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What drives the gender-cycling-gap? Census analysis from Ireland

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ABSTRACT

Cycling rates have been increasing in Ireland over the last ten years, but there is a large difference in male and female participation – only about a quarter of cyclists on Irish roads are female. This paper combines the latest census data with geospatial cycle lane data to explore the drivers of the *gender-cycling-gap* across 238 electoral districts in Dublin, Ireland. Our core hypothesis is motivated by previous literature which suggests that differences in female risk aversion could partly explain the gap. To test this hypothesis, we explore if areas with safer cycling routes to the city centre have relatively stronger effects for females, controlling for a range of area geographic and demographic factors. Both male and female bicycle participation is negatively correlated with an area's distance to the city, share of apartments and average income, and positively correlated with education. Comparing results across genders shows that the gender-cycling-gap is due to relatively larger negative effects for distance, income and apartments for females, which is partly offset by stronger positive education effects. Routes with very high shares of separated or off-road lanes (top quartile) have significantly higher cycling rates. This effect, although stronger for females, is not statistically different across genders. We highlight a number of gender-based policy recommendations related to cycling infrastructure, bicycle storage and bicycle supports (electric bicycles).

1. Introduction

The transport sector accounts for about 25% of the EU's greenhouse gas emissions (Eurostat, 2019), most of which is attributable to road transportation. In Ireland, the latest census figures from 2016 (CSO, 2018) show that 59% of Irish employees commute to work by car, with a higher dependence for females (65%) than for males (53%). Ambitious EU climate targets will require a faster transition towards more sustainable mobility practices, including walking, cycling and public transport.

While cycling participation rates in Ireland have been increasing since 2006 (Fig. 1), they are considerably lower than the mid 1980's.[1] Furthermore, the gender balance of cyclists has changed significantly – in 1986, female participation was higher than male (6.1% versus 5.4%). By 2016, just 1.7% of females cycled to work (versus 3.9% for males), and current rates are considerably below national 2020 targets of 10% (Department Of Transport, 2009). Within the Dublin region (the focus of this paper), cycling is more prominent (7.6% overall), but females are again underrepresented and account for about a quarter of cyclists on the roads (CSO, 2018c). This underrepresentation of females is common in many countries with low overall cycling rates, such as the US, UK, New Zealand and Australia (Winters and Zanotto, 2017).

Our area of focus – Dublin, Ireland – has an extensive bicycle network, with lanes of varying quality distributed throughout the four local administrative authority areas. While much of this infrastructure has been constructed within the last ten to fifteen years, the quality of bicycle lanes varies considerably across the region. Significant gaps in the network, lack of continuity, loss of priority to other modes of transport at junctions, and insufficient lane widths that make overtaking difficult, have all been identified as factors that may impact the quality of the user's experience (National Transport Authority, 2013).

This paper follows calls for more targeted efforts to increase female cycling rates in Ireland (Caulfield, 2014). We examine the factors that impact both female and male cycling participation and contribute to a better understanding of the *gender-cycling-gap*. Following much of the literature, our analysis focuses on the effect of improved cycling infrastructure, controlling for a large range of structural, geospatial and demographic factors. Our core hypothesis is motivated by a common

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[1] Growth since 2006 occurred during a period of policy change, most notably, a bicycle sharing scheme in major cities and bicycle cost reductions facilitated through tax rebates for employees.

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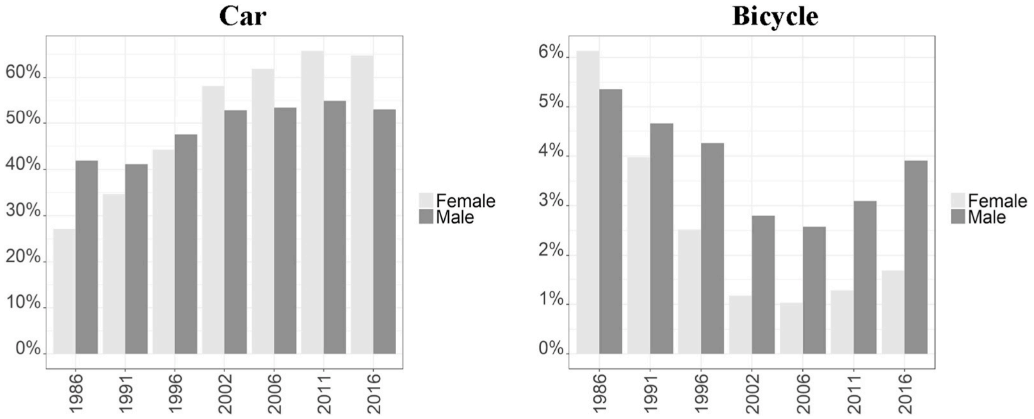

Fig. 1. Commuter car and cycling shares, by year and gender.
Source: Authors' calculation based on Central Statistics Office census data (downloadable from www.cso.ie)
Notes: Data are based on population aged 15 and over usually resident in the State at each census.

theoretical assumption and empirical finding in previous literature – that differences in female risk aversion likely explain part of this difference in male and female participation rates.

