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E-scooters and Traffic Accidents: Evidence from Staggered Roll-Out in Swedish Municipalities

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Abstract

The rapid rise of e-scooters (electric scooters) in cities around the world, boosted by the introduction of shared e-scooter services has visibly reshaped the way people move around cities, sparking both excitement and controversy. With the increase in popularity of these vehicles, concerns regarding their impact on traffic safety and accidents have become a rising public concern. In this paper, we investigate the frequency of traffic accidents involving e-scooters following the introduction of shared e-scooter services in Swedish municipalities during the period 2019-2022. We use a staggered difference-in-difference regression to identify the causal effect of shared e-scooters on various types of traffic accidents using municipalities without e-scooters as a control group. We present three main findings. First, overall accidents increase by approximately one standard deviation in the first quarter following the introduction of shared e-scooters, but the overall effect decreases (0.5-1 standard deviation) over five quarters and vanishes over nine quarters. Second, the increase in accidents involving e-scooters is not associated with an increase in pedestrian or bicycle accidents. Instead, e-scooters are predominantly involved in accidents with cars. Third, the observed increase in accidents is largely attributable to large metropolitan areas, where urban traffic is usually more complex and intensive.

Keywords: Urban mobility, traffic accidents, e-scooters.
JEL-codes: R41, O18

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1. Introduction

The rapid rise of e-scooters (electric scooters) in cities around the world, boosted by the introduction of shared e-scooter services in the latter half of the 2010's, has been a notable trend in urban transportation in recent years. This phenomenon has visibly reshaped the way people move around cities and has sparked both excitement and controversy. With the increase in popularity of these devices, concerns regarding their impact on traffic safety and accidents have become a rising public concern and a prioritised research frontier.

Neither e-scooters nor shared micro-mobility services are new, but dockless shared e-scooters provide a novel digital addition to cities. The successful integration of a new mode of transportation like this depends on the complex interaction between technology-driven innovation by service providers, the behaviours of users as well as other road users and pedestrians, and regulatory responses from city officials and national legislators. Changes in one of these relations are likely to affect the others. Traffic safety not only constitutes an important end in itself, but also provides a valuable indicator by which to measure the outcome of these interactions.

Traffic safety and accidents is a prioritised venue of future research on urban micro-mobility in general and e-scooters in particular. To date, few studies investigate the impact of electric scooters on traffic accidents and most focus on hospital admissions and e-scooter riders rather than overall traffic accidents. We address this gap in the literature by studying overall traffic accidents in Swedish municipalities following the introduction of shared- e-scooter services in the years 2019-2022. Our data set enables us to analyse injuries related to bikes, pedestrians, e-scooters, and cars separately. By examining the impact of introducing e-scooters on each category, using a difference-in-difference strategy, we contribute to a more nuanced understanding of their role in urban traffic dynamics and injury patterns. The results contribute to the growing literature on urban micro-mobility and e-scooters, as well as providing valuable insights to the ongoing policy debate surrounding e-scooter regulation and public safety concerns.

The analysis yields three main findings. First, there is a statistically significant increase of one standard deviation in overall traffic accidents following the introduction of shared e-

scooters. However, the observed effect subsequently decreases and more or less vanishes. These results show that there is no steady increase in accidents over time due to the new mode of micro-mobility thus far. Second, breaking down the results on mode of transport we find that the increase in accidents involding e-scooters is not associated with a rise in accidents involving pedestrians or bicyles, but for cars. This finding provides important information about what type of problem the integration of e-scooters face in urban traffic. Third, much of the average observed effect is attributable to Sweden's three largest metropolitan areas (Stockholm, Gothenburg, and Malmoe). These also present the most complex urban traffic environment.

2. Fitting e-scooters into urban mobility and traffic safety

2.1 Digital innovation in the city

Digital technologies hold significant potential to remedy pressing urban issues (Townsend 2013, Offenbauer and Ratti 2014, Ratti and Claudel 2016, O´brien 2018, Vermiglio et al 2020, Ang et al 2022, Shi et al. 2023). The internet's connectivity and searchability, combined with the ubiquity of smartphones and the growing internet of things, allow people to better leverage positive density externalities in cities while counteracting negative ones. Much like cities contribute to lower transaction costs by bringing people together in geographical space, digitalization lowers transaction costs within cities by making it easier to exchange information as well as to match supply and demand in large populations of interconnected actors.

Digital technologies are associated with a considerable potential for innovation and scalability because they are wide-spread within the economy, general-purpose and can be combined in a large number of ways (Varian 2003, Varian 2010, Wagner 2011, Brynjolfsson and McAfee 2014, Ito and Howe 2016, Branstetter et al. 2019). Yet, within a city, this innovation potential is restricted in several ways. Urban interactions and exchanges are conditioned by scarcity of physical space, competing uses, as well as slow and path-dependent change to the built environment. These constraints shape the distribution and structure of social and economic activities in the city and by extension also the use of digital technologies (Batty 2013, Wernberg 2017, Bettencourt 2021). The way commercial digital innovations are introduced into urban environments is shaped by these physical constraints,

but also by institutional conditions and regulatory concerns. Regulatory responses to new and emerging technologies require a balance between the potential benefits of innovation and the need to safeguard consumers and citizens.

