceived crime risk and unwillingness to use autonomous public transport. Across all three national contexts, female respondents expressed significantly higher concerns about both the likelihood of crime occurrence and the risk of personal victimization. These findings align with the established "gendered fear of crime" framework (Zahra et al., 2024; Johansson and Haandrikman, 2023; Stark and Meschik, 2018), which emphasizes that women's perceived vulnerability arises not merely from actual rates of victimization, but from the intersection of social norms, routine experiences, and the symbolic meanings attached to mobility and public space.

In Pakistan and India, where harassment and intimidation in public transport are widespread and frequently underreported, these fears are grounded in structural gender inequality and systemic institutional neglect (Useche et al., 2024; Ilyas and Garg, 2023). The absence of accountability mechanisms, limited female representation in enforcement agencies, and normalized everyday harassment contribute to a pervasive sense of exposure (Tabassum and Suhail, 2022; Berik et al., 2024). When extended into autonomous settings, the removal of the human driver, traditionally seen as both a practical overseer and symbolic guardian (Lorenc et al., 2013; Gekoski et al., 2017), intensifies women's perceived vulnerability. As a result, automation may reproduce existing gender asymmetries in mobility safety rather than alleviating them, unless explicit design and policy interventions are integrated from the outset.

In Chinese context, women reported comparatively higher willingness to use autonomous transport than their counterparts, suggesting that trust in surveillance technologies and institutional monitoring moderates gendered fear. This observation aligns with the "surveillance reassurance hypothesis," which posits that visible surveillance systems (e.g., CCTV, facial recognition) enhance perceived safety by signaling formal control and deterrence (Welsh and Farrington, 2008). However, such reassurance is culturally contingent, while it may foster confidence in contexts where state surveillance is normalized and trusted, it may not have the same psychological effect in settings where institutional reliability is contested. Thus, designing gender-responsive AV systems require approaches that extend beyond technical risk mitigation toward fostering perceived control and emotional security.

## 5.4 Role of prior experience

As shown in Table 3, a consistent and powerful pattern across all three countries is the strong association between prior exposure to



crime and increased perceived risk of autonomous transport. Respondents who had witnessed or personally experienced incidents such as theft, harassment, or assault while commuting reported significantly higher perceptions of both crime occurrence and victimization and expressed greater unwillingness to use autonomous public buses or ride-pooling services. This consistent pattern supports cognitive-behavioral theories of risk perception, which posit that emotionally salient experiences, rather than objective probabilities, dominate how individuals evaluate risk in uncertain or unfamiliar settings (Skagerlund et al., 2020). In contexts marked by frequent harassment, theft, and weak enforcement, the memory of insecurity becomes deeply institutionalized (Olowo, 2025). Consequently, even technologically advanced systems such as autonomous transport are not perceived as inherently safer but are interpreted through the same cognitive schema of vulnerability and limited control.

### 5.5 The “capable guardian” reconsidered in autonomous contexts

As shown in Tables 3, 4, the absence of human supervision, whether in the form of a driver, security officer, or visible surveillance measures such as CCTV and emergency buttons, was consistently associated with higher perceived risks of crime occurrence and victimization, as well as greater unwillingness to use autonomous public buses and ride-pooling services. Across all three national contexts, this pattern underscores that automation not only transforms vehicle operation but also reshapes passengers’ perceptions of personal security and social control within shared transport environments.

One of the most salient theoretical implications of these findings lies in the reaffirmation and recontextualization of Routine Activity Theory (Cohen and Felson, 1979). According to this framework, crime occurs when a motivated offender encounters a suitable target in the absence of a capable guardian. In conventional public transport, drivers, conductors, or security officers fulfill this guardianship role by exercising informal social control and providing visible deterrence (Loukaitou-Sideris, 2014; Lorenc et al., 2013; Gekoski et al., 2017; Kruger and Landman, 2007). The transition to autonomous public buses and ride-pooling services effectively removes this human intermediary, replacing embodied oversight with algorithmic and technological substitutes.

Empirical evidence from all three countries demonstrates that this structural change carries perceptual consequences: the absence of a human driver or security officer significantly increased respondents’ perceived crime risk and unwillingness to use autonomous vehicles. This highlights that passengers’ sense of safety derives not only from the objective capacity of guardians to intervene, but also from the symbolic reassurance their presence conveys (Liu et al., 2020; Cozens et al., 2005). In other words, the perception of guardianship is as critical as its functional reality. Even when technological safeguards such as CCTV cameras and emergency buttons were included, respondents reported lower confidence, suggesting that these devices have not yet achieved equivalence with the psychological comfort provided by visible human authority (Tykesson, 2025; Zhang et al., 2019). Theoretically, these findings extend Routine Activity Theory into the technological domain, emphasizing that guardianship in autonomous mobility must be understood as dual in nature, both functional, concerning the capability to intervene, and perceptual, concerning the visible assurance of safety. Unless both dimensions are simultaneously addressed, even the most advanced safety technologies may fail to generate the public confidence necessary for widespread adoption of autonomous public transport.

