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It Is How You Build Them: Attractivity of Separated and Mixed-Use Cycling Infrastructure in Bologna Using Long-Term Time Series

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Abstract

Implementing effective cycling mobility requires infrastructure that enhances safety and reduces travel time. A common metric for tracking progress is the total length of dedicated cycling infrastructure. However, this does not always correlate with increased cycling usage. For instance, in Italy (2008–2015), cycling infrastructure grew by 48%, but ridership remained unchanged. Design quality and behavioral and contextual factors all influence this dynamic. This study analyzes a 16-year time series (2009–2024) of monthly cyclist flows surveys in Bologna, Italy. It focuses on flows, gender, and bike lane usage. It represents the most detailed and longest series of its kind in the country. The findings show a positive correlation between infrastructure growth (meters per inhabitant) and cyclist flows, though this weakened significantly after COVID-19 and the extensive introduction of non-exclusive bike lanes on mixed-use roads from 2020. Regression analyses reveal that new bike flows per new meter/inhabitant of infrastructure were 3 times greater before 2020. This study identifies two likely causes: the insufficient perceived safety of the newly introduced mixed-traffic lanes from 2020 and the lack of attractivity of cycling for the female population, as highlighted in the decreasing trend in the usage of bike infrastructure by female riders after 2020.

Keywords: bike infrastructure; infrastructure policy; active mobility; bike ridership; mixed-use bike lanes; protected bike lanes; gender gap in bike transport

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1. Introduction

Urban planning has increasingly focused on promoting active and sustainable modes of transport, as they can play a crucial role in reducing congestion, urban pollution, dependence on fossil fuels, and physical inactivity [1,2]. A growing number of cities are investing in new or improved cycling infrastructure in order to realize safe and comfortable cycling mobility; thus, there is the need to understand what policies on new bikeway construction can be effective in incentivizing new bike trips. Not every cycling infrastructure is the same though, as the level of separation from the motorized traffic is a characterizing aspect of the infrastructure. For simplicity, in this paper, we will refer to separated bike infrastructure, whether on-road or grade-separated, as bike paths and to cycling infrastructure that allows mixed bike and motorized traffic as bike lanes. The former provide a physical or visual (e.g., solid painted lines) separation, while the latter do not offer any separation (e.g., dashed painted lines). Numerous studies have found a positive correlation between bike facilities and cycling frequency [3–6], with evidence suggesting that grade-separated bike paths can attract new users to cycling [7]. However, not all cycling infrastructure is perceived equally by users. Many studies, based on stated preference surveys, have tried to identify environmental and infrastructural elements that can encourage or discourage cycling [8–18]. These studies indicate that cyclists generally prefer bike paths that are physically separated from motorized traffic or at least with road marking delimiters, as well as routes with fewer intersections. Moreover, Nelson and Allen [4] found a positive correlation between the length of bike paths per capita and cycling mode share, measuring a 0.069% increase in bike commuting for each additional mile of bikeway per 100,000 people. Existing infrastructure and local environmental factors can also heavily influence route and mode choice, as stated by Winters et al. [15] in a study conducted in Vancouver, Canada. Dill and Carr [3] analyzed 35 large U.S. cities and found that higher levels of bike infrastructure were associated with greater bicycle commuting rates.

More information can be found from revealed preference surveys, increasingly available through GPS tracking from smartphones. A study by Dill [19] in Portland, USA (166 users for 1955 trips), suggests that a well-connected network of low-traffic, low-priority roads may be more effective at encouraging cycling than new bike paths or lanes on high-traffic, high-priority roads. Menghini et al. [20], in a study conducted in Zurich, Switzerland (2498 trips), found that the primary environmental factors influencing cycling trips were trip distance and maximum road gradient, while the presence of grade-separated bike paths had a comparatively lower impact. Hood et al. [21] analyzed GPS traces (366 users for 2777 trips) in San Francisco, USA, and found that grade-separated bike paths were the preferred infrastructure, particularly among infrequent cyclists. Both Hood et al. [21] and Broach et al. [22] (164 users, 1449 trips) confirmed that factors such as route length, maximum road grade, traffic volume, number of turns, and intersections deter cyclists when choosing their paths. Bernardi et al. [23] compared the effects and frequencies of disturbances on off-street bicycle facilities (from other cyclists and pedestrians) with disturbances (from motorized vehicles) in mixed traffic by analyzing the speed reductions from different types of disturbances. Three extensive studies by Rupi et al. [24–26] (1123 users for 4272 trips) in Bologna, Italy, revealed that cyclists prefer safer, low-traffic roads even at the cost of significantly longer travel distances (+20.7% on average). The studies also confirmed that many cyclists avoid intersections and traffic lights; only a few users showed a strong preference for signalized crossings.

Interest in cycling is also influenced by the topology and density of the cycling network. An extensive review by Buehler and Dill [27] shows that cities and countries with high bike usage have extensive networks of separated bike paths and traffic-calmed streets; moreover, demand for cycling infrastructure is more elastic in areas where networks are already dense and well-connected and have shortcuts where car traffic is low. Furthermore, there are many studies that report a women's preference for protected infrastructure that separates them from interactions with motor vehicle traffic [28–31]; protected and connected infrastructure can be very useful for meeting the preferences of female cyclists, and consequently, it is a key factor in increasing and diversifying bike riding participation. While infrastructure is surely a major driver of change in cycling mobility, recently, the COVID-19 pandemic also influenced urban transportation in the world and in this paper's case study of Bologna. In Italy, a progressive increase in bike mobility has been registered after COVID-19 in terms of modal share that grew from 3.3% in 2019 to 5.2% in the first semester of 2025 [32].

