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# Potential distributional impacts of road pricing: A case study

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ABSTRACT

Using data on number of car commuting trips, routes and speeds, we estimate the initial generalised cost changes, traffic reductions and likely distributional impacts of a £2 congestion charge on inbound car commuting traffic in the city of Cardiff, UK. We find that the initial potential reductions in the number of commuting trips by car finishing in Cardiff are likely to be 3.7% and 11.1%, for elasticities of number of trips with respect to generalised costs of −1 and −3, respectively. We also find that higher percentage reductions of up to 14.6% to 43.7% could be achieved by also charging trips with origin and destination in Cardiff. Not charging commuting trips by car that start and finish in Cardiff, which represent over half of the car commuting traffic with destination in Cardiff, will result in the share of charge revenues contributed by car commuters coming to Cardiff from other local authorities being roughly twice as high as the share of car commuting traffic they generate in Cardiff. We also find that the charge would be regressive but the number and percentage of commuting trips by car from different local authorities are quite different, and so the number and percentage of households from these local authorities that would be negatively affected, would also be different. The regressive impacts from the charge, however, have the potential of being reverted as long as the public transport improvements planned by Cardiff Council are in place before the congestion charge is implemented. Ideally, these should be combined with a reallocation of road space to public transport, pedestrians, and cyclists. Although this is a case study, there are valuable lessons for other cities considering the introduction of a congestion charge.

## 1. Introduction

Traffic congestion imposes substantial costs on the UK economy, motorists and cities. On average, British people wasted 115 h in congestion in 2019, costing the economy £6.9 billion and each driver, £894 (INRIX, 2019). INRIX (2019) ranked the UK's top 10 most congested cities, with Cardiff being sixth, as shown in Table 1.

Road pricing, or congestion charging, can be used to tackle congestion, and existing schemes show that road pricing can be effective in reducing congestion. In the 1920 s, Arthur Pigou, a Cambridge economist, introduced the idea of road pricing using the example of two roads (Pigou, 1920, p. 194). The rationale behind a congestion charge is to confront the trip maker with the true social cost of his journey to ensure that only cost-justified journeys are made and the scarce road space is allocated to those who value it the most. The intended effect of congestion charging is to increase the generalised cost of travel to reduce demand and congestion, and increase speeds.

A hundred years on since Pigou, there are only a handful of congestion charging examples around the world, which include those in Singapore, London, Stockholm, Milan and Gothenburg, as discussed in Section 2.

Local road charges can be introduced in England, Wales and Scotland. There are four pieces of legislation: the Greater London Authority Act (Acts of Parliament, 1999), the Transport Act 2000 (Acts of Parliament, 2000), the Local Transport Act 2008 (Acts of Parliament, 2008), and the Transport (Scotland) Act 2001 (Acts of the Scottish Parliament, 2001), updated in 2019 (Acts of the Scottish Parliament, 2019). These Acts give local authorities in England, Wales, and Scotland, and the Mayor of London, legal powers to introduce road user charges to help tackle congestion as part of a local transport plan.

Cardiff, one of the UK's most congested cities, is currently looking into potential policies that could be implemented. These are set out in the Transport White Paper (Cardiff Council, 2020a) and include congestion charging, amongst other alternatives. The proposal is to levy a £2 charge on vehicles coming into Cardiff (Cardiff Council, 2020a, p. 3). Santos et al. (2020) find that road pricing would face opposition in Cardiff. Cardiff Council's idea of an inbound cordon toll has already led to concerns from politicians and their constituents, especially from the

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**Table 1**
Top 10 most congested UK urban areas in 2019.

| Congestion rank | Urban area | Hours lost in congestion per driver | Cost of congestion per driver | Cost of congestion per city (millions) |
|---|---|---|---|---|
| 1 | London | 149 | £1,162 | £4,900 |
| 2 | Belfast | 112 | £874 | £117 |
| 3 | Bristol | 103 | £803 | £207 |
| 4 | Edinburgh | 98 | £764 | £177 |
| 5 | Manchester | 92 | £718 | £176 |
| 6 | Cardiff | 87 | £679 | £109 |
| 7 | Birmingham | 80 | £624 | £325 |
| 8 | Southampton | 79 | £616 | £74 |
| 9 | Nottingham | 78 | £608 | £84 |
| 10 | Hull | 75 | £585 | £90 |

Source: INRIX (2019).

surrounding local authorities, including Blaenau Gwent and Caerphilly. These politicians perceive that the scheme would unfairly penalise their residents, who are highly dependent on the car, due to a lack of realistic alternative modes of transport. Some perceive the proposal as a "valleys tax" (BBC News, 2020a), and there is mounting political pressure to consider the impact that the charge would have on the wider region, as some of the most deprived communities in Wales are located there (BBC News, 2020b).

In this paper, we focus on commuting trips by car, to assess the initial potential impacts of a £2 congestion charge in Cardiff on travel costs and traffic, and conduct a preliminary distributional analysis. The reason why we concentrate on commuting trips is that these are to blame for the morning and evening congestion. We contribute to the literature on congestion charging case studies on two fronts: (a) we provide an insight into the initial regressive impacts that a congestion charge on inbound traffic in Cardiff is likely to have, and (b) we reflect on how this result can be reverted. In a nutshell, congestion charging revenues earmarked to public transport improvements, with potentially, the provision of fare-free public transport from neighbouring local authorities into Cardiff or reimbursements targeted at lower income groups, combined with a reallocation of road space to favour public transport, pedestrians and cyclists, has the potential to make the distributional impacts from congestion charging in Cardiff progressive or at least, neutral. On the policy side, our results could inform not just Cardiff Council but also other cities in the UK or elsewhere, currently considering the introduction of a cordon charge.

The paper proceeds as follows. Section 2 critically reviews the literature on key case studies, the problem of induced demand, and the controversial issues related to distributional impacts from congestion charging. Section 3 sets out the methodology used in this study to collect, analyse and interpret quantitative secondary data. Section 4 presents, analyses and discusses the findings and Section 5 concludes, and provides policy recommendations and lines for future research.

## 2. Previous work

Congestion is a negative externality, and an example of market failure, since driving imposes external costs on society. The market is incapable of reaching an efficient equilibrium (Newbery, 1990) and therefore government intervention is needed.

The simple idea behind a congestion charge is to confront drivers with the full marginal social cost of their journeys. In theory, a congestion charge should be equal to the Marginal Congestion Cost (Walters, 1961; Glaister, 1981; Newbery, 1990). A congestion charge ensures that only cost-justified journeys are made and the scarce road space is allocated to motorists who value it the most, as evidenced by users' willingness to pay (Blauwens et al., 2002; Small and Verhoef, 2007).

Congestion charging has been advocated by transport economists for decades, but its implementation has been limited (Lindsey and Santos, 2020). Lack of public and political acceptability, typically linked to equity concerns, has acted as a barrier (Morrison, 1986; Jones, 1998; Marcucci, 2001; Viegas, 2001; Schade and Schlag, 2003; Lindsey, 2006). Having said that, using congestion charging revenues to improve public transport may increase public acceptability (Jones, 1991; Schlag and Teubel, 1997; Verhoef et al., 1997; Schlag and Schade, 2000; Thorpe et al., 2000; Jaensirisak et al., 2005).

In this section, we conduct a rapid review of the literature focusing specifically on key case studies, the potential problem of induced demand, and the controversial issues related to distributional impacts from congestion charging.

### 2.1. Congestion charging around the world

This section summarises the traffic impacts of congestion charging schemes that are in place in Singapore, London, Stockholm, Milan and Gothenburg.

The first road pricing scheme ever implemented was the Area Licensing Scheme (ALS) in Singapore in June 1975, which was essentially a cordon toll. The objective of the ALS was to reduce congestion and increase average speeds in the Central Business District (Santos, 2005). Vehicles were charged to enter and exit the 7 km$^2$ Restricted Zone, which included the Central Business District. Operating hours were initially between 07:30 and 09:30 every day except Sundays and public holidays, but these were extended and modified several times over the years (Santos, 2005). Drivers were required to purchase an area paper licence in advance and display it on their windscreen.

The ALS was effective in reducing traffic volumes and increasing speeds in Singapore's Restricted Zone. Commuting trips by car into the Restricted Zone decreased by 18% (Holland and Watson,1978) and speeds increased from 19 km/h to 36 km/h (Phang and Toh, 1997). The short-run elasticities of traffic volume entering the Restricted Zone with respect to ALS charges were approximately −0.15 in 1976, when the charges were increased for the first time (Menon, 2000, p. 44).

In June 1995, a paper-based Road Pricing Scheme (RPS) was introduced on an expressway (East Coast Parkway) at peak times, and in 1997, the scheme was extended to other expressways (Goh, 2002, pp. 31–32). The RPS charged per passage along an expressway rather than on entry to a Restricted Zone.

Due to problems including its complicated manual operation and bunching of traffic before and after charging hours, Electronic Road Pricing (ERP) replaced the ALS and the RPS in September 1998 (Menon, 2000, p. 40). The system combines a cordon-based congestion pricing around the Central Business District with point-based congestion pricing for specific roads and expressways (Goh, 2002, p. 32). The objective of ERP was (and still is) to maintain certain speeds set as target speeds by the government. ERP rates vary by vehicle type, time of day and location. Charging applies every day except Sundays and public holidays, from 07:30 to 19:00, and there are no exemptions for cleaner vehicles.

ERP rates have not varied much over the years. The highest ERP rate before the COVID pandemic was S$6[1], just S$1 more than in 2007 (Singapore Ministry of Transport, 2021a). These rates were reduced during the COVID pandemic, with many reaching S$0, such as those on the Central Business District cordon and on some expressways (Land Transport Authority, 2021). With the easing of COVID restrictions, however, some roads saw congestion increase, and in April 2021 ERP

[1] Congestion charges in this section are reported in the original currency, to avoid the distorting effects of fluctuating exchange rates. Relevant exchange rates for 2020, using the International Monetary Fund 2020 exchange rates (International Monetary Fund, 2021), are: Euro: €1 = £0.89 = US$1.14, Pound Sterling: £1 = €1.12 = US$1.28, Swedish Kronor: 10 SEK = €0.95 = £0.85 = US $1.09, Singapore Dollar: S$1= €0.64 = £0.57 = US$0.72, US dollar: US$1 = €0.88 = £0.78.

rates were adjusted. At the time of writing this paper, ERP rates are charged at 12 gantries, compared to 77 gantries pre-COVID, with the highest ERP rate of S$3, much lower than the S$6 pre-COVID (Land Transport Authority, 2021).

The ERP has been successful in reducing traffic volumes and maintaining target speeds (Menon, 2000, p. 42). ERP charges are reviewed quarterly and when necessary, changes are made to optimise traffic flow if average speeds fall outside the government's preferred range of 20 to 30 km/h on arterial roads, and 45 to 65 km/h on expressways (Singapore Ministry of Transport, 2021a), which makes the scheme, effective. The short-run elasticities of traffic volume entering the Restricted Zone with respect to ERP charges in 1998 were in the range of −0.12 to −0.35 (Menon, 2000, p. 44).

One of the main reasons for Singapore's success in reducing congestion was their integration of transport policies, which were introduced over many years, and include a vehicle quota system, high car ownership taxes, a mass rapid transit system, an expanded railway network, and improved quality of bus services (Santos et al., 2004), on top of road pricing.

The London Congestion Charging Scheme (LCCS) was implemented in February 2003. Its main objective was to reduce congestion in and around the Congestion Charging Zone. The LCCS is an area licensing scheme covering 21 $km^2$ in central London, representing 1.3% of the total 1579 $km^2$ of Greater London.[2] At the time of implementation, the scheme operated Monday to Friday, excluding public holidays, from 07:00 to 18:30 and the initial charge was £5 per day. This was subsequently increased to £8 in 2005, to £10 in 2011, and to £11.50 in 2014 (Santos et al., 2020). In 2020, Transport for London introduced temporary changes to the charge in response to the COVID pandemic, increasing the daily charge from £11.50 to £15 and changing the operating times to 07:00 to 22:00 every day (Transport for London, 2020a). All vehicles entering, leaving, or driving inside the Congestion Charging Zone during operating hours have to pay the charge. There has always been a number of exemptions and discounts, which have varied over the years, especially those for cleaner vehicles. Exemptions from the charge for cleaner vehicles are set to be completely terminated by 2025 (Transport for London, 2020b), given the increasing market penetration of electric vehicles.[3]

Between 2002 and 2014, car traffic entering central London fell by 39% (London Assembly: Transport Committee, 2017, point 3.1, p.22). However, after an initial increase in average speeds, these went down again to pre-charging levels due to a reallocation of road space to give priority to public transport, pedestrians and cyclists, road works by utilities and general development activity, and van traffic; and an increase in ride hailing traffic, such as Uber (Santos et al., 2020). Santos and Shaffer (2004) estimate the initial short-run elasticities of the total number of cars (excluding taxis but including minicabs) entering and leaving the Charging Zone during charging hours with respect to generalised costs when the charge was introduced at −1.32 (excluding car fixed costs) and −2.10 (including car fixed costs). Evans (2008, Table 2.3) estimates the elasticity of the number of all cars entering the Charging Zone during charging hours with respect to the initial £5 charge at −0.35. This elasticity increases to −0.55 when only chargeable cars are taken into account. He also estimates the elasticity of the number of all cars entering the Charging Zone during charging hours with respect to generalised costs (including time and money costs, but excluding car fixed costs), at −2.02. This elasticity increases to −3.18 when only chargeable cars are taken into account. The differences between the estimates reported in Santos and Shaffer (2004) and in Evans (2008) are mainly due to slightly different assumptions regarding trip lengths and vehicle counts.

The most important policy implemented in conjunction with the LCCS was the improvement of the bus network by providing larger buses, additional routes and higher frequencies (Transport for London, 2004).

The congestion charge in Stockholm, known as the congestion "tax", was first introduced on a trial basis for seven months (from January to July 2006) and implemented on a permanent basis in August 2007. In a city with an already well-functioning public transport system, the cordon toll was expected to reduce congestion, increase accessibility and improve the environment (Eliasson et al., 2009). Vehicles are charged when crossing the cordon of the 30 $km^2$ charging zone in both directions. Charges apply per passage and vary by time of day. They originally ranged from 10 SEK to 20 SEK (Eliasson et al., 2009) but increased in January 2016 to 11 SEK to 35 SEK, when the congestion tax started to also be levied on the Essinge bypass, running North to South (Swedish Transport Agency and Swedish Transport Administration, 2015), and increased again in January 2020 to reach 11 SEK to 45 SEK (Swedish Transport Agency, 2019). Cleaner cars were exempt until 2012 (Börjesson and Kristoffersson, 2018, p. 42). Charging applies Monday to Friday, excluding public holidays, from 06:00 to 18:30, although the start time was 06:30 until January 2020. The congestion tax was never levied during the month of July but changes implemented in January 2020 included the introduction of the congestion tax in the first week of July because that is a week when congestion reaches similar levels to those recorded at other times of the year (Swedish Transport Agency, 2019). Other changes implemented in January 2020 include adjusting congestion charges to season because in late spring, and in summer and autumn, congestion is higher than in winter and early spring (Swedish Transport Agency, 2019). The total daily payment per vehicle was originally capped at 60 SEK (Eliasson et al., 2009), but increased to 105 SEK in 2016 (Swedish Transport Agency and Swedish Transport Administration, 2015). In 2020, the daily cap was raised to 135 SEK for the peak season, and kept at 105 SEK for the off-peak season (Swedish Transport Agency, 2019).

The Stockholm's congestion tax has been effective in reducing traffic. The tax initially led to a 22% decrease in traffic entering the charging area (Eliasson et al., 2009), followed by relative stability (Börjesson et al., 2012). The initial short-run elasticities of number of vehicles crossing the cordon per hour with respect to the average monetary cost of trips (excluding any time costs) were −0.67 for peak hours and −1.13 for off-peak hours (Börjesson and Kristoffersson, 2018, Table 8, p. 44).

The congestion charge in Gothenburg was introduced in January 2013, coinciding with measures aimed at improving public transport (Börjesson and Kristoffersson, 2015). The main objective of the congestion tax was to generate revenues to help finance a rail tunnel, although other objectives included congestion reduction and local environment improvement (West and Börjesson, 2020). The scheme consists of a cordon. Charges apply per passage and vary by time of day. The scheme operates Monday to Friday, excluding public holidays, from 06:00 to 18:30 (Swedish Transport Agency, 2019). Vehicles are charged when crossing the cordon in both directions. The charges originally ranged between 8 SEK and 18 SEK but in January 2015 they were increased and the range is now 9 SEK to 22 SEK (Börjesson and Kristoffersson, 2018, pp. 38-39; West and Börjesson, 2020, p. 148). A single charge rule applies by which a vehicle that passes several tolling stations within 60 min is only taxed once, and the amount that must be paid is the highest one (Swedish Transport Agency, 2019). The total daily

[2] The Charging Zone was extended to the West, and doubled in size, between 2007 and 2010.

[3] In addition, in April 2019, an Ultra Low Emission Zone was introduced. The zone coincides exactly with the Congestion Charging Zone, and operates 24 h a day, every day of the year, except Christmas Day (Transport for London, 2021a). Vehicles not meeting certain emission standards cannot enter the Ultra Low Emission Zone unless they pay a charge. The zone will be extended in October 2021 (Transport for London, 2021a) to become over 14 times bigger. The Ultra Low Emission Zone is not to be confused with the Low Emission Zone, which has been in place since 2008, and covers the whole of Greater London, defined as the area inside the M25. This zone also operates 24 h a day, every day of the year, but only targets the most polluting heavy diesel vehicles (Transport for London, 2021b).

payment per vehicle has always been capped at 60 SEK (Swedish Transport Agency, 2019). The initial reduction in traffic volumes crossing the cordon in both directions was 12% (Börjesson and Kristoffersson, 2015), and the initial short-run elasticities of number of vehicles crossing the cordon per hour with respect to the average monetary cost of trips (excluding any time costs) were −0.53 for peak hours and −0.93 for off-peak hours (Börjesson and Kristoffersson, 2018, Table 8, p. 44).

