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COVID-19 as a window of opportunity for cycling: Evidence from the first wave

Beda Büchel *, Alessio Daniele Marra, Francesco Corman

Institute of Transport Systems, ETH Zurich, Switzerland

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ABSTRACT
Across the world, the COVID-19 pandemic has forced people to reconsider their habits in terms of how they work, how they interact with each other, and of their mobility. During lockdowns, mobility was in general significantly reduced. Means of collective transportation were used much less, and people preferred means of individual transport. Evidence from some cities suggests that people turned to cycling as a resilient and reliable option with a small risk of contagiousness. This spike in demand led some governments to respond by opening additional bike lanes, reducing the fees of bike-sharing systems, banning cars on selected streets, or giving monetary incentives for the purchase of new bikes. We analyze the bike traffic in Basel and Zurich, two major Swiss cities. Throughout the pandemic, no specific measure to promote cycling was implemented in any of the two cities; we can thus see latent demand patterns exposed when conditions change. As cycling depends on the season and weather, we incorporate these data and correct the traffic counts hereby. We can identify a distinct change in cycling traffic over the course of the day. During the lockdown period, relatively more traffic is observed in the afternoon, possibly associated with leisure activities. Furthermore, there is a short-term drop in the corrected cycling traffic and a fast recovery, demonstrating cycling as a resilient transport mode. Soon bike traffic reached pre-lockdown levels, but no significant increase could be identified, possibly attributed to the absence of explicit policy measures. We furthermore survey a panel of bike policy experts to identify policy actions that could be taken in Basel and Zurich to increase bike usage. The COVID-19 pandemic disrupts life as we know it, leading people to reconsider their travel choices. Given authorities’ desire to increase bike usage, it represents a window of opportunity to test new policy measures, increase bike trips of active cyclists, and attract new cyclists. As long as this window is open, people are susceptible to policy measures to reconsidering past choices. However, if no policy measures are conducted during the pandemic, as in the case study, it is likely that bike usage is not increased in the long run. Authorities are well-advised to take this opportunity to strengthen cycling and to lead to a more resilient, accessible, safe, and sustainable urban transport system.

1. Introduction
The COVID-19 pandemic is, in many aspects, the end of life as we know it - but is that necessarily a bad thing?

The COVID-19 epidemic began no later than December 2019 (Xu et al., 2020) in Wuhan, China. From there, the virus spread around the world, resulting the WHO to announce the COVID-19 outbreak as a pandemic on 11 March 2020. To contain the spread of the virus, countries have taken unprecedented measures, like partial or full lockdowns. People’s everyday life, as well as economic production and supply chains, were disrupted. A rapid decline in mobility could be seen during the lockdown periods. Transit operators around the globe have curtailed their transit operations due to reduced ridership and health concerns. Also, during the recovery phase, people depreciate collective transport due to the difficulty of adhering to social distancing.

A big crisis is also a big chance. During an extraordinary situation, and the current pandemic is beyond doubt such one, past decisions, habits, and policies are reconsidered. Regarding urban transport, the situation yields the opportunity to create a more sustainable and resilient transport system. We focus on cycling as it has been identified as a sustainable, healthy, and efficient means of transportation, and it is increasingly promoted at all policy levels, especially in urban areas.

This paper aims to study specifically the opportunity to increase bike usage in the long term. We base policy recommendations on the
Cycling allows the mobility of people while being compliant with morbidity (Oja et al., 2011). It is affordable to large parts of society and mode choice and travel patterns during the lockdown. However, in case the ratio to this choice decreases (Gärling and Axhausen, 2003).

The contributions of this paper are to

- provide an overview of strategies and external factors impacting bike usage in general.
- show that people have been confronted with and reconsidered their mode choice during the pandemic. In specific, there has been a change in total bike traffic with respect to the pandemic, which confirms cycling as resilient.
- show that people have been confronted with and reconsidered their travel patterns. The daily cycling pattern changed distinctly during the first lockdown; bike usage was shifted to the afternoon hours.
- show that, once the influences from external factors have been taken into consideration, only a minor increase in long-term bike usage is evident due to the pandemic itself. This suggests that mid-term policy measures are needed to increase bike usage. Throughout the pandemic, no specific measure to promote cycling was implemented in Zurich and Basel. The identified change comes only from demand-side adaptations to new conditions.
- put the changes observed in the Swiss cities during different phases of the pandemic in the context of strategies implemented in response to the disruption.
- give recommendations for policies during a pandemic based on the observed changes in the data and a panel of experts.

2. Background

2.1. The role of cycling as an urban transport mode

Many city centers in Europe and North America have experienced a revival of cycling in the last decades (Pucher and Buehler, 2017). Cycling can be considered environmentally sustainable as it causes no emissions in the form of noise or air pollution and consumes far less non-renewable resources than any motorized transport mode (Pucher and Buehler, 2008a). The only energy cycling requires is directly contributed by the traveler, resulting in health benefits. Studies consistently show a positive relationship between cycling and health: cycling improves cardiorespiratory fitness, reduces disease risk, and all-cause morbidity (Oja et al., 2011). It is affordable to large parts of society and therefore creates equity. Compared to cars, it requires only a fraction of urban space for the use and parking, resulting in lower infrastructure costs. Compared to walking, the travel speed is much higher, making it possible to also cover longer distances by bike. In short, it is hard to beat cycling when it comes to environmental, social, and economic sustainability (Pucher and Buehler, 2008a). During the COVID-19 pandemic, the mentioned advantages are furthermore complemented. Cycling allows the mobility of people while being compliant with measures of social distancing. It allows people to do physical activity, remain healthy, and get outside. As people are more likely to have reduced income or have lost their jobs, money can be saved by cycling. During the pandemic and its recovery, collective transport became less favorable and the demand for individual transportation rose (Tirachini and Cats, 2020). Hence, some previous riders of public transport might shift to cycling, which complements motorized individual traffic.