Digital innovations that shift peoples' behaviour and use of existing resources may create friction with institutional and regulatory frameworks. The sharing economy provides ample examples of this phenomenon (Sundararajan 2017, Bergh et al 2018, Bergh et al. 2021). Ride-hailing services like Uber or Bolt, especially in combination with GPS-based map services, have challenged traditional taxi markets in several countries and cities (Elert et al. 2016, Wernberg 2018, Spicer et al. 2019, Elert and Deerfield 2023). Similarly, rental platforms like Airbnb have altered the way people utilise their housing and the incentives for investing in housing (Sans and Quaglieri 2016, García-Hernández et al. 2017, Cocola-Gant and Gago 2021).

Furthermore, when a digital innovation introduces a combination of new resources or artifacts and novel activities into the urban environment, it may also come into conflict with existing institutional and regulatory frameworks. The introduction of autonomous vehicles and commercial unmanned aerial drones in cities raise policy concerns with respect to the regulation of both the new artifact and the activities it is associated with (Martinez and Viegas 2017, Primatesta et al. 2019, Nikitas et al. 2020, Aoyama and Leon 2021, Dowling and McGuirk 2022).

Thus, successful city-centric commercial digital innovations are the outcome of interactions between technological capabilities, constraints in physical space and the built environment, shifting behaviours among users, and institutional or regulatory responses. A shift in one of these relations is likely to affect the others, making it an experiment-driven and complex process of adaptation, or a form of learning by using (Rosenberg 1982). At its best, digital urban innovation is a combination of the data-driven experimental logic associated with digital technologies and entrepreneurship as experimentation (Varian 2010, Kerr et al. 2014, Klepper 2015, Luca and Bazerman 2021). At its worst, it's a catch-22 where new digital solutions can only be integrated into urban economies if they result in little or no change to the way cities work, effectively upholding a form of lock-in which makes it difficult to employ new technologies to solve current urban issues.

The recent growth in shared micro-mobility, and in particular shared e-scooters, is the result of commercial digital innovation and it occurs at the intersection of all of these challenges. While the scooter itself is not new, it was popularized through shared micro-mobility service providers and largely constitutes a new addition to the street view. It does not have a given place in urban traffic, which has for instance resulted in users alternating between riding on the sidewalk and in the street and irregular parking patterns. Based on how the shared e-scooters are used, service providers have iteratively developed new models to better fit the needs of riders as well as to prevent wear and tear. Providers have also faced a mix of different regulatory responses from city officials as well as national legislators in different countries.

2.2 Previous research on shared e-scooters

Research on shared personal micro-mobility has proliferated since 2012, but the rise of shared e-scooters is a fairly new phenomenon and the literature has until recently largely focused on shared bicycles (O´Hern and Estgfaeller 2020). The scooter is not a new vehicle, and shared micro-mobility services aren't new, but the novel combination of dockless shared e-scooters is has grown considerably in recent years and appears to have boosted shared micro-nobility overall (Oeschger et al. 2020, Şengül and Mostofi 2021).

Research specifically on shared e-scooters is still in its infancy and consists mainly of survey and traffic data from specific countries, making it hard to generalise findings since local conditions, culture and regulations vary considerably (Bai and Jiao 2020, Liao and Correia 2022). Even so, some empirical regularities between studies from several countries and cities suggest that e-scooter riders oftentimes tend to be well-educated men in their 20-40's, trips are mostly concentrated to busy areas with high employment density and university campuses, and usage include both first/last mile transport, commuting and leisure transport (Degele et al. 2018, Bieliński and Ważna (2020), Boglietti et al. 2021, Baek et al. 2021, Laa and Leth 2020, Lee et al. 2021, Christoforou et al. 2021, Nikiforiadis etl al. 2021, Bai and Jiao 2020, Jiao and Bai 2020, Caspi et al 2020, Chicco and Diana (2022), Liao and Correia (2022) Orozco-Fontalvo et al. 2023). Demand for shared e-scooters is based on user's perceived benefits. Among these are travel time savings, convenience, hedonic motivation, and perceived utility benefits to well-being (Cao et al. 2021, Fitt and Curl 2020, Kopplin et al. 2021, Kazemzadeh and Sprei 2022). However, these observed regularities may not hold for a larger population of countries and cities or remain stable over time.