The congestion charge in Milan had a predecessor, the Ecopass, which was designed to price pollution, and operated between 2008 and 2012. In 2012, the Ecopass was replaced by the Area C congestion charge. The charging zone covers an 8 $km^2$ area in central Milan (Lehe, 2019). A daily charge of €5 is levied on cars entering or driving inside the charging zone Monday to Friday, excluding public holidays, from 07:30 to 19:30 (Comune di Milano, 2021). There are a number of exemptions in place, including for residents and cleaner vehicles. The original Ecopass led to a reduction in traffic of 16.6% between 2007 and 2011, and the Area C charge, introduced in 2012, led to a further reduction of 31.2%, with respect to traffic levels in 2011 (Croci and Ravazzi, 2015, Table 10.2, p. 146). To the best of our knowledge, at the time of writing this paper, there are no estimates of demand elasticities after the Area C charge was implemented. There are, however, estimates of demand elasticities with respect to the Ecopass, a charge which varied according to fuel type (petrol or diesel) and vehicle Euro standard. Long-term elasticities of the number of cars entering the Ecopass Area with respect to the Ecopass charge were −0.66 for Euro 1 and Euro 2 petrol cars, which had to pay €2 for the Ecopass, and −0.46 for Euro 0 petrol cars, Euro 1, 2, 3 and 4 (without particulate filter) diesel cars, Euro 4 (without particulate filter) diesel commercial vehicles, and Euro 3 diesel commercial vehicles, all of which had to pay €5 for the Ecopass (Croci and Ravazzi, 2015, p. 151).

#### 2.1.1. Technologies

The ERP in Singapore uses Radio Frequency Identification technology, which allows the automatic deduction of the congestion charge on any vehicle passing under a road pricing gantry during its operating hours (Singapore Ministry of Transport, 2021b). Vehicles need to have an In-vehicle Unit installed, which is a radio transponder in which a stored-value smart card is inserted, and from which charges are deducted (Menon, 2000). The system, however, is currently being replaced with a next-generation ERP (nexgen ERP), which will use Global Navigation Satellite System instead of gantries, and will incorporate value-added services such as traffic information (Land Transport Authority, 2020). It will also use a new On-board Unit, provided free of charge, with installation starting in the second half of 2021 to be completed over 18 months ready for the switch from ERP to nexgen ERP in mid-2023.

The congestion charging schemes in London, Stockholm, Gothenburg and Milan all rely on cameras and Automatic Number Plate Recognition.

#### 2.1.2. Public acceptability

The implementation of road pricing in Singapore was never subject to a public consultation or referendum, yet there have not been any important issues with public acceptability (Walker, 2011). The Singaporean government has convinced the public that it is important to control congestion (Santos et al., 2004). Congestion charging in Singapore has been in place for over 45 years under different schemes, and the policy is now ingrained. The People's Action Party has won all elections since 1959, including the elections held in 2020, effectively making Singapore a one-party democracy. Although this may have helped with the introduction of a number of policies, including those in the transport sector, it would appear that Singaporeans understand the rationale and support such policies (Santos et al., 2004).

The case of London was quite different. In May 2000, Ken Livingstone was elected mayor of London based on a manifesto promising the introduction of congestion charging. There was never a referendum but there were a number of public consultations.[4] Stakeholders and the general public had plenty of opportunities to voice their concerns and let their views known, but Mayor Ken Livingstone did not, at any point, make any of his decisions subject to the result of any referendum.[5] The LCCS has been in place for over 18 years, and survived three Mayors from different political parties, all of whom were re-elected after their first term: Ken Livingstone (2000–2008, Independent, Labour), Boris Johnson (2008–2016, Conservative), and Sadiq Khan (2016- , Labour). The situation in London was quite unique because (a) almost 90% of people entering central London during the morning peak used public transport or a non-chargeable mode before the LCCS was implemented (estimated from Fig. 2.5, Transport for London, 2015, p. 38), (b) 40% of car trips inside the charging zone were business trips (Evans, 2007, point 2.6, p. 4), (c) average speeds in Central London in 2002, the year before the LCCS was implemented, were 14 km/h (Transport for London, 2003, point 3.5, p. 51), lower than the speed of horse and carriage.

The issue of public acceptability of the congestion tax in Stockholm is interesting, as this has always been quite high. Before the congestion tax was implemented, 77% of commuting trips crossing the cordon were made by public transport (Storstockholms Lokaltrafik, 2013, cited in West and Börjesson, 2020). The congestion tax in Stockholm was introduced after a seven-month trial, which finished on 31 July 2006. Following the trial there was a referendum in the City of Stockholm in September, where 53% of those who voted, voted for “yes” to a permanent implementation of the congestion tax, and 47% voted for “no” (Transport & Environment, 2006). Polls in the years that followed showed an increase in public support: 66% in December 2007, and 70% in May 2011 (Börjesson et al., 2012, p. 8).

In addition to the referendum held in the City of Stockholm, 14 of the 25 other municipalities in Greater Stockholm also held a referendum in September 2006 with a result of 39.8% votes for “yes” and 60.8% votes for “no” (Transport & Environment, 2006). However, the municipalities that held the referendum were more against the congestion tax than the entire County as a whole, including the municipalities that did not hold any referendum (Börjesson et al., 2012, p. 2). To the best of our knowledge, at the time of writing this paper, the reasons for the “no” vote in the neighbouring municipalities have not been scrutinised in depth. In an early paper on the effects of the trial, Eliasson et al. (2009) highlight that two-thirds of workers commuting to workplaces inside the cordon were coming from outside. We speculate that this may have had an influence on the “no” vote from neighbouring municipalities, although there is no study to back this up.

In contrast with the “no” vote, the reasons for the “yes” vote in the City of Stockholm have been scrutinised. Hårsman and Quigley (2010), for example, find that the time savings and the amount of congestion tax paid by drivers affected voting behaviour. Eliasson and Jonsson (2011) analyse a survey conducted after the referendum and find that low car dependence, good public transport provision, beliefs about the charges' effectiveness, and pro-environmental attitudes were all correlated with

[4] The Mayor's draft Transport Strategy, which included proposals for a central London congestion charging scheme, was published on 11 January 2001 and sent to public consultation until 30 March 2001. This was followed by his final Transport Strategy, published on 10 July 2001. The proposed congestion charging scheme was then sent out for public consultation in its own right from 23 July to 28 September 2001. Modifications to the proposed scheme were the result of this consultation. Following the publication of the proposed modifications to the Scheme in November 2001, there was a further consultation period until 18 January 2002. After the Scheme was implemented in 2003, there were a number of public consultations on a number of modifications too (Santos, 2008).

[5] The cities of Edinburgh in Scotland and Manchester in England, on the other hand, made the decision of congestion charging subsequent to affirmative referendums, which took place in 2005 and 2008, respectively. About 74% of those who voted in Edinburgh and 79% of those who voted in Manchester voted ‘no’ and congestion charging never materialized in either city.

support for the congestion tax.

Moving on to the case of Gothenburg, the congestion tax did not and does not have much public support (West and Börjesson, 2020). Only 26% of commuting trips crossing the cordon are made by public transport (Björklind et al., 2014, cited in West and Börjesson, 2020). There is high car dependence, even amongst low-income groups, probably because the sparse population and city pattern of development make efficient public transport provision difficult (West and Börjesson, 2020). In a referendum held in the City of Gothenburg in September 2014 on the continuation of the congestion tax, which had been introduced 20 months earlier, 57% of those who voted, voted for “no”. The congestion tax, however, was kept because the revenues, mostly paid by commuters from surrounding municipalities, which did not hold a referendum, went to fund a major infrastructure package in Gothenburg, and the national government committed to topping up the congestion tax revenues with a grant (West and Börjesson, 2020). Public support has increased since the referendum, probably because familiarity with the scheme has increased (Hansla et al., 2017).

The Area C charge in Milan constitutes another interesting case, with a referendum where 79.1% of those who voted, voted for “yes” to turning the Ecopass into a congestion charge (Boggio and Beria, 2019). Residents living inside the cordon, who were going to get exemptions and discounts, and those living in zones well served by public transport especially the underground, were more likely to vote in favour of the charge (Boggio and Beria, 2019). Cost heterogeneity, measured by the difference between median and average marginal cost in an area, was also a determinant of the probability of the residents in that area voting for “yes” (Percoco, 2017).

### *2.2. Induced demand*

Congestion charging deters some drivers from making trips by increasing the generalised costs (GC) of travel. As a result of increased GC, some trips are suppressed, congestion decreases, speeds increase, and travel times decrease. If travel times decrease, then the GC of travel decreases. In other words, the GC increases because of the congestion charge, and then decreases because travel times decrease as a result of a reduction in traffic. There is typically still a net increase in GC for most drivers (as the decrease is typically smaller in absolute terms than the initial increase), but this net increase in GC will typically be smaller than the initial one. As a result, (wealthy) drivers with high values of time may be *attracted* onto the roads, as would drivers exempt from the charge. This may in turn increase congestion and travel times again, at least to some extent.

These ideas were initially developed and confirmed with evidence for the case of new road construction, which often induces demand. New road capacity can generate its own demand, thus eliminating any expected reductions in traffic congestion that would have been expected from building a new road (Goodwin, 1996; Cervero, 2002; Noland and Lem, 2002; Goodwin and Noland, 2003). As congestion is reduced, road users who previously did not drive may be attracted onto the roads as the GC of travel is lower, resulting in higher levels of traffic and hence, of congestion.

In the context of congestion charging, the idea is that reducing congestion and travel times will inevitably attract some drivers. Santos and Bhakar (2006), for example, find that a large number of commuters, especially from outer London boroughs, switched from other modes to the car as a result of the London Congestion Charge.

### *2.3. Distributional impacts*

The distributional impacts refer to the distribution of costs and benefits across groups that differ by income or social class (Litman, 2002). A policy is progressive/regressive if it imposes a burden that is a larger/smaller fraction of income for higher-income groups compared to lower–income groups (Safirova et al., 2004).

There is a lack of consensus in the literature regarding whether the distributional impacts of congestion pricing are progressive or regressive. Eliasson and Mattsson (2006), predicted that the then proposed Stockholm congestion charging scheme was going to have progressive effects with respect to income. The authors concluded that high-income groups would be more affected by the charge than low-income groups because high-income groups make more car trips and consequently pay more than low-income groups. A more recent study by Franklin et al. (2009) confirms the progressive effects of Stockholm’s scheme.

The empirical and simulation literature supporting that congestion charging is regressive is more extensive. Eliasson (2016) analyses the distributional impacts of Stockholm and Gothenburg’s actual systems, a hypothetical cordon toll in Lyon and a proposed per kilometre charge in Helsinki. He concludes that the congestion charges in all four cities are regressive because low–income groups pay a larger percentage of their income in tolls. A more recent study of the distributional impacts of the Gothenburg congestion charging scheme confirms the regressive nature of Gothenburg’s congestion charge (West and Börjesson, 2020). Studies simulating the distributional impacts of an inbound cordon toll in Paris (Bureau and Glachant, 2008) and a proposed cordon toll in Madrid (Di Ciommo and Lucas, 2014) also report that impacts would be regressive, since the schemes would affect the incomes of the lowest income groups most.

Importantly, the definition of the charging area relative to the spatial distribution of low-income areas has a large impact on equity results. A study of hypothetical cordon tolls in Cambridge, Northampton and Bedford, finds that cordon pricing can be regressive, progressive or neutral depending on how incomes are distributed in a region, where people live and work, and the mode of transport they use to get to work (Santos and Rojey, 2004).

Ultimately, the distributional impacts of congestion pricing schemes also depend greatly on the way in which the revenues are used (Crawford, 2000; Eliasson and Mattson, 2006). Two early papers on revenue allocation suggested “rules of three”. Goodwin (1990) proposed that to make road pricing popular, one-third of revenues could go to road improvements, one-third to public transport, and one-third to either tax reductions or increased general expenditure. Small (1992) proposed that one-third of revenues could be used to reimburse travellers, one third-third to reduce taxes, such as fuel duties and vehicle excise duties, or even value added taxes, and one-third to pay for new transport services, such as new roads or public transport. He argued that reimbursing travellers could be done, for example, by subsidising employers to provide their employees with a commuting allowance, which would give commuters the flexibility to drive and pay the congestion charge or change mode, route, or time of travel (if possible). He also highlighted that using revenues to improve public transport could be seen as “linked compensation”, for those switching from the car to public transport.

Although insightful, these early discussions on revenue use are not relevant in practice to congestion charging schemes in the UK given that the Transport Act 2000 specifically requires spending of revenues on measures for improving local transport (Department of the Environment, Transport and the Regions, 2000). This legal requirement may help to limit the negative distributional impacts, if any, of a congestion charge in Cardiff.

### *2.4. What can be learnt from the literature on urban road pricing schemes currently in operation?*

There are a number of points to take away from the literature on urban road pricing schemes currently in operation. The first point is that despite the theoretical concept of congestion charging having been discussed and scrutinised for decades, implementation has been limited, with only five prime examples around the world.

The five road pricing schemes currently in place are all quite different. The Singaporean ERP combines cordon-based congestion pricing around the Central Business District with point-based congestion pricing for specific roads and expressways. The charges vary with vehicle type, time of day and location. The London congestion charge and the Milan Area C charge are essentially area licences. Vehicles pay a uniform charge that allows them to enter, exit or drive inside the charging zone, regardless of how much they drive or how many times they enter the zone. The congestion taxes in Stockholm and in Gothenburg are essentially cordon charges. Vehicles pay per passage (to enter or exit) an area, and charges vary with time of day. All schemes rely on cameras and Automatic Number Plate Recognition, except for the scheme in Singapore, which uses Radio Frequency Identification technology.

All five schemes led to reductions in traffic. The degree of responsiveness to the congestion charge/tax can be measured in different ways, as is evident from Section 2.1, which reports elasticities with respect to the GC of travel, with respect to the monetary costs of travel, and with respect to the congestion charge. Obviously, for the same percentage reduction in number of trips, the elasticity is highest if computed with respect to GC of travel, lower if computed with respect to monetary costs of travel, and lowest if computed with respect to the congestion charge. Table 2 summarises the different elasticity values estimated in previous studies. Although they relate to different percentage changes in costs and quantity, elasticities are in general higher the more components are included in the costs.

Public acceptability, which has often acted as a barrier to the introduction of road pricing, seems to have increased in all five cases. The congestion tax in Stockholm and the Area C charge in Milan constitute very interesting examples of cities that had a trial or predecessor for drivers to get familiar with, held a referendum, and the result was in favour of keeping the scheme. The city where the congestion tax has encountered most public opposition is Gothenburg. This is a city where people are highly reliant on the car, even those on low incomes, and the congestion tax is, overall, regressive. Despite a negative referendum result, the congestion tax was kept, as it helped fund a large infrastructure package.

The schemes reviewed show that good public transport provision and less reliance on the car can increase public acceptability. A regressive charge can have a negative impact on public acceptability. The regressiveness of a charge and low public acceptability can be somewhat reverted by earmarking the charge revenues to the transport sector in a way that those initially losing out are compensated, at least to some extent.

These are points of utmost interest for the case of Cardiff because the congestion charge proposals bear a number of similarities with those already in place: (a) the proposed congestion charge will entail a cordon, like in Stockholm and Gothenburg, (b) the percentage of commuting trips crossing the cordon by public transport in Cardiff is very low, as is the case in Gothenburg: in Gothenburg it is 26% and in Cardiff it varies between 10% and 22%, depending on local authority (Office for National Statistics, 2011a), (c) most of the burden will fall on commuters from neighbouring local authorities, as is the case in Stockholm and Gothenburg, and (d) the revenues from the congestion charge in Cardiff will be earmarked to the transport sector, with an emphasis on improving public transport (as was and is the case in London).

We now turn our attention to the specific case of Cardiff.

**Table 2**
Summary of elasticity values estimated in previous studies.

| Type of elasticity | Elasticity values | Source |
|---|---|---|
| Elasticities of number of cars entering and leaving the Charging Zone with respect to GC | −1.32 to −2.10 (London congestion charge) | Santos and Shaffer (2004, p. 175) |
| Elasticities of number of cars entering the Charging Zone with respect to GC | −2.02 to −3.18 (London congestion charge) | Evans (2008, p. 5) |
| Elasticities of number of vehicles crossing the cordon per hour with respect to the average monetary cost of travel (excluding any time costs) | −0.67 for peak and −1.13 for off-peak (Stockholm congestion tax)<br>−0.53 for peak and −0.93 for off-peak (Gothenburg congestion tax) | Börjesson and Kristoffersson (2018, p. 44) |
| Elasticities of number of cars entering the Restricted Zone in Singapore or Charging Zone in London with respect to the congestion charge | −0.15 (Singapore ALS)<br>−0.12 to −0.35 (Singapore ERP) | Menon (2000, p. 44) |
| | −0.35 to −0.55 (London congestion charge) | Evans (2008, p. 5) |
| Elasticities of number of cars entering the Ecopass area with respect to the Ecopass charge* | −0.46 to −0.66 (Milan Ecopass) | Croci and Ravazzi (2015, p. 156) |

Source: compiled by the authors.
* There are no estimates of elasticities with respect to the Area C charge in Milan.

## 3. Data and methods

Commuting trips into and inside Cardiff originate from the following Welsh local authorities: Blaenau Gwent, Bridgend, Caerphilly, Cardiff, Merthyr Tydfil, Monmouthshire, Newport, Rhondda Cynon Taf, Torfaen, the Vale of Glamorgan, Swansea, Neath Port Talbot, Pembrokeshire, Carmarthenshire, Ceredigion and Powys, as well as from England (StatsWales, 2020). Specifically, commuting flows from England to Cardiff originate from Bristol, Herefordshire, North Somerset and South Gloucestershire (DataShine Commute, 2011)[6]. Some local authorities were grouped in some parts of the analysis according to how the commuting figures in DataShine Commute (2011) were organised, namely Pembrokeshire and Carmarthenshire, Ceredigion and Powys, and the English local authorities.

In this study, Cardiff's proposed congestion charging scheme was assumed to be a cordon scheme, with the charge applied to drivers from other local authorities crossing the boundary into Cardiff, as shown on Fig. 1.

The data used in the analysis, along with their sources, are detailed in Table 3.

### 3.1. Generalised costs

We estimated the generalised costs (GC) of commuting to Cardiff by car from different local authorities. The GC of travel can be expressed as:

$$GC = VOC + VOT \times T \tag{1}$$

where:

GC = generalised costs in pence per km,
VOC = vehicle operating costs in pence per km,
VOT = value of time in pence per hour,
T = travel time in hours per km.

Vehicle operating costs include fuel and non-fuel costs, such as parking charges or congestion charges, if applicable (Department for Transport, 2017). Non-fuel costs include oil, tyres, maintenance and mileage-related depreciation (Department for Transport, 2017).

