CRIME HIGHWAYS: THE EFFECT OF MOTORWAY EXPANSION ON BURGLARY RATES

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ABSTRACT

Burglars can exploit a high-quality road network to transport stolen goods quickly. To study the effect of motorway connections on burglary rates, spatial variation in connectivity to the motorway network and the timing of new connections are exploited using an annual panel of 562 policing sub districts in Ireland during 2004-15. On average, burglary rates rise by 10% in the year of motorway connection. This paper shows for the first time that major road construction affects the spatial distribution of crime.

JEL Codes: H54; K42; R12; R42. Keywords: crime; transport infrastructure; spatial analysis.

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1. INTRODUCTION

Transport infrastructure is an integral component of the production and consumption process because it helps goods move between locations. The transfer of goods is also required in criminal activity, such as the transfer of stolen goods to the market where they are traded for cash. There is a large literature that documents how transport infrastructure reduces trade costs and shapes economic outcomes, such as urban growth, trade flows and land values (Atack et al., 2010; Donaldson and Hornbeck, 2016 and Michaels, 2008). However, little is known about the effect of new transport infrastructure on illegal activity, such as crime.

This paper attempts to fill this gap by investigating the causal effect of new motorways on crime. This paper focuses on the construction of the Irish motorway network and the impact on burglaries. Motorways are the highest standard of road in Ireland, providing high speeds (120 km/h), free flowing traffic and connections between major cities and towns. Analysis from the Irish police service details how specialized burglary gangs have been exploiting the motorways connectivity to burgle rural targets while evading police detection (An Garda Síochána, 2015).

Identification is achieved through exploiting the combination of the spatial variation in motorway connectivity, the timing of new connections and the inclusion of geographically detailed fixed effects. In the analysis, connection to the motorway network is captured by measuring the first motorway junction to be placed within a ≤50 km radius of a Sub District. Vice versa, disconnection occurs when there is no motorway junction nearby. To note, all motorways in Ireland, except one, connect to the capital city of Dublin and therefore connection to the motorway network intrinsically measures connection to Dublin City. Arguably this is important because Dublin is presumably where the majority of the trade in stolen goods takes place.

This paper finds that the average Sub District experiences a 10% rise in the burglary rate (or equivalently, 5 burglaries) in the same year a motorway is placed within 30 km. A larger effect may be expected, however, the result is intuitive as presumably burglars seeking to evade police attention will disperse the location of their crimes. Furthermore, the rise in burglaries is found to be temporary, as burglary rates spike in the year of motorway connection and plateau thereafter. The immediate response of burglars to motorway expansions is a curious result. A possible explanation is that the probability of being caught by the police is lowest in areas recently connected to the motorway network, because motorway-related burglaries have not yet happened and so police vigilance has not been initiated. Furthermore, even if the police are alerted, it will take time for policing action to be organized and implemented. Criminals may exploit their ability to react quicker to insufficient policing, in comparison to that of the police force. Indeed, results hold when Dublin and its surrounding counties are excluded from the analysis, and this is where the majority of policing resources are concentrated.[1]

Another important aspect to the rise in burglaries is whether motorway expansion increases the amount of burglary activity in the economy or whether it relocates existing burglaries (Chandra and Thompson, 2000). No formal test is conducted, but it is hypothesized that motorways are the artery to attractive crime locations, rather than increasing the stock of burglaries nationwide. Among other reasons, the biggest indication of reorganization is that the number of burglaries in Ireland remains relatively steady between years (Figure 2), despite vast motorway growth. It is roughly estimated that 490 burglaries were displaced during motorway expansion.

The novelty of this paper is to show that major road construction influences the spatial

[1] There is no available data on policing numbers but there are accusations of bias towards the Irish Government because of 'Dublin-centric' policing e.g. rural burglars appear to receive lighter jail sentences, see https://bit.ly/2U5Umjr, and https://bit.ly/3aUAu8X

distribution of crime. This paper details how the spatial distribution of burglaries is influenced by motorway expansion as motorways reduce a burglar's escape time. The primary contribution of this paper is to the economic geography literature. Specifically, it contributes a new economic outcome to the literature on the economic effects of transport construction, as this is the first paper to causally identify the effect of road construction on crime.

There is a large literature that focuses on understanding the way that transportation infrastructure reduces trade costs and how this affects economic activity (e.g. Garcia-López et al., 2017; Li and Xu, 2018). The empirical literature provides causal estimates on the effect of roads, railroads and subways on a range of economic outcomes. Donaldson and Hornbeck (2016) use a historical sample of U.S counties and find that counties that receive rail access in a year experience an increase in agricultural land rent. While Faber (2014) finds that industrial GDP, total GDP and government revenue decrease with proximity to the Chinese highway network. The trade literature has generally focused on the transportation of goods, but other studies find transport costs are important in the movement of people. For example, Duranton and Turner (2011) find that an approximate 1% increase in the stock of roadways increases driving by 1%.

The second contribution of this paper is to the economics and crime literature, through showing that high-quality road networks influence local crime rates. The economics of crime literature documents how the geography of crime differs depending on crime type (Cracolici and Uberti, 2009; Fabricant, 1979; Glaeser and Sacerdote, 1999). The decision to commit a burglary or theft in an area is argued to depend on the tradeoff between the probability of arrest and the possible stolen goods there (Deutsch, Hakim, and Weinblatt 1987; Deutsch and Epstein 1998). There is an abundance of criminological research showing that environmental features, such as the layout of the road network, are predictive of crime because they influence how criminals are able to move around and thus influence their likelihood of being detected (Brantingham and

Brantingham, 1981; Davies and Johnson, 2015).

There is a small and growing literature on the relationship between major transportations routes and criminal activity. Crime rates surrounding the Interstate Highways in the U.S exhibit a positive relationship with the presence of an interstate exit, with burglaries and robberies higher near the interstate (McCutcheon et al., 2015; Jarrell and Howsen, 1990; Rephann, 1999). Rephann (1999) finds that the likelihood of being targeted by criminals is higher in rural U.S counties connected to an interstate highway, relative to rural counties with no interstate. Vandeviver et al. (2015) studies the border region between France and the Netherlands, and finds that journey-to-crimes distances increase when burglaries are committed in communities near a motorway. Similarly, Van Daele and Beken (2011) find that crime sprees outside of cities in Belgium tend to take place near motorways.

This paper also relates to the crime literature on temporary hot spots, as the findings show that burglary rises temporarily after motorway expansion. In this literature, the temporal nature of crime has been relatively neglected in contrast to the attention given to spatial perspectives (Townsley, 2008). A number of recent studies focus on the spatio-temporal variation in crime patterns. For example, Herrmann (2015) conducts a temporal analysis of violent crimes in New York City and finds that hot spots shift by hour of day and day of week. In the context of this paper, it is very likely that burglars return to previously targeted areas after a period of time, but the revisitation does not appear to be patterned with the year of motorway connection, making it difficult to quantify. It is for this reason that this paper does not provide an estimation of all motorway-related burglaries and focuses instead on the immediate aftermath of motorway expansion.

It is important to note that although this paper focuses on the role of the motorway network, the results do not preclude the importance of lower level roads. Even when using the motorway to travel between regions, the burglar must interact with lower level roads to travel to targets.[2] Furthermore, the function of motorways in aiding crime cannot reasonably be applied to all burglary crimes, as evidence from Irish Police intelligence indicates that specialized travelling burglary gangs are exploiting the motorway. Data on burglar characteristics is not available which limits an extension of the analysis to burglar characteristics.

Concerns about potential endogeneity are relaxed using detailed robustness checks. The most important robustness check is that the causal effect of motorway connection is unique to burglary, as no effect is found among seven other types of crime including theft and vandalism. This strongly suggests that there is no omitted variable bias present. Conceptually, the uniqueness of the relationship can be explained by the need to quickly transport bulky stolen goods away from a property, either to storage or to the selling market. A potential source of endogeneity is the endogenous placement of motorways, as motorways are generally placed in areas of strong economic growth. However, connections to randomly postponed motorway junctions yield no statistically significant effect on burglary rates. Lastly, the main result is robust to the inclusion of a control variable measuring local economic activity. These three robustness checks combined provide a solid basis to express confidence in the reliability of the results.

For policymakers, the findings identify that there can be local crime externalities generated by major road developments. Policymakers may wish to incorporate the externality into any economic impact assessment for future road infrastructure developments. The main cost is the need for immediate targeted law enforcement on all new major roads, such as police checkpoints at motorway entry and exit points. The results are particularly relevant to prosperous EU member states in Western and Northern Europe e.g. France and Belgium, where the majority of organized

[2] For example, Davies and Johnson (2015) uses street-level data in an English city and finds that burglary risk is larger on busier streets.

property criminals are operating (Europol, 2017). Organized property crimes (thefts, robberies, burglaries, ATM theft and motor vehicle theft) are a relatively new and understudied crime (EU Commission, 2017). Future research may wish to investigate this type of criminal behavior further, such as, other factors determining crime location and the structure of criminal networks.

The remainder of the paper is structured as follows. Section 2 discusses the contextual background of the organized burglaries. Section 3 outlines a simple conceptual framework to guide the empirical analysis. In Section 4, the data sources and the variables used in the empirical analysis are described. The empirical strategy is described in detail in Section 5. In Section 6, the empirical results are explained. Robustness checks are provided in Section 7, while Section 8 concludes.

2. CONTEXT

Organized property crimes carried out by highly specialized and mobile crime groups are one of Europol's priority crime areas under the EU policy cycles of 2014-17 and 2018-21 (EU Commission, 2017).[3] The property crime offences include organized burglaries, thefts, robberies and motor vehicle crimes. Burglary is one of the only crimes in the EU that grew in intensity during 2007 to 2010, rising by approximately 7% in the period (De Stercke et al., 2014). Approximately one burglary is committed every one and half minutes in the European Union (EU), and some member states register one thousand burglaries per day (Europol, 2017).