The cited studies generally analyze data collected over short periods, ranging from a few days to several months. Such windows capture momentary preferences but not temporal evolution or the medium- to long-term effects of policies and infrastructure changes. Stated-preference studies, on the other hand, rely on self-reported information from users. By contrast, this study assembles a 16-year time series, from 2009 to 2024, of bicycle counts at key locations across the city. This span captures a major shift in Bologna's cycling infrastructure policy in 2020, when on-road bike lanes became the primary option for new cycling infrastructure, replacing the previous emphasis on separated bike paths. The authors are not aware of any study providing a time series of comparable length, and while this dataset cannot prove a causal relationship, it allows us to analyze the correlation between infrastructure choices and growth in bicycle flows.

The literature analysis shows, via evidence, a research gap regarding long-term empirical time-series analyses of cyclist flows linked to infrastructure typology. This research aims to fill this gap by relating the provision of cycling infrastructure per inhabitant to cycling flows for the period of 2009–2024 for the city of Bologna. This study investigates how bike lanes and bike paths differ in their ability to attract new bicycle flows. In particular, this study aims to test the effectiveness of on-road mixed-traffic bike lanes and quantify their usage during the 2020–2024 period, when they were first introduced, by studying the relation between bike infrastructure provision per inhabitant and flow counts. Linear regressions are carried out to highlight the influence of bike infrastructure on cycling traffic. Regressions are carried out for both the period before and after 2020, when the bike infrastructure expansion policy shifted rapidly from adding bike paths to almost only on-road bike lanes. This allows a comparison in terms of attractiveness between the infrastructure built up to 2019 and those built from 2020 onward.

This paper is organized into four sections. The Case Study section describes the main characteristics of the study area and examines the evolution of the bicycle network and flows within the municipality of Bologna from 2009 to 2024. The Results section presents linear regression outcomes, carried out to highlight the influence of different types of bike infrastructure on cycling traffic. The Discussion section synthesizes the findings and assesses their implications for planning and operations. The Conclusions section summarizes the main contributions, highlights practical points for operators and planners, and indicates priorities for future research.

2. Case Study

2.1. Study Area

Bologna is a medium-sized Italian city with approximately 392,000 inhabitants [33]. The city is located in the north of the country, and the climate is favorable for all-year cycling, with an annual average temperature just below 15 °C and moderate–low precipitation (around 700 mm of rainfall per year over 74 rainy days). Over the years, the municipality of Bologna has promoted the development of cycling mobility, achieving better results than the Italian national average, as demonstrated by the data on the modal split of urban travel. Indeed, for Bologna, the home-to-work bicycle mode share was 10.0% [34], while in Italy, in 2023, the share of commuters using bikes was 5.8% [35]. Instead, in 2019, the average bike mode share across 28 European Union member states was 8.0% [36], significantly higher than the Italian average.

Initially, the municipality of Bologna promoted the development of cycling mobility by investing in and creating bike lanes physically separated from motor traffic, as well as promoting shared active micro-mobility [37]. In 2020, the municipality of Bologna changed its strategy, promoting the spread of cycling mobility through coexistence between cyclists and motorized road users. This policy reflects the approach defined in Biciplan adopted by the Municipality of Bologna within the SUMP [38]. Therefore, 2020 was significant for Bologna's bikeway infrastructure evolution as the municipality started introducing mixed-traffic cycle lanes, first introduced in Italy by Legislative Decree in 2020 (Figure 1).

Figure 1. Example of mixed-traffic cycle lane (on the right of the carriageway, painted red) in the city of Bologna.

This analysis is conducted starting from the kilometers of cycle infrastructure, distinguishing the various typologies and, in particular, referring to the kilometers of mixed-traffic bike lanes in the roadway that were first introduced in 2020. This study is based on a series of cyclist flow measurements, both through automatic counters and operators who manually collected a series of information on the characteristics of cyclists. In this paper, the term "bicycle" is used as an inclusive term for all vehicles powered partly or completely by pedal power, including bicycles, mountain bikes, fat bikes, cargo bicycles, and pedal-assisted bicycles.

2.2. Data on Bicycle Network

During the last 16 years, the city of Bologna has made significant enhancements to its bikeway network. In 2024, the total extension of the bike infrastructure reached 187 km, comprising different types of bikeways, such as grade-separated bike paths, on-road bike paths, and on-road bike lanes [39]. The bike network features some main radial paths that connect the city center and suburbs, as well as many other paths connecting them (Figure 2).

Figure 3 reports the bike infrastructure growth referenced with respect to 2009 for the Italian territory and Bologna: Italian bikeway provision data from 2009 to 2022 were obtained by ISTAT (Italian institute of statistics) [40], while data for 2023 were obtained from the Ancma-Legambiente report [41]; Bologna bikeway network extension data from 2009 to 2024 were provided by the city's municipality. As is evident from Figure 3, in the analyzed period, Italy and Bologna's cycling infrastructure grew at similar rates (Bologna +117% from 2009 to 2024; Italy +102% from 2009 to 2023).

