The impact of labour market disruptions and transport choice on the environment during COVID-19

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ABSTRACT
Since late 2019, COVID-19 has devastated the global economy, with indirect implications for the environment. As governments’ prioritized health and implemented measures such as the closure of non-essential businesses and social distancing, many workers have lost their jobs, been furloughed, or started working from home. Consequently, the world of work has drastically transformed and this period is likely to have major implications for mobility, transportation and the environment. This paper estimates the potential for people to engage in remote work and social distancing using O*NET data and Irish Census data and calculates the potential emission savings, by commuter type from a switch to remote working and occupational social distancing. The results show that while those who commute by car have a relatively high potential for remote work, they are less likely to be able to engage in social distancing in their workplace. While this may be negative for employment prospects in the short run, our analysis indicates that this pattern has the potential for positive environmental implications in the short and long run.

1. Introduction

At the time of writing, COVID-19 has resulted in over 115 million confirmed cases and over 2.5 million deaths globally (Worldometer, 2021). Non-essential businesses, schools and public areas temporarily closed across many countries, with half of the world’s population having spent time under some form of lockdown (Muhammad et al., 2020). Social distancing, self-isolation and travel restrictions have impacted all sectors of the economy (Nicola et al., 2020). While many have lost their jobs, others have switched to working-from-home (Adams-Prassl et al., 2020; Brynjolfsson et al., 2020; Dingel and Neiman, 2020; Foucault and Galasso, 2020). The related reduction in commuters has had unexpected positive consequences for the environment (Gupta et al., 2020; Helm, 2020; Isafian, 2020; Muhammad et al., 2020). While vaccines offer a new line of defence against the virus, the World Health Organisation (2021) emphasised that for the foreseeable future we must continue to physically distance from others – implying the continuation of social distancing and remote working. Now, as governments ease lockdown measures (for the third time in the Irish context), this paper examines whether a worker’s ability to practice socially distancing and to work remotely relates to their commuting choice and whether this has implications for emissions.

COVID-19 has provided data for an important environmental experiment (Helm, 2020). A consensus has emerged in recent decades about the need to reduce greenhouse gas (GHG) emissions. With the adoption of the Paris Agreement in 2015, 189 countries agreed to limit global warming to between 1.5 and 2 °C above pre-industrial levels. While global integrated assessment modelling (IAM), which underpins the scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) to develop pathways consistent with the Paris agreement, has mainly focussed on CO2 mitigation from low-carbon fuel and technology measures (Sims et al., 2014), recent focus has turned to the importance of demand-side measures (Faber et al., 2012; Hickel and Kallis, 2020; Mundaca et al., 2019). Studies have found that down-sizing
the global energy system by reducing energy service demands, such as personal transport, will dramatically improve the feasibility of meeting the Paris Agreement temperature targets (Grubler et al., 2018).

Transportation, accounting for 23% of global energy-related GHG emissions, is a major source of ambient (outdoor) air pollution and has many implications for human health.\(^1\) Carbon dioxide (CO\(_2\)) emissions from road transport in Ireland amounted to 12 million tonnes in 2018, representing 31% of total energy-related emissions (EEA, 2020). Emissions from road transport have grown by nearly 150% since 1990, notwithstanding efficiency gains in the vehicle fleet (O’Mahony et al., 2012). Despite policies to mitigate this growth including a carbon tax, and regulations to mandate and incentivize electric vehicles, biofuels and engine efficiency, emissions from road transport are projected to continue growing (EEA, 2019). This contradicts Ireland’s obligation of reducing emissions from transport, heat, and agriculture by 30% on 2005 levels by 2030 (European Commission, 2018).

Any changes in commuting behaviour, related to an increase in remote working or social distancing, will have implications for transport emissions and environmental outcomes. The introduction of stay-at-home restrictions, to slow the spread of COVID-19, has greatly reduced transport-related emissions. NASA (2020) and ESA (2020), for example, have shown that lockdown measures have resulted in significant reductions in nitrogen dioxide (NO\(_2\)),\(^2\) while the European Environment Agency (2020) found that NO\(_2\) levels have almost halved in many major European cities. While the number of people being vaccinated against COVID-19 is rising and people are beginning to return to their workplace, concerns about new variants entails that they will need to continue to practice social distancing. Workers need to keep at least one metre from anyone outside their household, including their colleagues, customers, and those they interact with on their daily commute (Block et al., 2020; Galabadage et al., 2020; World Health Organization, 2020). Workers who cannot practice social distancing are encouraged to work from home or to remain off work.

The literature teaches us little about the relationship between occupation, commuting choice and the ability to socially distance in the workplace (or to work from home). The literature notes that the majority of workers commute to work by car (90.5% in US (Kopf, 2016); approx. 70% in Europe (Blankaert, 2019)) and that while public transport, walking and cycling are less utilised means of commuting, they are crucial if Europe is to meet its long-term sustainability goals (EEA, 2019). However, little is known about whether workers who drive to work will find it easier to practice social distancing than those who walk, cycle or take public transport. Nor is it known if their occupations can facilitate working from home, or, if they are more likely to lose their jobs. This paper examines the variability of people to engage in remote work and social distancing by commuter type in Ireland.

The rest of the paper is organised as follows. Section 2 presents a brief overview of the related literature. Section 3 presents the data and explains how the social distancing and remote working indices are calculated for Ireland. Section 4 presents the results, while Section 5 concludes the study and presents the implications of the findings.