Illegal activity in the Irish economy is estimated to be 1.1 per cent of GDP, which is more than the Irish Government's annual expenditure on the police service in 2016 (Savona and Riccardi, 2015).[4] This is smaller than the 7 percent of Italian GDP, but it is still one of the highest

[3] Further information on the policy cycles is available at "EU Policy Cycle- EMPACT" available at https://bit.ly/38Pkvr6.
[4] See 'Organised crime in Republic worth at least €1.7bn annually' available at https://bit.ly/2uEriVI.

percentages in the EU (Savona and Riccardi, 2015; UNODC, 2011).[5] Organized crime tends to conjure up imagery of the traditional Mafia-type models such as the Sicilian Mafia (Hess, 1973; Arlacchi, 1986; Gambetta, 1993). However, a recent EU-funded Organised Crime research project shows that removing the prominent Italian criminal networks from the picture, organized crime groups in Europe are largely similar and reflect a new strand of organized criminal activity (Savona and Riccardi, 2015). Criminal organisations are changing and adapting their strategies by shifting their interests to new areas of activity that are less risky and less violent (Savona and Riccardi, 2015).

The Irish police service has reported that specialized burglary gangs are exploiting the motorways connectivity and speed limits to burgle distant targets.[6] For example, after the Gort to Tuam motorway in Western Ireland opened in November 2017, the number of burglaries reportedly doubled in a few days.[7] Figure 1 illustrates that burglary rates are higher in communities closer to the motorway network, relative to more isolated parts of the country. There was virtually no targeted law enforcement against criminals exploiting motorways, until 2016, when a €5 million ($5.7 million) national anti-crime strategy called 'Operation Thor' launched across the country, consisting of high visibility checkpoints near motorways, increased motorway surveillance, covert operations to target known offenders, increased police presence in communities and a national awareness campaign (An Garda Síochána, 2015). Coinciding with the introduction of the policing measures, the number of burglaries dropped nationally by 30% during 2015-16.[8]

[5] The top 7 are Ireland, Spain, France, Italy, Netherlands, Finland, and the United Kingdom.
[6] For example see https://bit.ly/36BbOiz; https://bit.ly/3aWKz5B; https://bit.ly/2O8oHue; https://bit.ly/3aQKu39.
[7] See https://connachttribune.ie/new-motorway-opens-rural-parts-galway-criminals-911/.
[8] As all regions in Ireland received anti-burglary measures, the causal effect of the targeted measures could not be estimated.

Criminals using motorways as an escape route does not appear to be investigated by police services abroad in the same detail as it has been in Ireland, but it has been cited in crime and media reports for several other EU member states, including the United Kingdom and Belgium.[9] The lack of police attention towards motorway burglaries, and organized property crimes more generally, is not necessarily a reflection of a lack of this type of crime in other countries, but possibly due to the classification of individual incidents as petty criminality (EU Commission, 2017).

The Irish police service estimates that 75% of all burglaries are carried out by 25% of offenders (An Garda Síochána, 2015). The most common items stolen are jewellery, cash and televisions.[10] There are at least seven known criminal gangs involved in the burglaries, with one gang committing up to 25 burglaries per week, and therefore multiple burglaries per day.[11] Unlike traditional Mafia-type gangs, these gangs do not appear to compete territorially with another, but instead they are reported to cooperate by selling information to rival gangs.[12] The burglars exhibit a preference for targeting rural areas, presumably because police presence is lower than in urban areas. Flying drones, night vision goggles and high-powered armoured cars are among the technologically savvy tactics used by the professional burglars to secretly commit crimes.[13] It has been reported that the Irish police won't chase a burglary gang going faster than 200 km per hour.[14]

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[9] For Belgium see https://eucpn.org/focus-day, and for the United Kingdom see https://bit.ly/2vp2IbE.
[10] See 'Home Burglary Stats in Ireland' available at https://bit.ly/2RW62CM.
[11] See Irish media report at https://bit.ly/2RzCP1E.
[12] See "Gardai alert over postbox burglars" at https://bit.ly/340wT6p.
[13] See media reports available at https://bit.ly/315kKeX and https://bit.ly/2UhcMOD
[14] See media report available at https://bit.ly/33UZM3Y

Although based in Irish cities, the criminal gangs have connections and bases across the country and reportedly hire local informants to carry out reconnaissance missions to scope out targets.[15] The burglars are not all Irish residents and one of the gangs reportedly travelled to Ireland from Eastern Europe to commit crimes.[16] The Irish police have detailed how it is difficult to catch these travelling burglars because they often offload their stolen loot as quickly as possible, and in some cases, they reportedly travel immediately from the crime location to the selling market (An Garda Síochána, 2015). In other cases, they reportedly store the stolen items; for example, they put stolen items into padded envelopes and post them to a pre-arranged address, or they store the goods in outside wheelie bins overnight.[17]

3. CONCEPTUAL FRAMEWORK

A conceptual framework is discussed in this section which provides a general intuition in which to expect the allocation of burglaries to areas near a motorway. It relies on a synthesis of the current relevant empirical and theoretical findings. The section begins by outlining Becker's seminal contribution on the economic theory of crime, next the location decision of crimes is discussed, followed by the role of motorways in this decision. The section ends by summarizing the discussion and linking it to the empirical results of this paper.

3.1 Rational choice theory of crime

[15] This information was found in the following newspaper articles: https://bit.ly/319ZgNZ and https://bit.ly/2GDPxG5

[16] See 'Highly sophisticated' Eastern European thieves making a fortune in burglaries targeting rural Ireland' at https://bit.ly/2GzUboS.

[17] See media report at https://bit.ly/340wT6p

The economic analysis of criminal behavior is based on the premise that criminals are concerned with maximizing profit and avoiding detection. The economic incentives of crime are rooted in Becker's (1968) seminal contribution and later extended by Ehrlich (1973). Under this rational choice framework, an individual decides to commit a crime if the expected benefits from the crime are greater than the losses from crime. In other words, rational individuals take into account the monetary gain from crime, the likelihood of being caught and convicted, the type of punishment, and money they could alternatively earn in legal work. The model has mainly been applied to property crimes, but a small literature has applied the model to violent crimes (Grogger, 2000).

3.2 Crime location choice

Becker's theory of crime deals primarily with why criminals choose to commit crimes, and is less concerned with where they choose to commit these crimes, but the latter can also be viewed through a rational decision making process that takes into account the spatial environment (Clarke & Cornish, 1985; Deutsch, Hakim, and Weinblatt 1987; Deutsch and Epstein 1998). Research in criminology propagates the view that the location decision is a result of a multiple-stage selection process, in which the offender seeks to maximize profit while minimizing effort, all while balancing the costs and benefits associated with each prospective location (Brantingham & Brantingham, 1984; Bernasco & Nieuwbeerta, 2005). The determining factors of crime location vary by the type of crime, but generally, property criminals will take into account the transport network and street layout which will determine the ease at which they can travel to, from and between targets. Offenders may also consider the relative affluence of a neighborhood and how the likelihood of being caught by law enforcement varies between locations.

There is long-standing empirical evidence in the journey-to-crime literature that treats distance as one of the major costs in the target selection process (Lottier, 1938). Empirical evidence demonstrates that offenders have limited mobility with respect to location choice (Rengert, Piquero, and Jones, 1999; Smith, Bond, and Townsley, 2009; Townsley and Sidebottom, 2010). Firstly, criminals have a limited amount of time, and secondly, they prefer to not be recognized as outsiders in target areas (Ratcliffe, 2006). This has given rise to the distance-decay effect, in which the number of crimes decreases with increasing distance from the offender's home address.

3.3 Proximity to the motorway

The majority of crime studies find that journeys to crime are short and mostly local in nature (McIver, 1981; Wiles and Costello, 2000). However, an increasing number of studies find that long crime trips are more frequent than previously thought (Gabor & Gottheil, 1984; Van Koppen & Jansen, 1998; Rattner & Portnov, 2007; Morselli & Royer, 2008; Polisenska, 2008; Vandeviver et al., 2015). In a rational choice framework, the criminal is able to reconcile the cost of longer journeys, in terms of both time and transport cost, with the benefit of higher valued stolen goods. Consequently for the criminal, travelling further can be more profitable (Vandeviver et al., 2015). Motorways provide the least-cost path by connecting far away locations through high-speed limits and a lack of traffic barriers. Thereby, decreasing the time that the offender is in transit with the stolen goods and providing a quick escape. Additionally, Van Daele and Beken (2011) explain that mobile property criminals compensate for longer distances, not only by targeting affluent areas and using fast transportation, but possibly by committing several offences in a short time.

3.4 Connecting the theory to the data

In summary, burglars choose to commit crimes in some areas over others, and this decision is a delicate balance between the associated benefits and risks across locations. This paper focuses on the role that proximity to the motorway networks plays in the spatial allocation of crimes across a country. As burglars seek to maximize return on their crimes, and minimize losses and effort, the motorway is a viable channel for a burglar to do this across long distances.

4. DATA

4.1 Geographical layout of policing

According to the 2016 Census, the (Republic of) Ireland has a population of 4.76 million people.[18] Northern Ireland is a political jurisdiction that is part of the United Kingdom, and is therefore not included in this study. For policing purposes Ireland is divided into 28 divisions.[19] Each policing division is made up of Garda Sub Districts, and in total there are 563 Sub Districts throughout Ireland with an average population of 8,150. The main analysis in Section 6 uses Sub Districts as the unit of analysis and the delineation of Sub Districts is illustrated in Figure 1. The Aran Islands are excluded because they are not connected to the mainland by a road network, and the main analysis uses the remaining 562 Sub Districts.[20] Each Sub District generally has 1 police station, the strength of which varies from 3 to 100 police officers. In some areas there are stations known as sub-stations, which typically feature one officer conducting administrative

[18] Census Population returns are available at: http://www.cso.ie/en/census/.

[19] Cork is split into Cork City, Cork North, and Cork West. Dublin is split into six Dublin Metropolitan Regions: North, South, East, West, North Central, and South Central. The remaining divisions are Cavan/Monaghan, Clare, Donegal, Galway, Kerry, Kildare, Kilkenny/Carlow, Laois/Offaly, Limerick, Louth, Mayo, Meath, Roscommon/Longford, Sligo/Leitrim, Tipperary, Waterford, Westmeath, Wexford, and Wicklow.

[20] This main result is robust to the exclusion of outliers and Sub Districts containing other inhabited islands.

work adjacent to the parent station.[21] Central Dublin (i.e., the City Centre area) is made up of 9 Sub Districts, and County Dublin contains 41 Sub Districts.