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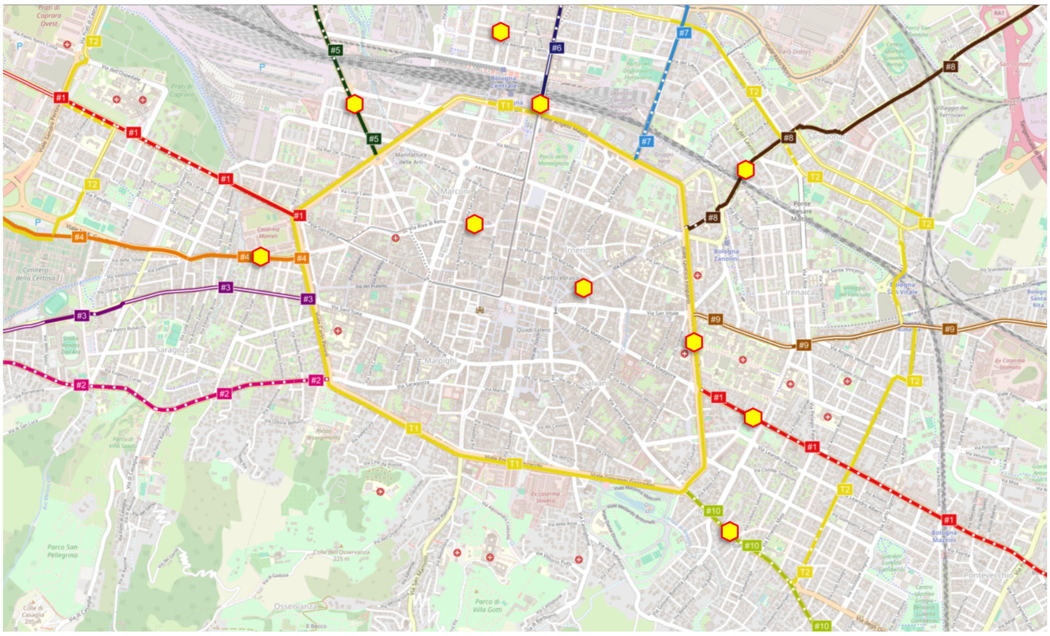

Figure 2. Map of Bologna's metropolitan bikeway network with measuring spots (red-yellow exagons) [38].

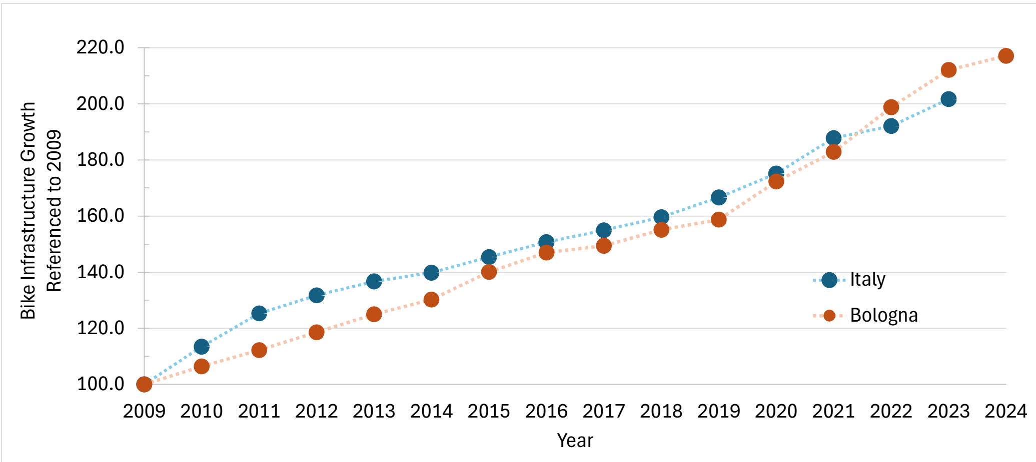

Figure 3. Growth of Bologna's and Italian bike infrastructure with respect to 2009 (Italian territory data of 2024 are currently unavailable).

The municipality of Bologna, which has continuously invested in new bike infrastructure in the past 16 years (Figure 4), until 2019 had only built grade-separated bike paths, while from 2020, the main increment in bike networks was due to bikeways painted on existing carriageways. These new lanes are of two types: solid-painted bike paths with exclusive bike access and mainly dashed-painted bike lanes for mixed-traffic use. The concept of dash-painted lanes was first introduced in Italy by Legislative Decree no. 76 on 16 July 2020 and subsequently amended by Law no. 120 on 11 September 2020. This represented a lower degree of separation from motorized traffic, with potential safety implications for the new infrastructure type.

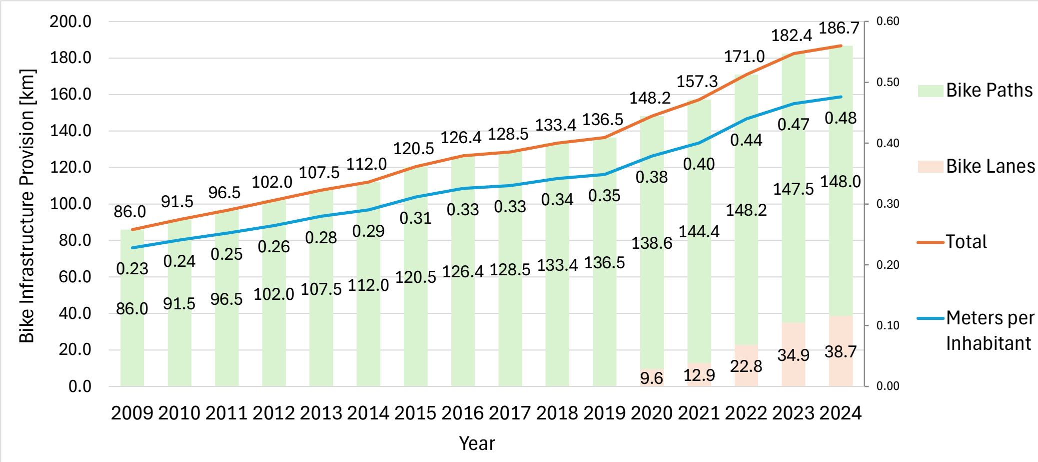

Figure 4. Length of Bologna's bike infrastructure per separation type from 2009 to 2024.