2. Literature review

Transportation modes such as air travel, public buses, trains and trams are linked to the accelerated spread of infectious diseases (Zhang et al., 2020; Troko et al., 2011). Early evidence from the COVID-19 pandemic indicates a positive relationship between cases, death rates and proximity to airports, train stations and public transportation (Gaskin et al., 2021). While commuting preferences and attitudes to travel normally remain constant over time (Berliner et al., 2015; Shamshiripour et al., 2020b; Frei et al., 2015), there is growing evidence that people change their behaviour during pandemics (Shamshiripour et al., 2020b; Abdullah 2020). Wen et al. (2005) noted that the SARS (Severe Acute Respiratory Syndrome) outbreak greatly affected people’s life, work, and travel behaviour. Lau et al. (2003) examining the effects of the SARS outbreak on Hong Kong residents noted that over 75% of those surveyed avoided crowded places and using public transport. Liu et al. (2011), analysing the impact of SARS on air travel between the U. S., China, Hong Kong, and Taiwan noted an overall reduction in travel, however, this varied based on the perceived risk in each region. Goodwin et al. (2011), using survey data for European residents during the early stages of the Swine Flu outbreak in 2009, found that 20% of those surveyed were planning to delay or cancel their travel plans, while 22% were planning to reduce their use of public transport. Kim et al. (2017) using smart card data from South Korea, found that travel patterns changed in response to the fear of getting infected during the Middle East Respiratory Syndrome outbreak. Examining travel-related decisions during influenza outbreaks, Hotle et al. (2020) found that people are less likely to travel to public places, to shops, and to use public transport when the perceived risk of infection is medium or high.

Recent studies examining the COVID-19 pandemic also find that the fear of contracting the infectious disease influences individuals travel behaviours (Warren and Skillman, 2020). Gutiérrez (2020) shows that the fear of infection has greatly reduced the number of people using public transport in Berlin, New York City, Sao Paulo and Taipei. Survey data for Germany, gathered at the start of the COVID-19 outbreak, has identified that individual modes of transport, particularly by car became more important (Anke et al. 2020). Similar empirical evidence showing the impact of COVID-19 on transport use exist for Sweden (Jenelius and Cebecauer, 2020), Switzerland (Molley et al., 2020), Spain (Aloi et al., 2020), the UK (Hadjidemetriou et al., 2020), and the US (Wilbur et al., 2020), amongst others. Gkotsisalitsis and Cats (2020) argue that changing risk perceptions along with concerns about public transport hygiene mean that passengers are re-evaluating the trade-off between time and crowding and are moving away from public transport. A change they speculate will have implications for public transport ridership long after the pandemic. While the effect of a pandemic on mobility behaviour is not surprising and recent research is beginning to examine the changing behaviours of different cohorts (e.g. differences by age, occupation and reason for travel), how the labour market disruptions of remote working and social distancing will affect commuting and, in turn, the environment in the longer term are largely unknown.

In commuting choice models, commuters are assumed to make deliberate evaluations around the attributes of the different transport options available to them and to choose the transport modality that will provide them with maximum utility (Ortúzar and Willumsen, 2011). However, it has also been posited that commuting behaviours are habitual and that changes to commuting choice are more likely at the time of major life events such as moving house, job, relationship breakdowns, or the birth of a child (Clark et al., 2016). The COVID-19 crisis will most likely represent a major life event for many commuters. Stay-at-home and lockdown measures have restricted commuting for all workers and particularly for those operating in non-essential businesses. Many transport modes such as buses, trains, taxis and underground transport systems represent high-risk environments for the spread of the coronavirus resulting in an increased likelihood of a structural break to commuting habits for many, as they attempt to avoid contracting the virus. Previously, in the US, Kopf (2016) found a link between commuting choice and occupation noting that those working in the Physical and Social Science are more likely to cycle to work while those working in Law, Computer Science, Finance and

\(^1\) The World Health Organisation (2018) estimates that 4.2 million deaths are caused by ambient (outdoor) air pollution each year. While many of these deaths occur in low- and middle-income countries, almost 500,000 occur in Europe, of which 1180 occur in Ireland (European Environmental Agency, 2019). An additional 1.35 million premature deaths worldwide are caused by road accidents.

\(^2\) Nitrogen dioxide (NO\(_2\)) emissions from traffic is a major cause of ambient air pollution (Bishop et al., 2010; Muhammad et al., 2020).
Media are more likely to take public transport. Hu and Chen (2021) identified that the COVID-19 pandemic led to an average 72.4 per cent drop in transit ridership for 95 per cent of stations in Chicago, but transit ridership declined less for those working in ‘essential’ jobs. Similarly, Aloi et al. (2020) observed a large drop in the numbers using public transport in Spain, with work remaining as the only important purpose for travelling. While the pandemic has completely altered normal everyday commuting activities, little is known about the relationship between commuting choice and occupational social distancing, or remote working potential. This is a topic that has important implications for transport planning in general as well as transport planning with a view to reducing greenhouse gases.

Since workplace interactions constitute the majority of social contacts among people of working age (Lewandowski, 2020), those who cannot practice social distancing are advised, where possible, to work from home. The concept of ‘social distancing’ and the important role it can play in mitigating pandemics is not new to the literature (e.g. Glass et al., 2006; Kelso et al., 2009; Rashid et al., 2015). Frequently used interventions include bans on public events, the closure of schools, universities and non-essential businesses, restrictions on travel, movement, and physical interactions (Block et al., 2020). The goal of these measures is to delay the spread of influenza while scientists search for a vaccine or treatment. While restrictions on travel and the cancelation of public gatherings have been shown to be effective, the effectiveness of business and school closures is less well understood (Aledort et al., 2007; Jackson et al., 2013; Rashid et al., 2015). Ahmed et al. (2018), focusing on workplace social distancing, note that when the reproduction number (R0) is low then social distancing in the workplace, combined with other interventions, is effective. More recent studies examining COVID-19 find that workplace social distancing is easier in some occupations (e.g. Agriculture, Forestry and Fishing, Information and Communication) than others (e.g. Retail Trade, Accommodation and Food Services, Human Health) (see Barbieri et al., 2020; Crowley and Doran, 2020; Koren and Petó, 2020a; Mongey et al., 2020). Nevertheless, even if the reproduction number is low and workplace social distancing is feasible, it is likely that people will avoid commuting to work, especially if they have the capacity to conduct their work remotely during COVID-19.