Data on the average speed and distance of a trip from each origin in question was required to calculate the monetary and non-monetary components of GC. Before any secondary data collection commenced, a representative route from each origin to Cardiff was chosen for analysis, informed by Google Maps (2020). For trips within Cardiff, the top five routes with the highest commuting flows on DataShine Commute (2011) were chosen (see Appendix A). Pembrokeshire and Carmarthenshire,

[6] DataShine is an output of the project "Big, Open Data: Mining and Synthesis (BODMAS)", funded by the Economic and Social Research Council in the UK. The project ran from 2013 to 2015 at University College London, and the main output is reported in O'Brien and Cheshire (2016).

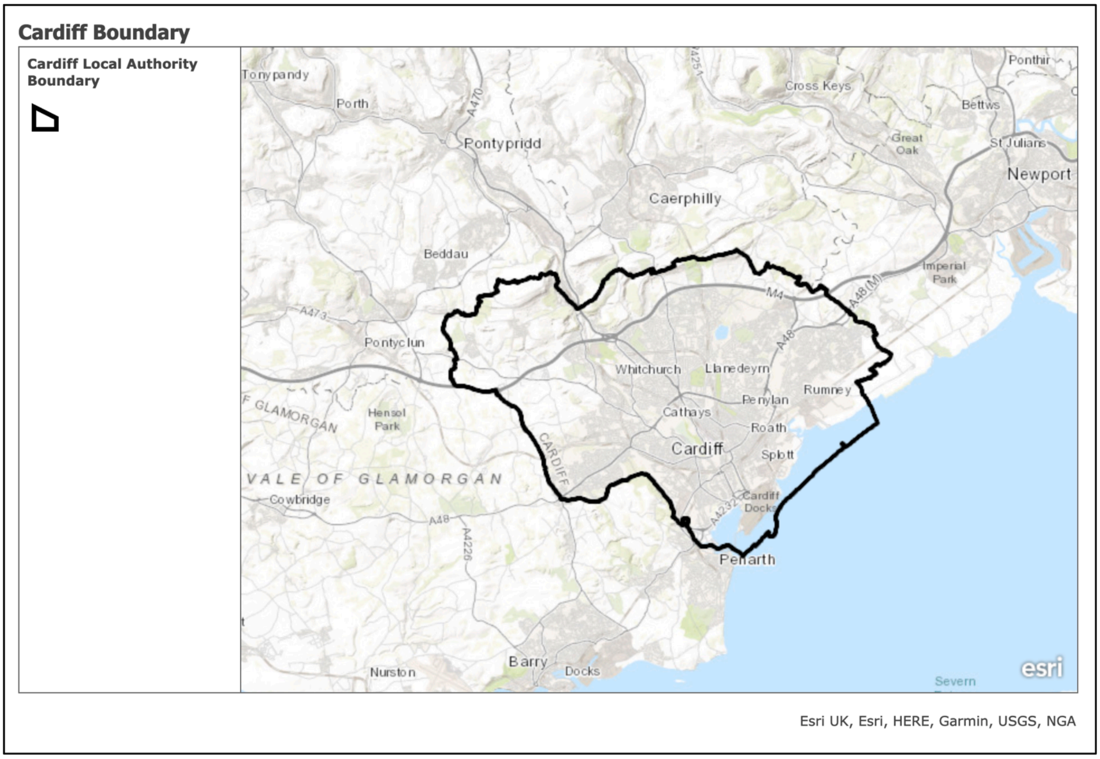


**Fig. 1.** Cardiff boundary.
**Source:** Office for National Statistics (2011b)

**Table 3**
Data and sources.

| Data | Source |
|---|---|
| Daily number of commuting trips | StatsWales (2020) |
| Average speeds | INRIX Roadway Analytics (2020) |
| Distance | INRIX Roadway Analytics (2020) |
| Vehicle operating costs | Department for Transport (2020) |
| Value of time | Department for Transport (2020) |
| Average annual household income | Office for National Statistics (2020) |
| Commuting mode split | Office for National Statistics (2011a) |

Ceredigion and Powys, the English local authorities, and the five Cardiff routes were grouped, respectively, and their combined average speed and average distance were used for the calculations.

INRIX Roadway Analytics[7] was used to retrieve information on the average speed and distance of each chosen route. INRIX Roadway Analytics (2020) is a traffic analysis tool that uses both roadway network and historical data. Each route chosen was loaded onto INRIX Roadway Analytics as a 'Corridor' by selecting the route's start and end point. The chosen date ranges for the data were January 1, 2018 to December 31, 2018 and January 1, 2019 to December 31, 2019, with only the weekdays included to reflect workdays, which is when most congestion takes place and when a congestion charge would apply. The 2-hour morning peak period selected for this analysis was 07:00 – 09:00, as this is the time segment with the highest congestion. The Performance Charts feature on INRIX Roadway Analytics was used to retrieve the 2018 and 2019 average speeds (in km per hour), which were then averaged for use in the calculations, for each route for the specified morning peak period.

The route distance (in km) was retrieved from the 'Corridor' information. Route details can be found in Appendix A.

After data on average speed and distance was collected, the monetary costs component of GC in pence per km was calculated. Following WebTAG Table A 1.3.13 (Department for Transport, 2020), fuel costs were estimated using the following function:

$$L = a/v + b + c.v + d.v^2 \qquad (2)$$

where:

L = costs in pence per kilometre,
v = average speed in kilometres per hour,
a, b, c, d are parameters for each vehicle category (in this case, petrol, diesel, or electric car).

We adapted WebTAG Table A 1.3.15 (Department for Transport, 2020), and calculated non-fuel costs per km (not per link) using the following formula:

$$C = a_1 + b_1/v \qquad (3)$$

where:

C = costs in pence per kilometre,
v = average speed in kilometres per hour,
$a_1$ is a parameter for distance related costs defined for each vehicle category.
$b_1$ is a parameter for vehicle capital saving defined for each vehicle category (only relevant to working vehicles).

The average speed for each route was obtained from INRIX RA. The parameters in Equations (2) and (3) were taken from Tables A 1.3.13 and A 1.3.15, respectively (Department for Transport, 2020) and converted to 2020 prices using the 2020 GDP deflator from the WebTag Annual Parameters Table (Department for Transport, 2020). The VOC

[7] Data was obtained from INRIX via public sector authority contract. Neither INRIX nor the South Wales Trunk Road Agent, which was the public sector authority, have any affiliation with the analysis, results or publication of this paper.

component of GC was calculated by adding the fuel and non–fuel costs for each route.[8]

To estimate the travel time costs component of GC, the VOT was multiplied by the inverse of speed on each route. The VOT per average vehicle commuting on a weekday during the morning peak, 07:00–10:00, was taken from WebTAG Table A 1.3.5 (Department for Transport, 2020), and updated to 2020 values and prices using the 2020 GDP deflator from the Annual Parameters Table (Department for Transport, 2020). One caveat is that this value of commuting time is a weighted average representative of the UK, not of Wales, or of each local authority.

Thus, the GC of travel in pence per km was calculated for each route. To calculate the GC per trip for each origin, the GC in pence per km for each route was multiplied by the route distance (in km). The detailed numbers are presented in Appendix B.

Following Di Ciommo and Lucas (2014), to understand the first effect of a congestion charge, before any response from traffic through mode or time of travel change, re-routing or trip suppression, we added the £2 congestion charge to the GC for each route. All commuting trips originate from home and need to return home, so the charge was assumed to be perceived by car commuters as affecting their outbound and return journeys. For this reason, only half of the proposed £2 charge in Cardiff was added to the GC of travel, i.e., £1 or 100 pence.

The increase in GC only represents the new GC before a new equilibrium has been found. The GC of travel will initially increase because of the introduction of the congestion charge, but soon after that, it will also decrease due to reduced travel times as a result of an initial decrease in traffic volumes (Santos and Bhakar, 2006). Typically, though, there will be a net increase.[9]

### 3.2. Potential reductions in commuting trips by car

A truncated trip matrix[10] was built to include the daily number of commuting trips by car from different local authorities to Cardiff in 2019, the baseline year. The number of commuting trips by car to Cardiff from each of these local authorities was estimated by multiplying the overall number of commuting trips to Cardiff from each origin by the percentage of commuting trips by car from each origin. The number of commuting trips to Cardiff from each origin was taken from the 2019 detailed commuting patterns in Wales by Welsh local authority (StatsWales, 2020).

The number of commuting trips by car from England was estimated as the difference between the total number of commuting trips by car into Cardiff and those originating from other Welsh local authorities. There are 69,036 commuting trips by car to Cardiff from other Welsh local authorities (StatsWales, 2020). The total number of commuting trips by car into Cardiff is 80,000 per day (Cardiff Council, 2020a). The number of commuting trips by car from England to Cardiff made up the remainder of trips from outside, i.e., 10,964.

The percentage of commuting trips by car was taken from the 2011 Census (Office for National Statistics, 2011a). Since StatsWales (2020) data combined Pembrokeshire and Carmarthenshire, and Ceredigion and Powys, and the English local authorities, the averaged car mode split for each of the combined origins was used.

Once the truncated trip matrix was built, the potential reductions in commuting trips by car from each origin was estimated under different elasticity assumptions. Since GC were used for the calculations, the elasticities assumed had to be elasticities with respect to GC. In the context of urban congestion charging projects in operation, to our knowledge, the only elasticities that have been computed with respect to GC were computed for London, as shown on Table 2. These elasticities range from −1 to −3, so these were the values assumed. For comparison purposes, a lower value of −0.5 was also used, especially bearing in mind that alternatives to the car in Cardiff are limited in comparison to London.

The caveat regarding the estimated potential reductions in the number of commuting trips by car is that we did not use a dynamic traffic assignment and simulation model with speed-flow functions calibrated to the Cardiff network and its incoming roads, so potential increases in speed and consequent reductions in time costs were not estimated. Reductions in time costs would eventually translate in subsequent increases in the number of commuting trips by car, both from former drivers and also from new wealthy drivers who might be attracted on to the roads. These increases, however, would typically be lower in absolute terms than the initial reductions.

Another point to note is that we did not include commuting trips originating in Cardiff and finishing in other local authorities. There are around 10,500 such trips per day. These trips impose some congestion within Cardiff (before they leave Cardiff) and would be liable to pay the charge on their return, when crossing the cordon inbound, probably in the evening, if charging were to apply then too.

### 3.3. Potential distributional impacts

A simple distributional impacts analysis was carried out to establish the potential impacts of the proposed charge on car commuters to Cardiff from different local authorities. This analysis was mainly based on the average income in each local authority and the percentage of the working population commuting by car to Cardiff from each local authority, informed by methods used by Santos and Rojey (2004) and Di Ciommo and Lucas (2014).

The analysis provides an estimate of the initial impact (i.e. additional cost) of a £2 charge on the average annual household income of car commuters from all the local authorities in question.

The average annual household income for each local authority was obtained from the Office for National Statistics (2020), which contains total household income in 2018 by Middle layer Super Output Area.[11] The £2 charge was multiplied by the number of working days in a year (261 days), which yielded an annual additional cost of £522. The annual cost of the charge as a percentage of the average annual household income for each local authority was then calculated.

The percentage of the commuting population from each origin that would be affected by the additional cost was then estimated. Firstly, the percentage of people who work in Cardiff was calculated for all origins using the 2019 detailed commuting patterns in Wales by Welsh local authority (StatsWales, 2020). This was then multiplied by the percentage of people from that local authority who commute by car as drivers, regardless of the destination (estimated on the basis of absolute numbers published by the Office for National Statistics, 2011a).

The share of car commuting traffic with Cardiff as its destination and the potential share of revenues generated by different local authorities were also explored to help establish the likely acceptability, fairness and overall impact of the proposed charge. Car commuting traffic with

[8] Parking costs were excluded from VOC due to the absence of information on the number of parking spaces in Cardiff from Cardiff Council and private providers. Parking costs would have inevitably increased GC and would have made the percentage increase in GC from a congestion charge smaller, as the starting point would have been a higher cost.

[9] Due to the lack of data on flows, it was not possible to estimate the final change in speeds and GC. This could have been done with data on flows using speed-flow relationships. However, more detailed estimates of the final net changes in flows, speeds and GC can usually be computed using traffic assignment and simulation software, provided it has been calibrated to the city in question.

[10] A trip matrix has N origins and also N destinations. In this project, the matrix was truncated because it had N origins and only one destination, i.e. Cardiff.

[11] Middle layer Super Output Area is a geographic hierarchy with an average population of 7,200.

**Table 4**
GC in pence per km and GC in pence per trip, including rankings.

| GC per km | | | | GC per trip | | | |
|---|---|---|---|---|---|---|---|
| GC Ranking | Local Authority | GC in pence | Average speed (km per hour) | GC Ranking | Local Authority | GC in pence | Average distance travelled (km) |
| 1 | Vale of Glamorgan | 66 | 29 | 1 | Pembrokeshire and Carmarthenshire | 4,118 | 132 |
| 2 | Caerphilly | 65 | 30 | 2 | Ceredigion and Powys | 3,778 | 102 |
| 3 | Cardiff | 60 | 32 | 3 | Swansea | 2,371 | 68 |
| 4 | Rhondda Cynon Taf | 53 | 38 | 4 | England (i.e. Bristol, Herefordshire, North Somerset and South Gloucestershire) | 2,360 | 71 |
| 5 | Newport | 43 | 49 | 5 | Neath Port Talbot | 2,128 | 63 |
| 6 | Merthyr Tydfil | 42 | 51 | 6 | Monmouthshire | 2,043 | 62 |
| = 7 | Torfaen | 41 | 52 | 7 | Blaenau Gwent | 1,973 | 51 |
| = 7 | Bridgend | 41 | 52 | 8 | Rhondda Cynon Taf | 1,579 | 30 |
| 8 | Blaenau Gwent | 39 | 56 | 9 | Merthyr Tydfil | 1,568 | 38 |
| 9 | Ceredigion and Powys | 37 | 60 | 10 | Torfaen | 1,513 | 37 |
| 10 | Swansea | 35 | 65 | 11 | Bridgend | 1,324 | 32 |
| 11 | Neath Port Talbot | 34 | 69 | 12 | Vale of Glamorgan | 1,077 | 16 |
| 12 | England (i.e. Bristol, Herefordshire, North Somerset and South Gloucestershire) | 33 | 70 | 13 | Newport | 1,001 | 23 |
| 13 | Monmouthshire | 33 | 71 | 14 | Caerphilly | 885 | 14 |
| 14 | Pembrokeshire and Carmarthenshire | 31 | 77 | 15 | Cardiff | 469 | 8 |

Source: authors' own, as explained in the text.

**Table 5**
Initial change to GC for commuting trips into and inside Cardiff as a result of a £2 congestion charge.

| Origin | GC in pence per km to Cardiff | | GC in pence per trip to Cardiff | | % change in GC (with congestion charge relative to GC) |
|---|---|---|---|---|---|
| | Original GC | GC including congestion charge | Original GC | GC including congestion charge | |
| Cardiff | 60 | 73 | 469 | 569 | + 21.3% |
| Blaenau Gwent | 39 | 41 | 1,973 | 2,073 | + 5.1% |
| Bridgend | 41 | 44 | 1,324 | 1,424 | + 7.6% |
| Caerphilly | 65 | 72 | 885 | 985 | + 11.3% |
| Merthyr Tydfil | 42 | 44 | 1,568 | 1,668 | + 6.4% |
| Monmouthshire | 33 | 35 | 2,043 | 2,143 | + 4.9% |
| Newport | 43 | 48 | 1,001 | 1,101 | + 10.0% |
| Rhondda Cynon Taf | 53 | 57 | 1,579 | 1,679 | + 6.3% |
| Torfaen | 41 | 44 | 1,513 | 1,613 | + 6.6% |
| Vale of Glamorgan | 66 | 72 | 1,077 | 1,177 | + 9.3% |
| Swansea | 35 | 37 | 2,371 | 2,471 | + 4.2% |
| Neath Port Talbot | 34 | 35 | 2,128 | 2,228 | + 4.7% |
| Pembrokeshire and Carmarthenshire | 31 | 32 | 4,118 | 4,218 | + 2.4% |
| Ceredigion and Powys | 37 | 38 | 3,778 | 3,878 | + 2.6% |
| England (i.e. Bristol, Herefordshire, North Somerset and South Gloucestershire) | 33 | 35 | 2,360 | 2,460 | + 4.2% |

Source: authors' own, as explained in the text.

Cardiff as its destination was defined as car commuting traffic that starts outside Cardiff and finishes in Cardiff, and car commuting traffic that starts and finishes in Cardiff.

## 4. Results

In this section, the research findings are presented, analysed and discussed.

### 4.1. Generalised costs

The GC of commuting trips into and inside Cardiff were computed using the methodology explained in Section 3.1. GC can be computed by km or by trip. As Table 4 shows, speed and distance play crucial roles in determining GC. When representative trips are sorted by GC per km, the order is the same as the order obtained when trips are sorted by average speed. In most cases, when representative trips are sorted by GC per trip, the order is the same as the order obtained when trips are sorted by average distance travelled. In turn, the rankings for GC per km and GC per trip are different, as displayed in Table 4.

As already mentioned in Section 3.1, the value of commuting time used in this study is a weighted average representative of the UK. In reality, individuals making these trips will have different values of commuting time reflecting heterogeneity (Hensher and Goodwin, 2004; Raux et al., 2012), but identifying these differences falls outside the scope of this research.

In summary, the GC of travel from different local authorities into Cardiff and inside Cardiff span a wide range and depend not only on distance travelled, but more importantly, on average speed. As Table 4 shows, the lower the speed, the higher the GC per km. Meanwhile, in most cases (with the exceptions of Swansea, Rhondda Cynon Taf and the Vale of Glamorgan), the longer the distance travelled, the higher the GC per trip.

Table 5 presents the initial change in GC that drivers coming to Cardiff would face if a £2 charge were introduced, before taking into account travel time savings, and before a new equilibrium were found. As mentioned in Section 3, all commuting trips from home to work need to return from work to home, so the charge can reasonably be assumed to be perceived by drivers as affecting both their trip out and their trip back. For that reason, only half of the proposed charge, £1, was added to the GC of travel.