2.2. Mode choice and habits

It is widely agreed that people do not make their travel decisions purely rational. Multiple cognitive biases influence decision-making processes. Especially when a choice is made multiple times, the ratio to this choice decreases (Gärling, 1998). A habitual choice, i.e., sticking to the status quo, is a non-deliberate choice, which is difficult to influence with rational arguments, since the person making the choice tends to discount relevant information (Gärling and Axhausen, 2003). Therefore, changes in travel decisions do not happen often. Several studies have investigated under which circumstances people reconsider their habits and are open to new decisions. Life change events (e.g., the start of the first job or moving to a new town) were identified as a major reason to reconsider the choice habits (Müggenburg et al., 2015). (Chatterjee et al., 2013) found that life change events are a major reason because of which people start using bikes. Life events are characterized as a window of opportunity for a change (Schäfer et al., 2012). In general, a disruption of existing habits provides opportunities for change without competition with established behavior patterns (Verplanken and Wood, 2006). In other words, when external or internal factors change, people are more sensitive to new information choices and evaluate them without bias. Furthermore, people are receptive to policy interventions in the context of these events (Verplanken and Wood, 2006; Verplanken and Roy, 2016). A similar case can be observed in an experiment investigating mode switch behavior (Abou-Zeid et al., 2012). A free public transport pass was given to habitual car drivers. Even though no car driver switched to public transport after the intervention period, a few participants used public transportation several months later at a higher rate than before the treatment.

2.3. Disruptions and their effect on transport

Disruptive events provide a window of opportunity for behavior change. They can be either planned disruptions, as major events (sports events, exhibitions) or infrastructure work on one side, or unplanned disruptions, as natural disasters (earthquakes, hurricanes, volcano eruptions, floods), security threats (terror attacks), or health pandemics. Disruptive events may force or provide a catalyst for behavioral changes (Walsh et al., 2015). Several case studies investigating the influence of natural hazards on mobility behavior exist (Guiver, 2011) investigated the mode choice of residents due to the closure of road links between North and South Workington (United Kingdom) in the aftermath of a flood. To mitigate the negative effects, frequent and free train service was provided and a footbridge was erected, while the available road trip was a heavily congested 29 km detour. In that period, commuters most commonly changed travel mode and shoppers to change their destination. Leisure and social trips were reduced. Once road connections were restored, many people resumed their pre-flood travel patterns, although there was a reduction in the total number of trips made and a small decrease in the proportion of those made by car (Kontou et al., 2017) investigated the effect of Hurricane Sandy (2012) on New York metropolitan area’s traveling behavior. They found that commuters with higher income or who were highly educated were more likely to prolong the time to return to regular working schedules and increase telecommuting duration.

Additionally, security concerns in the aftermath of a terrorist attack can lead to behavior change (Prager et al., 2011) examine the reduction in London Underground passenger journeys in response to the July 2005 bombings. They found a reduction of 8.5% in journeys over the next four months, and reductions appeared to still be present half a year later. This is a higher reduction compared with the one after the 2003 Madrid attacks, where train passengers decreased by 4–6% in the two months following the attack (I. o’pez-Rousseau, 2005). The decline in domestic airline demand in the aftermath of the September 11, 2001 attacks lasted much longer and is estimated to be 8% in the first year and 4% in the second year after the attacks (Gordon et al., 2007).

An example of the influences of planned disruptions is investigated in the course of the 2012 Olympic Games, where (Parkes et al., 2016) investigated the behavior change implications on commuter travel in London and their lasting consequences. For 6% of the respondents, their habits and their change in travel behavior (e.g., re-timing, reducing trips, re-routing, changing modes) was maintained 2–3 months after the Games.

Disruptions have the potential to change people’s habits and
therefore have a great potential for policy change. It can be learned that transport patterns are not as difficult to change as is commonly understood (Marsden et al., 2020). Behavioral changes due to disruptions are often massive, but generally not of long duration. Policy measures need to be implemented to maintain a change in transport patterns.

2.4. Bike policy

There is extensive and quickly growing literature stating the benefits of several measures concerning bike usage (Nello-Deakin, 2020). Measures can tackle infrastructure, accessibility, integration in the transport system, as well as training, education, information, and promotion programs (Pucher et al., 2010). We limit ourselves to a brief overview of fields of possible interventions and present, by no means exhaustive, examples. For a review of the quantitative effects of intervention strategies, we refer to (Pucher et al., 2010, 2011; Oldenziel et al., 2016). It is well known that aspects influencing cycling, for which policies can have only a limited control or aspect, involve demographic, weather, and trip characteristics (Hunt and Abraham, 2007; Heinen et al., 2010).

Infrastructure. Providing and improving bicycle infrastructure is the main approach to improve cycling safety and increase cycling usage (Pucher and Buehler, 2016; Heinen et al., 2010). The most common types of bike infrastructure comprise dedicated bike lanes on roads and separate bike paths. Furthermore, some cities allow bicycles, mostly in downtown regions, to travel on dedicated bus lanes or two-way travel for bikes on one-way streets (Pucher et al., 2010). Moreover, intersections can be modified to serve cyclists better, for example, by the introduction of advanced stop lines (“bike boxes”), where cyclists can stop in front of cars at red lights and become, hence, more visible to motor vehicles. The type and quality of bike infrastructure are of importance: Stated and revealed-preference studies suggest that cyclists prefer separation from motorized traffic and bad pavement quality can deter them from cycling (Buehler and Dill, 2016).

There is a consensus that the provision of bike parking possibilities, especially if secured and sheltered, increases the attractiveness of bike usage (Martens, 2007; Pucher et al., 2010). Parking infrastructure comprises bike racks on sidewalks, which can be sheltered or not; guarded stations to prevent theft and violation; and bike lockers, typically located at public transport stations. As bike usage becomes more common, parking facilities should be managed (Van der Spek and Scheltema, 2015).

Accessibility. People can only cycle if they have access to bicycles. Indeed, the availability of a bicycle in the household is the strongest predictor of cycling (Cervero et al., 2009). Hence, policies aiming to increase the share of bike ownership can lead to an increase in cycling. Trail programs giving free bikes in Denmark and Australia resulted in a strong increase in commuter trips done by bike (Bunde, 1997; Bauman et al., 2008).

The number of cities offering bike-sharing systems has increased rapidly in the last decades (Fishman, 2016). Bike-sharing has had profound effects on creating a larger cycling population (DeMaio, 2009; Midgley, 2011). (Goodman et al., 2014) show that bike-sharing may help normalize the image of cycling, i.e., reduce perceptions that cycling is “risky” or “only for sporty people”, hence attracting new cyclists. The introduction of bike-sharing systems might improve the coordination of cycling with public transport integration (Shaheen et al., 2010). The main factor for using a bike-sharing system is the “convenience” (Fishman, 2016).