4.2 Burglary

An Garda Síochána is the national police service in Ireland and is responsible for policing across the country. As part of their daily duties, police officers are required to record reported criminal offences on the PULSE system. The data is collated and added to the Garda Síochána Annual Report.[22] The Central Statistics Office (CSO) is the Government body tasked with publishing the recorded crime statistics and they are provided on an annual basis for Sub Districts.[23] Burglary is one of the largest crime types in Ireland and the Irish Crime Classification System (ICCS) defines a burglary as the unauthorized entering of a building or part of a building, either with the intent to commit an offence or having committed an offence.[24] To account for heterogeneity in Sub District size, the ratio of the absolute number of crimes committed in a Sub District to the population of the Sub District is used as the dependent variable (expressed per 10,000 persons). Population statistics for Sub Districts are only available in 2011, but Section 7.5 shows that the main results are robust to using population data constructed from population growth figures in the eight Regional Authority areas in Ireland. The average local burglary rate in Ireland is 48 per 10,000 persons (see Table 6 in Appendix A).

[21] See "Geographical Layout" available at https://www.garda.ie/en/About-Us/Organisational-structure/.
[22] See 'Report of the Expert Group on Crime Statistics' at https://bit.ly/314lwsx.
[23] Available at http://www.cso.ie/en/statistics/crimeandjustice/.
[24] 'Domestic burglary' is not included separately in the criminal code. See 'Criminal Justice (Theft and Fraud Offences) Act, 2001', at http://www.irishstatutebookie/eli/2001/act/50/enacted/en/html.

Figure 2 shows the annual number of burglaries for different parts of Ireland during 2004-15.[25] The number of burglaries in Ireland peaked in 2012 at 28,133, and was lowest in 2007 at 23,603. Burglaries are concentrated in the Dublin region, accounting for almost 40% of all burglaries during 2004-15. This is expected given that economic activity is concentrated in Dublin. However, more burglaries happened across regions served by a motorway, than in non-motorway regions and in Dublin.

There are some limitations associated with using Irish crime data that must be considered before analyzing criminal activities. Firstly, crime counts are often an under representation of the true count, because not all crimes are reported to the police. The CSO estimates that 62% of burglaries were reported to the police in 2015, and that burglary was the crime that was most likely to be reported at 73% (Central Statistics Office, 2016).[26] Furthermore, counting and recording rules typically mean that only the most serious offence is recorded in a criminal transaction. Secondly, recorded crimes may be incorrectly categorized or re-categorized. Thirdly, the length of time between reporting a crime and the recording of the crime on the PULSE system could result in the misspecification or omission of crime data. Of course, the use of yearly data will offset this concern to some extent. Lastly, evidence suggests crime data in Ireland is often incorrectly labeled “detected” or “invalidated”. Nevertheless, these issues are systematic and patterns of variance are unlikely to exist across Sub Districts, or be correlated with motorway expansion.

4.3 Motorway

[25] Figure 5 in Appendix C presents the graph in annual changes. See Table 7 in Appendix A for the number of burglaries each year per 10,000 persons.

[26] These figures are taken from the CSO’s Crime and Victimisation National Household Survey that asks respondents about their experiences with crime.

There is approximately 100,000 km of road network in Ireland. In 2015, there were 12 motorways, the highest standard of road, representing 916 km of the total road network. In order to construct a measure of motorway access, the location and year opening of each motorway junction is identified. There is no official database on junction locations so firstly, the names of motorway junctions in Ireland are compiled from a website that lists all motorway exits in Europe.[27] Secondly, the geographic coordinates for junctions are retrieved from Google Maps. Thirdly, the location of motorway junctions is verified with official documentation illustrating the location of motorway junctions provided by the Irish Roads Authority.[28] Fourthly, the year each junction opened is retrieved from a website that archives the development of the Irish road network.[29]

All motorways in Ireland form part of a pre-existing national primary route. The completion of the Major Inter-Urban Motorway Project in December 2010, saw Dublin the capital city connected to the cities of Cork, Limerick, Waterford and Galway by continuous motorway.[30] Motorway upgrades happen in segments and in some cases, motorway junctions open before the year the official motorway status is designated to the junction. This means that some road sections will be functioning as high-quality dual carriageways with motorway characteristics until the time that status is given. The year the junction opened is used to identify the timing of motorway connections, and not the year of designation. Despite not being officially designated in some cases, criminals are able to exploit the connectivity and high-speed limits. The speed limit

[27] Available at: http://motorways-exitlists.com/
[28] Available at http://www.tii.ie/tii-library/Network_Management/
[29] Available at http://www.irishmotorwayinfo.com/
[30] In the Governments past 'Transport 21' investment plan, it indicated the need to update major interurban routes on the island that experienced heavy traffic flow. The motorway connecting Dublin to the Irish border at Dundalk, which then connects to Belfast via a dual carriageway, is the E 01 road. This European route is part of the United Nations International E-road network, running from Larne in Northern Ireland to Seville in Spain.

on Irish motorways is 120 km/h (75 mph).[31] To note, no section of the motorway was downgraded during the period of analysis.

Prior to 2004, there were 53 junctions and 84 junctions opened during 2004-15 (See Table 1 and Figure 3). The biggest growth years for the motorway network were during 2008-10, when 35% of junctions opened. Infrastructure funding cuts after the 2008 recession, led to the delay of some motorway upgrades, and so no junctions opened during 2011-14. In Section 7.3, connections to postponed motorway junctions are used as a placebo test.

Using straight-line buffer distances in GIS software, a dummy variable indicating connection to the motorway network is calculated for each year and Sub District during 2004-15.[32] New connections to the motorway network are defined as the year the first junction within a given radius opens.[33] The main analysis uses buffer radius up to 50 km. For example, in 2005 a Sub District's nearest junction was 55 km away, and in 2006 motorway expansion places a junction 25 km away. In 2005, the Sub District was disconnected from the motorway network, but became connected the following year. Table 1 shows the number of annual motorway connections among nearby Sub Districts. A common problem in the transport literature is measurement error related to how road access is measured (Picot et al., 2015). This concern does not apply in this paper because by using the geographic coordinates for motorway junctions, the exact spatial distribution and local availability of motorways is taken into account.

5. EMPIRICAL STRATEGY

[31] 100 km/h (62 mph) for National Routes (Primary and Secondary) that do not have motorway status. 80 km/h (50 mph) for local and regional roads, but 50 km/h (31 mph) in built up areas.

[32] Studies find a very high correlation between straight line distances and drive time distances (Boscoe et al., 2012; Phibbs and Luft, 1995). However, exceptions exist near physical barriers (Boscoe et al., 2012). If the burglary rate is always low because of e.g. physical barriers such as rivers, then this will be accounted for in the fixed effect.

[33] Proximity to motorway junctions is used, rather than proximity to the nearest part of the motorway, because the exact entry and exit point of criminals is necessary to identify the effect of motorway access.

The causal effect of new motorways on burglary rates is analyzed using standard panel data methods. The fixed effects estimation takes the following form:

$$(1)\ burglary\_rate_{i,t} = \delta + \theta_i + \alpha_t + \beta_1 motorway\_nearby_{i,t} + \beta_2 new\_connection_{i,t} + \varepsilon_{i,t}$$

'burglary rate' is the annual burglary rate (per 10,000 persons), i is the Sub District (562) and t is time (2004-15). 'motorway nearby' is a dummy variable that indicates the presence of a motorway junction within 50 km radius of a Sub Districts centroid. While 'new connection' takes on the value of 1 when the first junction within a given radius opens. β_1 and β_2 are expected to be positive. The rationale being that the motorway network allows criminals to escape the Sub District more quickly, and thus avoid law enforcement.

Proximity to the motorway is not the only determinant of burglary location so a Sub District fixed effect (θ_i) is included, which removes time invariant unobservable characteristics that vary across Sub Districts e.g. topography and deprivation. α_t is a full set of year dummies that control for national trends in crime. Any additional effects on crime due to the 2008 recession will be absorbed by the year dummies, such as higher rates of criminal behavior (Bell, et al., 2018; Hargaden, 2016).

Exogenous variation in motorway connectivity is exploited through the combination of spatial variation in motorway connectivity, the timing of new connections and the inclusion of geographically detailed fixed effects. This is made possible by the geographically detailed nature of the data, which links Sub Districts to the motorway at a spatially granular dimension and overtime. Therefore, after adjusting for local and national factors that influence the level of crime, β_1 is interpreted as the causal effect of motorway connections on burglary rates.

The main endogeneity issues revolve around the three common issues experienced in transport infrastructure studies: omitted variable bias, reverse causality and the endogenous placement of roads (Picot et al., 2015). Unobserved effects causing crime may be present that can be time invariant or time varying. In the case of time-invariant effects, using spatially detailed location fixed effects alleviates the concern, but this will not solve the problem of time-variant effects (Holtz-Eakin and Schwartz, 1995).

In Section 7.2, the relationship with motorway connections is shown to be unique to burglary rates, as other types of crimes yield statistically insignificant effects when used as alternative dependent variables. This is a crucial result because it provides evidence that the results are reliable because if omitted variable bias is present, stemming from a variable that is changing overtime, other crimes will be similarly affected. The main omitted variable of concern is local changes in economic activity because it varies spatio-temporally. In Section 7.1, the main result is robust to the inclusion of a proxy measure of local economic activity. Furthermore, the uniqueness of the causal relationship of motorways on burglary relaxes reverse causality concerns. For reverse causality to exist within these results, motorway connections would need to be driven by only burglary rates and no other crime type, which is unlikely.

Moreover, motorways are generally allocated to specific locations according to unobserved characteristics not orthogonal to their economic potential (Picot et al., 2015), and so the endogenous placement of motorways might upwardly bias the estimates. This concern is eased because connections to postponed motorway junctions have no statistically significant effect in

Section 7.3. If problematic unobserved characteristics at motorway locations are biasing the result, this would be revealed by postponed junctions, because the unobserved variables exist even if the motorway is yet to.

6. RESULTS

Columns 1 to 5 in Table 2 present the main results of the effect of connection to the motorway network on nearby burglary rates, using buffer distances at motorway exit and entry points. The presence of a motorway nearby is measured using the dummy variable 'motorway nearby' that equals 1 if there is a motorway junction up to 50 km from a Sub District's centroid, and 0 otherwise. For example 'motorway nearby ≤30km' indicates the presence of a motorway junction within 30 km of the Sub District. On the other hand, the binary variable 'new connection' equals 1 in the year of connection only. For example, 'new connection ≤30km' represents connection to the motorway for those Sub Districts within 30 km of it. A positive coefficient is expected on all motorway variables because it is predicted that criminals will commit burglaries in Sub District's close to the motorway network, as detailed in the conceptual framework in Section 3. The average population in Sub Districts is 8,150 persons, given this, coefficients are scaled to show the number of burglaries per 10,000 persons.