To our knowledge, this is only the second paper to combine census data with cycling infrastructural network data (the first being Pistoll and Goodman (2014)). However, our analysis controls for a wider range of potential determinants which are motivated by prior stated preference (survey) findings. We show that both male and female bicycle participation is negatively correlated with an area's distance to the city, share of apartments and average income, and positively correlated with education. Comparing results across genders shows that the gender-cycling-gap is due to relatively larger negative distance, income and apartment effects for females, which is partly offset by stronger positive education effects. While the effects of infrastructure are stronger for females, this difference is not statistically significant.

The paper is structured as follows: Section 2 discusses the main findings from previous literature; Section 3 presents the methods and datasets, with a particular focus on the quantification of cycling infrastructure; Section 4 presents the results; Sections 5 discusses policy implications.

2. Literature review

The provision of safe bicycle infrastructure (safer or separated bicycle lanes), given that it is within the policymaker's toolkit, has received considerable attention in the literature. For example, infrastructural improvements are shown to be a key driver of cycling growth rates in the US, Canada (Pucher et al., 2011) and Australia (Pistoll and Goodman, 2014). However, this infrastructural pull-factor is not always persuasive. A recent paper by Song et al. (2017) for the UK found no relationship between an individual's physical proximity to bicycle infrastructure and participation.

Prior research also shows clear gender differences in this relationship, with safer infrastructure being more important for females. This has been attributed to higher levels of female risk aversion (Garrard, 2003) and to lower levels of bicycle confidence (Garrard et al., 2006). Horton (2016) describes this relationship in terms of 'fear', not just in terms of physical injury, but includes the fear of being 'on view', of appearing 'inept', and of physical exertion.

Stated preference analysis (surveys, interviews and focus groups) generally support such a hypothesis. In the US, females are more likely (than males) to accept longer routes in exchange for higher safety levels (Krizek et al., 2005), while in Australia, females are more likely to use safe off-road paths (Heesch et al., 2012). Similar findings are found in China (Lusk et al., 2014). Findings from revealed preference studies (based on count data) are, however, more mixed, with Garrard et al. (2008) showing that females prefer safer off-road paths in Australia, but Winters and Zanotto (2017) showing no increase in the female participation during a period of expanded and upgraded cycling routes in Canada.

Gender differences are also evident in the how the built environment affects bicycle participation. Factors which reduce journey distance, such as high density development and road networks, are particularly important for overall participation (Howard and Burns, 2001; Sener et al., 2009; Heinen et al., 2010) and such factors are considered particularly important for females (Pistoll and Goodman, 2014). Furthermore, infrastructure which supports cycling, such as parking sheds, bike signals, and public bicycles, are also considered more important to females (Lusk et al., 2014). Prior research also shows that bicycle-compatible workplaces, which include showers, changings facilities and lockers, encourage more people to choose to cycle (Heinen et al., 2010), although these results are not differentiated by gender.

3. Data and methods

3.1. Datasets and study area

This paper builds upon prior studies which explore the gender effects of cycling infrastructure. We combine commuting data from the Irish national census of 2016 (CSO, 2018) with a cycling network survey for Dublin in 2013 (National Transport Authority, 2018). Our unit of observation is the electoral district (ED) and our primary variable of interest is the percentage of adults aged 18–64 years that cycle to work by gender (termed the "*cycling share*" below).

Our cycling infrastructure variable explores lane coverage on routes between each ED and the city centre. Since our aggregate data do not contain exact start and finish points, an ED's cycling route is defined according to the shortest distance between ED boundary and city centre boundary, the latter defined as an area within 2 km around a central point (Dublin's "Spire").[2] An upper bound of 15 km was also applied as we consider this a reasonable cut-off point for maximum travel distance for the typical cycling commuter. After these exclusions, the final sample contains 238 EDs. This area contains 730,232 individuals aged 18 years and over, representing about a fifth of the national population within this age range.

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[2] This implies that the starting points are often located on the borders of the ED. The algorithm will be described in greater detail in the following section.