Integration in Transport System. The coordination of cycling and public transport is mutually beneficial. Improved integration of bikes and public transport results in an increased ridership of both modes, as cycling extends the catchment area of public transport stops far beyond the walking range and at a much lower cost than neighborhood feeder buses or park-and-ride facilities for cars (Pucher and Buehler, 2009). With access to public transportation, cyclists can make longer trips, and they have an alternative in case of bad weather, difficult topography, or mechanical failures (Pucher and Buehler, 2009). Martens, 2004) show that faster and higher quality types of public transport, such as train, attract substantially more bike-and-ride users than slower and lower quality types of public transport, such as local buses or trams (van Mil et al., 2020) show that people are especially willing to cycle longer to a station if by doing so they can avoid a transfer in their train trip thereafter.

The integration with public transport systems can be improved by providing bike parking at stations, by providing racks for short-term parking and lockers for long-term parking. Furthermore, public transport vehicles can be equipped with racks or storage space for bikes, enabling their transport. Finally, bike infrastructure leading to a public transport station can be improved and bike-sharing stations can be located at public transport stations, facilitating the bike’s role as feeders for public transport.

In addition to the integration in public systems, some policies discourage unwanted use of motorized vehicles (Piatakowski et al., 2019). These measures aim to de-prioritize automobiles on streets and include traffic calming or car-free zones.

Information, Promotion, Training, and Education. Providing information to cyclists and potential cyclists can furthermore increase bike usage. Information can be provided, e.g., by signed and managed bike routes or comprehensive bike maps.

Bike-to-Work Days are promotional events that encourage commuters to make their daily trip by bike. Such events might last from a single day to months and might include rewards, giveaways, or competitions. Such promotions aim to raise awareness of cycling in the short term and increase cycling mode share to work in the long term (Piatakowski et al., 2015; Rose and Marfurt, 2007). Other ways to advocate for cycling are the open street programs (Ciclovias), in which streets are closed to motor vehicles and available to individuals for leisure activities (Torres et al., 2013).

A variety of programs to increase cycling skills and knowledge of cycling-related laws exist for children, as well as for adults. In some European cities, comprehensive bike training and education programs exist and they are integrated into the regular school curriculum (Pucher and Buehler, 2008b).

Bike usage plays a crucial role as feeders for public transport and cycling has not been established yet as part of the transport culture (Buehler et al., 2017). Public transport out-competes cycling in many cases, especially with inexpensive monthly and annual passes (Buehler et al., 2017). In 2010, the mode share of trips done by bike was 16% in Basel, whereas in Zurich it was only 6% (Jod, 2017). This difference can be attributed to the better bicycle infrastructure present in Basel and the less hilly topography. In Basel, the cycling culture is much better established compared to Zurich. However, in the last decade, Zurich could close many gaps in its cycling network and improve the infrastructure; the total traveled kilometers increased from 2010 to 2018 by 65% (Stadt Zürich, 2019). In the same period, the bike frequencies in Basel increased by 29% (Basel-Stadt, 2019). These increases could also be
attributed to the introduction of bike-sharing systems and the current popularity of e-bikes.

The detailed modal split concerning trips done by residents of the two cities is shown in Fig. 1. Both cities aim to increase the mode share of bikes further. Zurich aims to double bike frequencies in the period 2011–2025 (Stadt Zürich, 2012), which seems realistic, considering the development in the last years. Basel aims to establish itself as the most cycling-friendly city in Switzerland. Both cities aim to reach their goal with an interplay of optimizing infrastructure, service measures, and promotion strategies (Stadt Zürich, 2012; Basel-Stadt, 2017).

3.2. The COVID-19 pandemic in Switzerland

On February 25, 2020, the first case of COVID-19 was confirmed in Switzerland, in the following of the COVID-19 outbreak in Northern Italy. As a first reaction, the Swiss Federal Council banned all events with more than 1000 participants. On March 16, the situation was classified as an “extraordinary situation” in terms of the Epidemics Act, leading to the informally called lockdown period. As of March 16, all shops, restaurants, bars, and entertainment and leisure facilities remained closed, except for food stores and healthcare institutions. Furthermore, checks on the borders to Germany, Austria, and France were introduced, and the borders eventually closed. The peak of the confirmed infections was reached in late March with 1000–1500 cases per day, while the peak in fatalities was reached in early April with 50–60 deaths nationwide. The easing of government measures started on May 11, when primary schools, restaurants, museums, libraries, and shops were allowed to reopen physically, following strict requirements. Further easing steps regarding group sizes, gatherings, and events were done on May 30 and June 6. As of June 19, the “extraordinary situation” was downgraded to a “special situation”. However, many recommendations, as home-office, were still applying and widely executed. At no point, the Federal Council ordered a curfew.

The public transport operation was heavily thinned out during the lockdown period. With the closure of borders, all international train connections were stopped. The frequencies of many public transport lines were reduced, even if a minimal supply remained. The airport traffic and pedestrian traffic are much more variable compared to motorized traffic due to weather effects. Mobility in Switzerland was investigated during the lockdown period with two GPS-tracking experiments (Molloy et al., 2020; Intervista, 2020). (Molloy et al., 2020) show that the total distance traveled by bike increased during the lockdown period compared with a baseline scenario in September and October 2019. Furthermore, the average travel time and distance of bike trips increased during the lockdown period, especially for men. It is possible that more leisure bike journeys were done, where cycling is a leisure activity and not means of transport (Intervista, 2020) report that, in general, people traveled shorter distances during the lockdown period.

4. Bike usage before, during, and after the first lockdown

In the considered cities, we observed how the traffic varied in the different phases of the first phase of the pandemic in Switzerland, which we refer as: pre-lockdown, the period from January 1 to 2020; lockdown, the period from March 16 (begin of lockdown) to May 10 (first easing measures); post-lockdown, the period from June 1 to July 1. The first two weeks of March and the last weeks of May are considered transition periods. This temporal division is based on the Swiss federal measures and not on the epidemic evolution.

4.1. Data

The traffic data used in this work are collected through bike counters disseminated in the two cities, counting the traffic volume every hour. The data are openly available, increasing the reproducibility of the analyses. Only counters constantly working during 2019 and 2020 were considered, to fairly compare the traffic during the different periods. Unfortunately, information on external sources affecting the traffic, as construction works, was not fully available for this study and their impact on the traffic was hardly quantifiable. Nevertheless, during 2019 for the selected stations there was no significant variation in traffic volume between any two consecutive periods (longer than a month), which could not be attributable to weather or seasonality effects. The collected data contains bike counts in intervals at certain places. These counts can be assumed to be a proxy for the total bike kilometers traveled, and we refer to it as traffic. It is not possible to deduct additional information, as the trip purpose or information about the cyclists.