The introduction of e-scooters do not only raise the questions of how they *should* be integrated into urban traffic, but also how they are actually used. There are issues of road use and allocation of space that are similar to those associated with bicycle traffic (Laa and Leth 2020, Caspi et al. 2020), but several studies also suggest that scooter riders do not know how to use scooter sin line with traffic regulations and "play" with traffic rules by alternating between behaving as road users and pedestrians and riding on the sidewalk (Boglietti et al. 2021, Şengül and Mostofi 2021). One case study on Rosslyn in Virginia, USA, finds highly divergent attitudes to safety concerns between people who use e-scooters and those who do not, indicating conflicting views of how they should be integrated into urban traffic (Swiderski et al. 2019).

Regulations, for instance speed limits on e-micromobility, vary between cities and countries (Şengül and Mostofi 2021, Orozco-Fontalvo et al. 2023, McKinsey 2023). One study on news media coverage before, during and after the introduction of e-scooters indicates that policy makers appear to have moved through a reactive process of trial-and-error when regulating the new vehicle, ending up with considerable differences between places (Gössling 2020). Uncertainty or lack of knowledge about local rules for using e-scooters, for instance among tourists, may contribute to risky behaviour in traffic. All in all, it is hard for policy makers to strike a balance between benefits of enhanced mobility and safety concerns, but providers of shared e-scooters face an equally challenging learning curve with respect to user behaviour and uncertain regulatory environment (Button et al. 2020, Field and Jon 2021). For these reasons, safety concerns come to the fore when studying the introduction of shared e-scooters as a digital innovation in urban space.

2.3 Research traffic safety, accidents and injuries associated with e-scooters

Apart from the need for more studies specifically on shared e-scooters and their use across different countries and cities (Oeschger et al. 2020, Bai and Jiao 2020), safety and injuries related specifically to e-scooters constitutes an important research frontier as well as a public concern (O´Hern and Estgfaeller 2020, Gössling 2020, Caspi and Smart 2022, Bloom et al., 2021, Cicchino et al. 2021, Kobayashi et al. 2019).

Because of the rapid rise in availability and use of e-scooters, there are some considerable challenges associated with analysing accidents and injuries. Some studies have focused on the number of hospital admissions to map increases in e-scooter-related injuries. Mayhew and

Bergin (2019) perform a retrospective chart review of patients with the word “e-scooter” between August and December 2018 in Auckland hospital in Texas, USA. They conclude that the introduction of shared e-scooters – which happened during that period – has resulted in an observable rise in injuries that required urgent radiology imaging. Namiri et al. (2020) compile US data from emergency departments nationally between 2014-2018 and find a 354% percent increase in the share of injuries in the age group 18-34-year-olds between 2017 and 2018. Similarly, Aizpuru et al. (2019) report 32,400 injuries related to motorized scooters between 2013-2017, with a 77% increase in scooter injuries among millennials between 2016 and 2017. However, they do not find a significant overall increase during the period they study. The demographics of these studies are in line with studies on typical scooter riders and echo the findings in the literature review by Boglietti and co-authors (2021). However, none of these studies control for the rise in number of scooters or their use which means it is hard to determine whether the number of injuries has gone up in proportion to the share of e-scooter trips in urban traffic or if the e-scooter trips that ended up in incidents substituted some other mode of transportation. Even if the number of e-scooter-related crashes would go up, the crash risk may be decreasing since it depends on the volume of e-scooter traffic (International Transport forum 2024).

Some studies suggest that the injury frequency is significantly higher for e-scooters compared to other means of transportation (Ioannides et al., 2022; Rix et al., 2021), while others argue that their overall effect on injury rates remains unclear (Santacreu et al., 2020). Félix et al (2023) used data from 1.4 million trips from one e-scooter operator in Lisbon and a user survey with 919 responses to find that the benefits generated by shared e-scooters are overshadowed by their safety issues (valued at almost 6M euro in annual costs).

Compared to other modes of transport, injuries with e-scooters appear to mainly (97%) include the scooter rider and not others (Boglietti et al. 2021). Scooter riders typically lost their balance (81%), were hit by an object (3%), or were hit by a car (16%). Through October 2019, two pedestrian fatalities due to e-scooter-related incidents were reported world-wide and 80% of fatalities among scooter riders involved another motorized vehicle (International Transport Forum 2020). A recent update from the International Transport Forum (2024) concludes that the causality risk for e-scooters has dropped by 26% in Europe between 2021 and 2022, and almost 80% of fatalities with bicycles and e-scooters involve a motor vehicle.

There are several things happening at once which may affect the resulting e-scooter related accidents and injuries. The number of scooters and scooter trips have increased which suggests, all else equal, that the number of injuries should grow proportionally to the share of scooter traffic. On the other hand, user behaviours have changed and an overall learning process between scooter riders and other road users (including pedestrians) which could arguably lead to a decrease in injuries per scooter traffic volume. Shifts in regulation could improve traffic safety, but to large differences in regulations between cities or countries, as well as unintended consequences of specific regulatory interventions may also have adverse effects on safety and injuries.