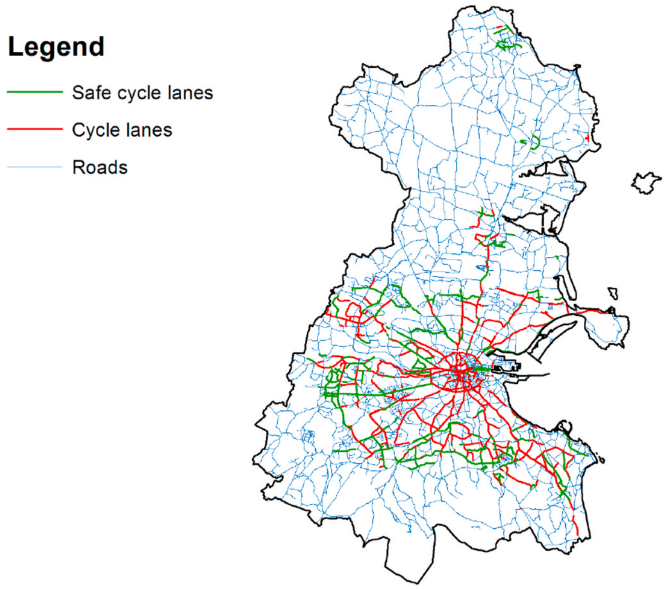

Fig. 2. Roads and bicycle lanes in Co. Dublin.
Source: Own calculations (ArcGis) using Open Street Map and the Dublin 2013 cycling network survey (National Transport Authority, 2018).

3.2. Cycling safety variable

Our safety variable is constructed in *ArcGIS* using a two-step procedure using geospatial data for the main road network (sourced from *Open Street Map*) and for cycle lanes (sourced from the cycling network survey for Dublin in 2013). For each ED, we first generate the most plausible route to the city centre using an algorithm that minimises travel time on the existing road and cycling network. The safety of this route is then defined as the share of route which is covered by bicycle lanes. Since we aim to estimate the most plausible route for cyclists, we exclude footpaths, pedestrian roads and motorways. Additionally, as we are interested in trips between the ED and city centre boundaries only, we exclude residential roads which we assume are used to move within EDs.

Once the most plausible cycling route is established for each of the ED, we compute two safety variables. The first one ('*Lane Coverage*' below), is simply defined as the share of the route for which *any* type of cycling lane is available. The second one ('*Safe Lane Coverage*'), is instead computed as the share of the trip on separated lanes, which are either completely off-road or separated from traffic by a traffic island (see Fig. 2).[3] Overall, around one third of the entire cycling network is labelled as "safe" following this rule.

To find the most plausible route between each ED and the city centre, we take into account two main factors: the estimated time it would take to cover the trip, and the quality of the cycling facilities available. More specifically, we divide the area into cells of ten square metres and assign each a 'speed' based on whether a road is available or not, and according to the type of cycling facilities. The *ArcGIS* algorithm ('cost distance') is then used to compute the quickest route between ED boundary and city centre boundary. We assign a speed of 20 km/h to the cells with a "safe" bicycle lane, 17.5 km/h to a regular bicycle lane, 15 km/h to the cells with a road but without bicycle lane and 4 km/h to those without any road. It is worth pointing out that these differences in speed are only meant to nudge the algorithm towards safer routes (reflecting the fact that cyclists are naturally drawn towards safer routes) as opposed to describing actual lower travel times when traveling on roads with safer cycling facilities. The values chosen are largely arbitrary, but the results do not change significantly when introducing more pronounced incentives for safe routes or without any incentive whatsoever. Fig. 3 displays the estimated travel time to the city centre for each cell and Fig. 4 displays the final routes between each ED and the city with and without incentives (i.e. different speeds for different cycling facilities). It can be seen that, with some minor exceptions, the preferred routes are generally not affected by the introduction of the speed corrections.

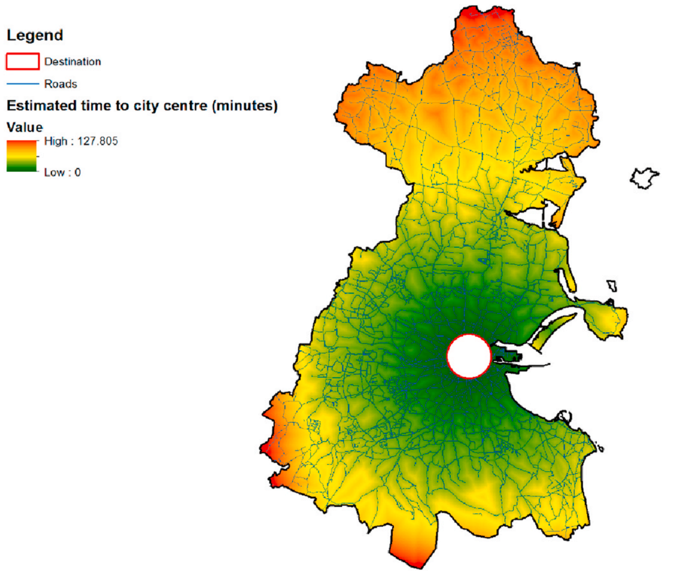

Fig. 3. Ed to city centre travel times (estimated).
Notes: Travel times are computed using the ArcGIS built-in command 'cost distance' and applying the speed corrections for safer cycle lanes.
Source: Own calculations (ArcGis) using Open Street Map and the Dublin 2013 cycling network survey (National Transport Authority, 2018).