2.3. Data on Bicycle Flows

The data used in this research study comes from multiple sources. Our team carried out manual and instrumental counting of flows from 2009 to 2020 for the municipality of Bologna. From 2021, the municipality decided to take the responsibility of performing the counts using instrumental methods, but our group kept carrying out manual counting to enrich flow data with information on gender, age, bike type, and use of helmet. The data presented in this paper comes from merging these data sources together.

Manual and instrumental counting from 2009 to 2020 was conducted between 15th September and 15th October of each year: While instrumental surveys were continuously conducted through temporary counters (pneumatic and radar traffic counters and camera-based traffic data collection devices) for at least two weeks in the monitoring period, manual surveys were carried out only during peak hours on weekdays. Some of the instrumental measures were taken at the same time as the manual ones at the same measurement points, allowing us to verify the reliability of the instruments. The manual counts were carried out by our team from 2009 to 2024 on each road section between 15th September and 15th October of each year from 08:00 to 10:00 and from 16:30 to 17:30 on weekdays. These periods coincide with the peak weekday hours, and the main trip's purpose during these time frames is most likely commuting for "work" or "study". Only days with good weather (not rainy) were retained for analysis. Since no significant differences were found across these working days, no further stratification by weekday was applied. The manual counts were carried out by 10 operators who simultaneously recorded the main characteristics of cyclists, like gender, age class, type of bicycle used (private or shared), use of the helmet, etc. Beginning in 2021, the municipality of Bologna assumed responsibility for instrumental measurements carried out between 15th September and 15th October of each year [42]. These measurements provided only bicycle flows, and in this study, their flow measures for 2021–2024 are used. The municipality's counting locations include the same sites used by our team in the 2009–2020 period, ensuring continuity. The manual counts carried out by our group allowed us to enrich these data with the categorical information of users. As these instrumental counting instances were not supervised by the authors of this study, the reliability of these measures was not under our direct control. To verify reliability, the instrumental counts from 2021 to 2024 were compared to our own manual counts, and no significant discrepancies were found.

The measuring locations sit on most of the main cycling corridors of Bologna, and they are distanced enough to reduce the chance of a single bike trip being measured in two measuring spots during the same counting session. The southern part of the city is not covered with measurement spots, as it is a very hilly area with very little bike traffic. For a visual reference of the positioning of spots, see Figure 2. The overall average two-way hourly flows were obtained by dividing the sum of the flows detected in the two directions by the total number of hours of detection, producing a yearly series of comparable data. Most of the sections are located on the main radial routes. Some of them are on physically separated bike paths, while others are on pedestrian paths with cycling allowed (bike path on footpath), on dashed painted bike lanes, and on bus lanes with cycling allowed (also considered bike lanes for the purposes of this study). Table 1 reports the evolution of average hourly flows measured from 2009 to 2024.

Table 1. Average hourly bicycle flows on all measurement spots from 2009 to 2024.

Year	Av. Flow [Bikes/Hour]	Year	Av. Flow [Bikes/Hour]
2009	1235	2017	2384
2010	1342	2018	2541
2011	1564	2019	2563
2012	1598	2020	2345
2013	1782	2021	2512
2014	1807	2022	2533
2015	2003	2023	2796
2016	2196	2024	2630

During the considered period, the total bikeway meters per citizen increased by 109%, starting with 0.228 m/citizen in 2009 and reaching 0.476 m/citizen in 2024. The total average flows recorded in the monitored sections increased between 2009 and 2024 by around 113%, which is, therefore, of the same order of magnitude as the increase in bikeway meters per inhabitant in the same period.

Another important element that characterizes the case study are the effects that the COVID-19 pandemic had on city mobility; in particular, the public transport sector registered a sheer 33.4% decrease in yearly passengers from 2019 to 2020, which has not yet recovered with respect to pre-COVID-19 values, as shown in Figure 5. Also, the cycling flows show a similar contraction, though on a smaller scale, during 2020, as shown in Table 1.

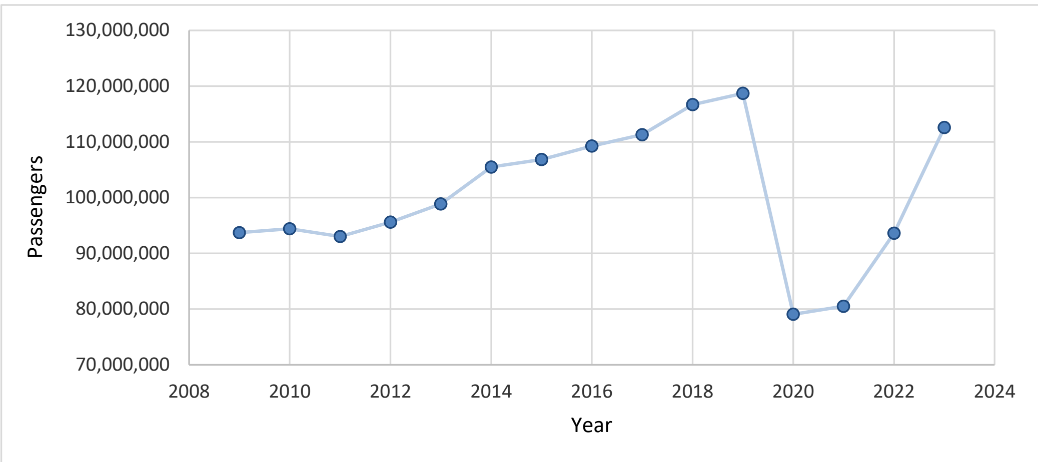

Figure 5. Public transport passengers in Bologna from 2009 to 2023.

