Predicting Urban Futures:

Scenarios with the CASA Land Use Transportation Interaction Models, **Simulacra** and **Quant**

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In this note, we demonstrate how we can use our land use transport interaction (LUTI) models **Simulacra** built for the London region and **Quant** built for England and Wales to test various land use transport futures set up as 'scenarios'. These are 'what if' speculations on the future distribution of population, employment, residential-work trips and trips to retail centres. They enable us to test the impact of a change in travel cost or in the configuration and volume of employment and population on the allocation of these activities within the region of interest. We can test a virtual infinity of such changes using these models but we will focus on three examples for the London region to demonstrate what the model frameworks are able to do.

This note is somewhat technical. It assumes knowledge of the models and is only designed to give the reader a quick idea of what is possible and what has been done. We will reproduce a much more considered note as part of our final reporting of the model and we will also produce something much more readable for the general informed reader and policy professional in due course.

We have used a combination of our **Simulacra** and **Quant** models to test three different scenarios for future development in Greater London and the metropolitan area. The **Simulacra** model is specifically designed for this region which consists of 1767 small spatial units (zones based on electoral units called 'wards') which have an average of some 7640 persons per zone based on Population Census data from 2001. The **Quant** model is a generalisation of **Simulacra** to the whole of England and Wales. It uses a different census geography whose small zones are based on 'middle layer super output areas' (MSOAs), not too dissimilar from the wards used in **Simulacra**. There are 7201 such MSOAs in the model where, using 2011 Population Census data, the average zone size is some 7787 persons, quite close to the figure for wards recorded some 10 years earlier by the 2001 Census. When we use the **Quant** model to test various scenarios for London, we do not constrain the model to impacts in London *per se* for as the model works for the entire national space economy, the impacts are across all zones in England and Wales. Our rationale for using the **Simulacra** model for the first scenarios based on road pricing is that this model was developed with detailed modal networks and was first used to test congestion charging and petrol price rises being specifically adapted for these kinds of policies (Batty, 2013; Batty et al, 2013).

The three scenarios that we have tested are as follows:

Road Pricing for London and Its Outer Metropolitan Area: this involves the imposition of two cordons – the first around the inner area of London which is wider than the current congestion charge area and coincides with the Inner London Education Authority Boroughs, the second including all the boroughs in Greater London itself which coincides with the low emissions zone area already established. The cordons that define both these areas are based on the boroughs as we will define below. The essences of these policies is to increase travel cost through one-off charges in the inner zone of some £5 for entry and some £2.5 for entry into the outer zone. Those entering both zones will not pay the cost of both zones but only the upper charge of £5. We will test the impact of these changes on the redistribution of population and service jobs using **Simulacra**.

The Impact of Crossrail 1 on Rail Travel Times and Population Density: Crossrail 1 is a high speed high volume line which will open in 2018 and runs from Reading in the west of the metropolitan area to Shenfield in the east. It has two spurs – one to Heathrow in the south west and one to Woolwich-Abbey Wood in the south east. The line runs under the central area from Paddington to Liverpool Street and thence to Stratford. The travel times on London rail will be much affected by this line. The impact of the reductions in travel time generated by this line is what we intend to evaluate with the **Quant** Model where we see impacts well beyond the western and eastern extents of the line itself.

The Impact of New Jobs in the Heathrow Airport Area: assuming a third runway is built at Heathrow, there will be substantial new numbers of jobs to be located in the vicinity of the airport. Currently there are some 150,000 jobs in the area and we will test the impact on the distribution of population of adding 50,000 more jobs. We will use the **Quant** model for this because Heathrow is very close to the Green Belt and we anticipate the population associated with these jobs will spread far west of the airport itself towards Reading and possibly beyond.

We will deal with these three policies in turn.