Subsequently, we measure the ED specific safety variables as the percentage of the most plausible route that is covered by *any* cycle lane ('*Lane coverage*') or by a safe cycle lane ('*Safe Lane Coverage*'). The results presented in the following section are based on the routes obtaining by applying this technique (red routes in Fig. 4), but are robust on a number of different specifications (among which are a complete removal of the incentives towards safer roads).

3.3. Descriptive statistics for regression variables

Fig. 5 provides an outline of the geographic distribution of cycling by gender throughout the Dublin region (females on left panel, and males on right). As these figures use the same colour coding and scaling, it is possible to make a direct comparison between the distribution of cycling shares within the male and female commuting populations. It is clear that the modal share of cycling is both smaller and more geographically concentrated for females compared to males, with female rates of cycling declining sharply as distance from the city centre increase.

Other independent variables for the models are created using census data. Previous literature has outlined a number of factors which are correlated with the decision to cycle, including availability of bicycle storage/parking facilities (Lusk et al., 2014; Heinen et al., 2010; Nkurunziza et al., 2012), education (Avila-Palencia et al., 2017), and distance (Garrard et al., 2006).[4] While we do not have data on storage facilities,

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[3] In some instances, cycle lanes are only available (or are of one of the "safe" type) in one direction only. In these cases, since we are assuming that the same route is taken to move to and from the city centre, we will always consider the best facility available in either direction (this applies to both the existence of a cycle lane and the quality of the cycle lane).

[4] The distance variable employed in the analysis is the distance between ED and city centre boundary on the preferred (fastest) route, as described in Section 3.2.

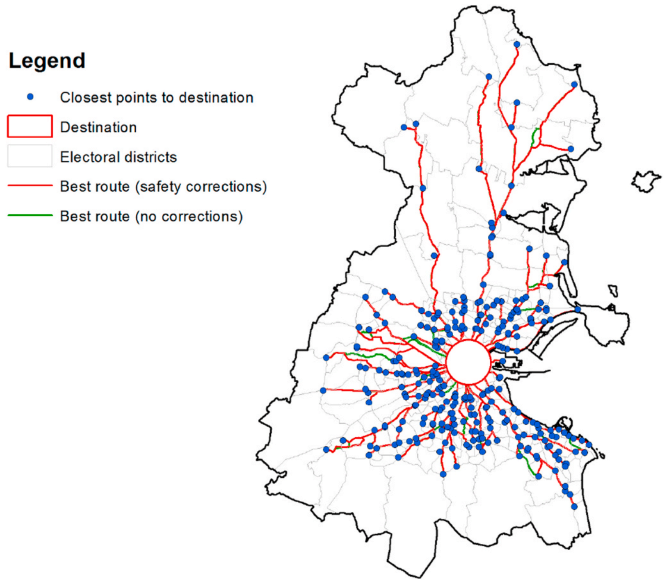

Fig. 4. Ed to city centre routes (estimated).
Notes: The best paths are computed using the ArcGIS built-in command 'cost path'. The starting points are the ones presenting the lowest travel time to the city centre for each of the ED.
Source: Own calculations (ArcGis) using Open Street Map and the Dublin 2013 cycling network survey (National Transport Authority, 2018).

we proxy this variable by including an ED's share of apartments, which in Ireland, often do not include secure, communal bicycle storage, and we expect that the inconvenience associated with transporting a bicycle from the building entrance to the individual's apartment may be high (higher for females according to prior research). For education, we include the ED's share of individuals with a higher level degree or above. We also control for household income (ED mean) and age (ED shares in each age cohort).

Table 1 presents descriptive statistics for all variables employed. Overall, about 7% of sample commuters cycle to work, with rates of 10% for males and 4% for females. However, cycling growth between 2011 and 2016 has higher for females – 55% compared to 31%. There are considerable differences in our route safety variables. *Lane Coverage* (any lane types) is generally very high with an average coverage on an ED route of 73%. However, *Safe Lane Coverage* is considerably lower at 17%.

4. Results

We employ a standard Ordinary Least Squares (OLS) regression model to explore the relationship between ED route safety and cycling participation. The models in Table 2 differ only in terms of the cycle route safety variable: Model 1 explores the effects of all cycling lanes ('*Lane Coverage*') while Model 2 explores safer lanes only ('*Safe Lane Coverage*'). In all cycling share models, we divide the dependent variable by the sample mean to facilitate direct cross-model comparisons of effect size. All regressions are weighted by ED population.