### 5.6 Situational and travel-related factors

The study’s findings, as illustrated in Table 4, showed that situational and travel-related conditions emerged as consistent determinants of perceived crime risk and unwillingness to use autonomous public transport across the three study contexts. In all countries, nighttime travel and longer trip durations significantly heightened respondents’ fear of crime and personal victimization, reaffirming the spatiotemporal dimensions of insecurity observed in conventional transport research (Wallace et al., 1999). These perceptions are rooted in the association between darkness, isolation, and reduced social visibility, factors that amplify perceived vulnerability regardless of actual safety levels (Williams et al., 2020; Yang et al., 2022).

Across modes, respondents generally regarded autonomous ride-pooling services as riskier than autonomous public buses. The semi-private and enclosed setting of ride-pooling, often shared with unfamiliar passengers and lacking a human driver, elicited stronger interpersonal crime concerns than the more open, collectively monitored environment of buses (Nguyen-Phuoc et al., 2020). This

perception was most pronounced in India, where over two-thirds of participants associated ride-pooling with elevated crime likelihood and victimization risk. In Pakistan, the difference was smaller but still evident, reflecting widespread distrust of semi-private travel and limited institutional mechanisms to ensure accountability in shared mobility systems. In China, respondents expressed comparatively lower mode-based differentiation, suggesting that stronger public security infrastructure and higher confidence in technological supervision (e.g., CCTV, real-time tracking) mitigate such situational anxieties.

Trip duration further shaped respondents' perceptions: longer journeys were consistently associated with greater perceived exposure to risk. This effect likely reflects cumulative uncertainty, the longer one remains in an enclosed or automated environment without visible supervision, the stronger the perception of potential danger. The interaction of time and mode was particularly relevant in South Asia, where the combination of nighttime travel and longer ride-pooling trips triggered the highest levels of perceived insecurity and unwillingness to use. These findings suggest that situational awareness in AV adoption is profoundly context-dependent. In environments with lower social trust and higher baseline crime exposure, as in Pakistan and India, travelers' evaluations of safety remain strongly tied to visibility, duration, and social proximity. Conversely, in higher-trust environments like China, the perceived risks of automation appear more manageable and mediated by confidence in institutional surveillance. These results underscore that temporal, spatial, and social cues, not just technology features, are central to building user confidence in autonomous public transport.

## 5.7 Policy implications

The findings from this comparative analysis provide critical insights for policymakers, manufacturers, and transport operators seeking to facilitate the safe and equitable deployment of autonomous public transportation across distinct socio-technological contexts. Crucially, security and interpersonal crime concerns must not be treated as secondary to technical reliability; rather, they should form a central pillar of early AV deployment strategy.

The results clearly demonstrate that security perceptions and adoption barriers vary substantially across India, Pakistan, and China, underscoring that localized governance frameworks are necessary rather than uniform, technology-driven rollouts. Consistent with prior research in transport psychology and technology acceptance (Nordhoff et al., 2018), public trust in automation is culturally mediated and deeply influenced by institutional credibility, enforcement quality, and collective experience with safety systems. For instance, while cost- or efficiency-oriented messaging may effectively promote adoption in India, where technological optimism is relatively high, similar strategies in Pakistan are unlikely to succeed without first addressing long-standing concerns about harassment, crime, and enforcement reliability (Pervez et al., 2025a).

A key operational implication concerns the role of visible human guardianship in cultivating trust. Across all three countries, respondents expressed clear discomfort toward fully driverless and unmonitored travel environments, revealing that human supervision remains indispensable for perceived security. Consequently, early deployment should follow a phased transition model that initially retains an onboard service agent or safety ambassador. This mirrors the automated shuttle trials in Berlin-Schöneberg, where a "hidden steward" improved perceived safety in mixed traffic (Nordhoff et al., 2020). Similarly, other shuttle experiments emphasized human presence for passenger comfort

(Fonzone et al., 2025). Legislation should require phased autonomy escalation, with mandatory human presence in high-crime corridors (e.g., nighttime urban routes). Therefore, regulators should mandate hybrid operation phases during the first years of rollout, especially along high-risk corridors or during nighttime service, where human operators, attendants, or remote tele-operators remain visibly engaged.