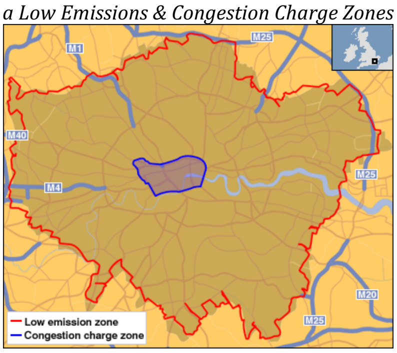
Case Study 1: Road Pricing for London

Determining the Cordons and the Congestion Charges

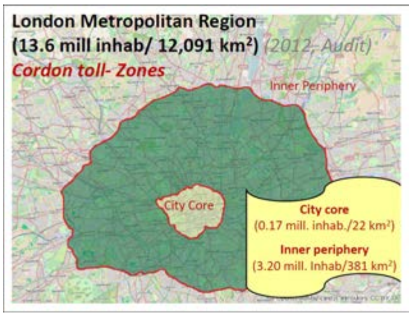
In WP 7, the Insight team have defined various cordons around each of the cities modelled in which increases in travel charges for automobile transport would be tested. In London, in February 2003, a congestion charge was imposed on a restricted area in the boroughs that lie within the city centre and this charge which has reduced traffic by over 10% per annum now stands at £11-50 per day and operates between the hours of 07-00am and 18-00pm during weekdays. In 2008, a low emissions zone was introduced for the whole Greater London Authority (GLA) Area for trucks greater than certain weight and this operates 24/7. Note that this area is almost the same as the GLA area except that it does not include the M25 orbital road which occasionally falls within the GLA area as the maps below show. These charges are already factored into our network times and costs and it was decided to test two new policies based on expanding the inner charge area to the inner boroughs that comprised the old Inner London Education Authority, namely the boroughs of Camden, City-of-London, Hackney, Hammersmith-and-Fulham, Islington, Kensington-and-Chelsea, Lambeth, Lewisham, Southwark, Tower-Hamlets, Wandsworth, and Westminster. These are Zones 1 and 2 in the figure below. Zone 1 is a similar to the congestion charge area as it currently exists. Zone 3 is the rest of the GLA area which covers the remaining 21 out of 33 boroughs. Zone 4 are all those local authorities in the rest of the region which constitute the distant outer suburbs of London, the so-called outer metropolitan area.

The various maps in Figure 1 show these definitions with the four zones in Figure 1 (c) being the zones used for imposition of the two new cordons we will test. The outer cordon lies between Zones 3 and 4 while the inner cordon is between Zones 2 and 3, noting that Zone 1 is within this cordon as well. The initial proposal in Figure 1 (b) is the congestion charge area with its western extension which has now been abandoned and the zone that is bounded by the Middle Ring which used to be the outer ring road, the North Circular Road. We consider the zones in Figure 1 (c) are more appropriate given the wider definition of the London region we are using. In terms of activities, the population and retail activity in these four zones is given in Table 1 and these values are consistent with declining densities with increasing distance from the centre of London.

a Low Emissions & Congestion Charge Zones



c The Initial Proposal in WP 7 for Zones



c The Cordon Zones Zone 1 Black 2 Blue 3 Red 4 White

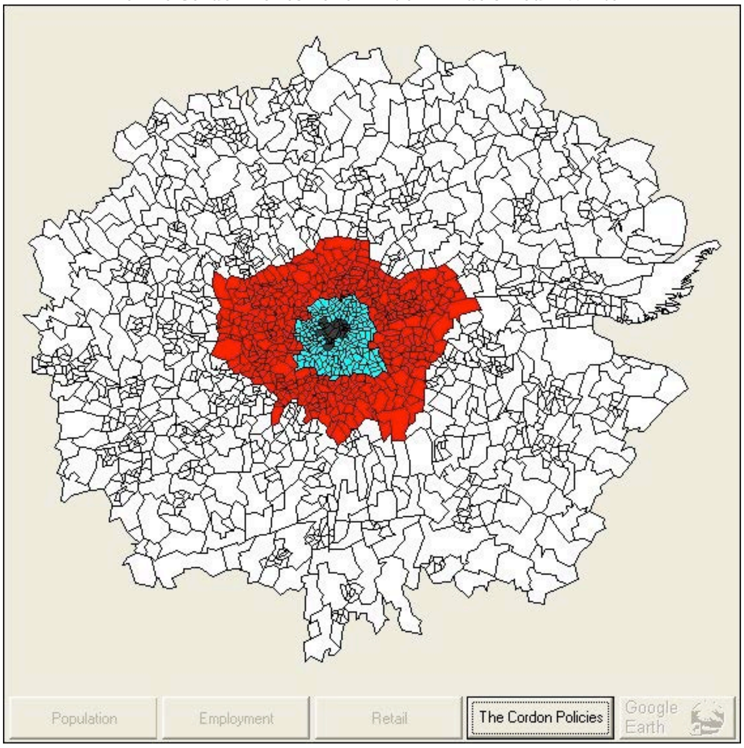


Figure 1: The Cordon Zones (a) Existing (b) Proposed (c) To Be Tested

Table 1: Population and Retail Activity in the Four Cordon Zones

	Zone 1	Zone 2	Zone 3	Zone 4	Total
Area (*in hectares*)	30,684	229,028	1,335,008	11,643,420	13,238,140
Population (%)	378,088 (0.028)	2,439,937 (0.182)	5,071,750 (0.378)	5,539,070 (0.412)	13,428,845
Pop Density	12.322	10.653	3.799	0.476	1.014
Retailing (%)	142,745 (0.087)	246,047 (0.150)	582,291 (0.355)	667,883 (0.407)	1,638,966
Retail Density	4.652	1.074	0.436	0.057	0.124