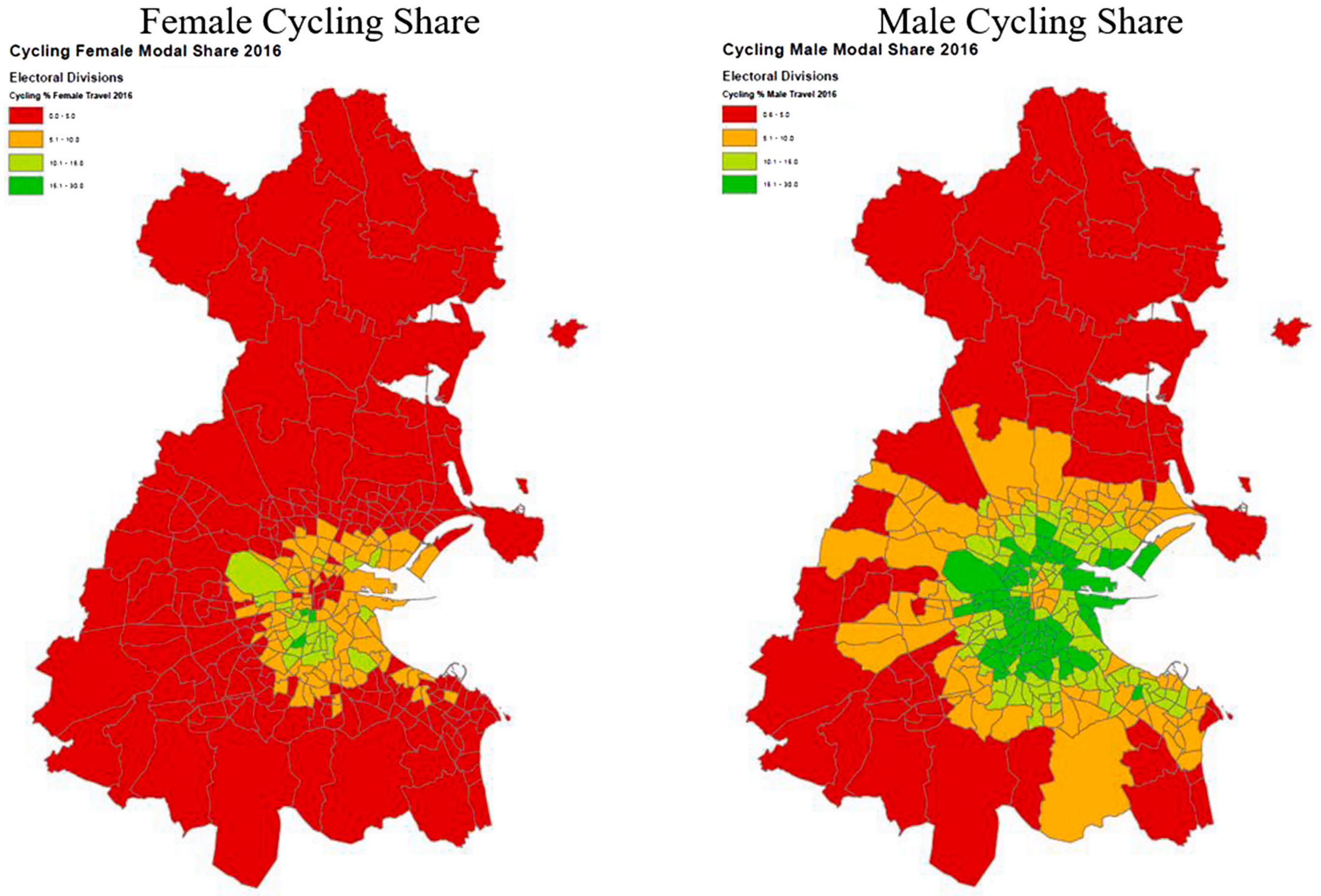

Fig. 5. Dublin cycling share in 2016, by electoral district and gender.
Source: own calculations using 2016 census data (Irish Central Statistics Office)

Table 1
Descriptive statistics for regression sample (N = 238).

	Mean	Standard Deviation	Minimum	Maximum
Cycling Share (%)	7.2%	3.9%	1.2%	21.9%
Female Cycling Share (%)	4.1%	3.2%	0.2%	17.2%
Male Cycling Share (%)	10.0%	4.8%	2.1%	26.8%
Cycling Growth 2011–2016 (%)	32.9%	22.0%	−16.9%	151.2%
Female Cycling Growth 2011–2016 (%)	54.7%	93.8%	−70.6%	1004.3%
Male Cycling Growth 2011–2016 (%)	31.2%	23.1%	−27.6%	102.3%
Lane Coverage (%)	72.6%	23.2%	0.0%	100.0%
Safe Lane Coverage (%)	17.2%	22.6%	0.0%	95.2%
Income (€ 000's)	57.2	16.0	29.0	105.9
Distance to City Centre (km)	7.3	2.9	2.3	14.0
Higher Education Share (%)	28.2%	16.5%	1.9%	63.2%
Apartment Share (%)	17.6%	16.7%	0.0%	97.1%
Age 18–29 Years (%)	23.4%	6.1%	13.0%	76.6%
Age 30–34 Years (%)	28.5%	7.6%	6.9%	58.3%
Age 45–64 Years (%)	29.9%	5.9%	8.9%	45.3%
Age 65+ Years (%)	18.2%	8.1%	1.8%	45.5%