Prior to the pandemic, only 14% of the Irish workforce worked remotely for some part of their working week according to recent statistics from the Irish Labour Force Survey (Redmond and McGuinness, 2020), with higher and lower professional workers being more likely to fall into this category (FU et al., 2012). While remote working was marginalised by businesses and lacked appropriate regulation and guidelines (Hynes, 2014), it allows for a substantial economic saving in terms of value of time saved. The latter has been estimated to be as much as €42m per annum in Ireland (Caulfield, 2015). The COVID-19 pandemic has shown that a greater proportion of jobs can be done from home, including those in the Educational Services, Professional, Scientific, and Technical Services, Finance and Insurance, and Information Technology sectors (Crowley and Doran, 2020; Dingel and Neiman, 2020; Gallacher and Hossain, 2020; Gottlieb et al., 2020; Mongey et al., 2020; Mongey and Weinberg, 2020; Montenovo et al., 2020). Restricted movement in Ireland resulting from the pandemic has forced and accelerated digital and remote working adoption by employers and employees, with 34% now stating that they are working from home (CSO, 2020). Until a vaccine to protect against COVID-19 is developed and freely available, many workers will be required to continue working from home. In the long term, many of these workers may choose to continue working from home for family, health, and productivity reasons (Kramer and Kramer, 2020).

Remote work is often suggested by policymakers as a remedy for reducing the environmental and socio-economic impacts of transport and mobility patterns on society (Cerqueira et al., 2020; Hynes, 2014; Van Lier et al., 2014). In Ireland, it has been estimated that if 20% of the working population worked from home one day a week, it could result in a 3.17 ktCO2 reduction (O’Keefe et al., 2016). Remote working has been identified to reduce travel distances and number of trips (Choo et al., 2005; Helminen and Ristimäki, 2007). Previously, using the Irish case, FU et al. (2012) identified that at least an average net saving of 9.33 kWh per day can be achieved from an individual converting to working from home. If the negative ‘rebound effects’ that have been identified with remote working, such as increases in personal non-work trips and residential relocation, can be minimised (Cerqueti et al., 2013; He and Hu, 2013), then the COVID-19 crisis may represent a strategic opportunity for policymakers to transform transportation networks. This could in turn reduce congestion and the negative externalities associated with transportation, such as greenhouse gas emissions. If those who normally drive can work remotely, then traffic pollution caused by commuters should reduce in the short and the long term, thereby resulting in a positive impact for the environment without harming the economy.

Next, the data used to examine the variability of people to engage in remote work and social distancing by commuter type in Ireland is outlined.

3. Data

This paper makes use of two datasets. Firstly, similar to many papers in this field of research information is acquired which provides information on worker tasks, context and activities from O*Net. This data facilitates the generation of social distancing and remote working potential indices. Secondly, 2011 Irish Census data from IPUMS international is used to examine what types of people are less (or more) exposed from social distancing and remote work. Specifically, the primary method of transport individuals use to go to work is examined in order to gain a better understanding of the potential impact of social distancing and remote working measures on their jobs and their travel patterns.

3.1. Social distancing and remote working index

The social distancing and remote working indexes included in this paper were constructed by Crowley and Doran (2020) and Crowley et al. (2020) and are detailed in these papers. A concise summary of these indexes and their construction is presented here. Interested readers are referred to the Appendix where details on the precise O*Net questions used in the construction of the indexes by Crowley and Doran (2020) and Crowley et al. (2020) are provided.

The indexes are based on O*NET data, which is the primary source of occupational information in the United States and is used to understand the changing world of work and how it impacts on the workforce and the economy. It has been used extensively in occupational studies of automation (Frank et al., 2018; Frey et al., 2017; Frey and Osborne, 2017) but recently also in the identification of the occupations which are most likely to be disrupted due to (i) enforced social distancing protocols in

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3. O*Net is the average number of secondary cases produced by a typical infectious case in a fully susceptible population.

4. While data for the 2016 census is available the anonymised micro data does not provide detailed information on occupational codes. Only 9 occupational codes are available in the 2016 census which does not allow for a detailed consideration of the degree to which an occupation can work remotely or engage in social distancing. Further to this while a census was scheduled in Ireland for 2021 this has now been postponed until 2022. This leaves 2011 as the most recent census available with the required level of occupational detailed.

5. Appendix 1 details the matching of US occupational codes to Irish occupational codes. Appendix 2 describes the O*Net questions used to generate the social distancing potential index. Appendix 3 describes the O*Net questions used to generate the remote working potential index.
workplaces and (ii) the ability/lack of ability to engage in remote working (Delaporte and Peña, 2020; Dingel and Neiman, 2020; Gottlieb et al., 2020; Mongey et al., 2020; Mongey and Weinberg, 2020). This data is based on US occupational codes and therefore it is necessary to translate this to Irish occupational classifications, which is completed by Crowley and Doran (2019) and results in 318 detailed occupations for the Irish case.