This, combined with the lack of detailed data, makes it very hard to study e-scooter incidents and safety. Data on injuries that is collected from hospital admissions most likely underreport the number of traffic incidents, while also omitting the total volume of e-scooter traffic. Thus, while traffic incidents, injuries and safety are an important frontier for research on micro-mobility and e-scooters, it is also hard to investigate due to its complexity.

We address some of these issues by analysing the effects of e-scooter introduction on traffic injuries in Swedish cities following the introduction of shared e-scooters. Our data set enables us to study injuries related to bicycles, pedestrians, e-scooters, and cars separately. By examining the impact of introducing e-scooters on each category, using a difference-in-difference strategy and comparing municipalities that got e-scooters with similar ones that did not, we aim to provide a nuanced understanding of their role in urban traffic dynamics and injury patterns. By doing so, we contribute to the research literature on micro-mobility and e-scooters in general and the research on traffic incidents and safety in particular with a quantitative statistical analysis on Swedish data. Our study also provides an important proxy for better understanding how a new digital innovation is integrated into urban traffic with all the constraints and complexities it entails. Finally, our results provide valuable insights for the ongoing policy debate on how to respond to e-scooter use and other emerging micro-mobility technologies.

3 Data

3.1 E-scooter introduction

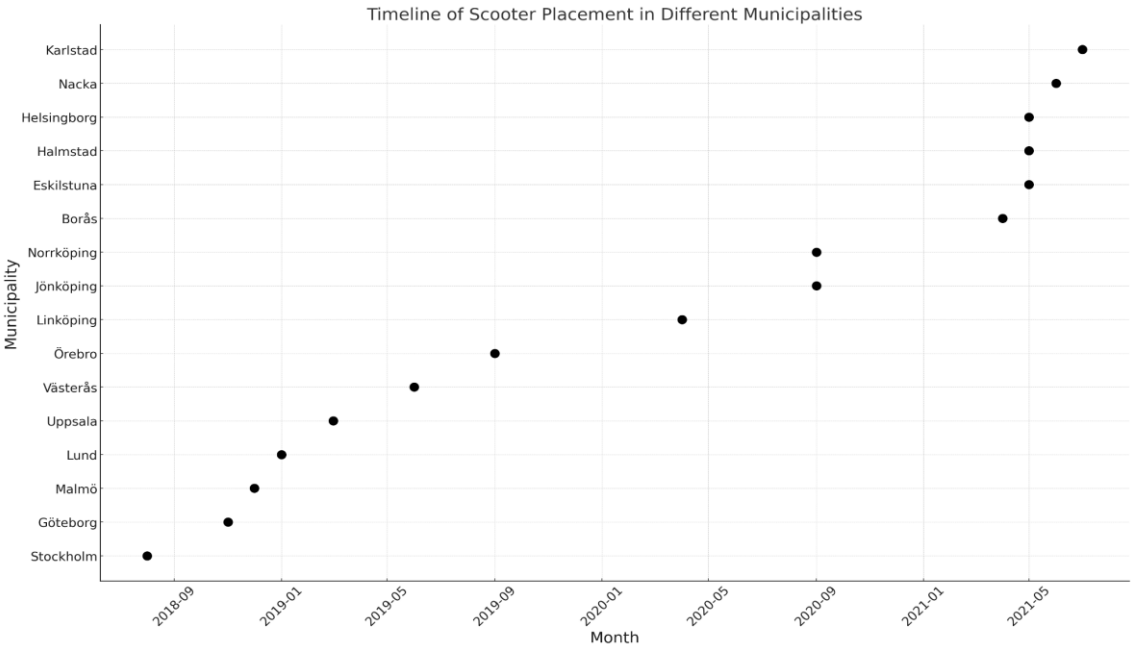
In Sweden, shared e-scooters first appeared in Stockholm in august 2019. Figure 1 illustrates when e-scooters first appeared in Swedish municipalities. Introduction dates are transparently available both from the scooter firms and also reported by local media outlets between the years 2019 and 2022.

Shared e-scooters first appeared in Sweden's capital Stockholm, followed by the second and third largest city Gothenburg and Malmö. Shared e-scooter services were also introduced early on in Lund and Uppsala, both of which are university cities with centrally located comapuses. After that, a number of smaller municipalities followed, with Karlstad (population 96 000) being the smallest by the time we collected the data.

In our model, the observed introduction of shared e-scooters in a municipality is compared to a control group consisting of the X largest municipalities that did not have any scooters at the time of adoption in the treated municipality. These are Botkyrka, Kristianstad, Huddinge, Gävle, Haninge, Södertälje, Växjö, Umeå, Sundsvall.[2]

[2] Botkyrka has a population of 95 000, Sundsvall 99 000, Umeå 132 000, Växjö 97000, Södertälje 102 000.