Source: own calculations using 2011 and 2016 census data (Irish Central Statistics Office) and cycle lane network (National Transport Authority, 2018).
Notes: unit of observation is the electoral district (238 observations). Regression sample consists of electoral districts between two and 10 km of city centre.

Table 2
Cycling share regressions (OLS) - ED cycling share.

	Model 1:All Lanes	Model 2: Safe Lanes
Lane Coverage - 1st Quartile (reference group)		
Lane Coverage - 2nd Quartile	0.060	−0.010
	(0.042)	(0.050)
Lane Coverage - 3rd Quartile	0.044	0.009
	(0.038)	(0.038)
Lane Coverage - 4th Quartile	0.063	0.088**
	(0.041)	(0.038)
Income (€ 000's)	−0.026***	−0.026***
	(0.002)	(0.002)
Distance to City Centre (km)	−0.108***	−0.103***
	(0.006)	(0.006)
Higher Education Share (%)	0.038***	0.038***
	(0.002)	(0.002)
Apartment Share (%)	−0.006***	−0.006***
	(0.001)	(0.001)
Age 18–29 Years (%) (reference group)		
Age 30–34 Years (%)	0.011***	0.009**
	(0.004)	(0.004)
Age 45–64 Years (%)	0.011**	0.008*
	(0.005)	(0.005)
Age 65+ Years (%)	0.005	0.004
	(0.003)	(0.003)
Constant	1.532***	1.645***
	(0.256)	(0.251)
Observations (Electoral Districts)	238	238
Adjusted R-squared	0.850	0.852
F statistic	135.370	137.794

Source: own calculations using 2016 census data (Irish Central Statistics Office) and cycle lane network (National Transport Authority, 2018).
Notes: ***, ** and * indicate significance at 1%, 5% and 10% level. Standard errors in parenthesis. Regression weighted by electoral district population. Dependent variable (cycling share) divided by sample mean.

R-squared values of 85% imply that this set of independent variables explain a large proportion of an ED's cycling share. In terms of non-core (i.e. non-safety) variables, most are statistically significant (at the 1% level) and are of the expected sign. For example, ED cycling shares are low in areas with lower education, more apartments, higher income, and further from the city centre. The magnitudes of these effects are extremely large. For example, the "cost" of longer distances (time and effort) appears to be particularly prevalent, and each kilometre increase in distance from the city centre is associated with at 10% decline in the mean cycling share (percentage change in the mean cycling share). This strong distance finding supports our directionality assumption (that commuters mainly travel from ED to city).

In terms of education, for each percentage point increase in the share of highly educated individuals (higher degree or above), cycling shares increase by almost 4%. Consistent with the apartment "hassle" theory, we observe the expected negative correlation, with overall cycling shares declining by 0.6% for each percentage point increase in ED apartment share. For income, a thousand euro increase in mean income (controlling for other factors) is associated with 2.6% decline in cycling shares. Finally, age effects are non-linear – cycling shares are lower in both the youngest (18–29 years) and oldest (65 and over) cohorts.

Lane safety is not an important driver of participation, with one exception. In Model 1 (all bicycle lanes), we find no relationship between route safety and ED cycling participation. However, in Model 2 (safer lanes only), it appears that EDs with very safe lanes (top quartile) have higher participation rates. In this regard, such EDs have cycling shares which are 8.8% higher.

In terms of robustness checks (not shown), we find that the road safety results are left virtually unchanged when we compute them using the routes predicted by the algorithm without speed corrections (i.e. the ones marked in green in Fig. 4). Furthermore, including route safety as a continuous variable rather than categorical, while showing a positive effect, is not generally significant (although significant at the 10% level in the Model 2).

In Table 3, the cycling share of females and males are explored in Model 4 and Model 5, respectively (Model 3 presents the total cycling share again to aid comparison). To test differences in effect size across these model, we appended these two datasets and include a female interaction term for each independent variable – Model 6 presents these interaction effects only (main effects excluded).