The social distancing index is constructed based on work by Koren and Peto (2020a), who constructed a social distancing index for the U.S. The index is comprised of information from 17 different questions using O*Net data. A detailed list and the precise questions and coding are displayed in Appendix 2. There are three broad categories to which the underlying questions in the index relate, which include teamwork requirements, customer orientation and physical presence. A further underlying commonality of the questions is how they relate to the degree to which face-to-face interaction is required for each occupational role and in turn, the ability of workers with the associated occupation to engage in social distancing measures in a workplace. Each variable takes a value ranging from 0 to 100 and an unweighted average of the social distancing indicator is used as a measure of social distancing potential for each occupation. The higher the value of this index then the less teamwork intensive, customer’s contact-intensive or physical presence intensive the job is.\footnote{This is the inverted form of the social distancing measure presented by Koren and Peto (2020), where the potential to social distance in a job ranges from low to high.}

The remote working index is based on work by Dingel and Neiman (2020). The construction of the index again exploits O*Net data using information from 17 questions. The precise questions obtained from O*Net which comprise this index are presented in Appendix 3. In summary, the questions contain data that relates to workers being able to use remote communications such as e-mail, whether the job requires the operation of specialized equipment, the degree to which workers need to use protective equipment and whether the worker performs for people or directly serves customers. Again, the values range for each indicator from 0 to 100 and the unweighted average of the 17 indicators is used as the indicator for remote working potential value for each occupation. The higher the value of this index then the greater the potential to be able to work from home.

\subsection*{3.2. Sample of ammonised individual level Irish Census Data 2011}

The individual level analysis uses data obtained from IPUMS International for the Irish Census of 2011. The analysis focuses on those in the sample who are in employment, which results in 156,287 observations of individuals in Ireland in the year 2011. In the 2011 Census, 1,807,369 individuals were identified as being in employment indicating that the sample captures 8.64% of all individuals in the year 2011. In the 2011 census of those in employment the following are the categories presented in Table 1. An ‘other’ category is also included but this is excluded from the analysis as this category captures a variety of alternative (non-comparable) transport options.\footnote{The number of individuals in this ‘other’ category is 11,645.} The data shows that the primary method of transport for individuals is auto (driver), accounting for a total of 71.53% of all individuals in the sample. This is followed by walking, bus or trolley bus, auto (passenger), railroad or train, bicycle, and finally, motorcycle or moped.\footnote{When comparing our sample to the overall census, the proportions traveling by each mode of transport are practically identical to the census population. The data is based on US occupational codes and therefore it is necessary to translate this to Irish occupational classifications, which is completed by Crowley and Doran (2019) and results in 318 detailed occupations for the Irish case.}

In addition to this, the Irish census provides detailed information on a variety of socio-economic characteristics which may also impact individual’s abilities to socially distance in their workplace or engage in remote work. Therefore, information is included on the gender of individuals, marital status, their highest level of educational attainment, whether the individual has a disability or not, the age of the individual, the region (Nomenclature of Territorial Units for Statistics (NUTS3) European sub-divisions for Ireland\footnote{NUTS classifications are the uniform sub-national geographical disaggregations of regions in Europe. In the case of Ireland, in 2011, the country was divided into 8 NUTS3 regions. These are the (i) Border Region, (ii) West Region, (iii) Midlands Region, (iv) Mid-East Region, (v) Dublin Region, (vi) South-East Region, (vii) South-West Region, (viii) Mid-West Region.}), whether they are a national or non-national and the NACE sector in which the individual is employed.

\section*{4. Empirical model}

When considering the relationship between individuals usual transport to work choice and their ability to engage in social distancing in their workplace and their ability to work remotely, we estimate equation (1) below. The model is estimated twice, once for each index.

\begin{equation}
\text{Index}_i = \beta_0 + \beta_i \text{TransportChoice}_i + \beta_i \text{Z}_i + \epsilon_i
\end{equation}

Where, \text{Index}_i is the dependent variable, which is the relevant index in equation (either the social distance or remote working index). TransportChoice is a series of dummy variables indicating the usual method of transport individual \(i\) uses to commute to work. \(\text{Z}_i\) is a matrix of control variables which were outlined in Section 3 previously. The \(\beta\) values are the coefficients of the model. \(\epsilon_i\) is the error term.

The model is estimated using ordinary least squares (OLS) with heteroskedastic robust standard errors. Variance of Inflation (VIF) tests for potential multicollinearity are applied and in all cases report a mean VIF of below 5, suggesting that multicollinearity is not a problem within the model.

\section*{5. Results}

We present the results of our empirical analysis in this section and discuss the implications of these results.

\begin{table}
\centering
\caption{Descriptive statistics for transport choice.}
\begin{tabular}{lrr}
\hline
Means of transportation to work & Freq. & Percent \\
\hline
Walking & 14,836 & 11.03 \\
Auto (driver) & 96,211 & 71.53 \\
Auto (passenger) & 6003 & 4.46 \\
Motorcycle or moped & 743 & 0.55 \\
Bicycle & 3612 & 2.69 \\
Bus or trolley bus & 8038 & 5.98 \\
Railroad or train & 5065 & 3.77 \\
\hline
\end{tabular}
\end{table}
5.1. The ability to socially distance and remote work based on means of transport

We begin by discussing the results of our estimation of equation (1) which are presented in Table 2.