Considering all the local authorities, the highest initial percentage

**Table 6**
Change in the number of commuting trips by car into and within Cardiff as a result of a £2 congestion charge under different assumptions of elasticities with respect to GC.

| Local authority (origin) | Baseline number of commuting trips by car to Cardiff | $\eta = -0.5$ Change | % change | $\eta = -1$ Change | % change | $\eta = -2$ Change | % change | $\eta = -3$ Change | % change |
|---|---|---|---|---|---|---|---|---|---|
| Cardiff | 83,654 | −8,910 | −10.7% | −17,820 | −21.3% | −35,640 | −42.6% | −53,460 | −63.9% |
| Blaenau Gwent | 1,320 | −33 | −2.5% | −67 | −5.1% | −134 | −10.1% | −201 | −15.2% |
| Bridgend | 6,821 | −258 | −3.8% | −515 | −7.6% | −1,031 | −15.1% | −1,546 | −22.7% |
| Caerphilly | 10,806 | −610 | −5.6% | −1,220 | −11.3% | −2,441 | −22.6% | −3,661 | −33.9% |
| Merthyr Tydfil | 1,968 | −63 | −3.2% | −125 | −6.4% | −251 | −12.8% | −376 | −19.1% |
| Monmouthshire | 1,685 | −41 | −2.4% | −82 | −4.9% | −165 | −9.8% | −247 | −14.7% |
| Newport | 6,577 | −329 | −5.0% | −657 | −10.0% | −1,315 | −20.0% | −1,972 | −30.0% |
| Rhondda Cynon Taf | 16,225 | −514 | −3.2% | −1,027 | −6.3% | −2,055 | −12.7% | −3,082 | −19.0% |
| Torfaen | 2,884 | −95 | −3.3% | −191 | −6.6% | −381 | −13.2% | −572 | −19.8% |
| Vale of Glamorgan | 16,435 | −763 | −4.6% | −1,526 | −9.3% | −3,052 | −18.6% | −4,578 | −27.9% |
| Swansea | 1,695 | −36 | −2.1% | −71 | −4.2% | −143 | −8.4% | −214 | −12.7% |
| Neath Port Talbot | 1,420 | −33 | −2.4% | −67 | −4.7% | −133 | −9.4% | −200 | −14.1% |
| Pembrokeshire and Carmarthenshire | 771 | −9 | −1.2% | −19 | −2.4% | −37 | −4.9% | −56 | −7.3% |
| Ceredigion and Powys | 432 | −6 | −1.3% | −11 | −2.6% | −23 | −5.3% | −34 | −7.9% |
| England (i.e. Bristol, Herefordshire, North Somerset and South Gloucestershire) | 10,964 | −232 | −2.1% | −464 | −4.2% | −929 | −8.5% | −1,393 | −12.7% |
| *Total* | 163,654 | | | | | | | | |
| *Total change, excluding Cardiff* | | −3,022 | | −6,045 | | −12,089 | | −18,134 | |
| *(% change with respect to baseline total)* | | (−1.8%) | | (−3.7%) | | (−7.4%) | | (−11.1%) | |
| *Total change, including Cardiff* | | −11,932 | | −23,865 | | −47,729 | | −71,594 | |
| *(% change with respect to baseline total)* | | (−7.3%) | | (−14.6%) | | (−29.2%) | | (−43.7%) | |

Source: authors' own, as explained in the text.

increase in GC as a result of the congestion charge would be for commuting trips inside Cardiff, followed by trips from Caerphilly. As Table 5 shows, the GC for commuting trips inside Cardiff would increase by 21.3%. These are precisely the trips that would not be liable to pay the congestion charge according to the proposals in the Transport White Paper (Cardiff Council, 2020a). Excluding Cardiff, commuting trips from Caerphilly would have the highest increase in GC. These percentage increases in GC are comparable to those reported in Snellen and Hilbers (2010, p. 10, Table 2), who find that, generally, a congestion charging scheme would increase the GC of commuting by 13.9% in the Netherlands, before taking into account travel time savings.

Overall, the higher the GC of a trip, the lower the impact of a constant congestion charge will be. Table 5 shows that Pembrokeshire and Carmarthenshire, for example, which have the highest GC per trip, would have the lowest percentage increase in GC. For drivers used to having a high GC per trip, paying the congestion charge will make little difference.

However, there are caveats to these results. The implicit assumption is that drivers perceive time costs and monetary costs in exactly the same way (Department for Transport, 2017). For instance, if GC increase by 10%, it is assumed that drivers will react in the same way, regardless of whether the increase is due to an increase in fuel prices, a decrease in speeds or the introduction of a congestion charge. Time and money are interchangeable once they have been converted into each other's units. Although this is standard practice in transport studies, it could be argued that perceptions vary when changes occur in different components of the GC of travel, even if the final change in GC is the same.

### *4.2. Potential reductions in commuting trips by car*

The purpose of introducing a £2 congestion charge would be to reduce the number of cars on the roads, especially during peak times. The reduction will depend on a number of factors, including the availability of alternative transport modes (discussed further down) and the income of those liable to pay the charge. Drivers with higher income tend to have a higher value of time, so they will be relatively more willing to pay the charge if by paying the charge, they experience reduced travel times and the time they save has a total value higher than £2 (Fosgerau, 2006; Santos and Bhakar, 2006).

The above factors will influence the driver's reaction to the congestion charge, or in other words, his elasticity. As explained in Section 3.2, we assumed elasticities with respect to GC of −1, −2, and −3, and a low elasticity of −0.5 for comparison purposes. Using these elasticity values and knowing the initial percentage change in GC as estimated in Section 4.1, the initial percentage reduction in the number of trips was estimated, along with the likely reduction in the number of trips. These are shown on Table 6. In reality, trips originating from local authorities with less reliable or less frequent public transport services into Cardiff are likely to have lower elasticities than trips originating from local authorities with fast and reliable public transport services into Cardiff.

As explained in Section 3.2, the caveat regarding the estimated potential reductions in the number of commuting trips by car is that we did not model potential increases in speed and consequent reductions in time costs. Reductions in time costs would translate in subsequent increases in the number of commuting trips by car, although these increases would typically be lower in absolute terms than the initial reductions.

As can be seen on Table 6, the initial potential reductions in the number of commuting trips by car finishing in Cardiff are likely to be between 3.7% and 11.1%. However, the highest percentage reductions would be for trips starting and finishing in Cardiff, if these were liable to pay the £2 charge. This would boost the reductions to 14.6% under an elasticity assumption of −1, and 43.7% under an elasticity assumption of −3. The current proposals, which do not contemplate charging trips that start and finish in Cardiff, miss a great opportunity. Needless to say, if trips starting and finishing in Cardiff were to be liable to pay the charge, then fast, reliable and affordable transport alternatives would need to be in place *before* the congestion charge was implemented. This would necessitate the cycle network, tram-train lines and additional metro stations to be fully operational before congestion charging went live, which would effectively mean moving its introduction back in time.

The current proposals include the introduction of a charging mechanism in 2025 and the completion of the cycle network, tram-train lines and additional metro stations over 2025–2028 (Cardiff Council, 2020a, p. 29).

Not charging trips that start and finish in Cardiff constrains the potential reductions in traffic and may also result in an increase in the number of those trips. The well-known effect of induced demand may have negative impacts in Cardiff. If the number of cars on the roads is reduced, thanks to reductions in commuting trips from neighbouring local authorities, speeds will increase and the GC of travel will decrease. With lower GC, commuters that previously did not drive may be attracted onto the roads, as was the case in London (Santos and Bhakar, 2006). The White Paper hints that the newly recovered road space will be reallocated to buses, through bus priority lanes (Cardiff Council, 2020a, p. 14), and to bicycles, through cycleways (Cardiff Council, 2020a, p. 20). This may go some way towards deterring induced traffic. It is worth highlighting, however, that the induced demand effect may also apply to trips originating from outside Cardiff, although those (probably wealthy) drivers would be liable to pay the congestion charge, unlike Cardiff drivers.

### 4.3. Potential distributional impacts

Households with at least one member commuting to Cardiff by car every working day would have an annual additional cost of £522 due to a £2 congestion charge, based on 261 working days a year. Fig. 2 illustrates the average annual household income, taken from the Office for National Statistics (2020), and the annual cost of the congestion charge as a percentage of the average annual household income by local authority. Those living in local authorities with lower average incomes would pay, on average, a higher percentage of their income towards a congestion charge when compared to those living in local authorities with higher average incomes.

Table 7 shows the number and percentage of commuting trips from each local authority that are made by car to Cardiff, estimated as explained in Section 3.3. Table 7 also shows average annual household income by local authority. There are some important differences across. For example, Blaenau Gwent and Rhondda Cynon Taf have the lowest average annual household incomes. As a result, on average, the congestion charge would take the highest percentage of the annual household income of commuters from these local authorities, as shown on Fig. 2. However, the number and percentage of commuters from these local authorities that would be negatively impacted would be quite different. Whereas from all commuting trips originating from Blaenau Gwent (including those with destination in Blaenau Gwent itself) 4.4% are trips made by car with Cardiff as destination, the number for Rhondda Cynon Taf is 15.7%. There are 1,320 commuting trips by car per day from Blaenau Gwent to Cardiff and 16,225 from Rhondda Cynon Taf. At the other end of the spectrum there is Monmouthshire. Monmouthshire has the highest average annual household income, with an income 1.23 times the average income of all the local authorities in question. From all commuting trips originating from Monmouthshire (including those with destination in Monmouthshire itself), 3.8% are trips made by car with Cardiff as destination. There are 1,685 commuting trips by car per day from Monmouthshire to Cardiff.

The potential distributional impacts of a £2 congestion charge are local authority specific, and crucially depend on whether workers from that local authority commute to Cardiff and what mode of transport they use to do so. These results are in line with findings from Santos and Rojey (2004), who find that the distributional impacts of a road pricing scheme are likely to vary from locality to locality, depending on where people live and work, and what mode of transport they use to get to work.

Table 7 also shows the percentage of car commuting traffic with Cardiff as its destination generated by each local authority and the percentage of congestion charge revenues that would be generated by each local authority, if current shares of traffic generation were to be maintained after the introduction of a congestion charge. The

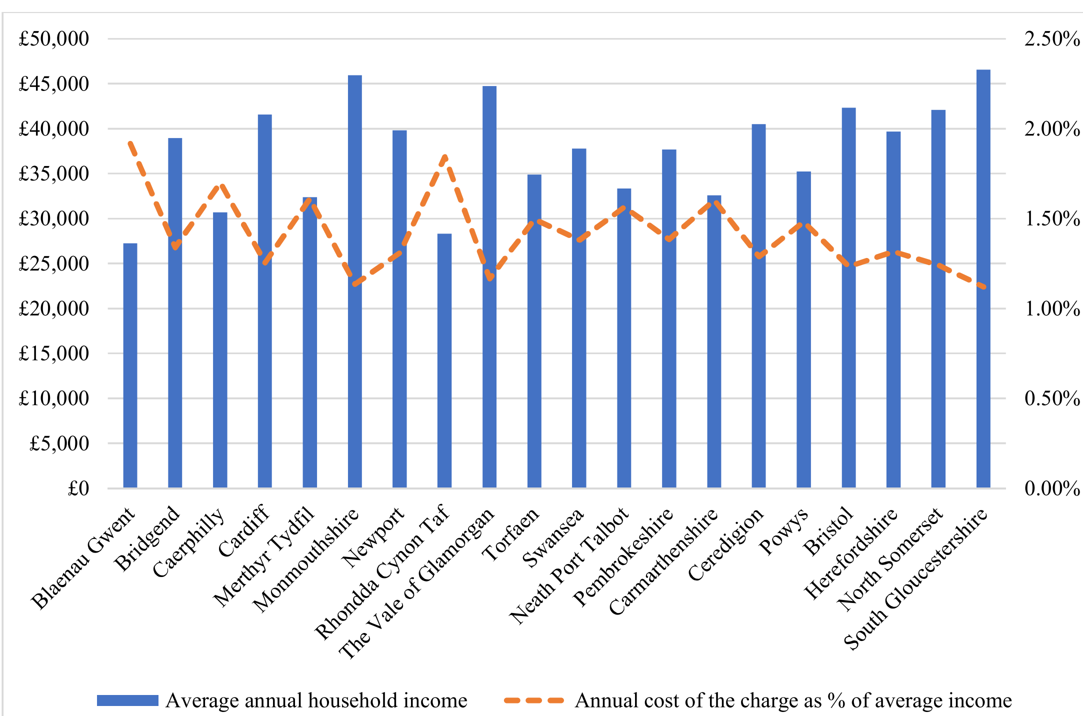


**Fig. 2.** Average annual household income and annual cost of the congestion charge as a percentage of average annual household income by local authority. **Source:** as explained in the text.

**Table 7**
Income, number and percentage of commuting trips by car to Cardiff, percentage of car commuting traffic generated in Cardiff, and percentage of congestion charge revenues likely to be generated by each local authority.

| Local authority (origin) | Average annual household income | Average annual household income for each local authority divided by average annual household income for all local authorities | Baseline number of commuting trips by car to Cardiff | Percentage of commuting trips by car to Cardiff relative to total number of commuting trips originating from each local authority | Percentage of commuting trips by car to Cardiff from each local authority relative to total number of commuting trips by car with destination in Cardiff | Percentage of congestion charge revenues likely to be generated |
|---|---|---|---|---|---|---|
| Cardiff | £41,579 | 1.11 | 83,654 | 43.3% | 51.1% | |
| Blaenau Gwent | £27,233 | 0.72 | 1,320 | 4.4% | 0.8% | 1.6% |
| Bridgend | £38,968 | 1.04 | 6,821 | 10.3% | 4.2% | 8.5% |
| Caerphilly | £30,713 | 0.82 | 10,806 | 13.4% | 6.6% | 13.5% |
| Merthyr Tydfil | £32,386 | 0.86 | 1,968 | 7.5% | 1.2% | 2.5% |
| Monmouthshire | £45,945 | 1.22 | 1,685 | 3.8% | 1.0% | 2.1% |
| Newport | £39,815 | 1.06 | 6,577 | 9.3% | 4.0% | 8.2% |
| Rhondda Cynon Taf | £28,313 | 0.75 | 16,225 | 15.7% | 9.9% | 20.3% |
| Torfaen | £34,877 | 0.93 | 2,884 | 7.1% | 1.8% | 3.6% |
| Vale of Glamorgan | £44,747 | 1.19 | 16,435 | 26.7% | 10.0% | 20.5% |
| Swansea | £37,803 | 1.00 | 1,695 | 1.5% | 1.0% | 2.1% |
| Neath Port Talbot | £33,363 | 0.89 | 1,420 | 2.2% | 0.9% | 1.8% |
| Pembrokeshire and Carmarthenshire | £35,139 | 0.93 | 771 | 2.6% | 0.5% | 1.0% |
| Ceredigion and Powys | £37,877 | 1.01 | 432 | 0.8% | 0.3% | 0.5% |
| England (i.e. Bristol, Herefordshire, North Somerset and South Gloucestershire) | £42,653 | 1.13 | 10,964 | 5.0% | 6.7% | 13.7% |

Source: authors' own, as explained in the text.

percentage of car commuting traffic generated by each local authority was simply computed as the number of trips starting in that local authority and finishing in Cardiff divided by the total number of car commuting trips starting outside Cardiff and finishing in Cardiff and car commuting trips starting and finishing in Cardiff. The percentage of congestion charge revenues likely to be generated by each local authority was computed as the number of trips starting in that local authority and finishing in Cardiff divided by the total number of car commuting trips starting outside Cardiff and finishing in Cardiff. Trips starting and finishing in Cardiff would not be liable to pay the charge.[12]

As can be seen from Table 7, 43.3% of Cardiff workers commute by car, and they generate over 50% of the car commuting traffic,[13] yet they would not be liable to pay the charge. As a result, car commuters coming from outside Cardiff would generate a percentage of revenues roughly twice as high as the percentage of traffic they generate. For example, car commuters from Blaenau Gwent would generate 1.6% of the revenues even though they are only responsible for 0.8% of car commuting traffic in Cardiff.

A flat £2 congestion charge applied uniformly regardless of household income would be, in principle, regressive because it would impose a burden that would represent a higher fraction of income for those on lower incomes. In addition, the fact that it would be imposed on those commuting from neighbouring local authorities but not on those starting and finishing their trips in Cardiff raises the question of public and political acceptability. Trips starting and finishing in Cardiff would not be liable to pay the charge, yet they would continue to make up most of the traffic. Residents from neighbouring authorities commuting to Cardiff and their local governments are likely to oppose the plans.

The regressive impacts from the congestion charge, however, could be reverted, depending on how the revenues were spent (Crawford, 2000; Eliasson and Mattsson, 2006). In the case of Cardiff, any revenues raised from congestion charging would be "spent directly on public transport" (Cardiff Council, 2020a, p. 28), in line with the Transport Act 2000 (Acts of Parliament, 2000).

Although revenue allocation is a crucial point, another crucial point is the timing of investments. Any improvements in public transport would need to be in place *before* the congestion charge were introduced (Cardiff Council, 2020a, p.28), or otherwise, commuters would not have feasible alternatives to the private car. Before congestion charging goes live, the plan is for Cardiff Council to team up with the Welsh Government and Transport for Wales, and neighbouring local authorities, and deliver a number of transport projects (Cardiff Council, 2020a, p. 28). These projects include extra train capacity on key Valley lines, new/improved Park and Rides, and the completion of Phase 1 of the Metro Plus (Cardiff Council, 2020a, p. 28). In addition, Cardiff Council is proposing a rapid-bus regional network with regular and affordable bus services, in order to connect towns across the city region directly to the centre of Cardiff (Cardiff Council, 2020a, 2020b).

One point to note is that if trips starting and finishing in Cardiff are eventually made liable to pay the congestion charge too, then the projects currently planned to be completed over 2025–2028 will need to be operational before the charge is implemented, not after. These projects include completion of the cycle network, tram-train lines and additional metro stations (Cardiff Council, 2020a, p. 29).

The availability of practical, fast, reliable and affordable alternatives to the car to reach Cardiff and travel inside Cardiff is key. Such a policy package is likely to increase the chances of the scheme being acceptable to the public (Jones, 1991; Schlag and Teubel, 1997; Verhoef et al., 1997; Schlag and Schade, 2000; Thorpe et al., 2000; Jaensirisak et al., 2005). Affordability is especially important. Revenues could be used to fund fare-free public transport, especially from neighbouring local authorities, or reimbursements to travellers. Reimbursements could be done by subsidising employers to provide their employees with a commuting allowance (Small, 1992). Fare-free public transport or reimbursements targeted at lower income groups could make the overall

[12] As noted in Section 3.2, workers commuting by car from Cardiff to local authorities outside Cardiff would cross the cordon inbound on their return, probably in the evening, and would be liable to pay the charge then, if charging applied during the evening peak.

[13] For comparison purposes, as explained in Section 2.1.2, in Stockholm, two-thirds of people commuting to workplaces inside the cordon are from outside the cordon (Eliasson et al., 2009).

distributional impacts of a congestion charge in Cardiff neutral or even progressive.