Consistent with previous research, longer commuting distances are a stronger deterrent for females: the negative effect of distance is 12.4% for females (Model 4) and 9.7% for males (Model 5), and this difference is statistically significant (i.e. female interaction term in Model 6 is statistically significant). There are other notable significant differences across genders. For example, the negative effect of apartments and income is twice as high for females, as is the positive effect of education. In terms of route safety, we include the significant variable from Table 2, that is, the top quartile within "safe" bicycle lanes. While the coefficient is considerably higher for females (Model 4 versus Model 5), this difference is not statistically significant (Model 6).[5]

Table 4 presents an additional robustness check and explores the effects of ED route safety on cycling share growth between 2011 and 2016 for all cyclists (Model 7), female cyclists (Model 8) and male cyclists (Model 9). Differences in female cycling growth rates, which are high between these years (55% growth), are not explained by route safety (measured in 2013). In fact, the growth cycling is not correlated with any of these variables, which implies that increases were similar across demographics.

5. Discussion

The results describe the role of various geographic, infrastructural, and socio-economic variables for cycling participation. Our core hypothesis builds upon previous research which suggests that lower female cycling participation may be due to higher levels of female risk aversion. While there does not appear to be a continuous relationship between

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[5] Safety results from Table 3 are unaffected by the inclusion of all lane quartiles.

Table 3
Cycling share regressions (OLS) by gender.

	Model 3: Cycling Share	Model 4: Female Cycling Share	Model 5: Male Cycling Share	Model 6: Female Interactions (only)
Safe Lane Coverage - 4th Quartile	0.087**	0.144***	0.064**	0.080
	(0.034)	(0.053)	(0.032)	(0.062)
Income (€ 000's)	−0.026***	−0.038***	−0.022***	−0.015***
	(0.002)	(0.004)	(0.002)	(0.004)
Distance to City Centre (km)	−0.104***	−0.124***	−0.097***	−0.026**
	(0.006)	(0.009)	(0.005)	(0.010)
Higher Education Share (%)	0.038***	0.059***	0.031***	0.027***
	(0.002)	(0.004)	(0.002)	(0.004)
Apartment Share (%)	−0.006***	−0.010***	−0.005***	−0.005**
	(0.001)	(0.002)	(0.001)	(0.002)
Age 18–29 Years (%) (reference group)	–	–	–	–
	–	–	–	–
Age 30–34 Years (%)	0.009**	0.009	0.010***	−0.000
	(0.004)	(0.006)	(0.003)	(0.007)
Age 45–64 Years (%)	0.009*	0.003	0.011**	−0.008
	(0.005)	(0.007)	(0.004)	(0.009)
Age 65+ Years (%)	0.004	0.000	0.006**	−0.006
	(0.003)	(0.005)	(0.003)	(0.005)
Constant	1.634***	2.152***	1.438***	1.438***
	(0.247)	(0.384)	(0.230)	(0.317)
Observations (Electoral Districts)	238	238	238	476
Adjusted R-squared	0.854	0.817	0.839	0.823
F-statistic	173.633	132.925	155.440	130.815

Source: own calculations using 2016 census data and cycle lane network (National Transport Authority, 2018).
Notes: ***, ** and * indicate significance at 1%, 5% and 10% level. Standard errors in parenthesis. Regression weighted by electoral district population. Dependent variable (cycling share) divided by sample mean.

Table 4
Cycling growth regressions (OLS) by gender.

	Model 7: Cycling Growth	Model 8: Female Cycling Growth	Model 9: Male Cycling Growth
Lane Coverage (safe) - 4th Quartile	−2.194	−11.088	−2.151
	(3.330)	(12.601)	(3.426)
Income (€ 000's)	−0.044	0.630	−0.050
	(0.219)	(0.829)	(0.225)
Distance to City Centre (km)	0.017	−0.199	0.525
	(0.558)	(2.112)	(0.574)
Higher Education Share (%)	0.034	−1.574*	0.153
	(0.218)	(0.827)	(0.225)
Apartment Share (%)	0.081	0.144	0.066
	(0.120)	(0.454)	(0.123)
Age 18–29 Years (%) (reference group)	–	–	–
	–	–	–
Age 30–34 Years (%)	0.350	−1.055	0.425
	(0.362)	(1.373)	(0.372)
Age 45–64 Years (%)	0.125	−1.532	0.229
	(0.455)	(1.724)	(0.469)
Age 65+ Years (%)	0.783***	0.803	0.875***
	(0.284)	(1.078)	(0.293)
Constant	5.209	125.643	−10.115
	(23.987)	(90.942)	(24.680)
Observations (Electoral Districts)	238	238	238
Adjusted R-squared	0.015	0.017	0.030
F	1.457	1.523	1.910

Source: own calculations using 2011 and 2016 census data and cycle lane network (National Transport Authority, 2018).
Notes: ***, ** and * indicate significance at 1%, 5% and 10% level. Growth is defined in the percentage change in the cycling share between both years. Standard errors in parenthesis. Regression weighted by electoral district population.

participation and route safety, results suggest that there may be a tipping point – areas with extremely safe (top quartile) routes to the city have higher cycling rates. However, and importantly, this relationship is common to both genders. We note that this result may not be causal – it is possible that areas with strong cycling communities have campaigned for better lane coverage in their areas.