Tables 3 and 4 present a summary of a series of t-tests for each transport coefficient against the others to determine a hierarchy in terms of which modes of transport are associated with individuals who have the greatest potential to engage in social distancing in work or work remotely. A plus sign (+) indicates that an individual travelling by mode of transport (listed in column 2) is more likely to be able to engage in social distancing/remote work than an individual in the corresponding mode of transport (listed in columns 3 through 8). A negative sign (−) indicates that the individual travelling by mode of transport (listed in column 2) is less likely to be able to engage in social distancing/remote work than an individual in the corresponding mode of transport (listed in columns 3 through 8). An equals sign (=) indicates that the individual travelling by mode of transport (listed in columns 3 through 8) is just as likely to be able to engage in social distancing/remote work than an individual in the corresponding mode of transport (listed in column 2).

Looking at row (5) in Table 3, as an example, individuals who commute to work by bike are more likely to be able to engage in social distancing in their workplace than those who commute by walking, auto (driver), or auto (passenger), but they are just as likely to be able to socially distance as those who commute by motorcycle or moped. The results clearly show that versus all other modal choices auto (drivers) are the least able to engage in social distancing at work. While those who use public transport, in the form of bus or trolley bus, and railroad or train, are the most likely to be able to engage in social distancing in their workplace.

Regarding Table 4, which shows the corresponding t-tests for remote working, there are significant differences in the patterns which are emerging relative to the social distancing index. Individuals who commute by railroad or train commuters are more likely to be able to remote work than any other type of commuter. Further, in this remote working index, auto (drivers) fare reasonably well. However, relative to those who walk or commute as auto (passengers) or use motorcycles or mopeds or use bicycles, individuals who commute by auto (driver) have higher remote work potential.

5.2. Emissions savings estimations

This section of the paper presents the potential emissions savings from working from home. The approach used to estimate these emissions was to apply emission factors (O’Keefe, et al. 2016) for each mode of transport used and multiply this by the activity data that was estimated from the data set examined and scenarios on the level of home working. The average travel to work distance in 2011 was 14.7 km and this was multiplied by the emissions factor and various numbers of days that individuals were assumed to work from home under different scenarios. The approach does not claim to be 100% accurate, but it does give an approximation of the extent of the emissions that could be potentially saved from promoting a work from home policy. Emissions savings are estimated for those that commute by car (either by driving alone or as a passenger) and by public transport.

Following Koren and Peto (2020b), the proportion of the sample with a high potential for remote work is estimated using a 62.5 threshold (for remote work) and an inverse of this figure, at a threshold of 37.5 is used for estimating the proportion that will have difficulty social distancing in their workplace due to government restrictions and may therefore not be returning to work in the short term. Table 5 presents the proportion of the population in the 2011 Census that have a high potential for remote work or occupational social distancing by transport type. Overall, 47 per cent of the sample has a high potential for remote work and 5 per cent of the sample has a low potential for social distancing. Based on these proportions and their breakdown by transport type, Table 5 also

| Table 2 |
|---|
| **Means of transportation to work - base** |
|  | Social Distance Index | Remote Work Index |
| **Variables** | (1) | (2) |
| **Means of transportation to work - base** | | |
| Walking | 0.396*** | −0.151** |
| Auto (driver) | (0.0497) | (0.0616) |
| Auto (passenger) | 0.245*** | −1.052*** |
| Motorcycle or moped | (0.0727) | (0.0901) |
| Bicycle | 0.626*** | −0.463* |
| | (0.199) | (0.246) |
| Bus or trolley bus | 0.675*** | −0.333*** |
| | (0.0929) | (0.115) |
| Railroad or train | 1.250*** | 1.110*** |
| | (0.0810) | (0.100) |
| Female | 1.530*** | 3.352*** |
| | (0.0322) | (0.0399) |
| Marital status | | |
| Married | −0.0381 | 0.329*** |
| | (0.0378) | (0.0469) |
| Separated (including divorced) | −0.0549 | −0.0804 |
| | (0.0713) | (0.0884) |
| Widowed | 0.173 | −0.119 |
| | (0.146) | (0.181) |
| Highest level of education completed | | |
| Lower secondary | 0.246*** | 1.583*** |
| | (0.0837) | (0.104) |
| Upper secondary | 0.921*** | 4.078*** |
| | (0.0773) | (0.0958) |
| Third level, non-degree | 0.852*** | 5.885*** |
| | (0.0947) | (0.117) |
| Third level, degree or higher | 1.357*** | 8.292*** |
| | (0.0798) | (0.0989) |
| Class of worker | | |
| Self-employed with paid employees | −1.109*** | 2.048*** |
| | (0.0793) | (0.099) |
| Self-employed without paid employees | −0.582*** | −0.686*** |
| | (0.0670) | (0.0831) |
| No disability | −0.0952 | −0.0440 |
| | (0.0641) | (0.0794) |
| Age | | |
| Age | 0.0428*** | 0.0734*** |
| | (0.00923) | (0.0114) |
| Age Squared | −0.000271** | −0.000359*** |
| | (0.000106) | (0.000131) |
| Region | | |
| Dublin | 0.245*** | 1.025*** |
| | (0.0559) | (0.0693) |
| Mid-East | −0.0260 | 0.330*** |
| | (0.0629) | (0.0792) |
| Midlands | −0.335*** | −0.142 |
| | (0.0784) | (0.0972) |
| Mid-West | −0.164** | 0.0107 |
| | (0.0714) | (0.0885) |
| South-East | −0.156** | −0.232*** |
| | (0.0672) | (0.0834) |
| South-West | −0.116* | −0.00360 |
| | (0.0614) | (0.0761) |
| West | −0.135** | −0.289*** |
| | (0.0680) | (0.0843) |
| Irish | 0.402*** | 1.953*** |
| | (0.0415) | (0.0515) |
| Constant | 43.45*** | 35.34*** |
| | (0.260) | (0.322) |
| Observations | 134,508 | 134,508 |
| R-squared | 0.283 | 0.441 |

Standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.
extrapolates based on these proportions the corresponding number in the total workforce that would have a high potential to remote work or socially distance by transport type for the Irish Labour force. This data is matched to emission estimations and Table 6 presents the estimated emissions reductions for each of the different working scenarios examined in this paper. The results show that the potential emission savings can be quite significant based upon the number of days that an individual could work from home. While it is not expected that 100% of those that could work from home would. The results do provide an indication that if they were able to do so for one or two days a week that it could result in substantial environmental benefits. To put the results into context, road transport is one of the highest sources of emissions in Ireland, and that if all those that could work from home did so for one day a week it would result in a 1% decrease in annual emissions in the transport sector, rising to 3% if all those who could work from home did so on a full-time basis. For context, total transport sector emissions in 2018 were 15,277 kt (SEAI, 2020). The predicted savings for social distancing, which will be more significant in the short run while government measures curtail occupational social distancing, are more modest, due to the small numbers in the workforce with a low potential for social distancing.

6. Discussion of results and policy implications

Policies to reduce road transport emissions have to date not addressed structural mobility patterns, which encompass the number and distance of trips people make and their choice of mode. The shut down of economic and social activity as part of measures to contain the spread of COVID-19 in 2020 have caused a dramatic change in mobility patterns and may represent a game changing situation for policymakers: within two days of the first stage of lockdown on March 12th, the number of cars counted by traffic cameras in Ireland halved. Ultimately, Irish car traffic fell by nearly 80% in April 2020 (O’Riordain and Daly, 2020). This trend has continued in subsequent lockdowns and as Ireland entered its third lockdown in December 2021 car volumes in the week commencing the 27th of December were 45.5% lower in Dublin and 45.1% lower in regional locations than in the same week the previous year (CSO, 2021). Nitrous dioxide pollution detected from air quality

| Table 3 | T-test of differences for transport variables for social distancing index. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Description     | Auto (driver)   | Auto (passenger)| Motorcycle or moped | Bicycle | Bus or trolley bus |
| Remote work (Census 2011) | 48.16% | 32.57% | 41.86% | 51.03% | 72.22% |
| Social Distancing (Census 2011) | 5.58% | 5.01% | 2.96% | 3.53% | 1.9% |
| Number in labour force who have high potential for remote work | 514084 | 22527 | 3534 | 46782 | 38095 |
| Number in labour force who have high potential for social distancing | 59564 | 3465 | 250 | 3236 | 1002 |

| Table 4 | T-test of differences for transport variables for remote working index. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Description     | Auto (driver)   | Auto (passenger)| Motorcycle or moped | Bicycle | Bus or trolley bus |
| Remote work (Census 2011) | + | + | + | + | + |
| Social Distancing (Census 2011) | + | + | + | + | + |
| Number in labour force who have high potential for remote work | 514084 | 22527 | 3534 | 46782 | 38095 |
| Number in labour force who have high potential for social distancing | 59564 | 3465 | 250 | 3236 | 1002 |

| Table 5 | Percentage of sample and number of workforce that can remote work or social distance by transport type. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Description     | Auto (driver)   | Auto (passenger)| Motorcycle | Bus or tram | Railroad |
| Remote work (Census 2011) | 48.16% | 32.57% | 41.86% | 51.03% | 72.22% |
| Social Distancing (Census 2011) | 5.58% | 5.01% | 2.96% | 3.53% | 1.9% |
| Number in labour force who have high potential for remote work | 514084 | 22527 | 3534 | 46782 | 38095 |
| Number in labour force who have high potential for social distancing | 59564 | 3465 | 250 | 3236 | 1002 |

| Table 6 | Estimated annual reductions in emissions. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Description     | Drivers & Passengers (kt CO₂) | Bus (kt CO₂) | Rail (kt CO₂) | Total (kt CO₂) |
| Number who can remote work | 1 day | 87.52 | 0.91 | 3.15 | 91.58 |
|                    | 2 days | 175.04 | 1.82 | 6.31 | 183.16 |
|                    | 3 days | 262.56 | 2.72 | 9.46 | 274.75 |
|                    | 4 days | 350.09 | 3.63 | 12.61 | 366.33 |
|                    | 5 days | 437.61 | 4.54 | 15.77 | 457.91 |
| Number who can social distance | 1 day | 10.21 | 0.06 | 0.08 | 10.36 |
|                    | 2 days | 20.42 | 0.13 | 0.17 | 20.72 |
|                    | 3 days | 30.64 | 0.25 | 0.33 | 31.07 |
|                    | 4 days | 40.85 | 0.31 | 0.41 | 41.43 |
|                    | 5 days | 51.06 | 0.31 | 0.41 | 51.79 |
monitoring stations halved, while the reduction in road traffic is estimated to reduce Ireland’s energy-related CO₂ emissions by 1.5 million tonnes in 2020, representing 5% of all energy-related emissions (Glyn et al., 2020). The initial carbon inventories created for 2020 in Ireland demonstrated that emissions from transport fell by 17%, this reduction should be considered in the light of rolling lockdowns during the pandemic (EPA, 2021).