In Columns 1 to 5 in Table 2 both the presence of a motorway and motorway connections are positive as expected for all distances. However, only connections in a 20 to 40 km radius reach statistical significance, with connections up to 30 km reaching 1% significance. The magnitude of the effect increases up to and peaks at 30 km, and decreases between 30 and 50 km. On the other hand, the presence of a motorway nearby never reaches statistical significance and is sometimes negative. The motorway effect on burglaries in the year of connection only is verified in Section 7.4 when lead and lag values of connection are not statistically significant either. Interpreting the results, when a Sub District is within 30 km of a new motorway junction, it experiences a 10% increase in the burglary rate in the year it receives this connection (or 5 burglaries).[34] A log-linear specification in Column 3 Table 9 (Appendix C) confirms this 10% rise in burglaries.

To delve deeper into the differing effect by distance to the motorway, Columns 6-10 in Table 2 show the estimation results of other distance specifications. In Column 6 and 7, all new connection variables are included in the same regression. In this case, only connections up to a 30 km radius reach statistical significance. In addition, Columns 8 and 9, include connection dummies for each distance interval up to 50 km: 0-10 km; 10-20 km; 20-30 km; 30-40, and 40-50 km.[35] The respective motorway nearby variables cannot be included in the same regression, so only motorways within 50 km are included in Column 8, and as an alternative measures the log of distance to the nearest junction (lnrdistance) is included in Column 9, and neither variables reach statistical significance as expected.[36]

Similar to the main result, the magnitude of the new connection coefficients increase and peak at 30 km, while connections within 20 to 30 km reach 5% statistical significance. In theory, 10 km should show the largest coefficient as one might expect burglary rates to be higher closer to the motorway. A possible explanation is the relative sparsity of housing close to the motorway network, relative to further away. This is particularly relevant for connections within 10 km

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[34] The average Sub district burglary rate is 48. By the end of 2015, 361 Sub Districts were connected to the motorway network and 201 were disconnected. See Table 6 (Appendix A) for descriptive statistics.

[35] Similar specifications were estimated using the number of motorway junctions nearby, but no statistical significance was found. This is an intuitive result because the year of connection represents the year an area becomes accessible by criminals. Secondly, the layout of the Irish motorway network means that junctions are spaced out, and built such that they service a particular region of the country.

[36] Column 10 in Table 2 includes distance to the nearest junction instead of motorway nearby for connections within 30 km, to show that the variable is not affecting the main result.

which is negative in Columns 6 and 7. Without having detailed data on the location of housing over the period relative to the motorway, it is not possible to be definitive about the reason.

Taking Columns 1-10 together, the main result is that motorway connections increase burglary rates in Sub Districts up to 30 km away. From the burglar's perspective, a 30 km cut off is intuitive, as beyond this the relatively larger escape time might discourage the criminal travelling that far. Multiplying the previously discussed effect of 5 burglaries (≤30km), by scaled Sub District population size, yields a national increase of approximately 490 burglaries due to new motorways.[37]

A small increase in burglaries is intuitive because Sub District's (562) are geographically small units, and criminals seeking to evade police attention will presumably spread crime across a wide range of Sub District's, rather than concentrate criminal activity. [38] To note, this figure does not include repeat burglaries from motorway criminals. Although the results show that the motorway does not permanently increase the burglary rate, temporary hotspots may continue to emerge over time. Unfortunately, with no data or observable pattern of reoffending, it is not possible to estimate the longer term effect of the motorway.

To put the estimated effect on burglaries (5 per 10,000 persons) in perspective, similar studies detailing the crime effects of the interstate highway find similar modest results. For example, McCutcheon et al. (2016) test for a relationship between the interstate highway and robbery at the county-level in Georgia in the United States. They find that an additional interstate exit in the

[37] Since the estimation results are scaled to per 10,000 persons, the estimated impact on burglaries in a treated Sub District is multiplied by the number of 10,000 people in that Sub District. For example, the estimated number of burglaries for a Sub District with a population of 8,000 people, is 5*0.8.

[38] It was not possible to analyze in detail from where to where burglaries shift to as the motorway expands as the shift can be across regions. Furthermore, burglars are likely to revisit previously targeted areas, and so it will be difficult to disentangle burglary reallocations due to new motorways, from those attributable to existing motorways.

county increases the average robbery rate by 17.25 robberies per 100,000 population. While Rephann (1999) finds that the presence of an interstate is associated with 140 extra crimes per 100,000 persons in rural U.S counties, attributable to rises in larceny, auto theft and robbery. The immediate response of burglars to recent motorway improvements discussed in this section provides evidence that the motorway forms part of the criminals risk assessment when choosing the location of their next burglary. Burglary statistics in Sub Districts are only available on an annual frequency, limiting more detailed analysis on the quickness of the response. One possible explanation for the fast response is burglars exploiting their ability to respond to lapses in policing, relative to the police forces ability to respond to rising crime. When a burglary is committed in an area, police attention might be drawn to the area, increasing the probability of apprehension with each additional offence committed there. In recently connected Sub District's, motorway-related burglaries have not occurred yet and police suspicion has not been raised, nor has there been sufficient time for police forces to coordinate and mobilize a response. There was virtually no targeted law enforcement at motorways until national anti-burglary measures were launched in 2016 (outside of the period of analysis). Interpreting the empirical results differently, the risk of apprehension outweighs the expected profit in a Sub District, after an average of 5 burglaries has been committed there.

It is hypothesized that motorways are the route to attractive crime locations, and do not increase the stock of burglaries nationwide. A major indication of reorganization is that the number of burglaries in Ireland remains relatively steady between years, seemingly unaffected by the vast motorway growth (see Figure 2). Secondly, the rise in burglaries occurs temporarily, suggesting that the criminals are committing the same crimes each year, but in different locations. Thirdly, it is intuitive that motorways do not induce criminal activity, because by virtue of the criminal tracking motorway expansions, they are signaling premeditation and intent to commit a crime, which implies that they are already engaged in crime.

The estimated value of stolen items gained from new motorway burglaries can be compared to the cost of the motorway. In 2007, the average value of goods stolen from break-ins in Ireland was estimated to be €5,390 ($7,450).[39] Multiplying this figure with the estimated 490 motorway burglaries, an estimated €2.6million ($2.9million) was stolen by motorway burglary gangs during 2004-15. This is a small percentage of the total cost of the motorway (€8billion or $9.8billion). This figure provides a rough guideline to the extent of the burglaries. Although the motorway has relocated burglaries rather than causing them, if motorways are the artery to attractive crime locations, then the motorway is likely to have increased the value of goods stolen for a fixed number of crimes.[40] The lack of data on returns to burglary hinders further analysis on the topic.

7. ROBUSTNESS CHECKS

This section presents robustness checks on the main result of burglary rates within 30 km of motorway connections.[41]

7.1 Economic activity

[39] See "House thefts total €86m in a year" available at https://www.irishtimes.com/news/house-thefts-total-86m-in-a-year-1.813645.

[40] Recent research posits a strong link between property crime rates and the change in world prices of metals and other commodities that can be stolen from properties (Draca et al., 2019). Possibly, higher returns attracted criminals to rural houses outside of Dublin e.g. farms, where there is greater availability of these metals, such as copper piping in farms. Irish media reports document this e.g. https://bit.ly/2RC3V8s.

[41] Robustness checks were repeated using all buffer distances up to 50 km, and the results in Table 1 hold.

The Sub District fixed effect removes unobserved effects that vary over space, and the year dummies remove unobserved effects that vary nationally over time, but neither account for the variables causing the local crime rate that vary over both space and time. Left unaddressed these effects can cause an omitted variable bias because identification rests on spatio-temporal variation. The main culprit is changes in local economic activity e.g. connections to the motorway network might simultaneously raise economic activity and the burglary rate, and in turn the burglary rate might rise with economic activity. As a proxy for local economic activity, the annual number of people registering for Jobseekers Benefit, Jobseekers Allowance and for various other statutory entitlements at individual local offices of the Department of Social Protection is used as a control variable, and the results are presented in Table 5.[42] To note, this proxy is not designed to measure unemployment because it includes part-time, seasonal and casual workers, but it provides a useful indication of the numbers of people entering unemployment at a detailed geographic level. Some welfare offices closed during the period of analysis, so registrations at welfare offices active every year during 2004-15 are used, of which there are 141 spread across the country. The variable 'welfare register' is the total number of registrations at the nearest social welfare office, and it is scaled to show the effect of 1,000 registrations. The number of social welfare recipients is associated with a statistically significant small increase in the burglary rate (.08), but the main result on new connection holds.

Moreover, the Greater Dublin Area is the economic center of Ireland and is the main motorway node of the country. One might suspect that economic activity in this region is driving the result on 'new connections'. Over the past two decades, urban sprawl has increasingly dispersed populations and activity to Dublin and its surrounding counties (Meath, Kildare, and Wicklow),

[42] The geographic coordinates of welfare offices are found in Google maps and the distance from the Sub District's centroid to welfare offices is used to identify the local number of registrations. Information on the live register is published by the Central Statistics Office in the form of a monthly release available at cso.ie.

which is defined as a core socio-economic region in Ireland.[43] For example, the Greater Dublin Area accounts for 40% of the population of the State, and during 2002-11 the population in it grew faster than the national average, partly due to an influx of immigrants.[44]

Excluding the Greater Dublin Area in the analysis in Column 5 Table 9 (Appendix C) does not change the main result. Conversely, adding the lagged burglary rate as a regressor in Column 6 of Table 9, increases both motorway coefficients and the lagged crime rate is statistically significant. However, this result is attributable to activity in the Greater Dublin Area, because when excluding this region in Column 7, the results mirror the main result in Table 2, and lagged crime loses its statistical significance. As the main result in this paper is robust to the exclusion of the Greater Dublin Area, this does not affect that result.