In total, 13 stations were selected for Zurich and 20 for Basel. The location of each station and their daily average traffic in 2019 are shown in Fig. 3. In both the cities, most cycling traffic can be observed at bottlenecks: the river divides Basel and the railway lines divide Zurich into two parts. Hence at bridges or underpasses, high cycling traffic is measured.

The aggregated hourly cycling traffic for the two cities is shown in Fig. 4. It compares the hourly bike traffic volumes during the lockdown period (2020) with the volumes during the same period in 2019. The

Fig. 1. Modal split for trips of residents of Basel and Zurich for the years 2010 and 2015. (MIT = motorized individual traffic, PT = public transport) Data source (Jud, 2017).

1 https://www.flughafen-zuerich.ch/unternehmen/laerm-politik-und-umwelt/lufigbewegungen/bewegungsstatistik.
2 The data and their description can be found publicly available at https://github.com/openZH/covid_19. The individual, bike, and passenger traffic is a sum of selected measurement locations. The public transport traffic is approximated with the traffic measurement at a single node of public transport.
3 Bike counting data form Basel is available at https://opendata.swiss/en/dataset/verkehrszahldaten-velo-und-fussganger, counting data form Zurich at https://opendata.swiss/de/dataset/daten-der-automatischen-fussganger-und-velozahlung-viertelstundenwerte.
average daily traffic during the lockdown in Basel is distinctively lower compared with 2019, whereas in Zurich there is a smaller reduction. This might be due to the initial higher bike usage in Basel, which makes cycling perceived more as a travel mode and less as a possible leisure activity. There is a strong reduction in the morning peak in both cities. Instead, the reduction of the evening peak is smaller and occurs only in Basel. During the lockdown, the difference between the traffic at the morning peak and around noon is lower compared to 2019. Besides that, part of the morning traffic seems to be shifted to the early afternoon. This suggests that parts of the activities usually done in the morning are shifted later in the day. Unfortunately, it is not possible to know the type of these activities from the available data. Fig. 5 shows the scaled distribution of the hourly bike traffic during the different periods of 2020, namely the pre-lockdown period, the lockdown period, and the post-lockdown period. In both cities, it is possible to see a big difference between the pre-lockdown and the lockdown periods. The percentage of
traffic in the morning is almost halved during the lockdown, in favor of more traffic in the early afternoon. The traffic volumes in the early afternoon became similar as during the morning peak. In contrast, during the post-lockdown period, with the easing of restricting measures by the Federal Council, the morning peak is again more dominant. Nevertheless, it is not as high as during the pre-lockdown period, since there are still some measures running, as the home-office that it is still recommended by the Federal Council whenever possible.

Cycling traffic heavily depends on weather conditions (Hunt and Abraham, 2007). Therefore, to predict the expected traffic in 2020, weather information was collected for both cities from metastats (Swiss federal office of meteorology and climatology). The weather dataset contains information collected on an hourly basis during 2019 and 2020. This information includes temperature, precipitations (during 1, 6, 12, and 24 h before), sunshine duration, humidity, air pressure, average wind speed, and maximum wind speed.

4.2. Bike traffic model

To compute the expected daily cycling traffic during the pandemic, we developed a prediction model, able to predict the traffic in pre-lockdown conditions. We trained a Random Forest Regressor to predict the total traffic volume at any hour of the day aggregated for all stations of a city. Therefore, two models were trained for each city: one for weekdays and one for the weekend. The features used for the model are external factors influencing bike usage that are not influenceable by policy measures. They comprise weather information, the hour of the day, the day of the week, and if the current day is a public holiday or a school holiday.

The model is trained, validated, and tested with the data of 2019 (6264 samples for the weekdays model and 2496 for the weekend model, corresponding to one sample every hour of the day). 67% of the dataset is used for training and cross-validation. The remaining 33% is used for testing.

The trained models are used to predict the expected amount of traffic during 2020, assuming non-pandemic conditions. Finally, the expected traffic is compared with the actual traffic to understand the impact of the pandemic through its different phases.

4.3. Trip scheduling and purpose patterns

The pandemic outbreak and the measures taken by the Swiss Federal Council forced the majority of the people to a radical change of their habits and daily routine. This had a strong impact on travel behavior, including trip, departure time, and mode choice. Given that a significant part of the population stopped commuting daily and spent more time than before at home, we can assume a change in weekly and daily scheduling occurred. We do not have access to detailed trip purpose and activity chains of the cyclists, but we can use the weekend traffic as a proxy for leisure trips, and the difference between a weekday pattern and a weekend pattern to identify peaks and their possible shift throughout the day. In other terms, we investigated if, during the lockdown period, the traffic was shifted from a weekday pattern, with a morning and an evening peak, to a weekend pattern, with a single peak during the day.

For this reason, we proposed a mixture model, which combines a weekday-based model with a weekend-based one, to predict the traffic during the lockdown. The model is a linear combination of the two Random Forest Regressors described in Section 4.2: one for the weekdays and one for the weekend. Formally, the model is a linear regression, described as follows:

\[ P_{\text{WD}} = \alpha P_{\text{WD}} + \beta P_{\text{WE}} \]  

where \( P_{\text{WD}} \) is the prediction assuming the day is a weekday (given by the weekday-based regressor), while \( P_{\text{WE}} \) assuming a weekend. \( \alpha \) and \( \beta \) are inferred training the model and their ratio represents how much the current traffic is similar to the weekday or the weekend traffic. The model is trained during the lockdown period, using a Lasso regression with cross-validation, and dividing the dataset in 60% training set and 40% test set.

5. Changes in bike traffic during the first wave

In this section, we analyze the changes in bike traffic during the first wave in depth by comparing observed and estimated bike traffic in Zurich and Basel.