Over 40% of the population live in the outer zone which has no cordon toll and the proportion of population in Zone 3 which is the outer GLA area contains some 38% of the area meaning that the these populations are subject to the least charge. In fact in the networks constructed for this model, the deterrence is measured in travel time not travel cost. We are using a version of the model with generalised travel time from all modes and in the model, the mean travel times at the morning peak are computed as 68 minutes for the journey to work trips and 62 minutes for journeys to commercial-retail censer. We show these measures in Table 2 where we also indicate the changes in travel time associated with imposing the cordons.

*Table 2: Average Travel Times and Cordon Charges**

	Average Travel Time 2001	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Residential Trips	68 minutes				
		+20 minutes	+20 minutes	+10 minutes	no increase
Retail-Trips	62 minutes				

Some indication of the charges between zones must be given as there is an accumulator as well as charges for travelling within the zone (unless you are a resident or have a permit). The matrix of charges is illustrated in Table 3 as

Table 3: Charges for Travelling Between Cordon Zones

	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
Zone 1 **Zone 2**	£5*		£5	£5
Zone 3	£5		£2-5	£2-5
Zone 4	£5		£2-5	0

*If driving in Zones 1 or 2, an additional charge is levied if the driver entered the congestion charge area. This has already been factored into the travel time matrices.

Estimates of the average travel cost in Greater London and the outer metropolitan area are complex. Our costings are indicative rather than definitive. In terms of distance, recent estimates suggest that the average distance travelled in the region is about 15 miles which takes some 56 minutes. Transport for London's (2015) **Travel in London** report suggests that the average travel time is now 67.8 minutes and we have rounded this to 68 minutes for the average journey to work (http://content.tfl.gov.uk/london-travel-demand-survey.pdf). In fact it is not critical to get the estimates of actual cost correct for the model works with relativities and if our estimates are out by a factor, then this factor will be picked up in the parameter values which are determined during the calibration of the model.

Predicting the Impacts of the Cordon Policies

It is a straightforward matter to run the models to test these policies. All this requires is for us to update the travel time matrix by adding the new one-off costs to the existing travel times according to the matrix above. Of course we need to recompute the shortest routes consistent with these changes. We have specified the charges originally in terms of additional minutes of travel and these are then simply added to the relevant zonal links in the travel time matrices for both retail and residential trips. Note that when we specify these increases in travel costs through cordon charges, the average travel time assumed is not the actual travel time predicted because the charge is levied before the trips adjust to this and this adjustment will then change average travel costs. **Simulacra** has been adapted to generate the relevant scenarios and the impact on average overall travel time and on the distribution of population and retailing activity is the main focus of the analysis. If we define population in zone j at the baseline year as P_j and the relevant variable for the cordon scenario as P'_j, then we first compute the displacement as $P_j - P'_j$ which sums to 0, that is $\sum_j (P_j - P'_j) = 0$. We need to measure the absolute displacement and then sum this to get a measure of impact and this is

$$Z_p = \sum_j \left| P_j - P'_j \right| \qquad \text{and} \qquad Z_s = \sum_j \left| S_j - S'_j \right| \quad .$$

We also show the retail measure along side where S_j and S'_j are the relevant variables. We will plot this variable and also compute the total percentage shifts as

$$\zeta = \frac{Z_p}{\sum_j P_j} = \frac{\sum_j \left| P_j - P'_j \right|}{\sum_j P_j} \qquad \text{and} \qquad \sigma = \frac{Z_s}{\sum_j S_j} = \frac{\sum_j \left| S_j - S'_j \right|}{\sum_j S_j} \quad .$$