3. Results

The aim of this study is to relate the provision of cycling infrastructure per inhabitant to flow counts. To this end, linear regressions are performed to highlight the influence of cycling infrastructure on cycling traffic.

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Tests and diagnostic checks on the residuals were carried out to assess the assumptions of normality, homoskedasticity, and independence. Normality was assessed visually using Q–Q plots, given the limited number of annual observations; these plots do not show gross violations of normality. Homoskedasticity was checked by inspecting residuals-versus-fitted plots, which suggest that the dispersion of residuals tends to increase with the fitted value, indicating possible heteroskedasticity. Independence was assessed using the Durbin–Watson statistic and Ljung–Box tests, which show that residual autocorrelation is present and statistically significant in many of the regressions. Given this evidence, we use heteroskedasticity- and autocorrelation-consistent (HAC) standard errors with a one-year lag for all models, using the Newey–West method.

As shown in Figure 6, bike infrastructure provision per inhabitant positively correlates with bike flows along the measurement sections for the 2009–2024 period. The estimated slope is 5777 additional cyclists per hour per additional meter of infrastructure per inhabitant, with $R^2 = 0.82$. The 95% confidence interval for the slope remains relatively tight, approximately $[4.2 \times 10^3, 7.4 \times 10^3]$, and the p-value is well below 0.01, confirming a strong and statistically robust association over the full period.

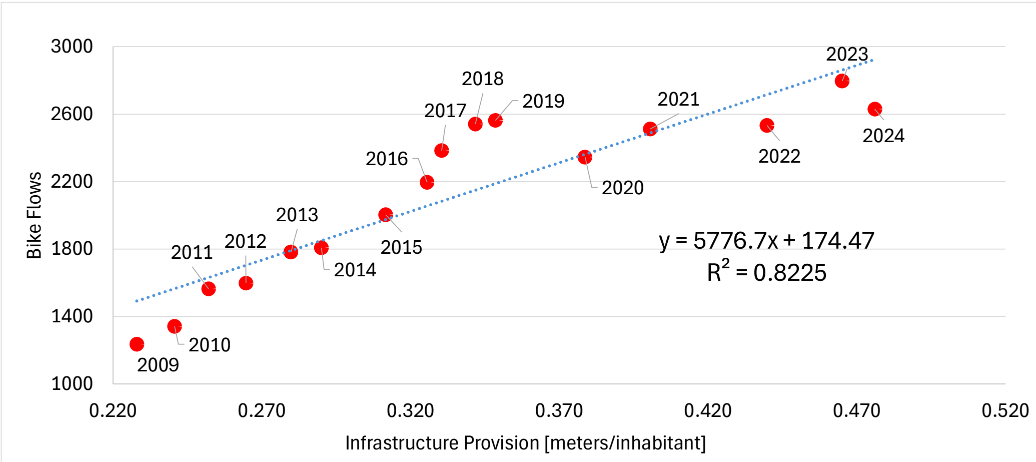

Figure 6. Bike flows measured (cyclists/hour) vs. bike infrastructure provision per inhabitant (meters/inhabitant). Regression line and its equation for the 2009–2024 period.

The trend suffers a steep change after 2019, during the COVID-19 outbreak and the change in bike network expansion strategy. If the regression analysis is repeated for the periods of 2009–2019 and 2020–2024 separately, the regression results differ greatly from those found in the 2009–2024 period (Figure 7). Before 2020, when the meters of infrastructure were mainly of the separated type (bike path), both slope and R^2 are substantially higher (slope = 10,871; $R^2 = 0.98$). The 95% confidence interval for the slope is $[9.8 \times 10^3, 1.2 \times 10^4]$, and the p-value is far below 0.01. After 2019, for the 2020–2024 period, the slope falls to about 3415, with $R^2 = 0.74$. The 95% confidence interval for the slope is much wider, $[1.5 \times 10^3, 5.3 \times 10^3]$, reflecting both the shorter time series (five annual observations) and the greater dispersion of the data, but it still excludes zero and yields a robust p-value around 0.01. In other words, additional infrastructure is still positively associated with higher flows after 2020, but the magnitude of the association is roughly one-third of that observed in 2009–2019, and it is estimated with less precision.

The same regression analysis was repeated using only meters of separated infrastructure per inhabitant instead of total infrastructure length per inhabitant (thus excluding dashed-painted bike lanes from 2020 to 2024). The regression for the whole period (2009–2024) features a higher slope (slope = 9456; $R^2 = 0.95$) (Figure 8). The 95% confidence interval for the slope is $[8.5 \times 10^3, 1.0 \times 10^4]$, and the p-value is again far below 0.01, indicating a very tight relationship between separated infrastructure provision and cycling flows.