5.1. Change in bike use

As described in Section 4.2, we applied a regression model based on Random Forest to predict the expected traffic during the lockdown period, to obtain a baseline for what bike usage could have been expected given the weather conditions. Table 1 shows the performance in terms of RMSE (Root Mean Square Error) and \( R^2 \) for four different models (two cities, weekdays and weekends). For all the models the \( R^2 \) value is very high (around 0.9), which indicates a good prediction performance. The RMSE is much smaller than the standard deviation, corresponding to the RMSE of a generic model predicting always the average traffic. This indicates a low prediction error of the models. Therefore, these results show a strong connection between the weather and the bike traffic in a city, and that it is possible to predict the hourly bike traffic from the weather conditions with high accuracy. Again, we

Table 1

| Layer | Zurich weekdays | Zurich weekend | Basel weekdays | Basel weekend |
|-------|-----------------|----------------|----------------|---------------|
| Average Traffic | 810 | 531 | 2094 | 1130 |
| Standard Deviation | 733 | 453 | 1765 | 931 |
| RMSE | 243 | 148 | 498 | 272 |
| \( R^2 \) | 0.89 | 0.89 | 0.92 | 0.91 |
remark that we cannot include any policy-sensitive parameters, as there was no specific policy recommendation or explicit action throughout the pandemic, favoring cycling.

Fig. 6 shows the weekly aggregated expected traffic in 2020 for weekdays. From January to early March (i.e., pre-lockdown period), the real traffic generally follows the expected one for both cities, with a relatively small error (especially in February). Instead, during the lockdown period (in Fig. 6, from March 16 to May 10), the expected traffic is always higher than the observed one. In particular, in the last weeks of March, there is a strong reduction in traffic. Afterward, the traffic oscillates due to weather effects. Despite some errors, the two curves (expected and real traffic) oscillate similarly, showing that the oscillation is predictable from the weather conditions. The absolute value is less predictable, we identify this as due to the pandemic. Finally, during the lockdown period, the bike traffic slightly increased.

Comparing the two cities (bottom plot of Fig. 6), we observe a similar trend, with two major differences. First, the reduction in bike traffic during the lockdown period is higher in Basel (on average 39% in Basel and 29% in Zurich). Second, during the post-lockdown period, there is a return to normal traffic in Basel, while an increase of traffic in Zurich. This shows that in Basel, where the bike is already a well-established transport mode, the pandemic did not significantly impacted bike usage. Instead, in Zurich, in the period immediately following the lockdown, the bike traffic slightly increased.

5.2. Changes in trip scheduling and purpose

To understand the daily bike usage pattern during the lockdown period, we evaluated the mixed model described in Section 4.3, which assumes the weekday daily traffic pattern during the lockdown as a combination of weekday traffic and weekend traffic before the lockdown. As shown in Fig. 5 and Section 4.1, the morning peak decreases during the lockdown and the traffic in the afternoon is more homogeneous and dominant, as typically during the weekend. Table 2 shows the coefficients obtained training two different models during the lockdown: the mixed model, assuming the weekday traffic can be explained by a weighted sum of pre-lockdown weekday and pre-lockdown weekend traffic, and a model assuming the traffic can be explained as reduced pre-lockdown weekday traffic only. In Zurich, the mixed model identifies 60% of weekday traffic ($\tilde{a} = a/(\alpha + \beta)$) and 40% of weekend traffic ($\tilde{b} = b/(\alpha + \beta) = 1 - \tilde{a}$), while in Basel the shares are 66% and 34%, respectively. This shows that the weekday daily traffic during the lockdown period follows a different pattern than the pre-lockdown weekday traffic. In fact, the training of the mixed model during the pre-lockdown period (January and February) leads to a match to only weekday traffic ($\tilde{b} = 0$), as expected (see Fig. 8). This demonstrates that the weekday traffic before the lockdown follows the same weekday pattern as in 2019.

Comparing the mixed model with a model assuming only weekday traffic ($\tilde{b} = 0$), the performances former, shown in Table 2, are better, especially considering Zurich. Fig. 7 shows the average daily traffic predicted by the two models, with an additional model assuming only weekend traffic ($\alpha = 0$). This last one diverges from the actual traffic since it does not identify a morning peak. The mixed model performs better than the weekday model, despite in some specific hours the weekday model is more accurate. This shows that the daily traffic during the lockdown can only be partially explained with a shift of part of the traffic from a weekday pattern to a weekend one. Therefore, the observed traffic can be described by a new traffic curve, with specific characteristics at different hours. In particular, the main characteristics are an overall traffic reduction (Fig. 6); a reduction of night traffic; a much lower morning peak compared to the evening peak; higher traffic

| City          | $\alpha$ | $\beta$ | $\tilde{a}$ | $\tilde{b}$ | $R^2$ | RMSE |
|---------------|----------|---------|-------------|------------|-------|------|
| Zurich mixed  | 0.57     | 0.37    | 0.60        | 0.40       | 0.81  | 248  |
| Zurich, only weekday | 0.78 | 0 | 1             | 0           | 0.75  | 283  |
| Basel mixed   | 0.55     | 0.28    | 0.66        | 0.34       | 0.89  | 412  |
| Basel, only weekday | 0.70 | 0 | 1             | 0           | 0.86  | 458  |

Fig. 6. Traffic and expected traffic in 2020 in Zurich (top left) and Basel (top right). The prediction error in percentage is also shown (bottom). Data are aggregated weekly, considering only weekdays.
in the early afternoon. Fig. 8 shows which share of the weekday traffic can be attributed to the weekend ($\hat{\beta} = \beta/(\alpha + \beta)$). The trend is similar between the two cities. $\beta = 0$ during the pre-lockdown period, confirming that the weekday traffic follows a similar weekday pattern as in 2019. With the beginning of the lockdown period, the traffic quickly shifts to a different pattern, with the share of the weekend traffic reaching 50% at the beginning of April. Afterward, with the first easing measures in May, the weekend traffic share starts to decrease until it reaches values below 10% during the post-lockdown period. In this regard, the low share of weekend traffic of the week starting the 11th of May can be explained by the easing measures starting that week. Looking at the overall trend in Fig. 8, it is evident how the pandemic influenced the daily traffic pattern, and that during the lockdown period the daily traffic became much more similar to the weekend traffic. On the contrary, during the post-lockdown period, the weekday traffic starts following again a weekday pattern, as during the pre-lockdown period. This distinct change in the cycling pattern over the course of the day can be attributed to more leisure traffic being present. However, it could also be attributed to a change in commuting departure times, or further changes in daily and working routines.