These are measures of the amount of population and retail activity which are displaced. We can plot this for each zone but we can also aggregate this for the four cordon zones which give a good measure of impact. We need to do the same kinds of displacement measure for density although in this case we cannot define percentage measures due to the fact that we cannot add dimensionless quantities. Then the density difference for each variable are defined as

$$\delta_j^p = \frac{P_j - P'_j}{\Delta_j} = \frac{P_j}{\Delta_j} - \frac{P'_j}{\Delta_j} \qquad \text{and} \qquad \delta_j^s = \frac{S_j - S'_j}{\Delta_j} = \frac{S_j}{\Delta_j} - \frac{S'_j}{\Delta_j} \quad ,$$

and we can also compute the ratio of the predicted and observed variables which are the same for both count and density variables as

$$\rho_j^p = \frac{P_j}{\Delta_j} \bigg/ \frac{P'_j}{\Delta_j} = \frac{P_j}{P'_j} \qquad \text{and} \qquad \rho_j^s = \frac{S_j}{\Delta_j} \bigg/ \frac{S'_j}{\Delta_j} = \frac{S_j}{S'_j} \quad .$$

We have altered the interface to the desktop version of **Simulacra** to test these various cordon policies. We can test the impact of any number of policies by altering the definitions of the cordons but in this version we enable the interface to simply test policies where either Zones 1-2, Zone 3, or Zones 1-2 and Zone 3 are each tested separately. In fact we will only evaluate one of these here – that is, the complete scenario which involves both cordons Zones 1-2 and 3. The interface where we show the predicted population is shown in Figure 2.

Displacements of Population and Retail Activity

The cordon policies which involve adding 20 minutes to all trips made from and into Zones 1 and 2 and 10 minutes to all trips made to Zone 3 lead to a shift in average travel times from 68 to 96 minutes – an increase of some 49 percent – for residential trip making and from 62 to 90 minutes – an increase of 45 percent for retailing. The overall change in populations for the entire region computed from ξ, the ratio of total displacement to total population, is about 6% (=764920/13427744) and this is slightly greater for retailing where σ is around 7% (=108377/1638966).

Before we introduce the spatial pattern of these predictions, it is important to first second guess what is likely to happen when travel costs are increased towards the centre of the city. The main question is will the city compact or will it begin to spread out. If it is more costly to travel to work and shop towards the centre, then it is likely that the city trip-makers will reduce their trip making. This might mean that commuters from well outside the congestion zone areas will no longer travel as much to the centre or may change their jobs and shopping habits to avoid the centre. Those living in the centre and inner areas may shop and work more locally and this may lead to some compaction but in general it is extremely difficult to figure out in advance what this policy might do. We have already seen that trip times increase but this is probably simply due to the fact that a very large proportion of travellers have to pay the charge anyway. The whole idea of road pricing in this manner is to reduce traffic and this suggests that we might expect trip times to reduce although the way they are computed here is not a good indication of their volumes. We will explore this in the next section but first let us look at the distribution of population and service employment.

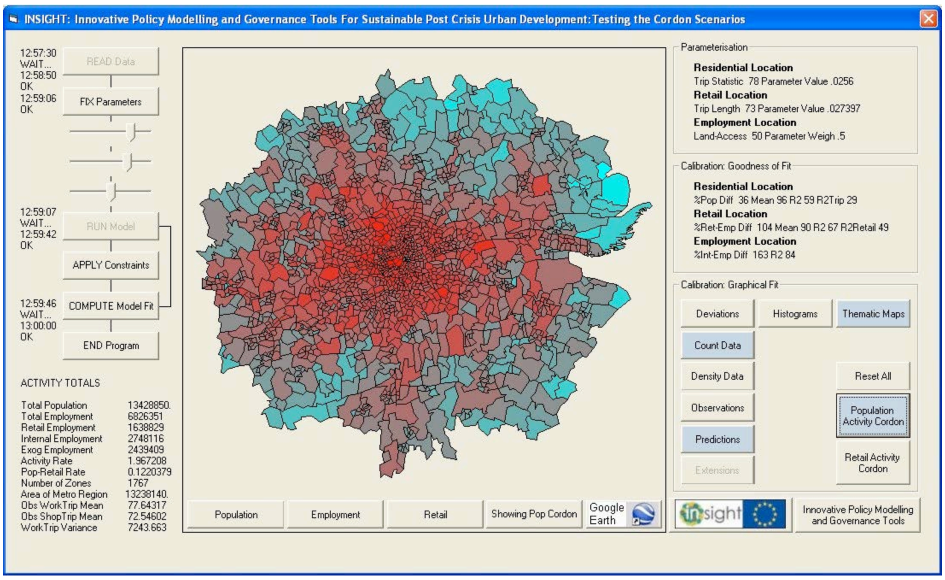


*Figure 2: The Full **Simulacra** Desktop Interface for Testing Cordon Policies Showing a Thematic Map of the Predicted Populations*