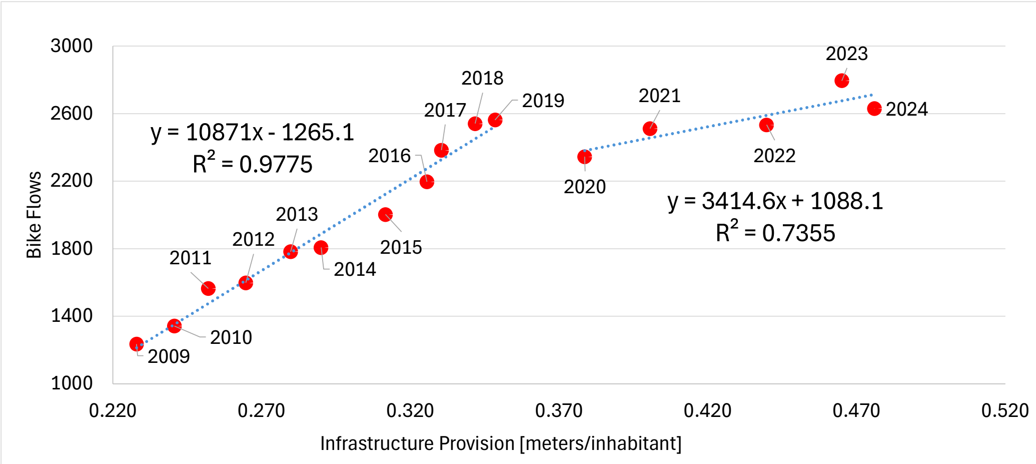

Figure 7. Bike flows measured (cyclists/hour) vs. bike infrastructure provision per inhabitant (meters/inhabitant). Regression lines and their equations for the 2009–2019 and 2020–2024 periods.

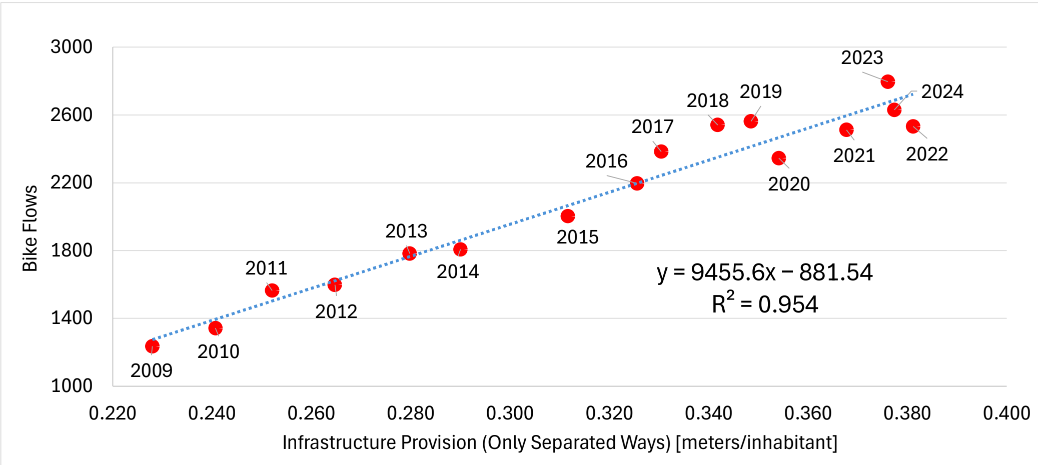

Figure 8. Bike flows measured (cyclists/hour) vs. separated bike infrastructure provision per inhabitant (meters/inhabitant). Regression line and its equation for the 2009–2024 period.

Some quite interesting results can be seen. When only separated bike paths are considered, the slope significantly increases, and this occurs also because the excluded dashed-painted kilometers reduce the x-axis values after 2020. At the same time, R^2 rises above 0.95. This suggests that the linear model based on separated infrastructure per inhabitant is much more capable of explaining the increase in bike flow than the model based on total infrastructure, which aggregates both bike paths and lanes. When the regression is estimated separately for 2009–2019 and 2020–2024 on separate infrastructure, the 2009–2019 period shows a slope of 10,871 and $R^2 = 0.98$, with a narrow 95% confidence interval $[9.8 \times 10^3, 1.2 \times 10^4]$. In the 2020–2024 period, the slope is slightly larger (11,090), but R^2 drops to 0.52, and the 95% confidence interval widens substantially to $[2.3 \times 10^3, 2.0 \times 10^4]$ (Figure 9). This reflects the very small number of post-2020 observations and the limited variation in separated kilometers in those years: where separated facilities still expand, they remain strongly associated with higher flows, but the uncertainty around the slope is too large to precisely quantify how much more effective they are in the recent period.

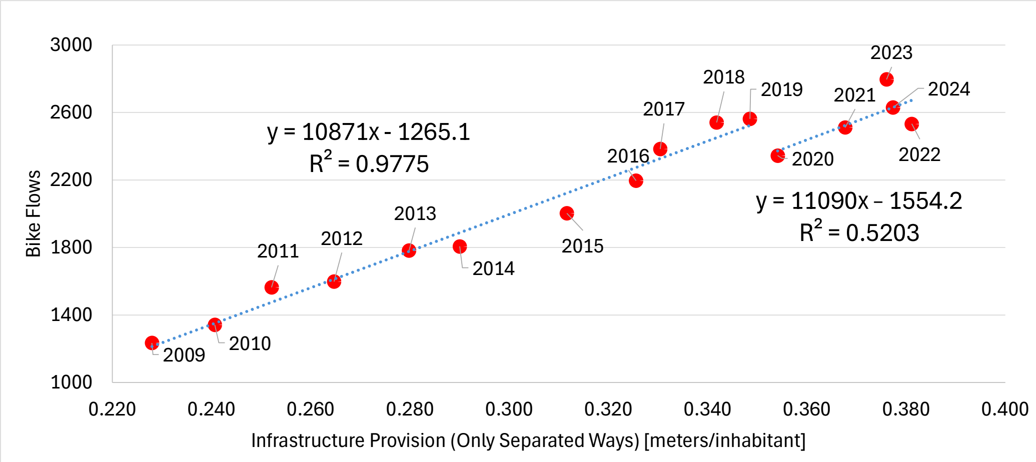

Figure 9. Bike flows measured (cyclists/hour) vs. separated bike infrastructure provision per inhabitant (meters/inhabitant). Regression lines and their equations for the 2009–2019 and 2020–2024 periods.