Finally, we highlight that the training of the mixed model on weekend data during the lockdown leads to $\alpha \approx 0$. Therefore, while the weekday traffic is different between the pre-lockdown and the lockdown period, the weekend traffic follows the same pattern in both periods.

5.3. Spatial changes

Fig. 9 shows the traffic increase at each station during the lockdown period compared to the potentially expected traffic. For each week, the traffic increase is computed as the ratio between the real traffic in 2020 and the expected one. This latter corresponds to the traffic predicted by the regression model based on data of 2019, taking into account the current weather conditions. Namely, the traffic increase of a week $w$ is computed as follows:

$$L_w = \frac{\text{traffic}_{2020} - \text{traffic}_{2019}}{\text{traffic}_{2019}_{\text{expected}}}$$

Fig. 9 shows the average increase among all weeks. Looking at Zurich, a general traffic reduction of 21% can be observed among the stations. Despite the absolute value of the traffic in the lockdown period was comparable in 2020 and 2019 (see Section 4.1), the expected traffic in 2020 is higher than the real traffic in 2019, because of better weather conditions. Therefore, even if the weather was better in 2020 than in 2019, bike traffic did not increase as expected. In some sense, we can impute this as a reduction due to the pandemic. One counting station detected a much higher traffic increase (+85%) compared to the others, and it is the station of Mythenquai (in red) in the South of the city. We can explain this anomalous observation by at least two reasons. First, the station is located near the west side of the lake, which is a main leisure place of the city. In good weather conditions, this is an attractive location for outdoor activities during the lockdown. Second, part of the East side of the lake was closed to the general public; therefore, it is expected that more people were going to the West side.

Looking at Basel, the average traffic reduction among the stations is 28%, which indicates a general traffic reduction. The reduction without considering the weather is 22%. The reduction is observed almost evenly inside the city, without any particular area affected by it. A particular decrease could be observed at the borders to France (North-West) and Germany (North), where traffic was restricted in general. The station with the highest increase (+20%) is near the park Birskopf (East part of the city). This underlines the observed trend in Zurich on the traffic increase for leisure activities.

6. General trend of changes in bike traffic during later stages of the pandemic

The previous section of the manuscript focuses on the first pandemic wave (i.e., March–July 2020). We did not consider a longer study period in the former analysis for the following reasons: the steady increase in bike traffic over the years can be neglected for short periods (months), but not for long periods (years) and the prediction model, trained on data of 2019, may be less accurate for periods more distant in time.

This section reports the analysis of the changes in bike traffic during the later stages of the pandemic. We extend the analysis done in Section 5 until May 2021. Namely, we predict the bike traffic in Zurich and Basel based on information regarding weather, time, day of the week and holidays. Slightly different data were used as compared to Section 5.2, as few stations (three in Zurich and one in Basel) were put out of operation, and needed to be neglected for this analysis. We remark once more how we cannot include any policy-sensitive measures, as there were no explicit actions from authorities towards cycling policy and cycling infrastructure in this period.

Fig. 10 shows the results, including the observed bike traffic, the predicted one, and their difference, referred to as additional traffic expected. The stringency index is also shown, indicating how restrictive the cantonal measures were at a given time (Hale et al., 2021; KOF Swiss
The relation between this index and the observed counts can only be analyzed qualitatively and descriptively. In fact, this index has several limitations. Overall, it is not possible to quantify with a single number the (perceived) effects of each different measure imposed during the pandemic. Moreover, the index considers also measures not strictly related to urban mobility, such as international travel controls. From the stringency index, one can identify the two periods with rather strict measures (spring 2020 and early 2021), commonly referred to as lockdowns. In the first (more stringent) lockdown, bike traffic was drastically reduced (up to 72% in Zurich). After the first lockdown, bike traffic went back to normal levels in Basel, whereas in Zurich, even an increase was observed. In the second lockdown, a distinct reduction in bike traffic can be found again, with a peak in February 2021. In the following months, bike traffic went back to normal as after the first lockdown. In conclusion, the bike traffic during the second wave follows the same pattern observed during the first one. This supports our choice to analyze mainly the first wave, as similar conclusions can be drawn in the subsequent period.

7. Policy implications

In the following, we give an overview of possible actions to increase bike usage during a pandemic. For policy actions covering the fields of infrastructure, accessibility, integration in transport systems as well as information, we provide examples where such strategies have been applied. We report the comments of a panel of experts regarding the applicability in the Swiss setting, as well as related costs, benefits and implementation time horizon. The expert panel consists of nine experts on Swiss bike policy. The expert opinion is in the following reported in italic in an aggregated and anonymous manner. Furthermore, the results of the expert panel are summarized in Table 3, where we report the means of the estimated costs and benefits (each in 1–10 scale; a larger value relates to a larger cost or larger benefits) and implementation time horizons identified by the experts. Of course, the estimates are rough and depend vastly on the exact measure and situation. In addition, we refer to a crowdsourced collection of applications of policy actions and corresponding explanations provided by the Pedestrian and Bicycle...
Policies promoting bike use in reaction to a pandemic, including estimates on costs and benefits (1–10 scale) and the implementation time horizon.

| Policy Area                  | Cost | Benefit | Cost/Benefit | Implementation Time Horizon |
|------------------------------|------|---------|--------------|-----------------------------|
| **Infrastructure**           |      |         |              |                             |
| build new infrastructure     | 7.0  | 9.6     | +            | 6+ years                    |
| build temporary infrastructure| 3.0  | 8.6     | ++           | 3+ months                   |
| **Accessibility**            |      |         |              |                             |
| improve bike-sharing         | 4.6  | 5.0     | +/-          | 2+ years                    |
| subsidize bike purchase      | 4.1  | 4.7     | +/-          | 1+ years                    |
| and maintenance              |      |         |              |                             |
| **Integration in transport systems** | |        |              |                             |
| improve integration in public transport | 5.0 | 6.0 | +/- | 1+ years |
| discourage the use of cars   | 3.4  | 7.7     | +            | 2+ years                    |
| **Information**              |      |         |              |                             |
| Information/Promotion        | 2.6  | 4.0     | +            | 3+ months                   |
| Training/Education           | 3.6  | 4.7     | +/-          | 1+ years                    |

Information Center\(^4\) as well as the overview provided by (Buehler and Pucher, 2019).