Figure 1. Timeline of e-scooter introductions in Sweden



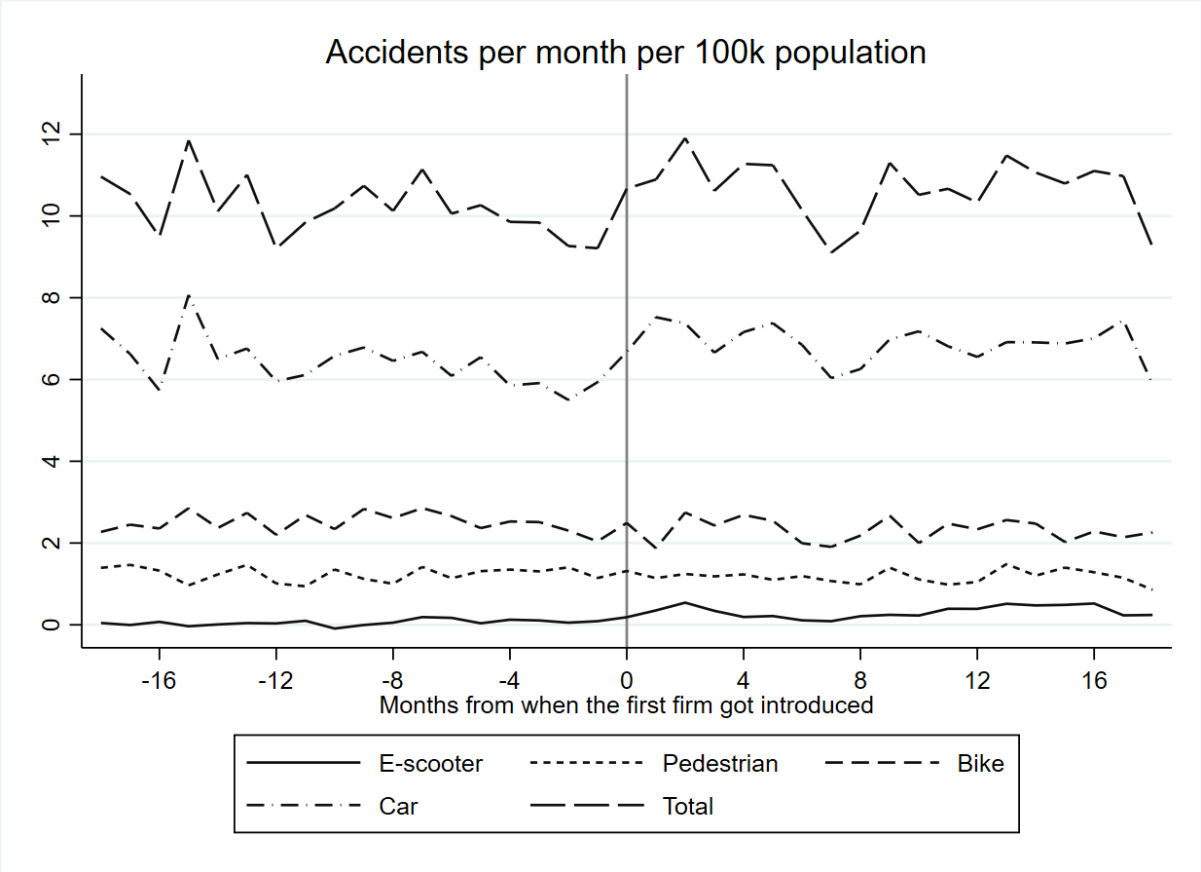
3.2 Traffic accidents

Since 2003, the police in Sweden report road traffic accidents with personal injury to a special database (Strada). Accidents involving personal injury must be reported to the Swedish Transport Agency within seven days, and the data includes details on the type of road user. Compared to studies based on the frequency of hospital admissions, this data set is based on observations of actual accidents, reducing the risk of omitting incidents in which no one went to a hospital.[3]

We arrange data by quarter because traffic incidents with human injuries are uncommon (especially in the smaller municipalities). As seen in Figure 2, accidents occur at a rate of about ten each quarter and per 100,000 population, with car accidents accounting for the vast majority of them.

[3] Smaller incidents without personal injury are not included in the data set.

Figure 2. Traffic accidents per month and per 100k inhabitants



The introduction of shared e-scooters is followed by an increase in e-scooter-related accidents which was previously close to zero or zero. This is consistent with the observation from previous literature that shared e-scooter services significantly increased the popularity and use of e-scooters (Oeschger et al. 2020, Şengül and Mostofi 2021). We now move on to analyse how the introduction of shared e-scooters affected overall accident frequency in urban traffic.