However, given this dramatic structural break in mobility and work practice, the question is whether emissions savings can be achieved from increased home working in the short and long term? The results in this paper suggest short and long run direct implications for commuting outcomes. In the short term, whilst vaccination rollovers continue, individuals who commute by train or bus are more likely to be able to work remote and to practice occupational social distancing than any other type of commuter. Since the perceived risk of contracting the virus is higher by going by train or bus, these commuters may switch to car commuting, which could have a negative impact on the environment. This is something policymakers will need to consider in the short to medium term, as the economy starts opening again. Further, in the short term, where social distancing measures are set to continue in workplaces, individuals who commute by car are less likely to be able to engage in social distancing in their workplace. This means that their physical presence in work may be restricted. As a result, it is likely that the number of commuters by car for work purposes will fall in the short term. While this will be negative in terms of the employment prospects of the individuals, it may have positive environmental impacts due to a reduction in car usage and greenhouse gas emissions. When this finding is coupled with the insights gained from the analysis on remote working, further potential long-term impacts emerge. The analysis shows that those who commute by car have a relatively high potential for remote work. This suggests that in the short term these individuals, who may not be able to attend work physically due to social distancing regulations, have a greater capacity to work from home, which estimated in this paper could result in a 1–3% decrease in annual CO₂ emissions in the transport sector, depending on the share of working time people work remotely.

In the longer term, if this trend of working from home was to be incentivized to last beyond the COVID-19 time horizon this would suggest that there would be potential to continue to reduce car commuting for work purposes and improve the environment, without a negative impact on employment outcomes. Although, increased remote working can have immediate and direct environmental benefits, in the longer run, indirect costs or ‘rebound effects,’ associated with non-urban residential relocation, an increase in non-work related trips, car dependency and a modification of consumption patterns for remote workers, may nullify any benefits (Cerqueira et al., 2020; He and Hu, 2015; Ory and Mokhtarian, 2006; Pérez et al., 2004). Another key impact of an increased amount of remote working would be how it impacts upon our current mobility networks. Does increased remote working result in transport planners reconsidering increasing the capacity of public transport? Remote working may also result in more frequent short trips occurring near the home as activities move from city centers. The knock-on impacts of such a movement on emissions and congestion also need to be considered. Consequently, policymakers need to carefully consider policy interventions and incentives that promote remote working, induced by the COVID-19 crisis, to ensure a positive net environmental impact.

It is difficult to ascertain the transferability of these results to other geographical contexts as settings and data differ. We know the majority of workers commute to work by car in the U.S and Europe (IEA, 2019). Additionally, the potential for Irish workers to be able to work from home (47 per cent) is similar relative to workers in the U.S (37 per cent) Sweden, UK, Denmark, Belgium and Norway (over 40 per cent) (Dingel and Nieman, 2020). The key question in other contexts, is what are the means of transportation to work for these workers? Significant changes in people’s travel behaviour have been experienced throughout the world with decreased mobility indicating that remote working carries a high potential for moving towards a more sustainable future (Bucksky, 2020; Shamshiripour et al., 2020a,b). However, there is also evidence of increased car use and/or reductions in travel by public transport users, which may negate any benefits from remote working for society and the environment (Bucksky, 2020; Molly et al., 2020; Zhang et al., 2021).

There are two notable limitations with this study. Firstly, the occupational data used for constructing the social distancing and remote working index uses U.S. O*NET data on the description of tasks associated with each occupation. As a result, this should be viewed as an approximation of the workplace environment for the same occupations in Ireland. Secondly, the individual data is not from the most recent Irish Census as ammonised individual level data and individual level transport choice decisions are currently unavailable for the 2016 Irish Census.

7. Conclusions

Literature examining the relationships between changing work practices due to COVID-19, transport choice and the impact on the environment are so far limited. This is the first study in the literature that connects remote working potential and occupational social distancing to transport choice. The analysis used O*Net data to construct social distancing and remote work indexes and Irish Census data to identify commuting choice and other individual factors that may affect social distancing and remote working potential. Finally, the potential emission savings from a switch to remote working and from occupational social distancing are estimated. The main findings from our analysis include:

- Overall, 47 per cent of the sample has a high potential for remote work and 5 per cent of the sample has a low potential for social distancing
- The results show that those who commute by car have a relatively high potential for remote work but are less likely to be able to engage in social distancing in their workplace.
- While this may be negative for employment prospects in the short run, our analysis indicates that this pattern has the potential for positive environmental implications in the short and long run.
- Road transport is one of the highest sources of emissions in Ireland, and if all those that could work from home did so for one day a week it would result in a 1% decrease in annual emissions in the transport sector, rising to 3% if all those who could work from home did so on a full-time basis.
- The predicted savings from social distancing are more modest, due to the small numbers in the workforce with a low potential for social distancing.

Appendix 1. Matching US occupational codes to Irish occupational codes

O*Net provides 968 occupational codes which match to 2010 US Standard Occupational Classifications (SOCs). These occupational codes do not directly match to Irish occupational codes as the Irish Central Statistics Office (CSO) bases their occupational classifications on the UK SOC system. We apply a crosswalk in the same was as Crowley and Doran (2019). The US and UK SOC are not directly comparable and there is no direct conversion available. Therefore, in order to convert the US codes to their UK counterparts (which are approximately identical to the Irish codes used by the CSO)
we transform these data using a series of established international classifications. This is accomplished through the use of the International Standard Occupational Classifications (ISOC). The US SOCs can be converted using the Bureau of Labour Statistics official conversion (Bureau Of Labor Statistics, 2012). The codes available from O*Net are 6-digit US SOCs. When converting these to the ISOC there is not a one to one match. This is due to the ISOC codes being at a higher aggregation level. Therefore, in some instances, two or more of the US SOC codes are combined into one ISOC code. Where this occurs, any data on occupations is averaged to provide a single value. Once the codes are in ISOC format it is possible to convert these ISOC codes to the UK SOC codes using a conversion framework developed by the Office for National Statistics (2010). In doing so, again there is a small number of occupations which have more than a one for one match and therefore there is a need to average any occupational details associated with these occupations. It is possible, once this process has been completed, to translate these UK SOC codes to Irish SOC codes in a perfect one for one match. When the merge process is complete, out of a possible 327 SOC codes available in Ireland we have occupational data for 318 of these codes at 4-digit level. As the census uses 3-digit occupational codes it is necessary to aggregate these 318 codes to the 88 3-digit codes. When doing so we calculate the weighted average of the 318 codes.