## 5. Conclusions, policy recommendations and lines for future research

In this paper, we assess the initial potential impacts of a £2 congestion charge on inbound car commuting traffic in Cardiff. We focus on the initial change in the GC of travel and, using a range of plausible elasticity values of number of trips with respect to GC, we estimate initial potential reductions in the number of trips. We also conduct a preliminary distributional analysis. Trips starting and finishing in Cardiff without crossing the cordon would not be liable to pay the charge but we still compute the initial change in the GC of travel and the potential initial reductions in the number of these trips to inform what would happen if they were liable to pay the charge.

We find that the initial potential reductions in the number of commuting trips by car finishing in Cardiff are likely to be around 3.7% and 11.1%, for elasticity assumptions of −1 and −3, respectively. The highest percentage reductions, however, could be achieved by also charging trips with origin and destination in Cardiff. If these trips were liable to pay the charge, the reductions in the number of commuting trips by car could be as high as 14.6% to 43.7%.

One caveat regarding the estimated potential reductions in the number of commuting trips by car is that we did not model changes in speed or time costs. These would result in subsequent increases in the number of commuting trips by car, although these increases would be lower in absolute terms than the initial reductions. Another caveat is that we did not include the 10,500 commuting trips starting in Cardiff and finishing in other local authorities, which cause some congestion in Cardiff. These trips would be liable to pay the charge when crossing the cordon inbound on their way back, probably in the evening, if charging were to apply then too.

Not charging commuting trips by car that start and finish in Cardiff, as currently proposed by Cardiff Council (2020a), would not help discourage those trips, and could actually trigger an increase in the number of those trips. Commuters that previously did not drive may be attracted onto the roads as they would benefit from faster travel times without paying the congestion charge. The White Paper hints that the newly recovered road space will be reallocated to bus priority lanes and cycleways (Cardiff Council, 2020a, p. 14, p. 20). This may help deter induced demand. This induced demand effect may also apply to trips originating from outside Cardiff, as some commuters who previously did not drive may experience time savings with a value higher than the congestion charge.

Another consequence of not charging commuting trips by car that start and finish in Cardiff, which represent over half of the car commuting traffic with destination in Cardiff, is that the share of charge revenues contributed by car commuters coming to Cardiff from other local authorities would be approximately twice as high as the share of car commuting traffic they generate in Cardiff.

The proposed £2 congestion charge would be overall regressive. It would amount to an average annual additional cost of £522 per household and would affect households with low incomes the most. Blaenau Gwent and Rhondda Cynon Taf, for example, have the lowest average annual household incomes from all the local authorities in question. However, the number and percentage of commuting trips from these local authorities that are made by car are quite different, and so the number and percentage of households from these local authorities that would be negatively affected, would also be different.

Unsurprisingly, the potential distributional impacts of a £2 congestion charge would be local authority specific, and would ultimately depend on the number and percentage of workers from that local authority that commute by car. Santos and Rojey (2004) find similar results.

Having said the above, if the planned public transport improvements, especially those relating to trains and buses from neighbouring authorities into Cardiff, were up and running by the time the scheme went live, as is currently planned (Cardiff Council, 2020a, p. 28), then, there would be potential for the scheme to be neutral or even progressive. Affordability would be crucial. One option, for example, would be to use the revenues from the congestion charge to fund free-fare fast and reliable public transport from neighbouring local authorities into Cardiff or reimbursements to lower income groups, and combine those with a reallocation of road space to favour public transport, pedestrians and cyclists.

Although these conclusions refer to the case of Cardiff, they provide lessons to other cities considering the introduction of a congestion charge. First, if a large proportion of car commuting trips start and finish in the city, there is a clear argument for these trips to be liable to pay the congestion charge. Second, if all car commuters are liable to pay the charge regardless of their income, the charge will be regressive, unless lower income groups do not commute by car. Third, initial regressive impacts can be reverted, especially if charge revenues are used to fund public transport improvements, potentially free-fare public transport or financial compensation, especially to lower income groups, through for example, commuting allowances.

### *5.1. Policy recommendations*

Our main finding is that the proposed £2 congestion charge in Cardiff would be regressive, but this negative impact could be turned around if the charge were implemented after practical, fast, reliable and affordable alternative modes of transport from neighbouring authorities into Cardiff were in place, as is currently the plan.

Our first policy recommendation is therefore that the provision of realistic public transport alternatives from all local authorities generating trips into Cardiff, becomes a condition for congestion charging implementation. Should these transport investments be delayed, so should the implementation of congestion charging be.

We also find that not charging car commuting trips that start and finish in Cardiff would reduce the impact from the scheme. If these trips were liable to pay the charge, higher traffic reductions would be achieved, and the effects of induced demand would be reduced. Charging trips that start and finish in Cardiff would probably generate a public backlash from Cardiff residents, and this would be costly for politicians who need votes to stay in power. Nonetheless, given the results found in the present study, if a congestion charge were indeed introduced in Cardiff, our second policy recommendation is that trips that start and finish in Cardiff should be liable to pay the charge, assuming the objective was to reduce congestion. Should these trips be liable, then, our third policy recommendation is that transport improvements within Cardiff take place *before* the charge is implemented, and indeed become a condition for the charge to be implemented.

### *5.2. Lines for future research*

Given that a £2 flat congestion charge in Cardiff would be regressive, future research needs to focus on revenue allocation that will revert, at least to some extent, the negative distributional impacts. In order to do this, a dynamic transport model including all modes should be used, allowing for different responses to the charge and heterogeneity in income and value of time. In addition, given that workplace parking levies in Cardiff appear to have higher public acceptability than congestion charging (Santos et al., 2020), a comparative study exploring the impacts from both workplace parking levies and congestion charging on traffic and equity seems to be in order.

## CRediT authorship contribution statement

**Georgina Santos:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Angelique Caranzo:** Data curation, Formal analysis, Writing - original draft.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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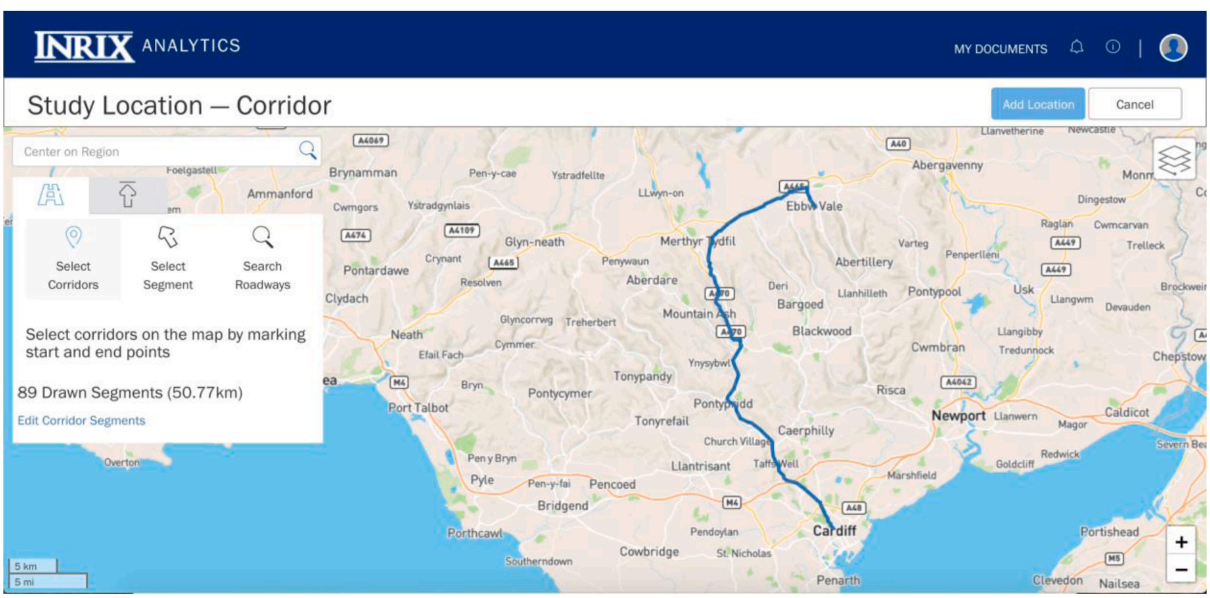
## Appendix A – Details of representative routes

Data source for distance and speed: INRIX Roadway Analytics (2020).
Date ranges: 2018-01-01 - 2018-12-31, 2019-01-01 - 2019-12-31.
Days of the week: Monday to Friday.
Averaged 2018 and 2019 speeds are for the morning peak period (07:00 – 09:00).

### TRIPS FROM OUTSIDE LOCAL AUTHORITIES TO CARDIFF

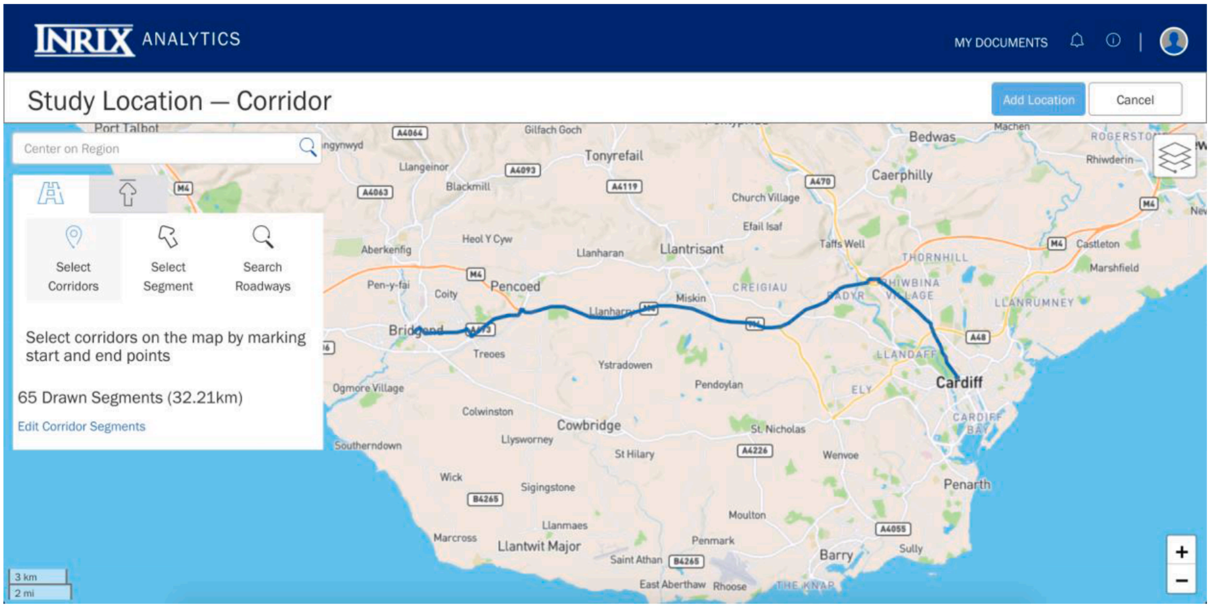
The end point of all trips from outside local authorities to Cardiff is the same.

*From Blaenau Gwent to Cardiff*



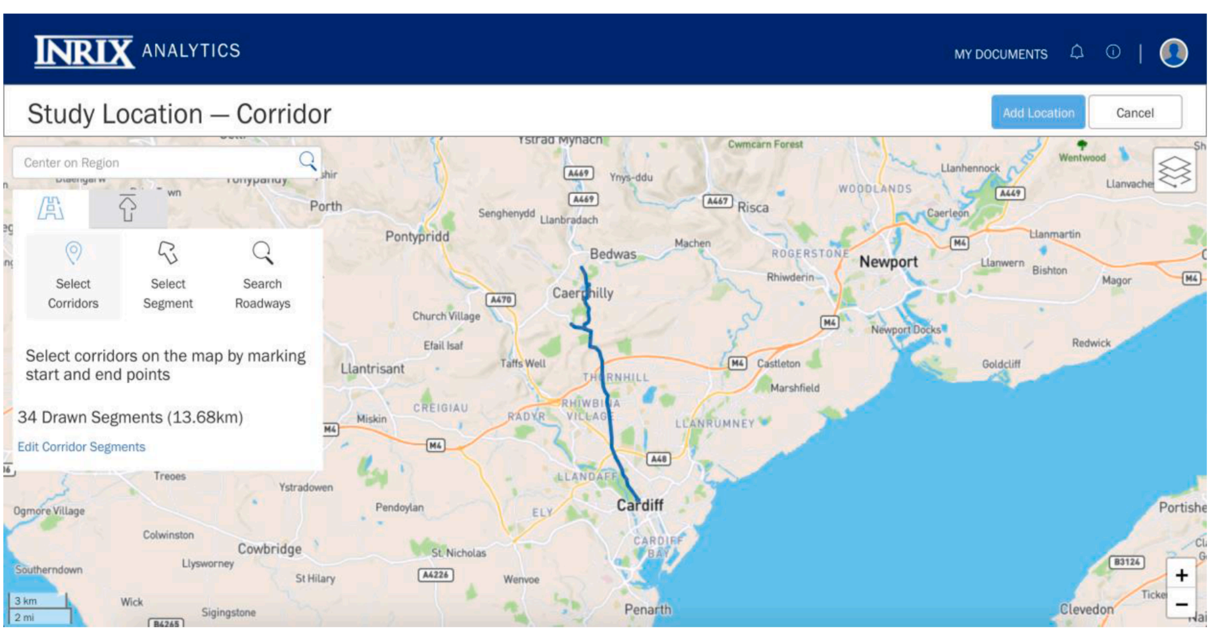

| | |
|---|---|
| Distance in km | 50.77 |
| Average speed in km per hour | 56.34 |
| Average travel time in minutes | 54 |
| Average travel time in minutes per km | 1.06 |

*From Bridgend to Cardiff*



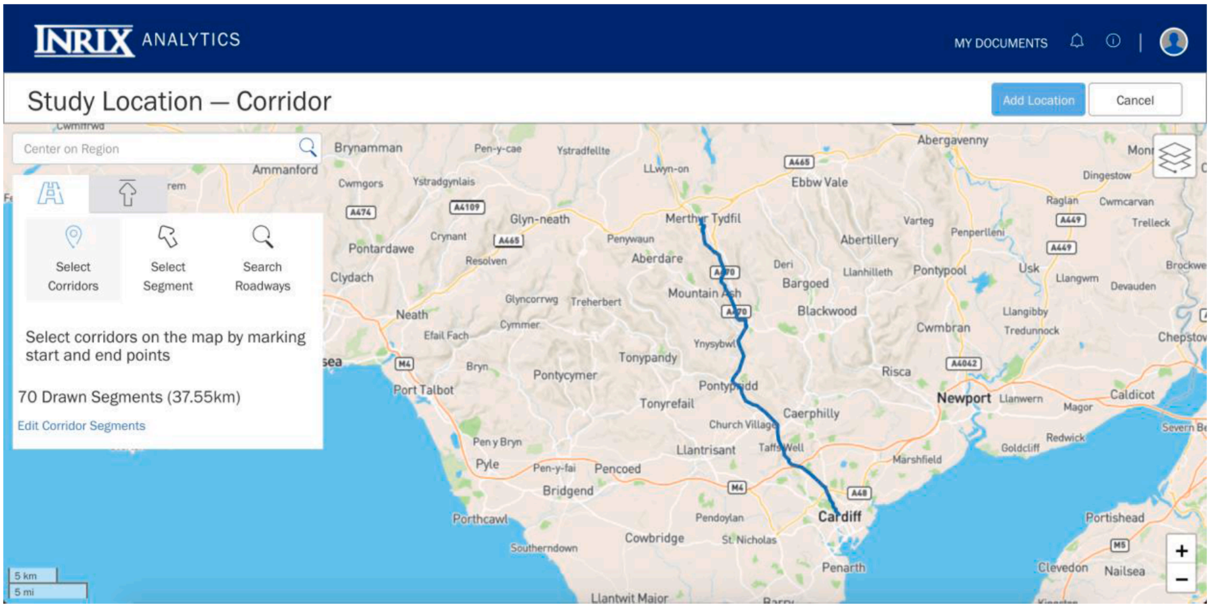

| | |
|---|---|
| Distance in km | 32.21 |
| Average speed in km per hour | 52.33 |
| Average travel time in minutes | 37 |
| Average travel time in minutes per km | 1.15 |

*From Caerphilly to Cardiff*



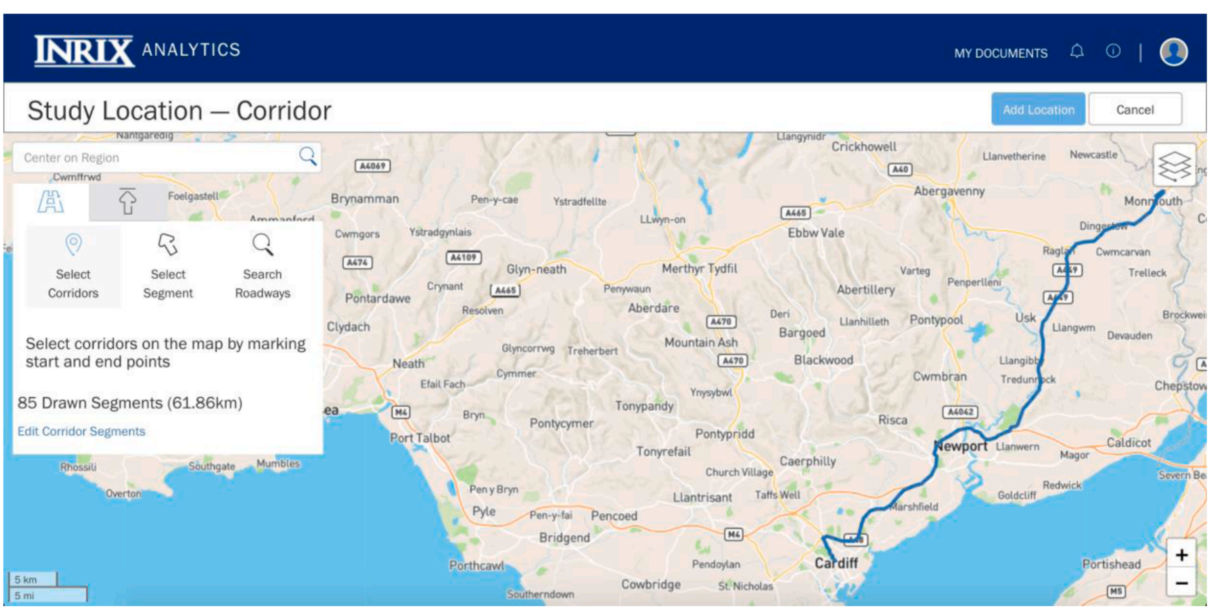

| | |
|---|---|
| Distance in km | 13.68 |
| Average speed in km per hour | 29.85 |
| Average travel time in minutes | 27 |
| Average travel time in minutes per km | 2.01 |