4. Analysis and results

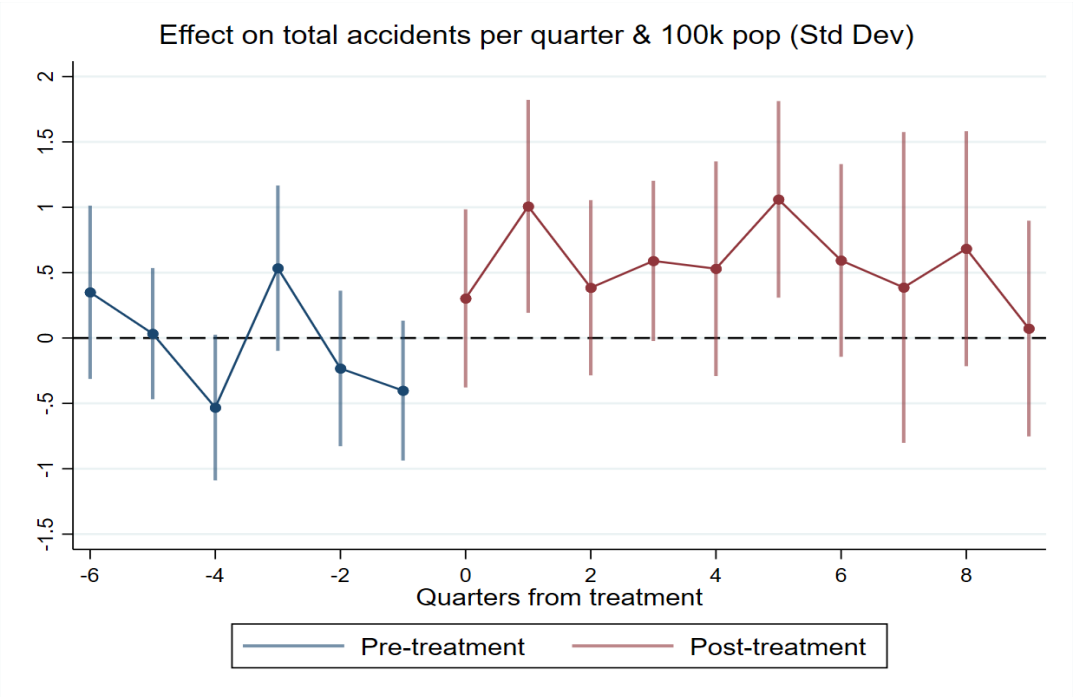
4.1 Accident frequency after e-scooter introduction

Our baseline results are derived using the staggered difference-in-difference method introduced by St'Anna and Callaway (2021), which allows multiple periods, seasonal adjustment and time varying treatment effects. Results are shown as event study graphs (figure 3).

The first quarter following the introduction of e-scooters, overall accidents increase one standard deviation (Figure 3). Looking at the first five quarters after the introduction of e-scooters together, traffic accidents increase by 0.5 to 1 standard deviation compared to untreated control municipalities. That translates to an increase by 3 to 6 accidents per quarter and 100 thousand inhabitants.

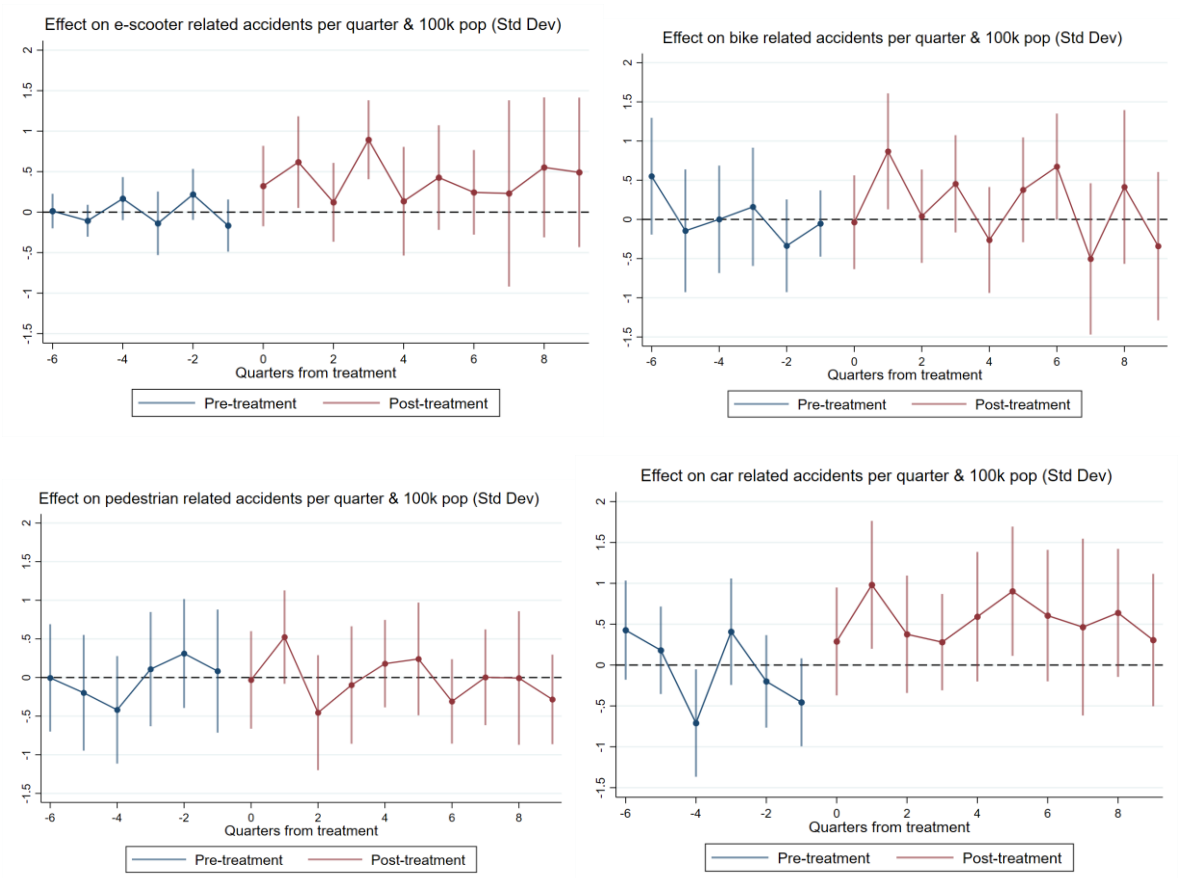
The long-term effect decreases and becomes statistically insignificant when comparing the first four quarters to the last five. After nine quarters it is very close to zero. The interpretation of this result depends on how the exposure to e-scooter traffic changes over time. If the number of e-scooters, vehicle development, and trips were to increase steadily, the result would imply that the crash risk is reduced as e-scooters are gradually being integrated into urban mobility. On the other hand, if the volume of e-scooter traffic decreases sufficiently, this may explain the decrease in accident frequency as well. Regardless, our results do not support the notion of a steady increase in reported accident frequency in municipalities with shared e-scooter services compared to municipalities without.