7.2 Other types of crime

One might expect that motorways will increase other crimes that require a physical escape, such as theft and vandalism. To test this, other crime types are used as alternative dependent variables and the results are presented in Table 3. See Table 7 in Appendix A for annual crime statistics.[45] To note, theft refers to the action of stealing, while burglary refers to breaking an entry with the possible intent to commit a crime, such as theft. Burglary exhibits a different relationship to motorways in comparison to others crimes. In general, the presence of a motorway nearby is associated with higher levels of crime, except for burglary. While motorway expansion has a negative effect on all crimes, except for burglary. In the case of motorways nearby, only property

[43] The Greater Dublin Area generates 59% of Ireland's personal income tax revenue and 67% of Ireland's corporate tax revenue, Economic activity in the Greater Dublin Area accounts for approximately 53% of Ireland's GDP, see https://bit.ly/36AhlWK.
[44] See 'Demographic Trends in Dublin' at https://bit.ly/2S0UEFI.
[45] Kidnap, robbery, fraud and weapon related offences are excluded because of low counts.

and environmental damage reach 1% statistical significance. Interpreting the results, a motorway nearby is associated with 9 damage-related offences each year. Motorway expansion decreases damage and drug offences, and the effect is statistically significant at 10%. However, the relationship only exists in the Greater Dublin Area, in contrast to Burglary whose result is robust throughout the country.[46] A possible explanation for the decrease in drugs and vandalism offences is criminals switching to burglary, as Irish police intelligence documents how criminal gangs in Ireland are often involved in multiple crimes.[47]

In summary, burglary has a unique relationship with motorway expansion that is not shared among other types of crime. This is an important result to ease endogeneity concerns because if there is an omitted variable being captured by new motorway connections, this would likely be revealed through connections having a statistically significant effect on other crimes.[48] Conceptually, the uniqueness of the relationship is perhaps because burglary requires the expedient transit of bulky stolen items such as televisions.

7.3 Postponed motorway junctions

Motorways are not assigned to locations at random, but on the basis of unobserved characteristics that affect economic activity, which in turn affect the level of criminal activity. Motorways will generally be placed in areas of above average economic prosperity, or areas with economic potential that are lagging behind. The variable measuring connections to the motorway may be inflated if it fails to adequately disentangle this relationship. Sections of the Irish

[46] For those crimes where the results excluding the Greater Dublin Area are not shown, they are robust to the exclusion, and there is no significant difference between the two sets of results.
[47] For an example see the following media report https://bit.ly/2U6QlLW.
[48] It is unlikely that population composition changes or wealth changes are driving the result, as these variables will affect other crimes in addition to burglary.

motorway planned to be built during 2004-15 were postponed and connections to these postponed junctions are included as a useful placebo test in Table 4.

There are twenty-two postponed junctions, belonging to two new motorways and extensions to three existing motorways (Figure 4 Appendix B). As the year of opening of postponed junctions does not exist, the earliest year of reference that can be found for each motorway expansion is used (Table 8 Appendix B). It is expected that connections to the motorway are exogenous, and that there will be no causal effect associated with the non-existent junctions. However, even though the junction does not exist, any problematic unobserved characteristics that affect economic activity and the level of criminal activity should be detected, because there is generally a delay between when a motorway is needed and when construction is given the go-ahead by the Government.

For this to be a reliable placebo test, the junction postponements must be random. To ensure the validity of the test, only those junctions that had official architectural plans drawn up are used, as they are the most likely junctions to have been built, had they not been cancelled. Indeed, one of the motorways opened in 2017 and a second was granted construction approval in 2018. Furthermore, the postponement of motorway upgrades was part of a wider cut in transport spending in 2011, including postponements to all bus and rail routes.

Postponed junctions are added to the existing motorway network, and the results are shown in Table 4, Column's 4 to 7. Column 4 defines new connection, as either the arrival of a built junction or a postponed junction, whichever is closest to the Sub District that year. While Column 5, isolates connection to a postponed junction in its own binary variable called ‘postponed connection’. Given that built junctions are included, statistical significance is expected on ‘new connection’ in Column 4. The inclusion of postponed junctions dilutes statistical significance to the 5% level, and this is confirmed in Column 5 when postponed connections do not reach statistical significance and the main result on ‘new connection’ is robust to its inclusion. In Column 8, the regression sample isolates only those Sub Districts that are within 30 km of a postponed junction. While Column 9, includes all Sub District’s in Ireland, and their respective distance to the nearest postponed junction.[49] However 2004 is excluded in the latter, because there are no postponed junctions that year. Both Column 8 and 9 yield statistically insignificant results.

7.4 Event study analysis

The main result in Table 2 shows that burglary rises in the year of motorway connection but the presence of a motorway junction nearby has no persistent effect on the rate of burglaries. To further test the temporary rise in burglary, Table 10 (Appendix D) includes lag and lead values up to three years as separate regressors, alongside the main variable of contemporaneous connections, and Figure 6 (Appendix D) plots the result. For example, period t is the year of motorway connection and period t+1 defines the year of connection one year later. The lead and lagged values are not statistically significant, and contemporaneous connections remain significant and of a similar magnitude to the main result in Table 2. The lack of statistical significance in any period other than the year of connection reaffirms that motorway expansion affects burglaries in the year of connection only. After motorway expansion the rise in burglaries falls to zero and later becomes negative.

[49] Columns 2, 3, 6 and 7 are added for comparison, showing distance to the nearest existing junction and distance to the nearest existing or postponed junction (whichever is closest), respectively, for all Sub Districts in the data.

Criminals rely on the properties of the motorway network, such as high speed limits and free flowing traffic. Theoretically, there should be no effect on burglaries before the year of connection. With regard to the assumption of common trends, concern might be expressed over the rise in coefficient in t-1. As discussed in Section 4.3, all motorways in Ireland form part of a pre-existing national primary route, either operating a single or dual carriageway before motorway development, and in many cases, road improvements happened in segments. This makes an exact date of "opening" difficult to pin down. Additionally, the use of yearly crime data makes it so that motorways which opened later in the year, increase burglary the following year. This is a possible explanation for the increase in crime spilling over to t+1, albeit not a statistically significant increase. It is not possible to formally rule out an unobservable underlying effect which is causing the larger coefficients in t-1 and t+1, but these factors do provide a logical explanation.

To note, the statistical insignificance of the lead and lag values of connection, does not rule out the revisiting of burglars to previously targeted Sub Districts, as it is likely that they do return (Bernasco and Luykx, 2003). It indicates that the pattern of revisiting is not based on the year of motorway connection. For example, returning 1-2 years later, and thus the pattern of return is not testable in this paper.

7.5 Population

The population in 2011 is used to construct burglary rates but populations do not remain constant overtime and this is not reflected in the burglary rates in the analysis. To alleviate concerns of measurement error, population growth rates for the eight Regional Authorities are used and yearly population estimates for each year during 2004-15 are constructed.[50] For example, in 2011 a Sub District had a population of 4,809. Between 2011 and 2012, the regional authority experienced a 0.78% decrease in its population. Using this growth rate the 2012 population is calculated as 4,772 persons. Column 4 in Table 9 (Appendix C) shows the results when the main analysis in Table 2 uses the yearly population estimates to construct burglary rates. Connections to the motorway remain statistically significant and the coefficient's magnitude is similar to the main result in Table 2.

7.6 The border with Northern Ireland

The border between the Republic of Ireland and Northern Ireland is a hard policing border but with free unchecked movement because both countries are in a Common Travel Area and are in the European Union. Each jurisdictions' police force is not legally permitted to continue the chase or to make an arrest in the other jurisdiction. From a burglar's perspective, the probability of being caught is smaller closer to the border, because the criminal can flee across the border after committing a crime. If the effect of the border is time invariant, it will be removed in the Sub District fixed effect, but road improvements in Northern Ireland may cause the border effect to vary overtime. It is not possible to include a border dummy variable alongside the Sub District fixed effect, so the 74 Sub District's whose centroid is within a ≤30 km radius of the border are excluded, and the results are shown in Column 2 in Table 9 (Appendix C). Connections to the motorway network remain statistically significant at 1% and the coefficient is a similar magnitude to the main result. This provides reassurance that the effect of the border on burglary rates is not disrupting the main result. Furthermore, as there is a hard policing between Ireland

[50] The Regional Authority is the smallest geographical level available that provides yearly growth rates. The Eight Regional Authorities are: Border, West, Midlands, Mid-East, Dublin, South-East, South-West and Mid-West. The population estimates are available at https://bit.ly/312lEss.

and Northern Ireland, this means that the exploitation of motorways by criminals is not driven by the isolation of Ireland, as an escape route from the country exists.

8. CONCLUSION

This paper studies the causal effect of new motorways on burglary rates using data from Ireland. The spatio-temporal variation in motorway connectivity is exploited in a fixed effects analysis, consisting of crime rates in 562 police Sub Districts and connections to the motorway network during 2004-15. Upon connection to the motorway network, the average Sub District experiences a 10% rise in the burglary rate, if they are within 30 km of a new motorway junction. The rise in crime occurs in the year of connection only, and no persistent effect on the burglary rate is found in the years after connection. It is likely that burglars return to previously targeted areas, but the year of return is not patterned with the year of motorway expansion. For this reason, this paper focuses on the immediate aftermath of motorway expansion. The immediate response of burglars to motorway expansion is a novel result and a possible explanation is that the probability of being caught by the police is lowest in areas recently connected to the motorway network, and criminals exploit the fact that the police may not have had sufficient time to increase policing in these areas.

The novelty of this paper is to show that major road construction influences the spatial distribution of crime. For policymakers, the findings indicate the need to incorporate local crime-externalities into any cost-benefit analysis of future road infrastructure developments. The measure of motorway connections can confidently be thought of as exogenous because the main result is robust to various detailed checks: no other tested crime type shares the causal relationship with motorways, postponed motorway junctions yield no statistically significant effect on crime and controlling for local economic activity is not disrupting the main result. Conceptually, the uniqueness of the effect on the burglary rate is plausible because the bulky stolen goods need to be transported from the property as quickly as possible to avoid detection.