Appendix 2. Definition of elements of Social Distancing Index

| Variable                                                                 | Original Coding | Recoding            | Context                                      |
|--------------------------------------------------------------------------|-----------------|---------------------|----------------------------------------------|
| How important is it to work with others in a group or team in this job?  | 0 - Not important at all | 0 - Extremely important | Face to face discussions several times a week and often more than e-mails, letters, and memos. |
| Providing guidance and expert advice to management or other groups on technical, systems-, or process-related topics. | 25 - Fairly important | 25 - Very important |
| Getting members of a group to work together to accomplish tasks.         | 50 - Important   | 50 - Important       |
| Providing guidance and direction to subordinates, including setting performance standards and monitoring performance. | 75 - Very important | 75 - Fairly important |
| Encouraging and building mutual trust, respect, and cooperation among team members. | 100 - Extremely important | 100 - Not important at all |
| How important is it to work with external customers or the public in this job? | 0 - Not important at all | 0 - Important |
| Performing for people or dealing directly with the public. This includes serving customers in restaurants and stores, and receiving clients or guests. | 25 - Fairly important | 25 - Very important |
| Providing personal assistance, medical attention, emotional support, or other personal care to others such as coworkers, customers, or patients. | 50 - Important | 50 - Important |
| Developing constructive and cooperative working relationships with others, and maintaining them over time. | 75 - Very important | 75 - Fairly important |
| Using hands and arms in handling, installing, positioning, and moving materials, and manipulating things. | 100 - Extremely important | 100 - Not important at all |
| Running, maneuvering, navigating, or driving vehicles or mechanized equipment, such as forklifts, passenger vehicles, aircraft, or water craft. | 0 - Not important | 0 - Important |
| Servicing, repairing, adjusting, and testing machines, devices, moving parts, and equipment that operate primarily on the basis of mechanical (not electronic) principles. | 25 - Fairly important | 25 - Very important |
| Servicing, repairing, calibrating, regulating, fine-tuning, or testing machines, devices, and equipment that operate primarily on the basis of electrical or electronic (not mechanical) principles. | 50 - Important | 50 - Important |
| Inspecting equipment, structures, or materials to identify the cause of errors or other problems or defects. | 75 - Very important | 75 - Fairly important |
| To what extent does this job require the worker to perform job tasks in close physical proximity to other people? | 100 - Extremely important | 100 - Not important at all |

Appendix 3. Definition of elements of Remote Working Index
| Variable definition                                                                 | Original coding                                                                 | New coding                                                                 |
|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| How often do you use electronic mail in this job?                                  | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | same as original                                                           |
| How often does this job require working outdoors, exposed to all weather conditions? | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How often does this job require working outdoors, under cover (e.g., structure with roof but no walls)? | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How frequently does this job require the worker to deal with physical aggression of violent individuals? | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How much does this job require wearing common protective or safety equipment such as safety shoes, glasses, gloves, hard hats or life jackets? | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How much does this job require wearing specialized protective or safety equipment such as breathing apparatus, safety harness, full protection suits, or radiation protection? | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How much does this job require walking and running?                                  | 0 - Never 25 - Less than half the time 50 - About half the time 75 - More than half the time 100 - Continually or almost continually | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How often does this job require exposure to minor burns, cuts, bites, or stings?   | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| How often does this job require exposure to disease/infections?                     | 0 - Never 25 - Once a year or more but not every month 50 - Once a month or more but not every week 75 - Once a week or more but not every day 100 - Every day | 0 – Every day 25 – Once a week or more but not every day 50 – Once a month or more but not every week 75 – Once a year or more but not every month 100 – Never |
| Performing physical activities that require considerable use of your arms and legs and moving your whole body, such as climbing, lifting, balancing, walking, stooping, and handling of materials. | 0 – Not important 100 – Important | 0 – Important 100 – Important |
| Using hands and arms in handling, installing, positioning, and moving materials, and manipulating things. | 0 – Not important 100 – Important | 0 – Important 100 – Important |
| Using either control mechanisms or direct physical activity to operate machines or processes (not including computers or vehicles). | 0 – Not important 100 – Important | 0 – Important 100 – Important |

(continued on next page)
| Variable definition                                                                 | Original coding | New coding |
|-----------------------------------------------------------------------------------|-----------------|------------|
| Running, maneuvering, navigating, or driving vehicles or mechanized equipment, such as forklifts, passenger vehicles, aircraft, or water craft. | 0 – Not important | 0 – Important |
| Performing for people or dealing directly with the public. This includes serving customers in restaurants and stores, and receiving clients or guests. | 0 – Not important | 0 – Important |
| Servicing, repairing, adjusting, and testing machines, devices, moving parts, and equipment that operate primarily on the basis of mechanical (not electronic) principles. | 0 – Not important | 0 – Important |
| Servicing, repairing, calibrating, regulating, fine-tuning, or testing machines, devices, and equipment that operate primarily on the basis of electrical or electronic (not mechanical) principles. | 0 – Not important | 0 – Important |
| Inspecting equipment, structures, or materials to identify the cause of errors or other problems or defects. | 0 – Not important | 0 – Important |

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