**Infrastructure.** The most obvious change to infrastructure, further the most seen measure during the COVID-19 pandemic, is the creation of additional bike lanes. Additional bike lanes can be created on curb space, by removing of on-street parking, or on outer traffic lanes (e.g., Rome, Italy; Dublin, Ireland; New York, USA). These lanes can be identified by coloring or traffic cones, as a quick and cheap solution, but can also involve construction works with paving. Such lanes are mostly of temporary use, even if they can be also maintained permanently (as in e.g., Bogota, Colombia; Torino, Italy) (Kraus and Koch, 2021) analyzed bicycle counts at 736 locations in 106 European cities, which built on average 11.5 km of provisional pop-up bike lanes in response to the pandemic. They found that cycling counts have increased between 11 and 48%.

Whereas typically infrastructure projects take long, during an adverse event, many projects can be heavily accelerated. Especially, pre-existing cycling infrastructure projects can be conducted in fast-track (e.g., Seattle, USA; Berlin, Germany; Bologna, Italy; Toronto, Canada). If construction sites can remain open during the disruption, construction projects can be executed faster due to the absence of interfering traffic. In addition to faster constructions, also the planning process can be temporarily simplified and hence be sped up (e.g., France).

The beg-buttons (i.e., a button cyclists have to press to be assigned a green phase at signal-controlled intersections) are identified to be a heat threat to cyclists during a pandemic. As cyclists should not be forced to touch a surface many others have touched before, cities can temporarily disable some beg buttons and replace them with light timing that automatically includes cycles for cyclists (e.g., Sydney, Australia; Auckland, New Zealand; many Californian cities). Additionally, cities with high cycling traffic can adjust the timing of traffic signals to reduce the queuing time for cyclists (e.g., Rotterdam, Netherlands; Amsterdam, Netherlands).

Policies targeting parking comprise the conversion of on-street parking to bicycle parking (e.g., Amsterdam, Netherlands) or temporary bike racks (e.g., Bordeaux, France).

The experts identified the provision of bike infrastructure as the most beneficial way to increase bike usage. However, planning and building new infrastructure is a long-lasting process in Switzerland, which can only be marginally accelerated during a pandemic. Introducing temporary infrastructure is considered promising. However, optimally, this should be accompanied by a complementary permanent measure to allow the same level of service, when the temporary infrastructure is removed.

**Accessibility.** To increase the accessibility of cycling, bike-sharing systems can be improved. This can be achieved by offering free use or reduced fares for bike-sharing systems to essential workers (e.g., Washington DC, USA; Los Angeles, USA; Wuhan, China). This offer can also be extended to all inhabitants (e.g., Colorado Springs, USA; Glasgow, Scotland). However, operators of shared bike systems need to increase the sanitizing efforts of the fleet. In this way, they ensure that the virus is not transferred similarly as recent studies showed for bacteria spreading via the handlebars of bike-sharing systems (Zou et al., 2019).

Policy actions can furthermore target private bike ownership. Governments can put efforts in domestic production of cheap bikes for the general population (e.g., Peru), providing free bikes to students (e.g., Amsterdam, Netherlands), or subsidizing the purchase of new bikes (e.g., Nice, France; Rome, Italy; Madrid, Spain; Lisbon, Portugal). Finally, also bike repairs can be targeted by subsidies (e.g., France).

The experts remain skeptical about efforts to increase the usage of shared-bike systems in the Swiss context. Increasing the supply (more stations and bikes) requires a relatively long planning horizon, and increasing the demand (e.g., by reduced fares) would reduce the overall system quality. Offering discounts for bike purchases is not perceived as productive during the pandemic, as the global supply chains were partially interrupted during the pandemic and there was not enough supply of bikes. Subsidizing bike maintenance would be desirable. However, it seems complicated to get a system to satisfy the induced demand running on short notice.

**Integration in Transport System.** The integration of bikes with public transport was an important asset of the promotion of bike usage before the COVID-19 pandemic (Pucher et al., 2010). However, during a pandemic public transportation loses a lot of ridership, due to the challenges with the adherence to physical distancing (Tirachini and Cats, 2020). Whereas public transport and bike usage are in normal cases cooperative modes (i.e., they complement each other), in short and mid-term perspective, bikes can replace public transport usage. Hence, no short and mid-term measures improving integration are suggested.

Short and mid-term policy actions seem appropriate to discourage motorized individual traffic. Such policies include reducing speed limits in given streets to 20–30 km/h on a temporary base (e.g., Brussels, Belgium; Birmingham, England), or on a permanent base (e.g., Washington DC, USA). It is furthermore possible that a disruption accelerates the implementation of reduced speed limits (e.g., Minneapolis, USA). Another measure constitutes of banning non-local traffic on certain streets (e.g., New York, USA; Kampala, Uganda), or declaring selected streets as “shared streets” (e.g., Vienna, Austria; Houston, USA). These measures aim to support social distancing and bicycle and pedestrian safety during the pandemic. Shared streets can support outdoor exercises while creating a safe environment for walking or cycling while obeying social distancing requirements. Also, these usually temporary measures can become permanent on a long-term perspective (e.g., Vancouver, Canada). Finally, authorities can even closed selected roads fully to motorized transport (e.g., Boston, USA; Salt Lake City, USA; San Francisco, USA; New York, USA).

The experts agree that a stronger integration of bikes into the public transport system is not a priority during the pandemic, as public transport usage is drastically reduced. Furthermore, the experts agree that car usage should not be discouraged during the pandemic, as a big share of people prefers individual traffic in this period.

**Training, Education, Information, and Promotion.** Bike training can help to attract new cyclists. People who have not used a bike for a long period can be helped to get used to cycling again by dedicated courses (e.g., Montpellier, France). Furthermore, in times of social distances, bike classes can be moved to an online offer or held via video-chat software (e.g., New York, USA; Thunder Bay, Canada). To improve information dissemination, temporary free access to bike routing apps can be provided (e.g., Stuttgart, Germany). Finally, authorities and media can promote cycling as a safe and convenient alternative.

\(^4\) pedbikeinfo.org/WalkBikeSocialDistance, accessed 09.07.2020.
The experts identified information and promotion strategies as valuable during the pandemic. People reconsidering their choices and experimenting with new means of transport are susceptible to such strategies. Also, temporary measures could be promoted. However, the potential of training and educational events is rather low during a pandemic, and it is difficult to conduct such events in a social-distancing or online setting.