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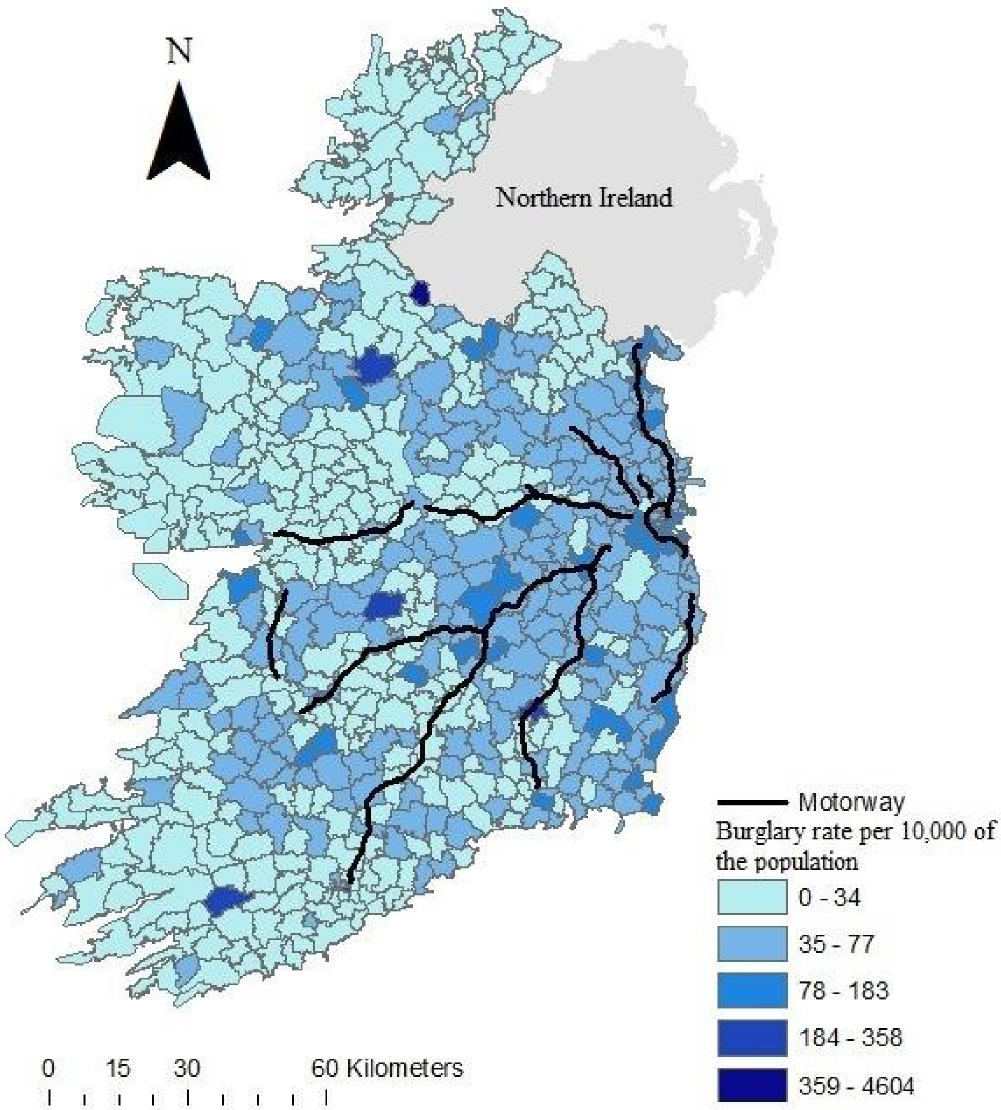
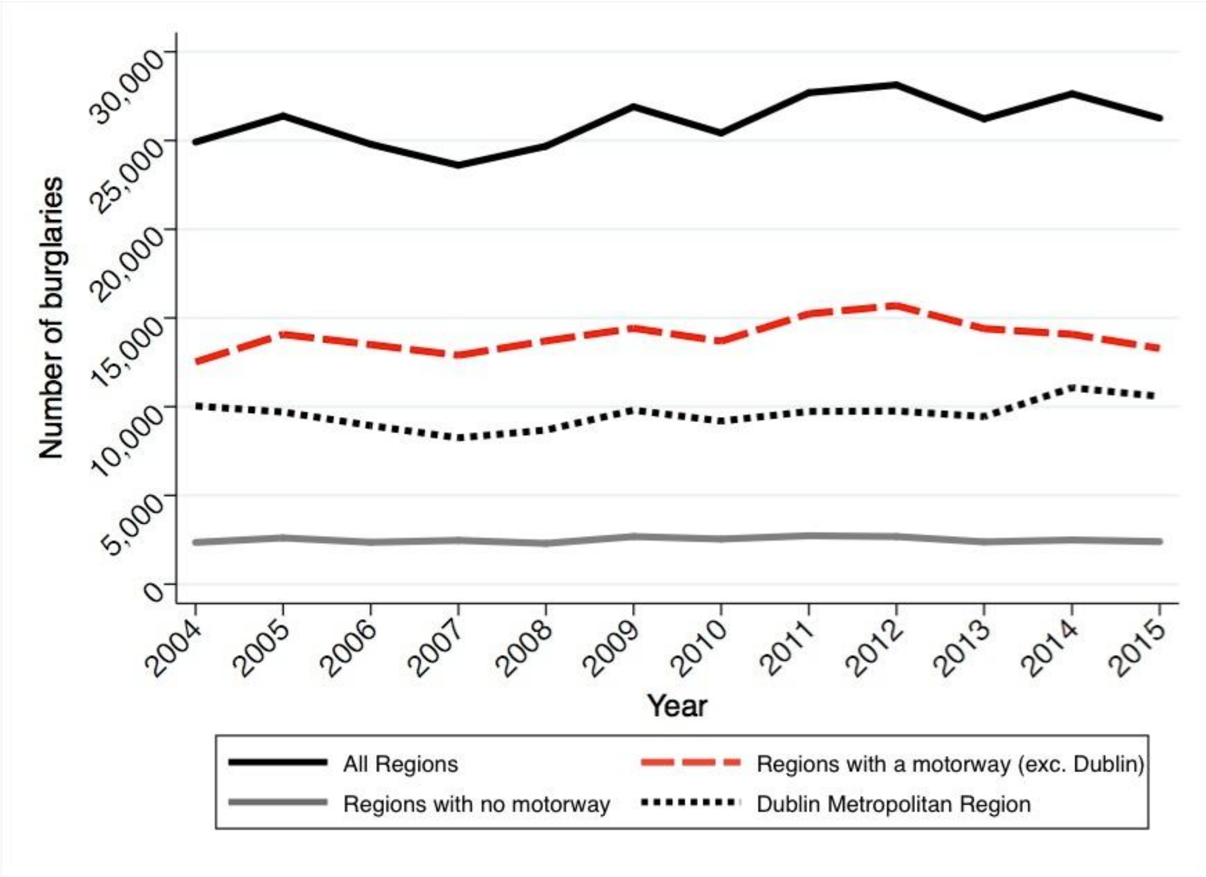
FIGURE 1: Burglary rates in police Sub Districts and the motorway network in 2015.



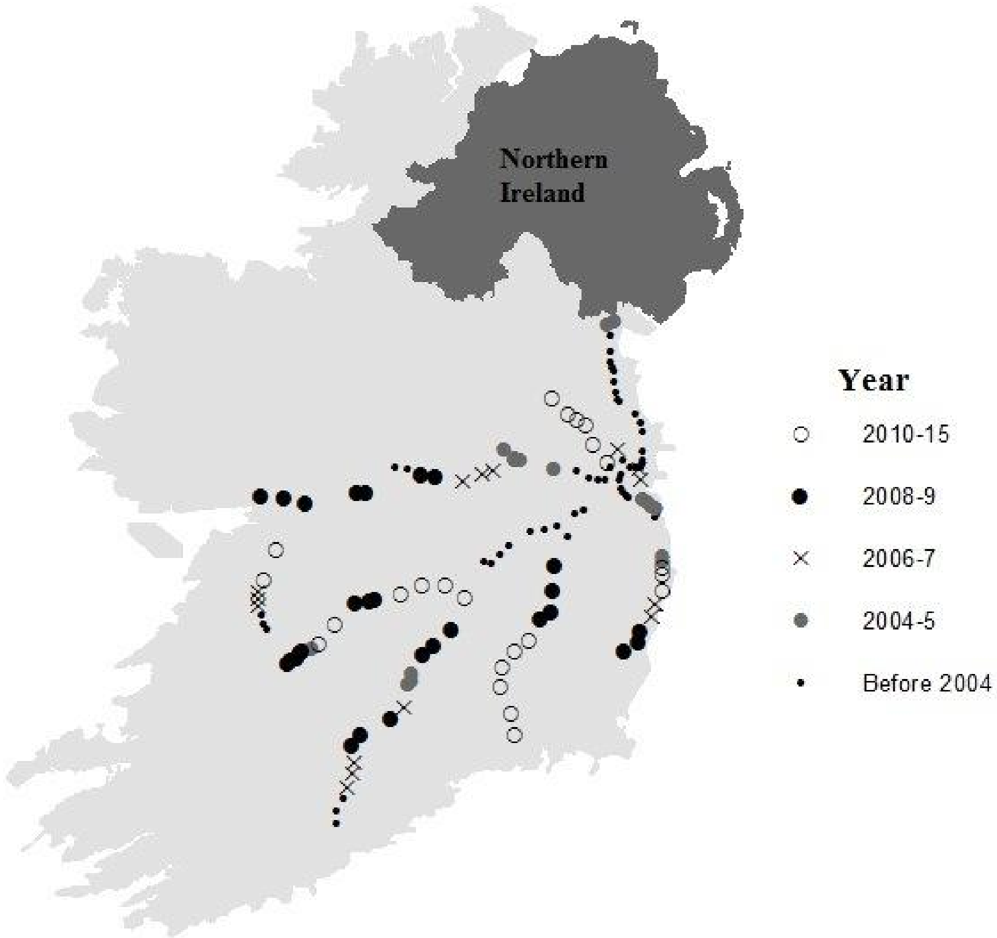
Notes: Sub Districts are the unit of analysis in this paper. In the (Republic of Ireland) there are 563 police Sub Districts. Northern Ireland is part of the UK, and is excluded from the analysis. Motorway polylines are retrieved from the Irish Road Authority (www.tii.ie), and crime statistics are retrieved from the Irish statistics office (www.cso.ie).

FIGURE 2: The number of burglaries each year in Ireland, 2004-15.



Notes: Categorization in the legend is based on Divisions with (or without) a motorway by the end of 2015. Crime statistics are retrieved from the Irish statistics office (www.cso.ie).

FIGURE 3: Motorway junctions by year of opening.