The study also highlights the urgent need for gender-responsive safety design in autonomous public transport. Female respondents consistently expressed higher fear of crime and greater unwillingness to use AV-based modes, with the strongest effect in China despite lower reported exposure to transport-related offenses. This persistent gender gap calls for design and policy measures that actively enhance perceived control and comfort for women. Options include women-only compartments, dynamic routing or seating algorithms, and priority boarding systems integrated into mobile applications. Real-world precedents illustrate the effectiveness of such measures: the Mexico City Metrobús women-only cars reduced reported harassment by over 50% and increased female ridership by 28% (Marley Pinsky, 2024), while similar programs in Indian cities showed marked improvements in travel confidence (Dunckel-Graglia, 2013). Embedding such inclusive strategies into autonomous systems, through AI-enabled gender recognition, emergency signaling, and real-time monitoring, can substantially mitigate perceived vulnerability and support equitable adoption.

Finally, public communication and governance frameworks must be tailored to national context. In China, high institutional trust and familiarity with surveillance technologies provide a strong foundation for public confidence in automated oversight. Conversely, in India and Pakistan, where institutional trust is weaker and exposure to transport crime is higher, public acceptance will rely on transparent demonstration of safety assurance and rapid incident response. Governments should therefore prioritize context-sensitive communication campaigns that clearly explain AV security mechanisms, data privacy safeguards, and emergency response capabilities. Cross-sector partnerships between technology providers, local governments, and community organizations can further enhance credibility and public engagement, ensuring that automation evolves as a socially trusted, rather than socially imposed, mobility solution.

## 6 Conclusion

This study addresses a critical gap in research on autonomous public transport adoption by examining how perceived crime risks shape public willingness to use autonomous buses and ride-pooling services across three diverse Asian contexts, India, Pakistan and China. Moving beyond traditional concerns with technical safety or cybersecurity, this research foregrounds interpersonal security: the influence of social norms, institutional trust, and everyday crime exposure on acceptance of autonomous mobility. Survey data from 2,241 urban respondents (India:  $N = 732$ ; Pakistan:  $N = 667$ ; China:  $N = 842$ ) were collected through a scenario-based stated-preference experiment varying automation level, security features, trip duration, and transport mode. The analysis combined descriptive statistics, Mann-Whitney U tests, and extended random-parameters ordered probit models to capture both systematic and unobserved heterogeneity in responses.

Results show that automation significantly increases perceived crime likelihood, victimization risk, and reluctance to use autonomous public transport. These effects were strongest in India and Pakistan,

where harassment concerns and institutional distrust are prevalent, and weakest in China, where advanced surveillance and technological familiarity mitigate perceived risks. Gender emerged as the most powerful predictor, with women, particularly in South Asia, expressing higher vulnerability and lower willingness to use autonomous modes, reinforcing entrenched gender inequalities in public mobility. The absence of human or CCTV guardians independently intensified feelings of insecurity and mistrust across all contexts. Situational factors such as nighttime travel, extended trip duration, and previous crime exposure further magnified perceived risks.

Theoretically, the study contributes to transport safety and behavioral research by integrating criminological constructs with technology acceptance models, highlighting that perceived interpersonal risk is as influential as functional performance in shaping AV adoption. Practically, the results highlight the need for localized and gender-responsive implementation strategies. Building public confidence will require phased deployment, initially with onboard attendants, visible security features, and transparent communication about safety mechanisms, before transitioning to fully driverless operations.

This study has several limitations. First, the reliance on hypothetical scenarios may not fully reflect real-world decision-making or behavioral responses once autonomous public transport becomes operational. Future research could address this limitation by incorporating revealed-preference data, field experiments, or longitudinal observations as real-world deployments become more common. Second, the sample, composed mainly of young and educated individuals, may overrepresent technologically literate populations and understate the concerns of older or less-connected groups. Thus, subsequent studies should aim to include more diverse demographic groups, particularly older adults and individuals with limited digital access, to capture a broader range of perceptions. Third, the cross-sectional design restricts the ability to track changes in perceptions over time or as exposure to autonomous systems increases. In this regard, longitudinal or panel-based study designs would allow future work to examine how perceived crime risk and willingness to use evolve with increasing familiarity. Lastly, contextual and cultural differences across cities were not explored in depth, which may limit the generalizability of findings beyond the surveyed urban settings. Future studies could explore city-level and institutional factors, such as governance structures and local transport environments, to better understand how contextual conditions shape perceptions of interpersonal security in autonomous public transport.

## Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

## Author contributions

AP: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. JL: Conceptualization, Resources, Supervision, Writing – review & editing. BM: Conceptualization, Resources, Validation, Visualization, Writing – review & editing.

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## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frsc.2026.1748749/full#supplementary-material>

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