*From Merthyr Tydfil to Cardiff*



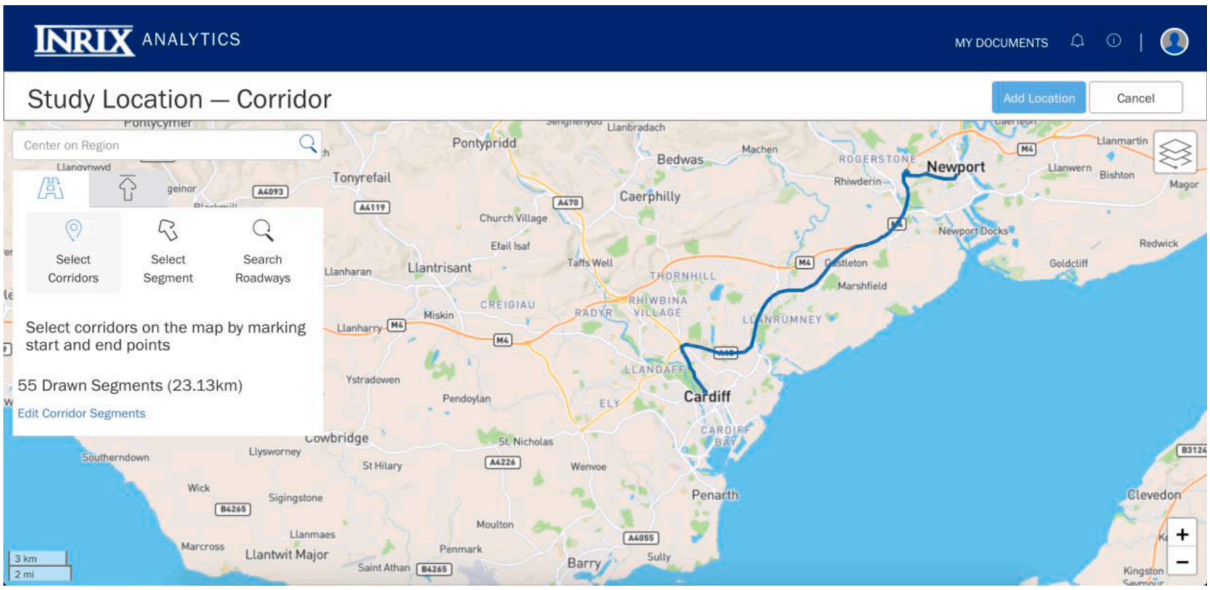

| | |
|---|---|
| Distance in km | 37.55 |
| Average speed in km per hour | 51.23 |
| Average travel time in minutes | 44 |
| Average travel time in minutes per km | 1.17 |

*From Monmouthshire to Cardiff*



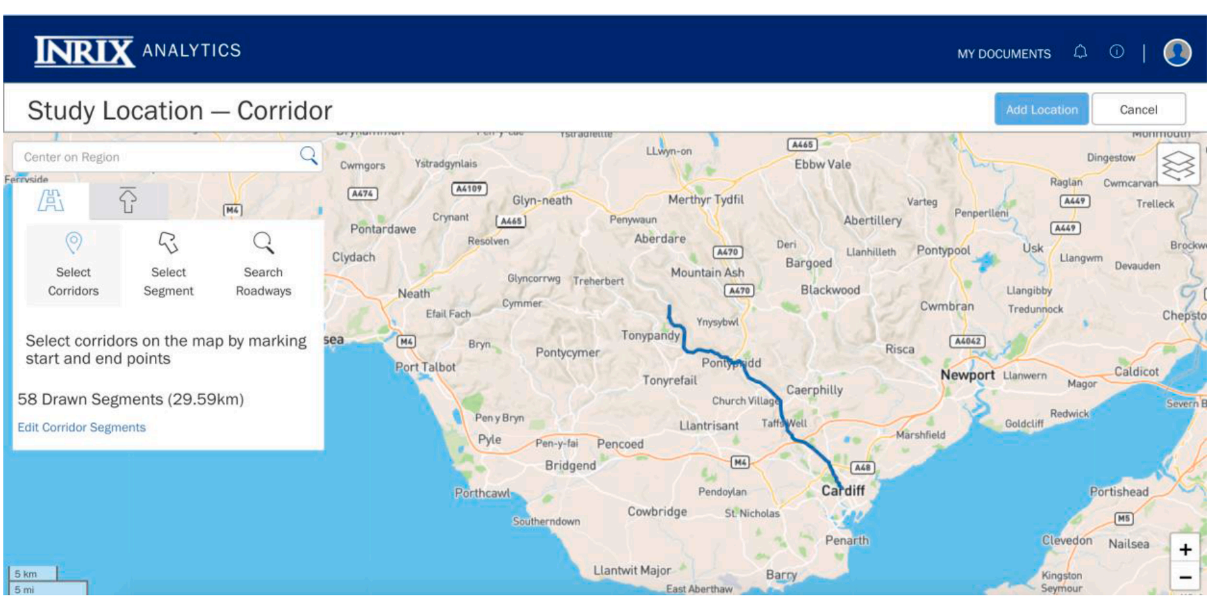
| | |
|---|---|
| Distance in km | 61.86 |
| Average speed in km per hour | 70.71 |
| Average travel time in minutes | 52 |
| Average travel time in minutes per km | 0.85 |

*From Newport to Cardiff*



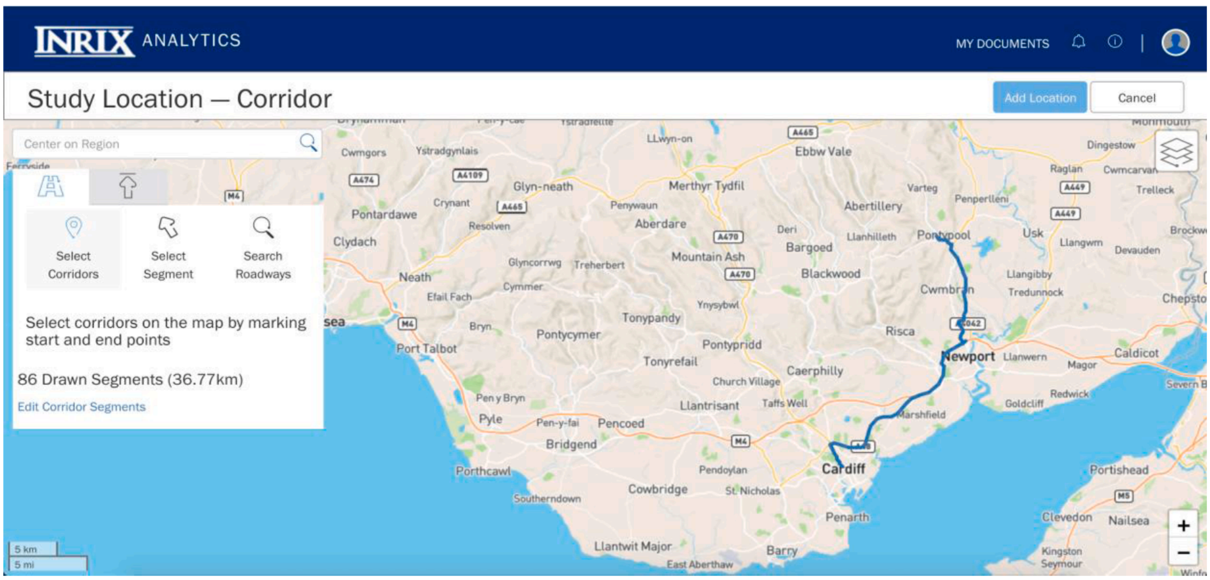

| | |
|---|---|
| Distance in km | 23.13 |
| Average speed in km per hour | 48.97 |
| Average travel time in minutes | 28 |
| Average travel time in minutes per km | 1.23 |

*From Rhondda Cynon Taf to Cardiff*



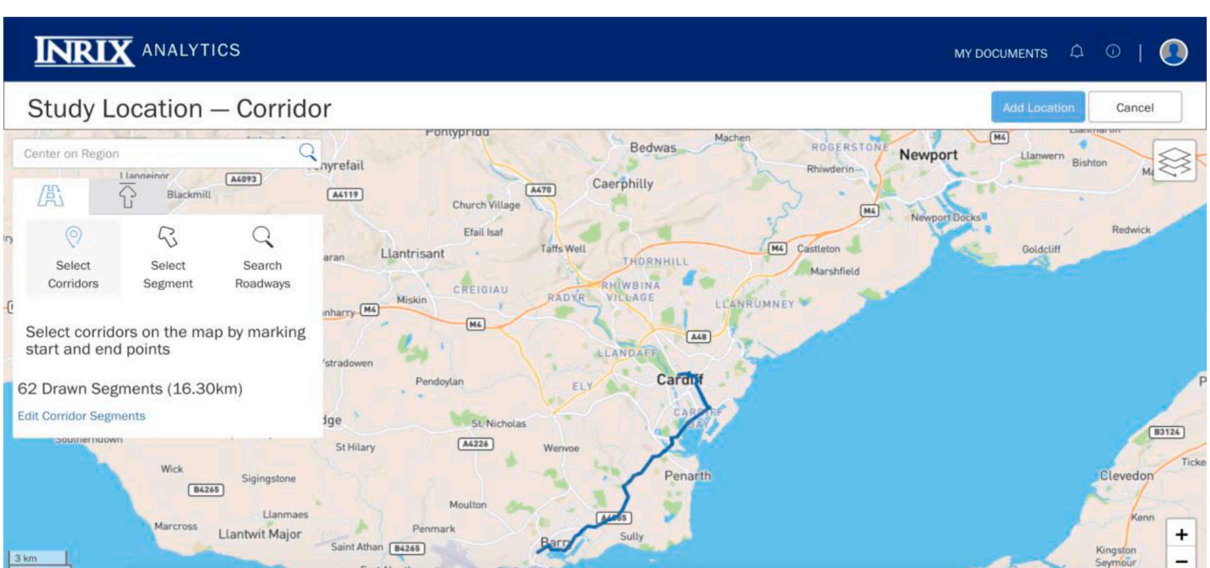
| | |
|---|---|
| Distance in km | 29.59 |
| Average speed in km per hour | 37.65 |
| Average travel time in minutes | 47 |
| Average travel time in minutes per km | 1.59 |

*From Torfaen to Cardiff*



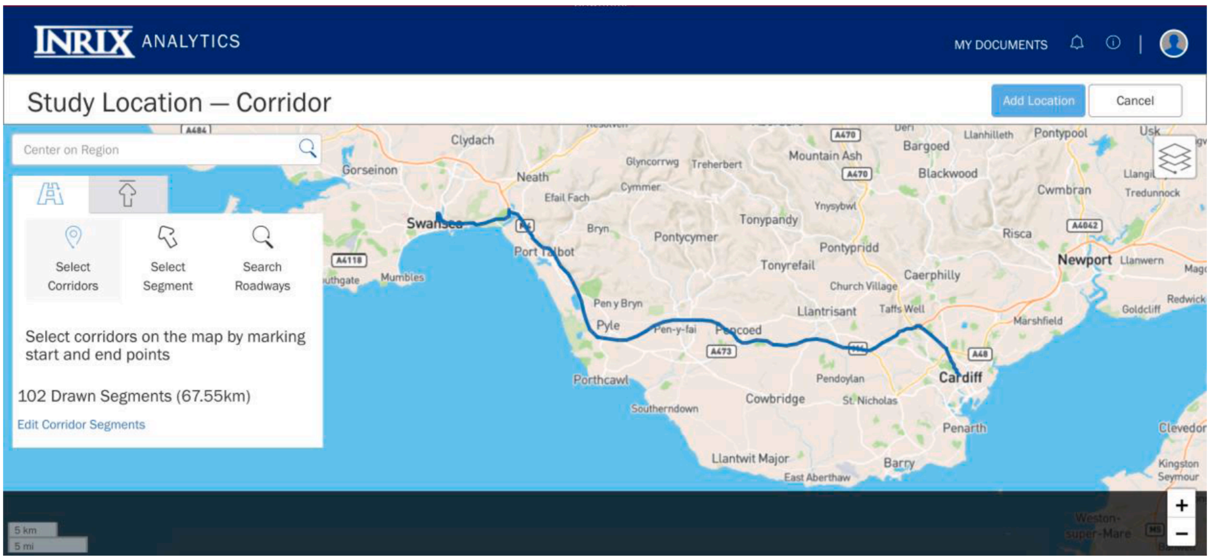

| | |
|---|---|
| Distance in km | 36.77 |
| Average speed in km per hour | 52.24 |
| Average travel time in minutes | 42 |
| Average travel time in minutes per km | 1.15 |

*From the Vale of Glamorgan to Cardiff*



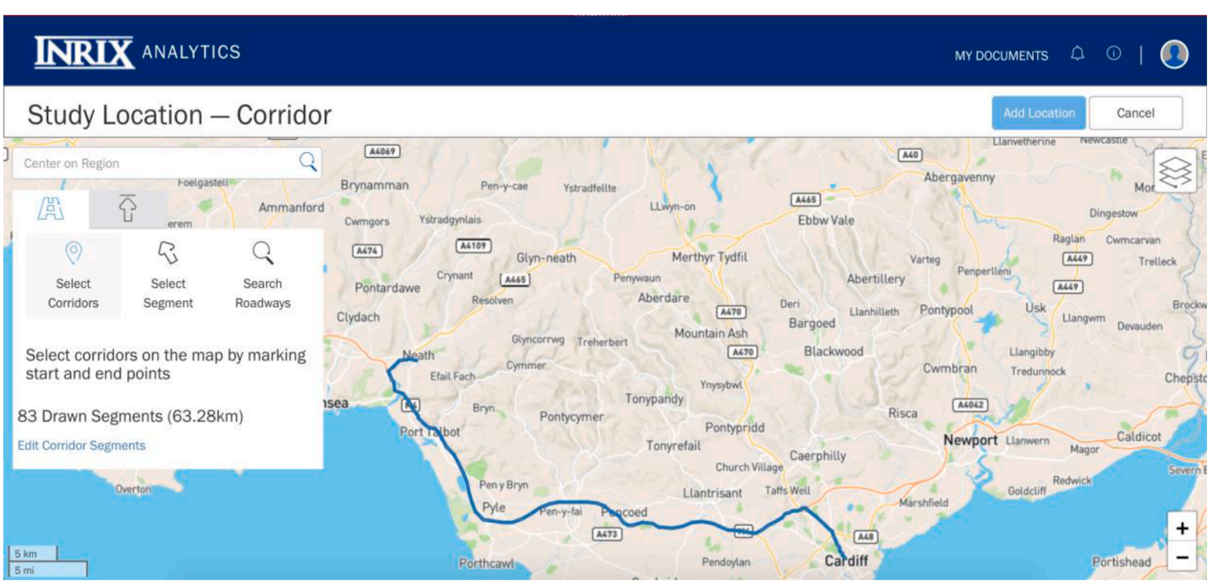
| | |
|---|---|
| Distance in km | 16.30 |
| Average speed in km per hour | 29.13 |
| Average travel time in minutes | 34 |
| Average travel time in minutes per km | 2.06 |

*From Swansea to Cardiff*




| | |
|---|---|
| Distance in km | 67.55 |
| Average speed in km per hour | 64.76 |
| Average travel time in minutes | 63 |
| Average travel time in minutes per km | 0.93 |

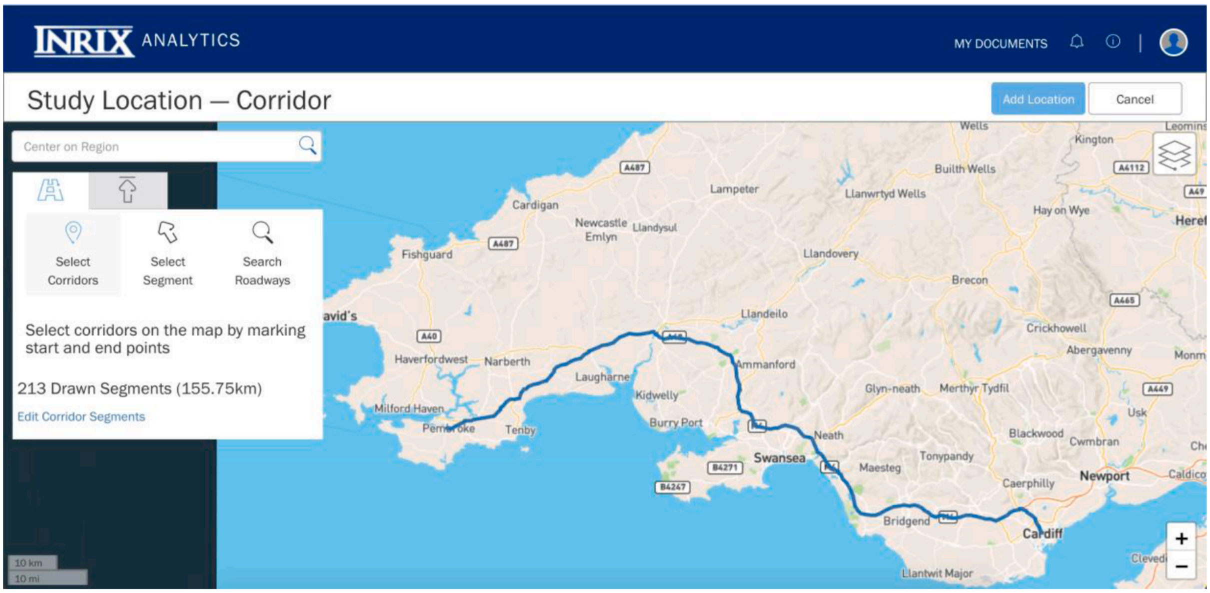
*From Neath Port Talbot to Cardiff*

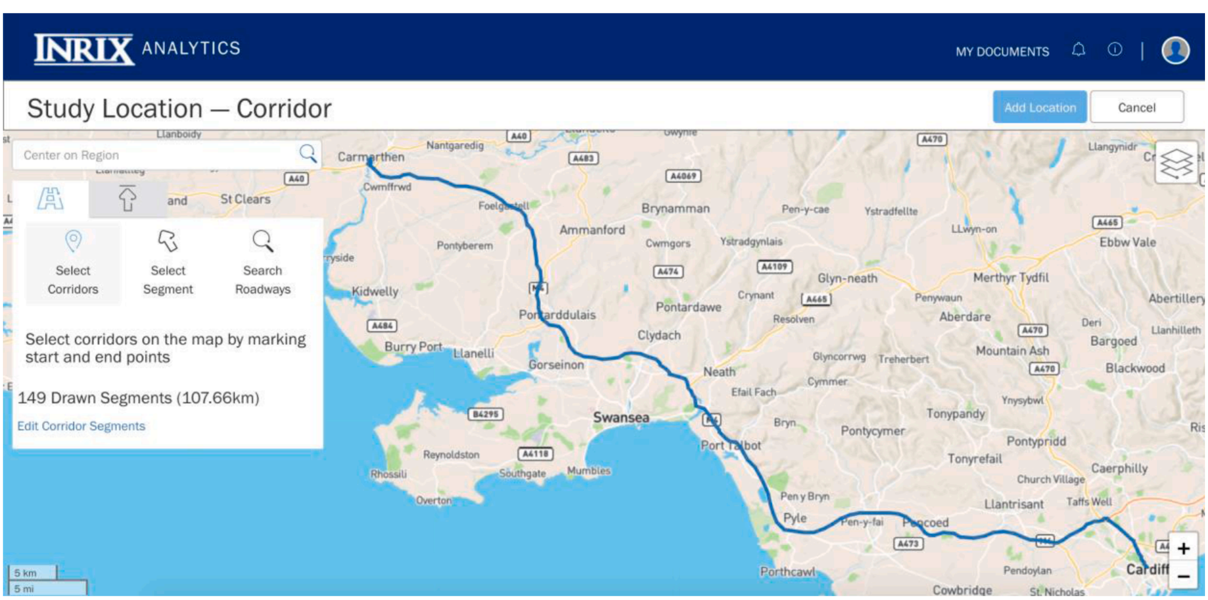


| | |
|---|---|
| Distance in km | 63.28 |
| Average speed in km per hour | 68.89 |
| Average travel time in minutes | 55 |
| Average travel time in minutes per km | 0.87 |

*From Pembrokeshire and Carmarthenshire to Cardiff*

The data below is the combined average for Pembrokeshire and Carmarthenshire.