Notes: Motorway upgrades happened in segments and in some cases, road sections will be functioning as high-quality dual carriageways with motorway characteristics until the time that status is given. The approximate year of junction opening is used, rather than the year of designation. See Section 4.3 for a detailed discussion of the data sources.

TABLE 1: Motorway junctions opened and Sub Districts within 30 km receiving a connection, by year, 2004-15.

Year	Junctions opened	Sub Districts connected
Before 2004	53	203
2004-15	84	158
2004	7	40
2005	11	9
2006	8	5
2007	7	16
2008	10	17
2009	18	40
2010	20	31
2011-14	0	0
2015	3	0

Notes: Sub Districts are defined as receiving a motorway connection when the first junction within 30 km of the Sub Districts centroid opens.

TABLE 2: The effect of motorway connections on Sub District burglary rates, 2004-15.

	(i) Baseline specification					(ii) Other distance specifications				
Burglary rate per 10,000 persons	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
motorway nearby ≤10km	1.17 (1.95)									
motorway nearby ≤20km		-2.77 (2.06)								
motorway nearby ≤30km			-1.47 (2.18)							
motorway nearby ≤40km				0.20 (2.75)						
motorway nearby ≤50km					0.35 (2.03)	-3.12 (2.46)		1.34 (2.60)		
new connection ≤10km	0.67 (2.77)					-1.30 (2.46)	-.86 (2.49)			
new connection ≤20km		4.77** (2.09)				2.07 (1.93)	2.19 (1.96)			
new connection ≤30km			5.34*** (1.88)			3.56* (1.87)	3.70** (1.87)			4.86*** (1.72)
new connection ≤40km				3.43* (1.94)		-.01 (2.24)	.14 (2.22)			
new connection ≤50km					1.86 (2.53)	0.65 (2.80)	1.48 (2.68)			
new connection 0-10km								1.14 (2.60)	1.44 (2.67)	
new connection 10-20km								2.56 (2.10)	2.88 (2.10)	
new connection 20-30km								4.31** (2.00)	4.27** (2.00)	
new connection 30-40km								-.80 (2.87)	-.15 (2.78)	
new connection 40-50km								1.75 (4.30)	2.83 (4.14)	
lnrdistance							-.22 (1.60)		.10 (1.05)	.17 (1.03)
Sub district FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Standard error	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.
R-squared	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
N	6,744	6,744	6,744	6,744	6,744	6,744	6,744	6,744	6,744	6,744

Notes: A full set of year dummies are included for 2004-15 and the reference period is 2004. 'motorway nearby' equals 1 if there is a motorway junction within the specified buffer radius of the Sub District, 0 otherwise. 'new connection' equals 1 in the year the first junction within the specified buffer radius opens, 0 otherwise. 'lnrdistance' is the log of distance from the Sub Districts centroid to the nearest motorway junction. Standard errors are clustered by Sub District (562) and are in parentheses. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.

TABLE 3: The effect of connections to the motorway network on Sub District crime rates ≤30 km, per 10,000 persons, 2004-15.

	Main Result	Exc. Greater Dublin Area			Exc. Greater Dublin Area		Exc. Greater Dublin Area				
	Burglary		Murder	Drugs		Property & environmental damage		Dangerous & negligent acts	Offences against government, justice procedures and organization of crime	Public and social order	Theft
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
motorway nearby	-1.47	-1.44	1.87	1.35	1.00	8.51***	5.50**	2.27	1.67	10.32*	0.14
	(2.18)	(2.20)	(1.38)	(2.18)	(1.56)	(2.86)	(2.86)	(2.40)	(1.55)	(6.10)	(0.40)
new connection	5.34***	4.83***	-1.44	-2.83*	-2.05	-4.72*	-1.72	-2.69	-.005	-7.35	-0.14
	(1.88)	(1.86)	(1.54)	(1.71)	(1.71)	(2.56)	(2.39)	(1.71)	(1.04)	(4.49)	(0.33)
Sub District FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Standard errors	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.
R-squared	0.94	0.72	0.90	0.84	0.78	0.93	0.84	0.78	0.86	0.88	0.78
N	6,744	5,676	6,744	6,744	5,676	6,744	5,676	6,744	6,744	6,744	6,744

Notes: A full set of year dummies are included for 2004-15 and the reference period is 2004. 'motorway nearby' equals 1 if there is a motorway junction within ≤30 km buffer radius of the Sub District, 0 otherwise. 'new connection' equals 1 in the year the first junction within ≤30 km buffer radius of the Sub District opens, 0 otherwise. The Greater Dublin Area refers to County Dublin and surrounding counties; Meath, Kildare, and Wicklow. The full crime types in order of appearance are: 1) Burglary and related offences, 2) Attempts/threats to murder, Assaults, Harassments and related offences, 3) Controlled drug offences, 4) Damage to property and to the environment, 5) Dangerous or negligent acts, 6) Offences against government, justice procedures and organization of crime, 7) Public order and other social code offences, and 8) Theft and related offences. Crime statistics are retrieved from the Irish statistics office (www.cso.ie). Standard errors are clustered by Sub District (562) and are in parentheses. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.

TABLE 4: The effect of connections from existing and postponed motorway junctions on Sub District burglary rates, 2004-15.

	(i) Existing junctions			(ii) Existing and postponed junctions				(iii) Postponed junctions	
Burglary rate (per 10,000 persons)	(1) Main Result	(2)	(3) Exc. 2004	(4)	(5)	(6)	(7) Exc. 2004	(8)	(9) Exc. 2004
motorway nearby	-1.47			-.48	-1.46			2.39	
	(2.18)			(1.86)	(2.21)			(2.36)	
new connection	5.34***			3.51**	5.26**			1.16	
	(1.88)			(1.69)	(2.42)			(2.20)	
postponed connection					0.10				
					(2.05)				
lnrdistance		-.04	.67			-.04	1.27		1.09
		(1.02)	(1.20)			(0.83)	(0.94)		(0.68)
Sub-district FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES
Standard errors	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.	Clust.
R-squared	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.82
N	6,744	6,744	6,182	6,744	6,744	6,744	6,182	2,244	6,182

Notes: A full set of year dummies are included for 2004-15 and the reference period is 2004. 'motorway nearby' equals 1 if there is a motorway junction within ≤30 km buffer radius of the Sub District, 0 otherwise. 'new connection' equals 1 in the year the first junction within ≤30 km buffer radius of the Sub District opens, 0 otherwise. 'postponed connection' equals 1 if a postponed junction, within ≤30 km buffer radius of the Sub District, was planned to open that year, and 0 otherwise. 'lnrdistance' is the log of distance from the Sub Districts centroid to the nearest motorway junction. Columns 1, 2, 4, 5 and 6 contain the full set of observations. While Columns 3, 7, and 9 have a smaller number of observations because they exclude 2004, as there are no postponed junctions in 2004. Column 8 only includes those Sub Districts within ≤30 km buffer radius of a postponed junction. Standard errors are clustered by Sub District (562) and are in parentheses. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.

TABLE 5: The effect of connections to the motorway network on Sub District burglary rates, 2004-15.

Burglary rate (per 10,000 persons)	(1)	(2) Main Result
motorway nearby	-1.78	-1.47
	(2.20)	(2.18)
new connection	5.12***	5.34***
	(1.88)	(1.88)
welfare register	0.08**	
	(0.04)	
Sub District FE	YES	YES
Year dummies	YES	YES
Standard error	Clust.	Clust.
R-squared	0.94	0.94
N	6,744	6,744

Notes: A full set of year dummies are included for 2004-15 and the reference period is 2004. 'motorway nearby' equals 1 if there is a motorway junction within ≤30 km buffer radius of the Sub District, 0 otherwise. 'new connection' equals 1 in the year the first junction within ≤30 km buffer radius opens, 0 otherwise. 'welfare register' denotes the number of people (per 1,000) claiming job-seeking related welfare payments at local welfare offices. Welfare data is retrieved from the Irish statistics office (www.cso.ie). Standard errors are clustered by Sub District (562) and are in parentheses. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.

Appendix A

TABLE 6: Burglary summary statistics across Sub Districts, per 10,000 persons, 2004-15

		≤10 km		≤20 km		≤30 km		≤40 km		≤50 km	
	All	Junction	No junction	Junction	No junction	Junction	No junction	Junction	No junction	Junction	No junction
Mean	48	62	46	56	42	51	43	50	43	49	45
Min	0	0	0	0	0	0	0	0	0	0	0
Max	4,604	485	4,604	485	4,604	485	4,604	485	4,604	1,143	4,604
Q1	19	33	16	28	15	25	13	25	13	23	12
Q2	33	54	28	48	26	42	22	42	23	40	22
Q3	57	77	45	70	42	65	36	64	37	63	35
N	562	108	454	169	393	361	201	389	173	422	140

Notes: summary statistics are for all 562 Sub Districts over the period 2004-2005. Statistics refer to the number of burglaries per 10,000 persons. N refers to the number of Sub Districts, for example, there are 189 Sub Districts within ≤10 km of a motorway junction by the end of 2015. Numbers are rounded to the nearest whole number.

TABLE 7: The number of crimes per 10,000 persons, across Sub Districts, 2004-15.