The results of the linear regressions, together with HAC significance tests and confidence intervals, are reported in Table 2. Models 2 and 5 yield identical results, since prior to 2019, all cycling infrastructure in Bologna was of the separated type, and the "all infrastructure" and "separated-only" measures coincide.

Table 2. Results and statistical significance of regression analysis.

Linear Regression Model	Model Parameter	Parameter Value	95% C.I. ^{iii}	t Stat	p	Model's SE	$R^2 \pm$ SE
1. All Inf. 09–24 ^{i}	β_0	174.47		0.6794	0.5080	217.7	0.822 ± 0.065
	β_1	5776.7	[4179, 7374]	7.7560	<0.0001 **		
2. All Inf. 09–19 ^{i}	β_0	−1265.1		−10.0432	<0.0001 **	73.5	0.978 ± 0.020
	β_1	10871	[9789, 11953]	22.7315	<0.0001 **		
3. All Inf. 20–24 ^{i}	β_0	1088.1		4.3834	0.0220 *	98.4	0.736 ± 0.098
	β_1	3414.6	[1504, 5325]	5.6872	0.0108 *		
4. Sep. Inf. 09–24 ^{ii}	β_0	−881.54		−7.3392	<0.0001 **	110.1	0.955 ± 0.036
	β_1	9455.6	[8513, 10398]	21.5168	<0.0001 **		
5. Sep. Inf. 09–19 ^{ii}	β_0	−1265.1		−10.0432	<0.0001 **	73.5	0.978 ± 0.020
	β_1	10871	[9789, 11953]	22.7315	<0.0001 **		
6. Sep. Inf. 20–24 ^{ii}	β_0	−1554.2		−1.5562	0.2175	132.5	0.520 ± 0.150
	β_1	11090	[2330, 19850]	4.0290	0.0275 *		

The coefficient β_0 denotes the intercept, and β_1 corresponds to the independent variable. t-statistics and p-values are based on HAC/Newey–West standard errors with one annual lag. ** The parameter is considered highly significant for $\alpha = 0.01$. * The parameter is considered marginally significant for $\alpha = 0.10$. ^{i} The model considers all types of infrastructure provision as independent variables. ^{ii} The model only considers separated infrastructure provision as independent variable. ^{iii} The 95% confidence interval is shown only for the β_1 parameter.

Gender-related data are available only from 2015 to 2024, with some gaps in 2016 (no data) and 2018 (only general female share data). From 2015 to 2020, the share of female cyclists increased constantly (Figure 10). In 2020, 45% of counted cyclists were female, while on separated infrastructure, they comprised 48% of the total flow. After 2020 and until 2024, there is a decreasing trend, with 2024 data featuring only 42% of female cyclists. In 2020, the bike network's expansion was mainly driven by bike lanes. The change in trend could be attributed to the more cautious behavior exhibited by female cyclists [43]. On-road dash-painted bike lanes could be ineffective in attracting many new female bike users, thus lowering the female-to-male ratio of cyclists. The gap between the share of female riders on all bikeways and only separated bike paths is either zero or in favor of separated infrastructure, though the gap registered was always quite small. Although the decline in female presence is non-negligible, the limited number of observations both before and after 2020 makes the underlying trend difficult to interpret. Additional measurement campaigns will be needed to clarify this pattern.

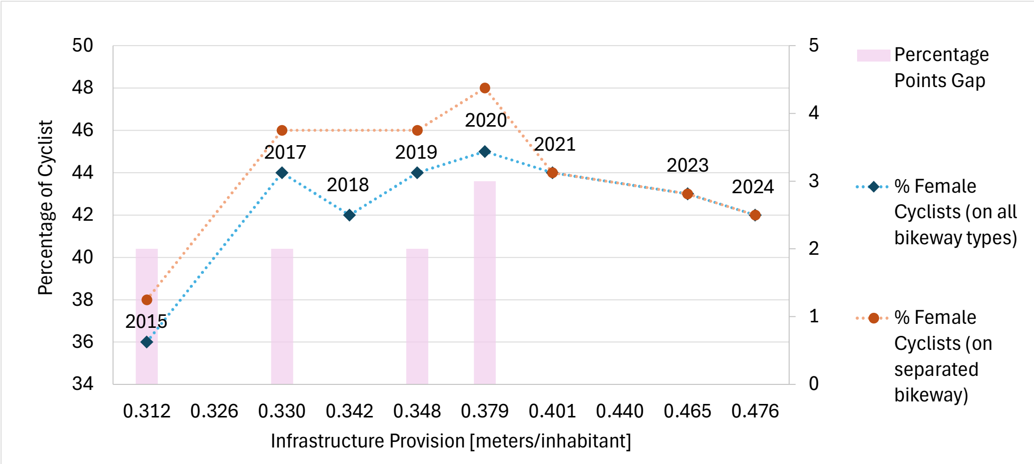

Figure 10. Share of female cyclists on generic (blue) and separated (orange) bike lanes and their percentage points gaps (pink blocks).

4. Discussion

After COVID-19, there was a significant drop in urban public transport users due to fear of contagion, thus creating favorable conditions for a significant increase in cycling. However, in some cities, this increase was much less widespread than expected. After 2020, in the city of Bologna, the rate of growth of bike flows with respect to new bike infrastructure decreased by almost 3 times compared with the 2009–2019 period. Even after the initial traffic disruptions caused by COVID-19, the trend does not give any sign of significant improvements.