Our weak safety findings, regardless of gender, may be due to the lack of consistent point-to-point cycling infrastructure in Dublin. Furthermore, while the number of cycling lanes in Dublin is increasing, most routes throughout the city have less than complete coverage – it may be the case that cycling infrastructure must reach a critical lower-bound "tipping point" before participation rates significantly increase. This hypothesis is supported by previous research (Sener et al., 2009). In short, the severe infrastructural deficiencies in our chosen area of analysis (Dublin) may imply that our infrastructural results are not externally valid. This possibility is, we believe, a strong motivation for future studies to replicate our methods in areas where infrastructure levels are higher.

With regard to distance, both the descriptive statistics and the regression models show that this is a key participation driver, particularly for females. This result suggests that females have a reduced cycling range for commuter trips compared to males. In this regard, policies which could reduce distance would likely be beneficial for both genders, but particularly so for females. For example, electric bicycles reduce the effort involved in commuting by bicycle and could be further incentivised through policy amendments (higher tax breaks combined with subsidies).

The stronger distance effects for females could be due to differences in workplace expectations regarding personal appearance (Peluchette et al., 2006; Peluchette and Karl, 2007; Gurung et al., 2018). The higher (negative) income effects for females may also be linked to this finding, if such workplace expectations rise with seniority. For example, it may be the case that the lack of workplace changing and showering facilities in Ireland is the underlying driver of gender differences in the distance results. Such facilities, which include showers, storage and lockers, have been shown to be very important in cycling participation in many countries (Garrard et al., 2006; Heinen et al., 2010) and can be improved through changes in building and employment regulations. Furthermore, the distance effect may be partly driven by household compositional factors (correlated with distance). For example, it is possible that households located further from the city centre have younger children, and that the caring for such dependents is less compatible with cycling. If this is the case, the positive effects of electric bicycle provision would be lower than expected. Such confounding factors (household composition and workplace issues) are both interesting areas for future research.

We also find that areas with higher shares of apartments have lower cycling shares, and this effect is twice as large for females. Our proposed mechanism for this relationship is that there is a personal, non-monetary cost relating to storing a bicycle in an apartment block that has no communal bicycle facilities (the physical exertion associated with bringing a bicycle from the apartment block entry point to the individual's apartment). If this hypothesis is correct, our results imply that this cost is higher for females. The policy response would be to ensure that all apartment blocks have a convenient, safe and street-level location for tenants to keep their bicycles. Therefore, while high density land use is generally deemed necessary for lower carbon living, such developments must explicitly account for low-carbon modes of transportation during design and planning to ensure that there are no unintended consequences.

In terms of caveats, our novel route safety classification method should be considered a proxy – measures based on aggregated units clearly ignore exact departure and destination points and are likely to be noisy. However, focusing only on routes which join electoral district boundaries to the city boundary should help to reduce this uncertainty at the start and end of journeys. Furthermore, the strong and significant effects of distance (to the city centre) supports our directionality assumption. Future research would certainty improve on our measures by using more precise point-to-point data, such as GPS data from mobile phones.

6. Conclusions

This paper explores the drivers of *the gender-cycling-gap*. While our motivation was to find differential gender effects for route safety in an attempt to isolate a higher hypothesised level of female risk-aversion, we generally find that cycle lane coverage has no effect on either gender. However, there is one exception to this – areas with high coverage of very safe lane (off-road, for example) have higher participation. This effect is statistically identical across genders.

Therefore, it appears that the main drivers of the gap are differences in geographic and demographic effects. For example, females appear to be more sensitive to distance than males, and the issue of range within the female population may be acting as a barrier to large-scale adoption of cycling. We also find that the negative effects of apartments and income are particularly evident for females. Education also shows very different gender effects, and is considerably stronger (positively) for women. Future stated preference and qualitative analysis would help to confirm the mechanisms which underpin these correlations.

From a policy perspective, we have highlighted the promotion of electric bicycles to reduce "distance" for females. Furthermore, the provision of secure communal bicycle facilities in all apartment blocks may increase the female cycling share. While not formally tested, the findings for distance and income might be related to workplace expectations imposed on females, which could be less acute for men. The provision of changing facilities in workplaces could help alleviate this problem, if this is indeed the underlying mechanism.

CRediT authorship contribution statement

James Carroll: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Supervision. **William Brazil:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **Bruno Morando:** Methodology, Investigation, Formal analysis. **Eleanor Denny:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2020.07.007.

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