Year	Burglary & related offences	Attempts and threats to murder/assaults/ harassments & related offences	Controlled drug offences	Damage to property & environment	Dangerous & negligent acts	Offences against government, justice procedures and organization of crime	Public order/ other social code offences	Theft/ related offences
2004	54	29	21	81	28	14	104	157
2005	57	30	29	87	32	17	121	159
2006	54	34	31	95	42	21	123	162
2007	51	39	40	94	46	24	132	164
2008	54	42	51	97	43	29	135	168
2009	59	40	48	92	34	26	125	168
2010	55	39	44	86	26	25	120	167
2011	60	37	39	78	22	22	107	168
2012	61	34	36	71	20	21	96	167
2013	57	32	34	63	17	20	79	172
2014	60	33	35	60	16	21	71	169
2015	57	37	33	57	16	25	73	165
Mean	48	31	25	58	26	11	81	13

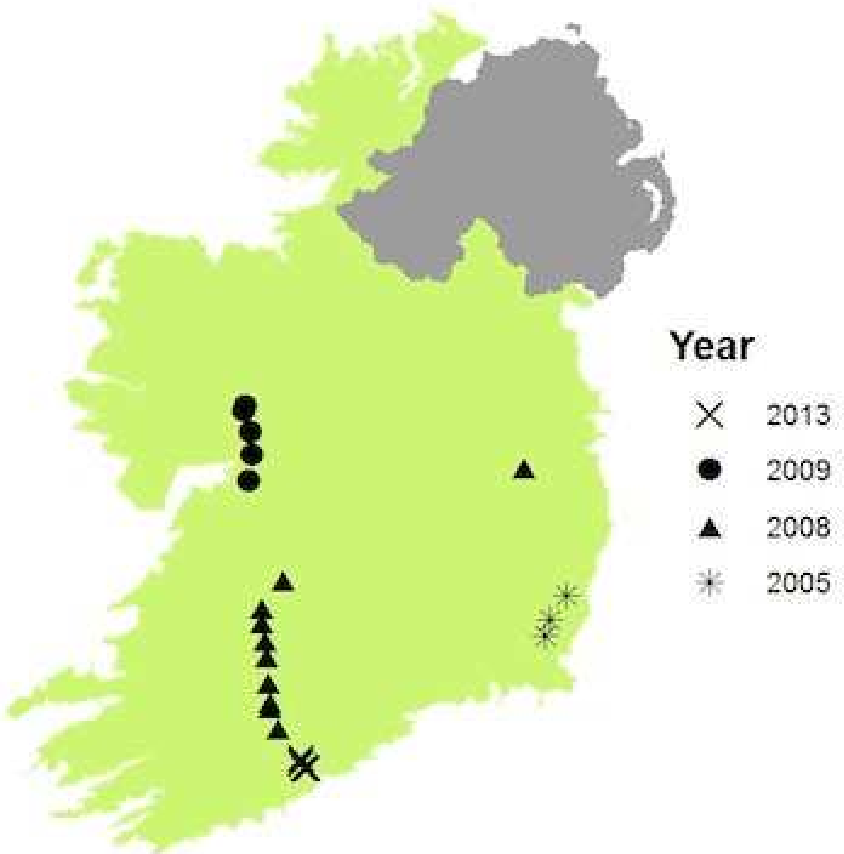
Notes: summary statistics are for all 562 Sub Districts over the period 2004-2005. Crime statistics are retrieved from the Irish statistics office (www.cso.ie). Crime rates are calculated using the 2011 population. Numbers are rounded to the nearest whole number.

Appendix B

TABLE 8: Sub Districts within ≤30 km radius of a postponed junction.

Year of connection	Number of Sub District's
2005	30
2008	112
2009	35
2013	10
Total	187

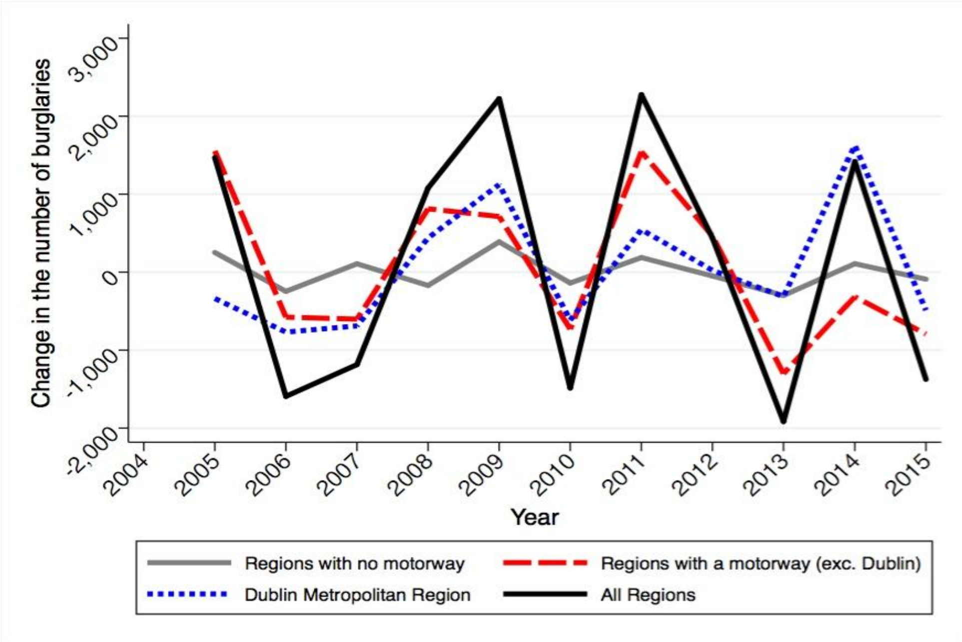
FIGURE 4: The location of postponed motorway junctions by proxied year of opening.



Notes: Sections of the Irish motorway planned to be built during 2004-15 were postponed, see Section 7.3 for a detailed description of postponed junctions. There are twenty-two postponed junctions, belonging to two new motorways and extensions to three existing motorways. As the year of opening of postponed junctions does not exist, the earliest year of reference that can be found for each motorway expansion is used.

Appendix C

FIGURE 5: The change in the number of burglaries each year in Ireland, 2005-15.



Notes: figure shows the change in the national number of burglaries between years. Categorization in the legend is based on Divisions with (or without) a motorway by the end of 2015. Crime statistics are retrieved from the Irish statistics office (www.cso.ie).

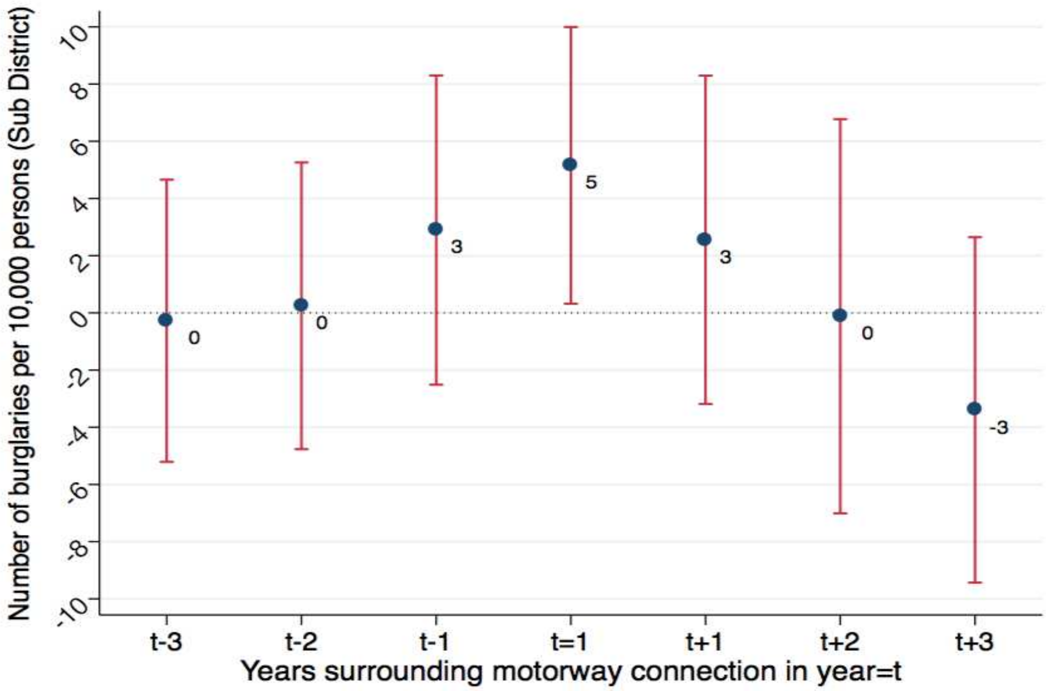
TABLE 9: Robustness checks. The effect of motorway connections (≤30 km) on burglary rates, 2004-15

Burglary rate (per 10,000 persons)	(1) main result	(2) >30 km from the Irish border	(3) log of burglary rate	(4) yearly population estimates	(5) exc. Greater Dublin Area	(6) Lagged crime rate & all Sub Districts	(7) Lagged crime rate & exc. Greater Dublin Area
motorway nearby	-1.47	-1.03	-.03	-1.40	-1.44	-3.63	-2.18
	(2.18)	(2.22)	(0.04)	(2.52)	(2.20)	(0.27)	(2.35)
new connection	5.34***	4.81***	0.13***	5.46***	4.83***	7.09***	6.17***
	(1.88)	(1.82)	(.04)	(1.98)	(1.86)	(2.25)	(2.18)
burglary rate $_{t-1}$						0.63**	0.09
						(0.27)	(0.06)
Sub District FE	YES	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES	YES
Standard errors	Clust.	Clust.	Clust.	YES	Clust.	Clust.	Clust.
R-squared	0.94	0.78	0.70	0.93	0.72	0.95	0.72
N	6,744	5,856	6,744	6,744	5,676	6,182	5,203

Notes: column 1 is the main result of the paper. Column 2 excludes Sub Districts within 30 km of the Irish border. Column 3 uses the log of the burglary rate as the dependent variable. Column 4 estimates yearly population and uses that to construct Sub District burglary rates 2004-15. Columns 5 and 5 exclude Dublin and its surrounding counties. Column 6 and 7 include the lagged burglary rate as a regressor. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.

Appendix D

FIGURE 6: Event study analysis of the effect of motorway expansion (≤30 km) on Sub District burglary rates



Notes: see Table 10 for the accompanying regression results. The event study includes all Sub Districts during 2004-15. Red bars display the confidence intervals, and the blue dots show the respective coefficients for each period of time surrounding motorway connections. For example, t-1 is the year before a Sub District receives motorway connection.

TABLE 10: The effect of motorway connections on Sub District burglary rates, in the years surrounding connection, 2004-15.

Burglary rate (per 10,000 persons)	(1)
new connection $_{t+3}$	-0.28 (2.51)
new connection $_{t+2}$	-.25 (2.55)
new connection $_{t+1}$	2.89 (2.75)
new connection $_{t}$	5.16** (2.46)
new connection $_{t-1}$	-2.55 (2.92)
new connection $_{t-2}$	-0.12 (3.51)
new connection $_{t-3}$	-3.39 (3.07)
R-squared	0.94
N	6,744

Notes: 'new connection' equals 1 in the year the first junction within ≤30 km buffer radius opens, 0 otherwise. For example, t-1 is the year before a Sub District receives motorway connection. Reference period is t-3. Numbers are rounded to two decimal places where possible. ***p<0.01 **p<0.05 *p<0.1.