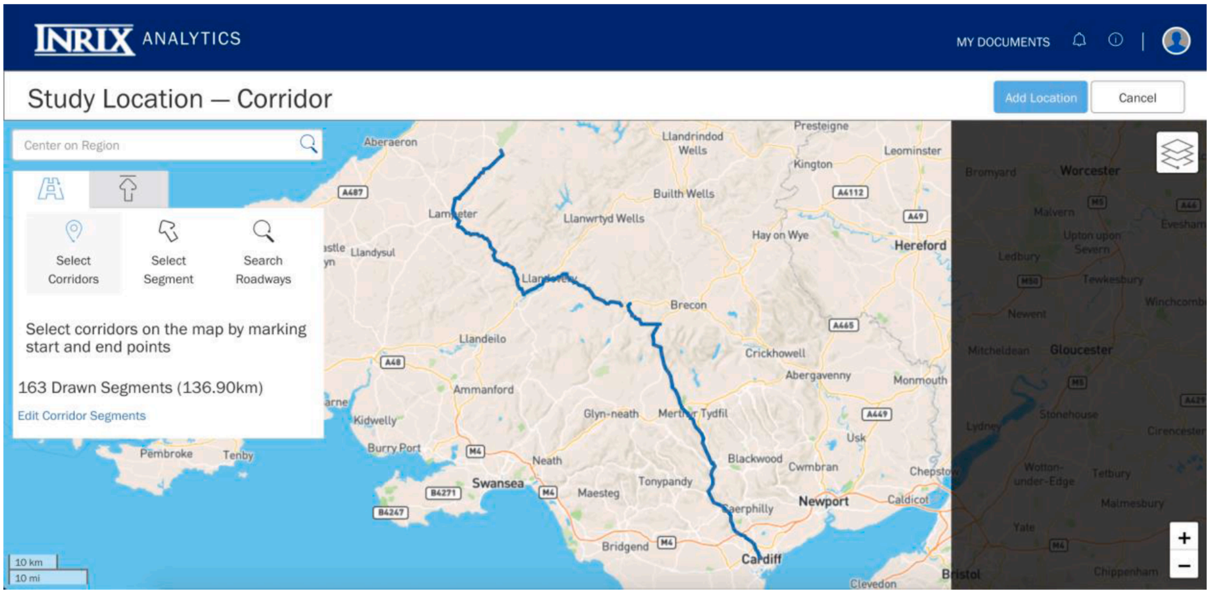


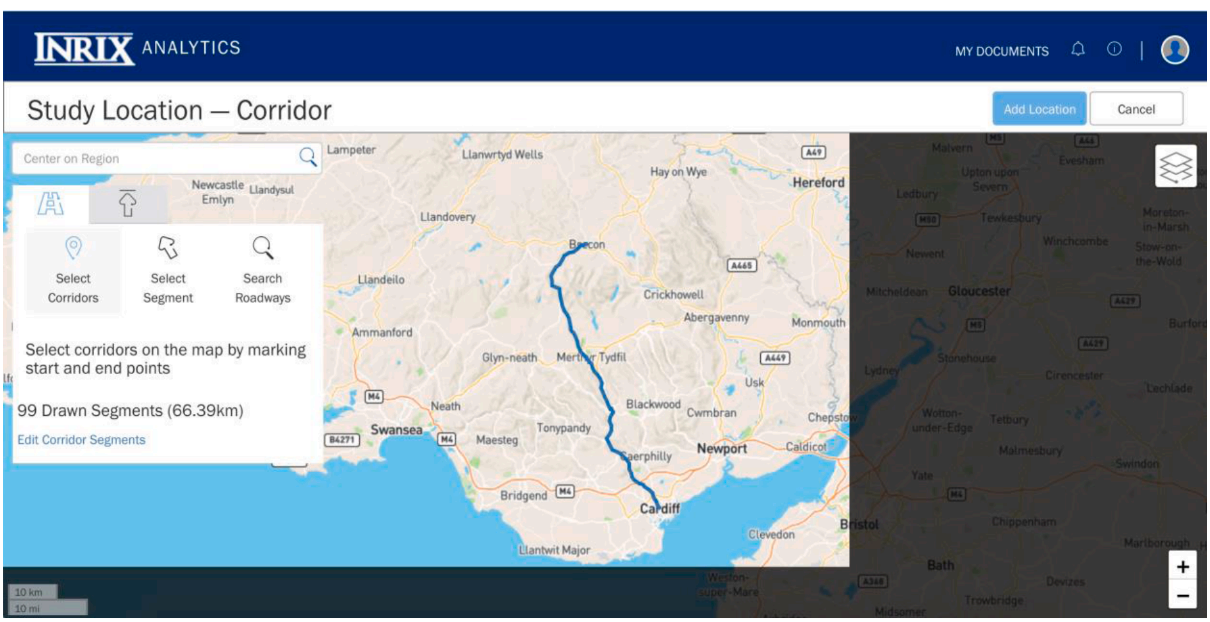




| | |
|---|---|
| Average distance in km | 131.71 |
| Average speed in km per hour | 76.89 |
| Average travel time in minutes | 103 |
| Average travel time in minutes per km | 0.78 |

*From Ceredigion and Powys to Cardiff*

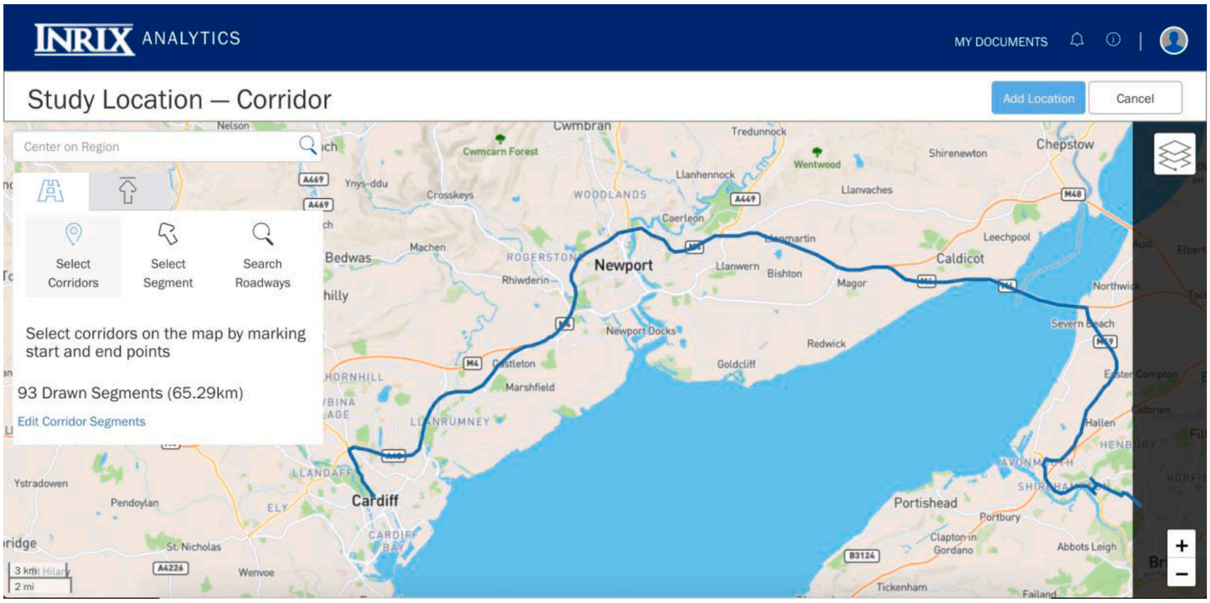
The data below is the combined average for Ceredigion and Powys.



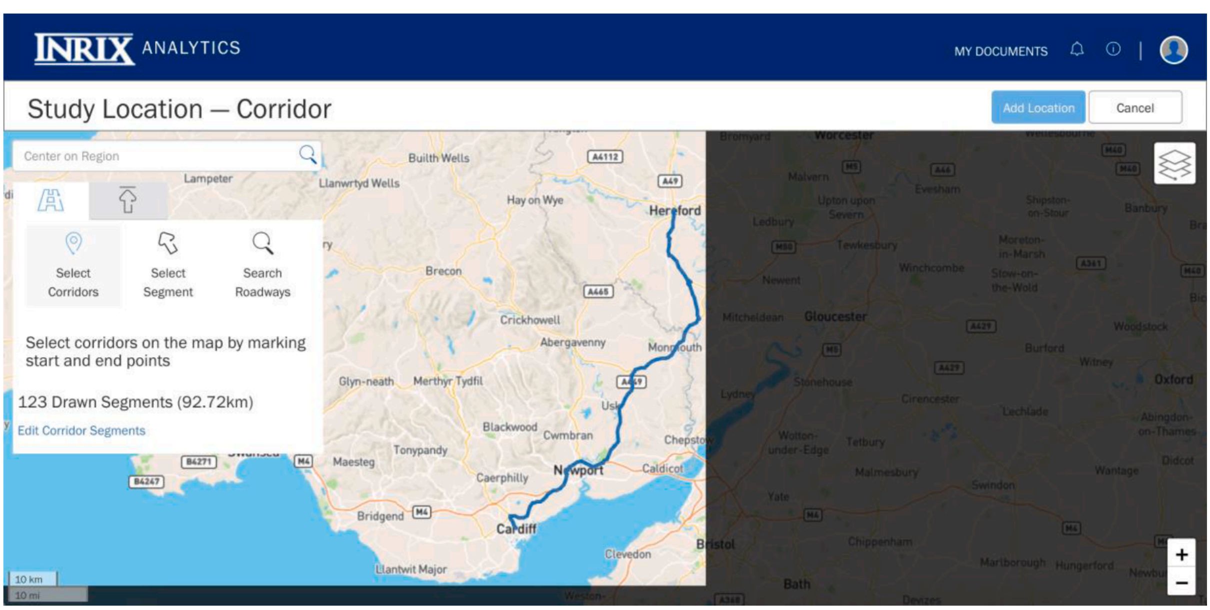

| | |
|---|---|
| Average distance in km | 101.65 |
| Average speed in km per hour | 59.82 |
| Average travel time in minutes | 102 |
| Average travel time in minutes per km | 1.00 |

*From Bristol to Cardiff*



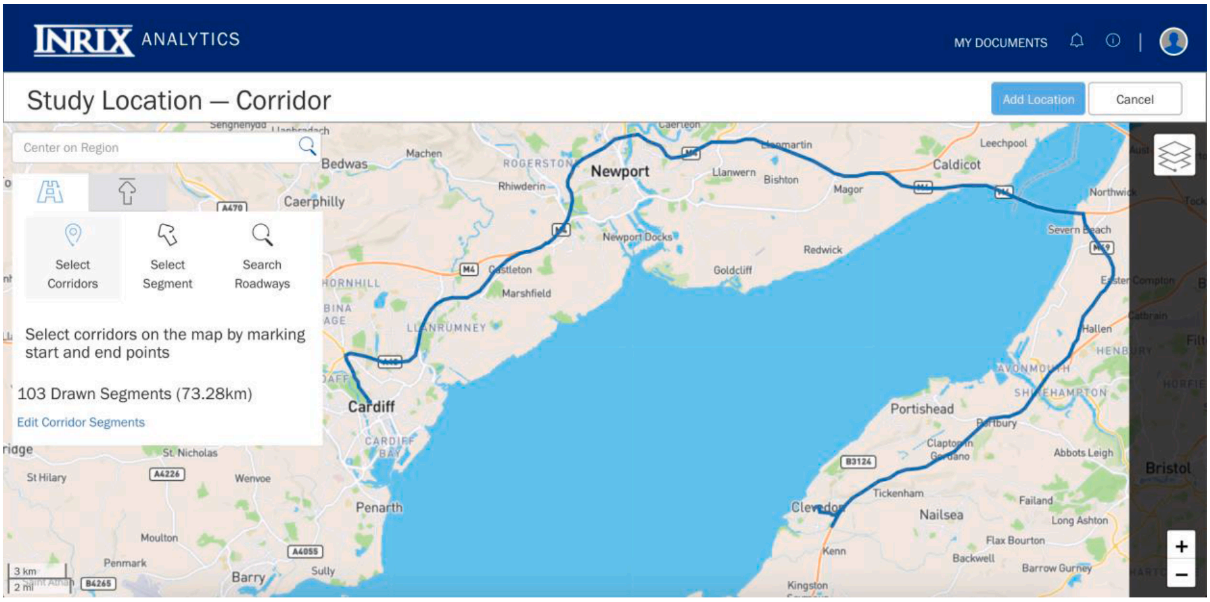

| | |
|---|---|
| Distance in km | 65.29 |
| Average speed in km per hour | 65.75 |
| Average travel time in minutes | 60 |
| Average travel time in minutes per km | 0.91 |

*From Herefordshire to Cardiff*



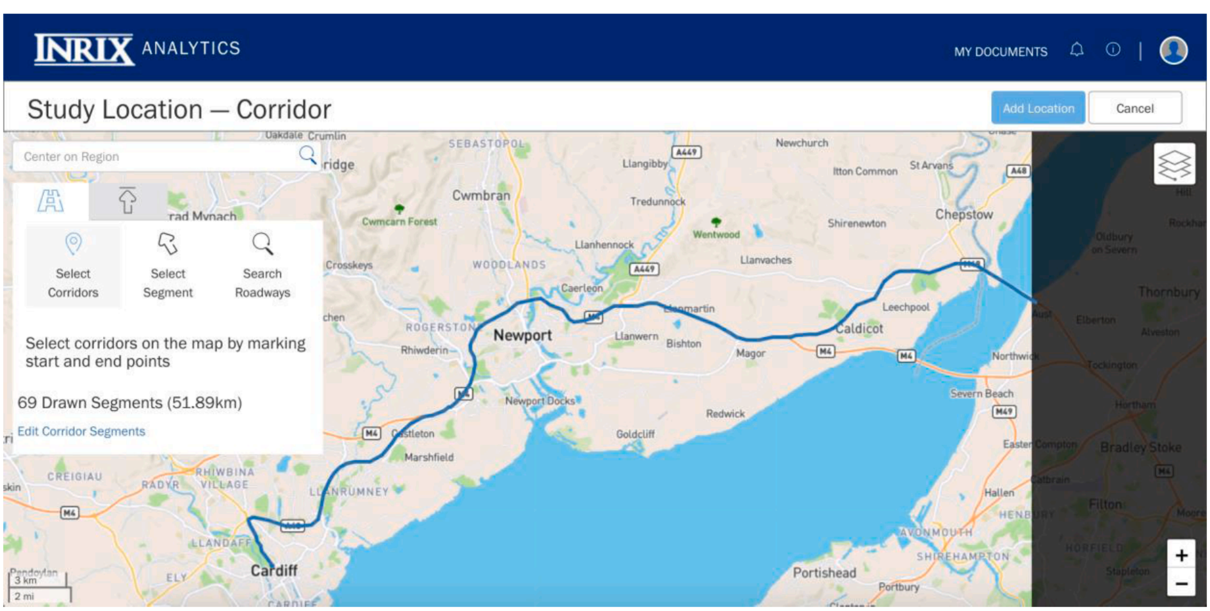

| | |
|---|---|
| Distance in km | 92.72 |
| Average speed in km per hour | 69.44 |
| Average travel time in minutes | 80 |
| Average travel time in minutes per km | 0.86 |

*From North Somerset to Cardiff*




| | |
|---|---|
| Distance in km | 73.28 |
| Average speed in km per hour | 73.72 |
| Average travel time in minutes | 60 |
| Average travel time in minutes per km | 0.81 |