Figure 3. Total accidents in treated municipalities compared to control municipalities (standard deviations)



By breaking down the total effect by the type of vehicle involved, we get a better picture of what other modes of transport and road users are involved in accidents with e-scooters (Figure 4). Apart from an increase in accidents that involve e-scooters (as expected) these results hold three related implications. First, that e-scooters have not affected pedestrians specifically, even though several previous studies report that e-scooter riders "play" with traffic rules and alternate between riding in bike lanes, car lanes and on the sidewalk (Boglietti et al. 2021, Şengül and Mostofi 2021).

Figure 4. Accidents by mode of transportation



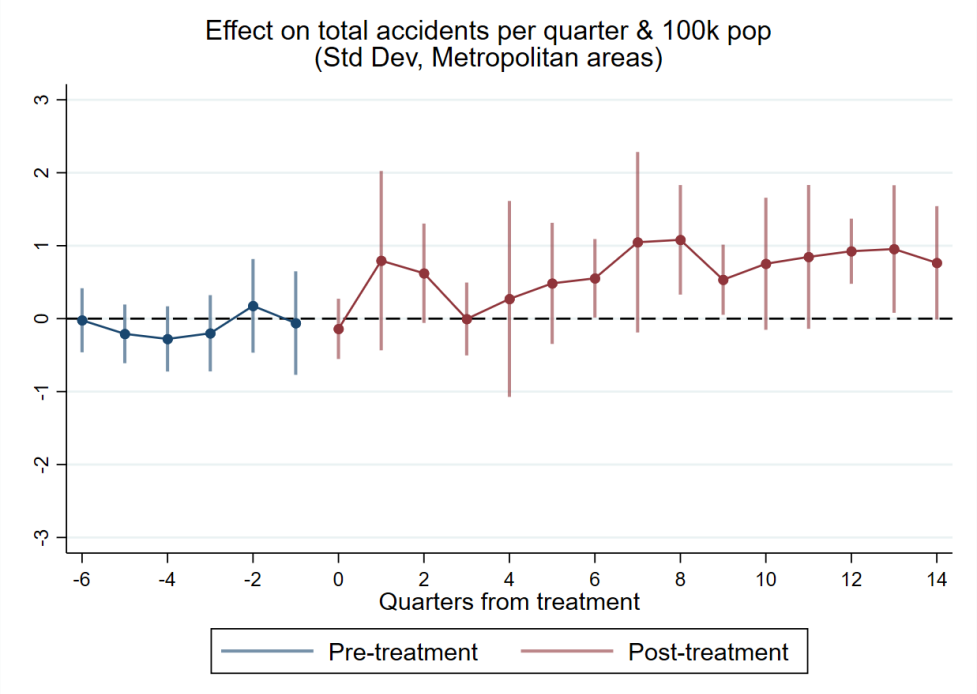
Second, the introduction of e-scooters is not associated with a steady increase in bike accidents, although bikes are the other mode of transport that most resembles e-scooters and bicyclists oftentimes share intended traffic lanes with e-scooter riders. The statistics on bike accident frequency following e-scooter introduction implies a significant increase in the first quarter following the introduction of e-scooters, but after that there is no significant increase.