8. Recommendations

8.1. Recommendations derived from data

From the analyses of Zurich and Basel, it can be concluded that during the lockdown period the bike traffic was reduced but recovered quickly, reaching similar or slightly higher traffic than could be expected from past data. The analysis in this paper shows an increase in bike usage under specific circumstances. While no specific policy action affecting cycling usage was implemented, the effects measured are the manifestations of a latent demand, during different conditions. We here link the effects to actions that can be further recommended as policy measures.

The daily pattern of bike traffic changed during the pandemic, as the traffic shifted to the afternoon and evening hours (see Section 5). This can possibly be attributed to more leisure trips, which is also underlined by the increased cycling traffic close to leisure places. From a policy point of view, this shows that people are already aware of cycling and willing to cycle, but they do not perceive it as a suitable choice for commuting home-work trips. Therefore, policy makers can further support cycling by showing that cycling is also suitable for work-home trips by addressing the following issues:

- Limited choice of destination. For leisure trips, one can choose where to go, for instance, places with good infrastructure (e.g., well advertised bike routes). Instead for work trips the destination is fixed, and people have to accept the infrastructure available. One can also argue that the bike trip was one of the few allowed leisure activities during the lockdown, as indoor activities were strongly limited.
- General geographic constraints of work locations. Work locations are mostly concentrated in urban areas, where space and bike infrastructure is more limited. Leisure can also extend to outskirts of the city, where more space is available for bike lanes and the environment is more enjoyable.
- Temporal dynamics and traffic congestion. Leisure (especially during home office) can be planned at times when traffic is low. Therefore, a more flexible choice of working time (avoiding peak hours, when traffic is too heavy to enable enjoyable cycling usage) would allow more cycling.
- Employers could support different working habits, i.e., accepting personnel with sporty comfort-able clothes, or enable suitable shower and changing facilities.

8.2. Recommendations derived from the expert panel

Here, we report on a thorough analysis of the findings and recommendations, suggested by a panel of nine experts in the Swiss bike policy. Their aggregated, anonymous feedback focuses on implementability, implementation time, costs and expected benefits. Basing on their feedback, we provide recommendations to utilize the window of opportunity for policy measures to permanently increase bike usage in response to the COVID-19 pandemic. In response, such actions should aim to test policy measures, increase bike usage of current cyclists, attract new cyclists, and keep the new attracted cyclists and the increased bike usage. Finally, we report on how the impacts of a policy action can be measured.

Test policy actions. Authorities have the unique opportunity to use their streets as testing grounds for policy changes. This experimenting (e.g., with shared streets or reduce speed limits) could reveal solutions that have far-reaching benefits for cities long into the future. Such tests are currently only done in a limited manner in Switzerland, although this would be a promising path to understand the gains and acceptance of an action.

Increase bike usage. The experts unanimously agree that improving infrastructure is the best way to increase bike usage. Measures should target occasional cyclists, i.e., people who know how to cycle and own a bike but only use it occasionally. This group of people desires dedicated infrastructure, which is separated from car traffic, broad paths, clear markings, and safe guidance at intersections. Especially, this group of cyclists can be reached by fast-track construction of new bike lanes, temporarily allocated bike lanes, or car-free zones, to gain skills and confidence during the pandemic, possibly leading them to continue cycling on the streets after the pandemic. To increase leisure trips, the introduction of car-free zones or shared streets could be highly beneficial, as these cyclists demand a pleasant journey, separated from traffic.

Attract new cyclists. People that are not used to cycle need access to a bike and learn how to use it safely. Even more, they have a strong need for infrastructure separated from traffic. A subsidized bike purchase would lower the bar for purchasing a bike, and online cycling classes would constitute a promising start to use it. Temporary measures such as car-free zones or shared streets can consolidate the confidence and provide new cyclists a promising start in cycling. Finally, the experts believe that new cyclists are particularly susceptible to information campaigns.

Keep cyclists. The process of coming back to normal is long. Even a year after the first wave of the pandemic, there are still some unavoidable changes and adoptions or exposure to new travel patterns and mobility behavior. Public transport might not transition quickly to some stable post-pandemic condition, as the perceptions of public transport as unhealthy might gain ground and might be sustained (Tirachini and Cats, 2020). Keeping the temporary increased bike traffic and the possibly positive perception of cycling is a challenge. There is a risk that if temporary measures are stopped, the use of cycling will be reduced again. Therefore, initially temporary planned measures, such as temporary lanes, should be evaluated carefully and it should be decided if it might be useful to keep them permanently. Otherwise, transitions strategies should be defined, including, for instance, promotion and information campaigns.

Evaluate the impact of policy actions. It is vital to continuously monitor changes in bike usage and evaluate the success of imposed policy actions. The effects can best be measured by automatic bike counters, which are installed at representative locations. Furthermore, crowd-sourced data (e.g., STRAVA) can inform about changes. A further proxy for a change in usage can be bike sales numbers. Finally, policy measures can lead to a change in accidents; hence accident statistics should also be considered to evaluate the change in bike usage.

9. Conclusions

A pandemic, as the COVID-19 pandemic the world is currently experiencing, shows the values of individual transport against shared and collective mobility. Cycling is the most resource-effective individual transport mode, resulting in health benefits and promoting urban quality. The pandemic is a unique opportunity for governments to rethink past assumptions and study the benefits of temporary measures. Cycling is a resilient mode of transport, i.e., provides mobility potential throughout a variety of various policy limitations, and can recover quickly to a previous level, once exceptional situations are resolved. The temporary and experimental measures taken should be evaluated carefully and used as a trail for long-term plans. Furthermore, temporary policies can evoke a remaining preference and behavior changes, may have a lasting effect and change the way we move in cities for years to come.
We analyzed two test cases in Switzerland and their interrelation between short- and mid-term policy measures taken and bike usage. We focused on the observed changes and shed light on the amount of bike traffic in the Swiss cities Zürich and Basel before, during, and after the lockdown. The data were corrected by weather and temporal factors to have a fair baseline. The bike traffic dropped substantially in the beginning of the lockdown period, and in the following rose quickly to the expected traffic. This proves cycling to be a resilient means of transport. After the lockdown, no distinct increase in bike traffic could be identified. We link those observed effects to latent demand, which is exposed in unusual conditions. We remark that the authorities in the two studied cities did not implement any explicit policy actions in favor of cycling (like additional infrastructure). Another pandemic or an additional wave of the current pandemic is likely. To increase bike usage, we recommend using this window of opportunity.

Declaration of competing interest
None.

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