Mode choice is a phenomenon driven by a multitude of factors thoroughly studied in the field of environmental psychology [44], but as the sheer decrease in new flow coincides with the introduction of new on-road dash-painted bike lanes instead of separated infrastructure, it would seem natural to identify the drop in perceived ride safety and comfort as the main driver of the phenomenon. These new bike lanes share the same carriageways as motorized vehicles and are delimited by dashed lines that allow other vehicles to temporarily occupy the bike lane space. Moreover, these new lanes are often packed between motor road on the left and roadside parking on the right, creating possible conflict points on both sides for cyclists. This precarious safety standard may have an even stronger impact on the female population, which is observed in the literature to have a more cautious behavior when moving by bike. Our counting is consistent with this phenomenon, as the share of female bike riders, even on separated bike paths, decreased from 48% in 2020 to 42% in 2024. This decreasing share of female riders could suggest that new bike infrastructures may be predominantly attracting male riders. Unfortunately, these results alone, related to the last four years, are not definitive evidence of a gender-related issue. To better understand if gender differences are a key driver of the phenomenon, it would be necessary to collect data related to successive years.

For the pre-2020 period and for models that only consider separated infrastructure, HAC confidence intervals for the slope are still narrow and far from zero, and the associated p-values remain very small, confirming a strong and statistically robust association between separated bike paths and bicycle flows. By contrast, when all infrastructure types are pooled, the HAC intervals become wider, and the slope estimated for 2020–2024 is clearly smaller than that for 2009–2019, even though it remains positive and statistically significant. This pattern reinforces the interpretation that not all kilometers of new infrastructure are equally effective: Separated facilities show a stable, high-intensity association with flows, while the post-2020 expansion dominated by dash-painted bike lanes is associated with a much weaker response. The results, therefore, give additional weight to the conclusion that infrastructure quality matters more than quantity.

Our results on the relation between bike infrastructure and bike flows are in line with previous findings in the literature but not all of them. Winters et al. [45] also develop a regression model relating bicycle mode share to an aggregate cycling infrastructure index that accounts for both bike infrastructure and its degree of separation in 24 cities in the USA and Canada, and they found that this index is positively correlated with bicycle usage. However, while all studies reviewed in this paper agree on the importance of bike infrastructure, only some of them underline the central importance of separation from the motorized traffic. Dill [19] found that in Portland, USA, bike networks on secondary roads may be more effective than those on main high-traffic roads, as cyclists prefer avoiding motorized traffic. Hood et al. [21] also found in San Francisco, USA, that users have a preference for separated infrastructure. On the other hand, a study in Zurich, Switzerland, by Menghini et al. [20] found that cycling was mainly influenced by trip distance and the maximum road gradient, and the influence of separated infrastructure was only minor. Our results are perfectly in line with former findings and studies in the city of Bologna from Rupi et al. [24–26]. Bologna has a user base that is clearly in strong favor of separated bike infrastructure and tries to avoid trafficked roads even at the cost of long detours, as highlighted in previous studies.

There might also be other causes generating these results. One possibility is that the COVID-19 pandemic and the relative routine changes impacted travel behaviors in the medium to long term, for example, through an increase in remote working that reduced commuting demand or through changes in the perceived attractiveness of public transport and car use. Fluctuations in fuel prices and broader macro-economic conditions may also have affected mode choice. Weather clearly influences cycling flows, but in our case, this effect is partly mitigated by the counting protocol, which restricts observations to non-rainy days within the same September–October window of each year. Another possibility is that some of the newly built infrastructure outside the main monitored corridors may have diverted flows towards areas not fully captured by our counting locations, even though the measuring spots were carefully chosen to intercept the main radial routes to and from the city center. These potential factors cannot be fully disentangled with the available data, and they constitute an important limitation of the study. Nevertheless, the combination of a long, consistently collected time series provides strong evidence that the large-scale expansion of separated cycling infrastructure has been accompanied by a substantial increase in bicycle flows, whereas the more recent emphasis on on-road mixed-traffic lanes has been associated with a much weaker marginal effect.

5. Conclusions

This study provided a regression analysis based on the longest time series in Italy known to the authors, and it concludes that separated bike paths offer 3 times as much cycling attractivity than bike lanes.

While there might be possible secondary effects that partially bias our results, the change in trend is too sudden and precisely timed with the change in infrastructure-building policy for the authors to discard the decrease in safety standards as the main driver of the phenomenon, especially considering the extensive body of literature documenting

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the strong positive effect of separated bike infrastructure. Future research could extend this work through broader comparative analyses using similar metrics across Italian, European, and global cities. The main challenge will be gathering the long time series of bicycle flows, although estimates may be derived from mobility reports and smaller counting campaigns stored in municipal databases. Such comparisons could inform policy by highlighting how outcomes vary with context, planning approaches, and local culture. Moreover, the regression analysis shown in this study would greatly benefit from considering new parameters controlling socio-economic variables like car ownership or household income, but to carry this out, more years of observation are needed, especially as there are only 5 years of data that comprise the new bike lanes. Also, stated preference surveys could help confirm or contradict our thesis on perceived safety and gender-related issues.

Building on the existing literature and our findings, we recommend maintaining a strong focus on separated cycling infrastructure. Budget constraints may limit the total kilometers delivered, yet separated facilities offer a more robust long-term strategy, as they attract more trips per kilometer and are more likely to support gender equity by appealing to both male and female users. We do not argue against on-road lanes in all circumstances, since, in some contexts, they may be the only viable or economically sustainable option, and they still provide usable space for cyclists. However, given their proximity to motorized traffic, their design must be carefully studied to mitigate safety risks.

Fostering bike mobility is to provide safe and comfortable infrastructure for users. Bike mobility is not merely a matter of how much you build; it is about how you build it.

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