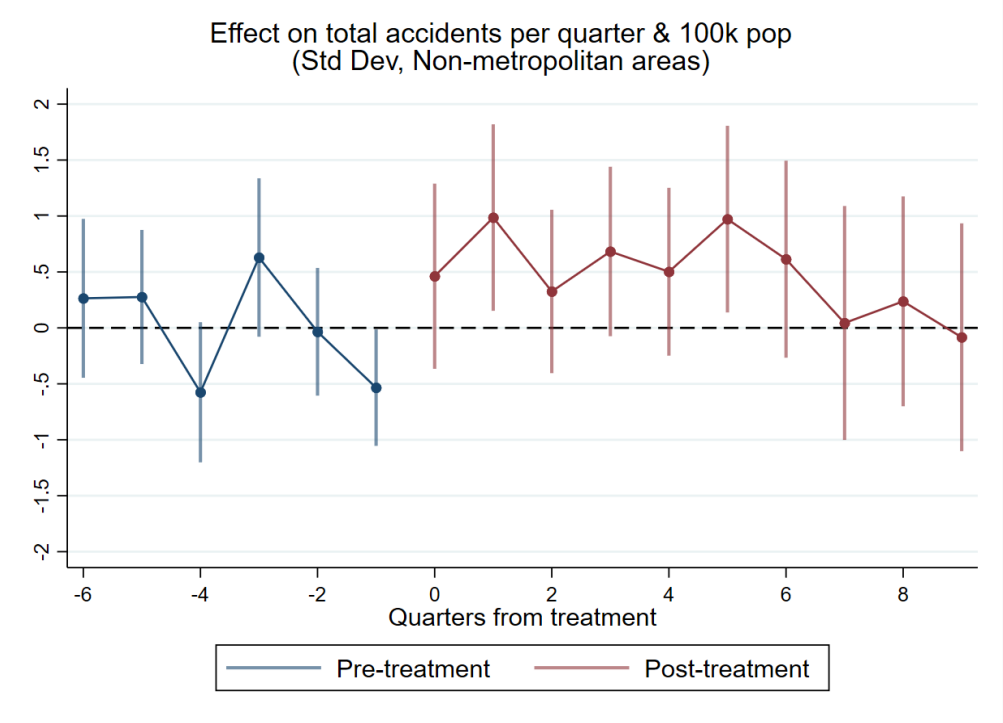
Third, when e-scooter riders are involved in accidents they tend to involve cars. Thinking about the introduction of a new mode of transport as a complex learning process in urban traffic, the interactions involving car users is expectedly the ones associated with the largest risks for personal injuries. This finding is in line with previous research indicating that in e-scooter accidents, it is predominantly the scooter rider who is injured (Boglietti et al. 2021).

These result are stable even when analysing monthly instead of quarterly observations, as well as when the analysis is conducted using a standard difference-in-difference regression model instead of the St Anna & Callaway estimator.

4.2 Effect in Metropolitan areas

Examining the effect in Sweden's three largest cities (Stockholm, Gothenburg and Malmoe) separately (using other never treated municipalities as controls) reveals that these cities account for a large part of the average effect in all municipalities. However, large metropolitan areas on their own still do not exhibit a steady significant rise in traffic accidents over time following the introduction of shared e-scooter services.





5 Concluding remarks and future research

In this paper, we have investigated the frequency of traffic accidents involving e-scooters following the introduction of shared e-scooter services in Swedish municipalities during the period 2019-2022. We present three main findings. First, there is a significant increase of approximately one standard deviation in overall accidents during the first quarter following the introduction of shared e-scooters, and a somewhat smaller increase of one half to one standard deviation over five quarters. This translates to three to six more traffic accidents per quarter and 100.000 inhabitants. However, over a longer time span (nine quarters), the effect shrinks and becomes statistically insignificant. These results suggest that the introduction of shared e-scooter services is not correlated with a steady increase in traffic accidents. However, how the results should be interpreted depends heavily on the volume of e-scooter traffic, which calls for further investigations using traffic volume data in future research. If the e-scooter traffic volume has been maintained or grown over the studied period, our results suggest that there is an effective learning process in urban traffic where the new mode of transport is gradually integrated into existing traffic patterns.

Second, breaking down accident statistics on modes of transport, we find that e-scooters are not associated with an increase in accidents among pedestrians or bicycles, but among cars.

Thus, an increase in accidents involving e-scooters predominantly involves collisions between cars and e-scooters.

Third, much of the observed effect is attributed to an increase in overall traffic accidents in Sweden's three largest metropolitan areas (Stockholm, Gothenburg, and Malmoe), which arguably also exhibit the most complex and extensive traffic situations. However, these regions still do not represent a significant steady rise on traffic accidents following the introduction of shared e-scooter services.

To our knowledge, this paper is the first attempt to quantify the effect of shared e-scooters on traffic accidents over time. There is a clear need for further research, especially involving data on e-scooter traffic volume, on how this new mode of micromobility is introduced and integrated into urban traffic to better understand how urban mobility can be changed and shaped to shifting needs and conditions in the future.

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