*From South Gloucestershire to Cardiff*



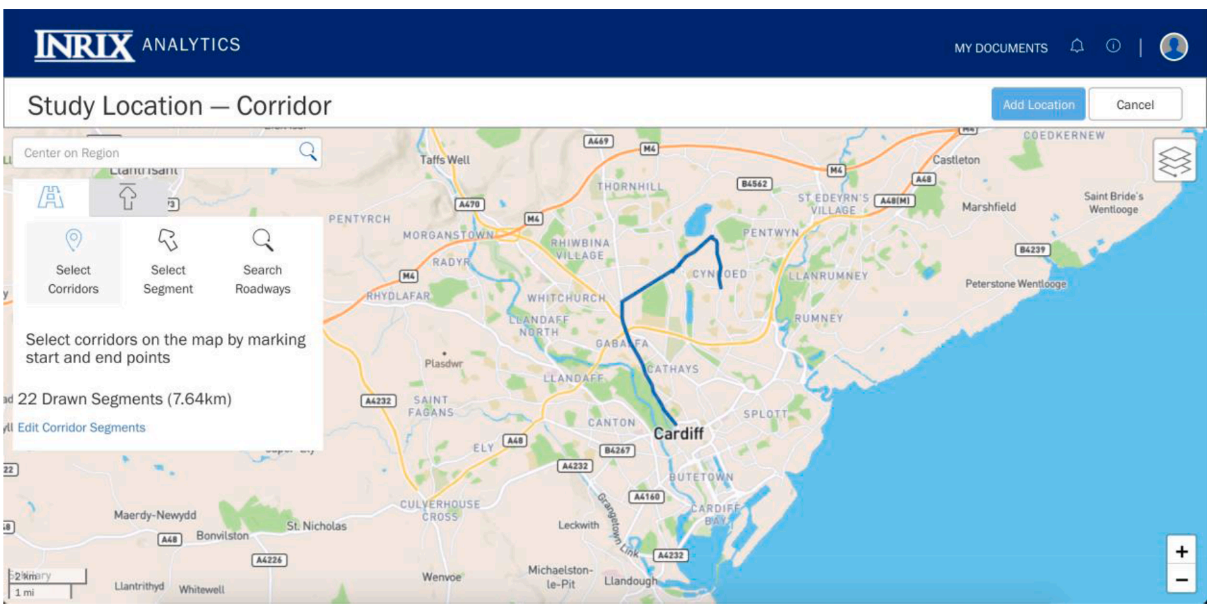
| | |
|---|---|
| Distance in km | 51.89 |
| Average speed in km per hour | 70.07 |
| Average travel time in minutes | 44 |
| Average travel time in minutes per km | 0.86 |

*Representative trip from England (combined average for Bristol, Herefordshire, North Somerset and South Gloucestershire)*

| | |
|---|---|
| Average distance in km | 70.80 |
| Average speed in km per hour | 69.74 |
| Average travel time in minutes | 60.90 |
| Average travel time in minutes per km | 0.86 |

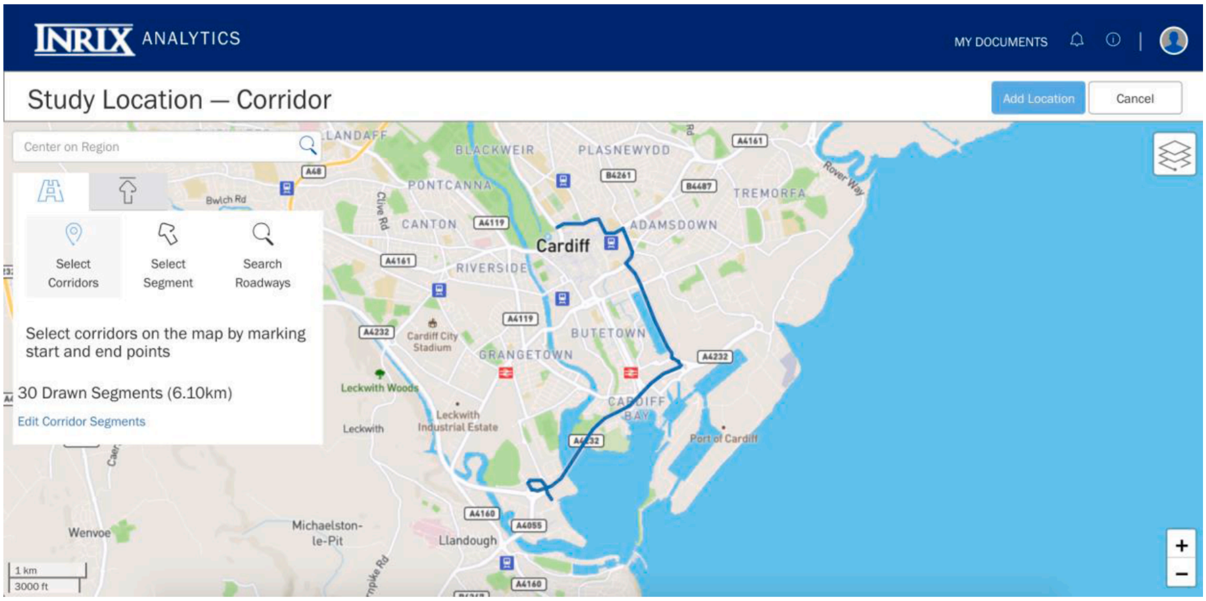
**TRIPS ORIGINATING AND ENDING IN CARDIFF**

*From Cyncoed to Cardiff City Centre*



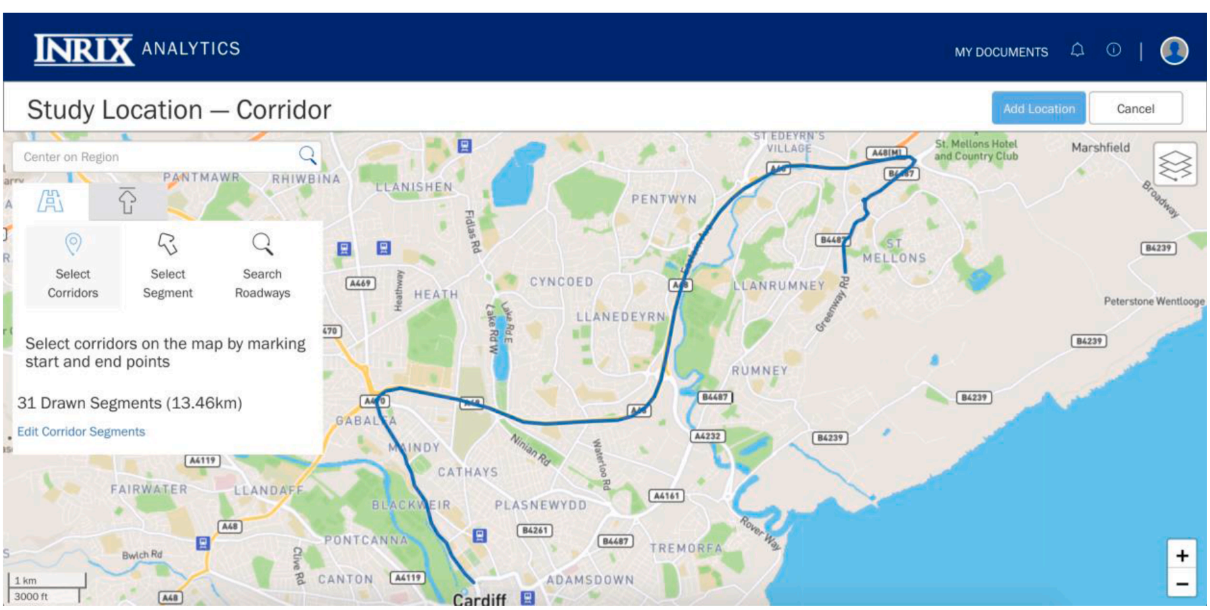

| | |
|---|---|
| Distance in km | 7.64 |
| Average speed in km per hour | 28.03 |
| Average travel time in minutes | 16 |
| Average travel time in minutes per km | 2.14 |

*From Butetown (i.e. Cardiff International Sports Village) to Cardiff City Centre*



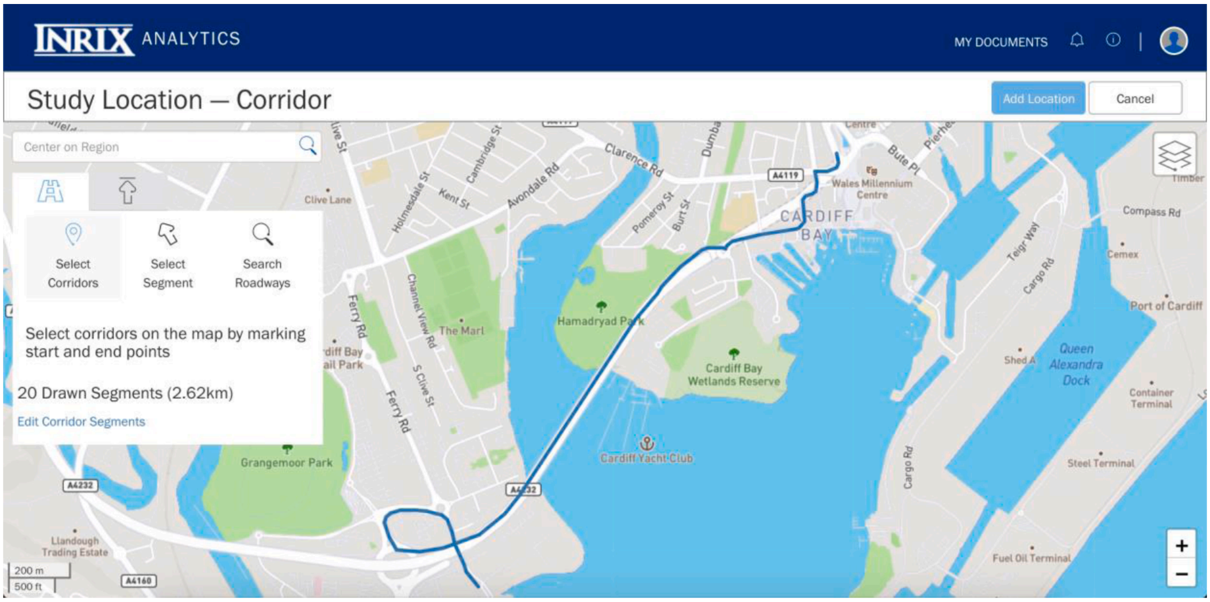

| | |
|---|---|
| Distance in km | 6.10 |
| Average speed in km per hour | 31.49 |
| Average travel time in minutes | 12 |
| Average travel time in minutes per km | 1.91 |

*From Trowbridge to Cardiff City Centre*



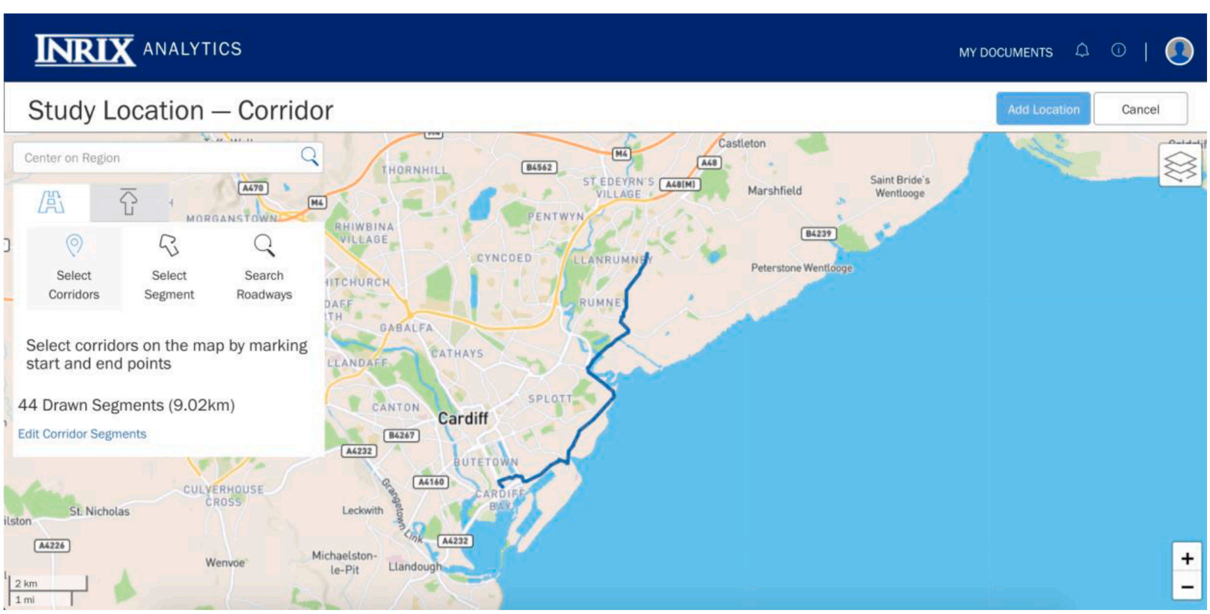

| | |
|---|---|
| Distance in km | 13.46 |
| Average speed in km per hour | 37.82 |
| Average travel time in minutes | 21 |
| Average travel time in minutes per km | 1.59 |

*From Butetown (i.e. Cardiff International Sports Village) to Cardiff Bay*




| | |
|---|---|
| Distance in km | 2.62 |
| Average speed in km per hour | 39.05 |
| Average travel time in minutes | 4 |
| Average travel time in minutes per km | 1.54 |

*From Trowbridge to Cardiff Bay*




| | |
|---|---|
| Distance in km | 9.02 |
| Average speed in km per hour | 25.60 |
| Average travel time in minutes | 21 |
| Average travel time in minutes per km | 2.34 |

*Representative trip within Cardiff (combined average for the five routes above)*

| | |
|---|---|
| Average distance in km | 7.77 |
| Average speed in km per hour | 32.40 |
| Average travel time in minutes | 14.39 |
| Average travel time in minutes per km | 1.85 |

## Appendix B – Components of generalised cost

Distance and average speed data are from INRIX Roadway Analytics (2020) (see Appendix A). Values for vehicle operating costs and value of time per car are from the TAG Data Book (Department for Transport, 2020).

*Trip from Blaenau Gwent to Cardiff*

| | |
|---|---|
| Distance in km | 50.77 |
| Average speed in km per hour | 56.34 |
| Vehicle operating costs in pence per km | 12.18 |
| *Non-fuel* | *5.06* |
| *Fuel* | *7.12* |
| Value of time per car in pence per km | 26.68 |

*Trip from Bridgend to Cardiff*

| | |
|---|---|
| Distance in km | 32.21 |
| Average speed in km per hour | 52.33 |
| Vehicle operating costs in pence per km | 12.37 |
| *Non-fuel* | *5.09* |
| *Fuel* | *7.29* |
| Value of time per car in pence per km | 28.72 |

*Trip from Caerphilly to Cardiff*

| | |
|---|---|
| Distance in km | 13.68 |
| Average speed in km per hour | 29.85 |
| Vehicle operating costs in pence per km | 14.38 |
| *Non-fuel* | *5.37* |
| *Fuel* | *9.01* |
| Value of time per car in pence per km | 50.35 |

*Trip from Merthyr Tydfil to Cardiff*

| | |
|---|---|
| Distance in km | 37.55 |
| Average speed in km per hour | 51.23 |
| Vehicle operating costs in pence per km | 12.43 |
| *Non-fuel* | *5.09* |
| *Fuel* | *7.34* |
| Value of time per car in pence per km | 29.34 |

*Trip from Monmouthshire to Cardiff*

| | |
|---|---|
| Distance in km | 61.86 |
| Average speed in km per hour | 70.71 |
| Vehicle operating costs in pence per km | 11.77 |
| *Non-fuel* | *4.99* |
| *Fuel* | *6.79* |
| Value of time per car in pence per km | 21.26 |

*Trip from Newport to Cardiff*

| | |
|---|---|
| Distance in km | 23.13 |
| Average speed in km per hour | 48.97 |
| Vehicle operating costs in pence per km | 12.56 |
| *Non-fuel* | *5.11* |
| *Fuel* | *7.45* |
| Value of time per car in pence per km | 30.69 |

*Trip from Rhondda Cynon Taf to Cardiff*

| | |
|---|---|
| Distance in km | 29.59 |
| Average speed in km per hour | 37.65 |
| Vehicle operating costs in pence per km | 13.46 |
| *Non-fuel* | *5.23* |
| *Fuel* | *8.22* |
| Value of time per car in pence per km | 39.92 |

*Trip from Torfaen to Cardiff*

| | |
|---|---|
| Distance in km | 36.77 |
| Average speed in km per hour | 52.24 |
| Vehicle operating costs in pence per km | 12.38 |
| *Non-fuel* | *5.09* |
| *Fuel* | *7.29* |
| Value of time per car in pence per km | 28.78 |

*Trip from the Vale of Glamorgan to Cardiff*

| | |
|---|---|
| Distance in km | 16.30 |
| Average speed in km per hour | 29.13 |
| Vehicle operating costs in pence per km | 14.48 |
| *Non-fuel* | *5.38* |
| *Fuel* | *9.10* |
| Value of time per car in pence per km | 51.59 |

*Trip from Swansea to Cardiff*

| | |
|---|---|
| Distance in km | 67.55 |
| Average speed in km per hour | 64.76 |
| Vehicle operating costs in pence per km | 11.89 |
| *Non-fuel* | *5.01* |
| *Fuel* | *6.88* |
| Value of time per car in pence per km | 23.21 |

*Trip from Neath Port Talbot to Cardiff*

| | |
|---|---|
| Distance in km | 63.28 |
| Average speed in km per hour | 68.89 |
| Vehicle operating costs in pence per km | 11.80 |
| *Non-fuel* | *5.00* |
| *Fuel* | *6.81* |
| Value of time per car in pence per km | 21.82 |

*Trip from Pembrokeshire and Carmarthenshire to Cardiff*

The data below is the combined average for Pembrokeshire and Carmarthenshire.

| | |
|---|---|
| Distance in km | 131.71 |
| Average speed in km per hour | 76.89 |
| Vehicle operating costs in pence per km | 11.72 |
| *Non-fuel* | *4.97* |
| *Fuel* | *6.76* |
| Value of time per car in pence per km | 19.55 |

*Trip from Ceredigion and Powys to Cardiff*

The data below is the combined average for Ceredigion and Powys.

| | |
|---|---|
| Distance in km | 101.65 |
| Average speed in km per hour | 59.82 |
| Vehicle operating costs in pence per km | 12.04 |
| *Non-fuel* | *5.04* |
| *Fuel* | *7.00* |
| Value of time per car in pence per km | 25.13 |

*Trip from England to Cardiff*

The data below is the combined average for Bristol, Herefordshire, North Somerset and South Gloucestershire.

| | |
|---|---|
| Distance in km | 70.80 |
| Average speed in km per hour | 69.74 |
| Vehicle operating costs in pence per km | 11.79 |
| *Non-fuel* | *4.99* |
| *Fuel* | *6.80* |
| Value of time per car in pence per km | 21.55 |

*Trip within Cardiff*

The data below is the combined average for the five Cardiff routes chosen (see Appendix A).

| | |
|---|---|
| Distance in km | 7.77 |
| Average speed in km per hour | 32.40 |
| Vehicle operating costs in pence per km | 14.04 |
| *Non-fuel* | *5.32* |
| *Fuel* | *8.72* |
| Value of time per car in pence per km | 46.39 |

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