Population Count Deviations $P_j - P'_j$ Population Density Deviations δ_j^p

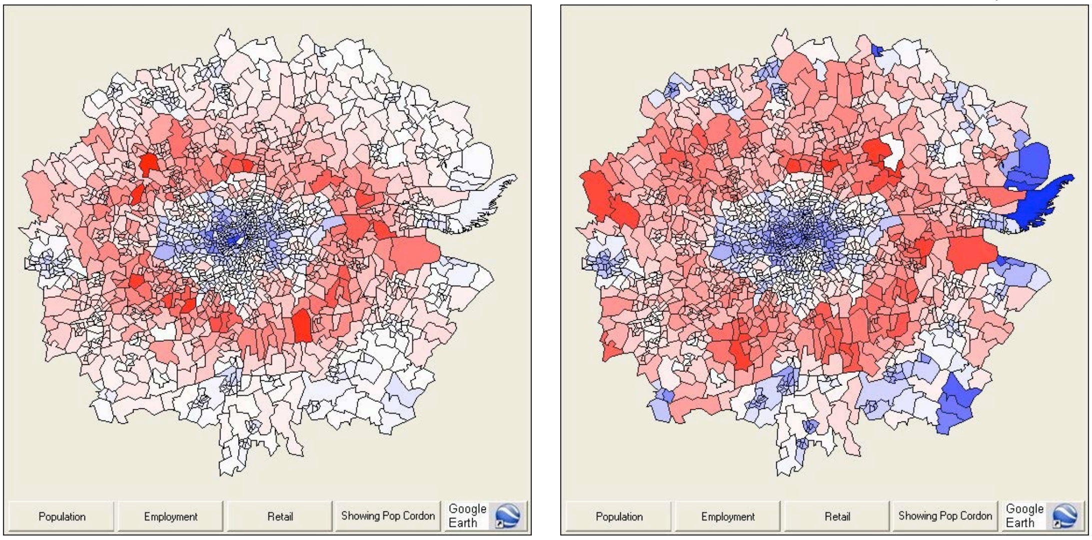


Figure 3: Population: Deviations from the Baseline Model Predictions

In Figure 3, we show what happens to the population differences based on counts $P_j - P'_j$ and densities $\delta_j^p = (P_j - P'_j)/\Delta_j$ where the red shading denotes increases in population counts and densities and the blue decreases. It is very clear from both these maps that populations decentralise quite considerably due to these policies with most population relocating outside the cordons in Zone 4. The biggest losses are in the centre – within Zones 1 and 2 which also covers the original congestion charge area. In fact we are not considering modal switch in this model and it is entirely possible that there could be considerable switches to rail with these policies. To test this, we would have to invoke the four mode **Simulacra** model or the **Quant** model (which we will do so to test **Crossrail 1** in the next scenario). In fact capacity constraints on rail and surging house prices in central and inner London would certainly reinforce the trends shown by these predictions. If we look at the density map in Figure 3 then this reinforces the picture too but we have losses of population on the edge of the region. In fact populations are small in these areas apart from towns such as Reading which in fact are probably affected by some commuters relocating to be nearer the centre without incurring any greater congestion charges. That is, those who travel very long distances into central London have additional travel costs due to the cordons and could well reduce their overall costs by relocating within Zone 4 outside the cordon but a lot closer to the London centre.

We illustrate similar results for the predictions of retailing employment in Figure 4. However for the count data, the pattern is extremely concentrated. Retail employment is very distinct in terms of locations and although the density pattern which is the second map is fairly similar to the population maps, the count data is very concentrated. You can only just make out the concentrations from the left map in Figure 4 so to make this a little clearer we will graph the total counts for the baseline predictions and the cordon prediction in Figure 5 where we show the actual counts rather then differences. In fact these predictions are very hard to see at this scale – one of the perils of trying to display quantitative predictions for many zones on the printed page – but it is just about clear that Wembley and the ring of towns around Zone 3 do gain retailing. A detailed examination of these patterns reveals these differences but in future analysis, we need to represent these changes using different scales while at the same time making sure that the overall impact of the distributional changes are clear.

Retailing Count Deviations $S_j - S'_j$ Retailing Density Deviations δ_j^s

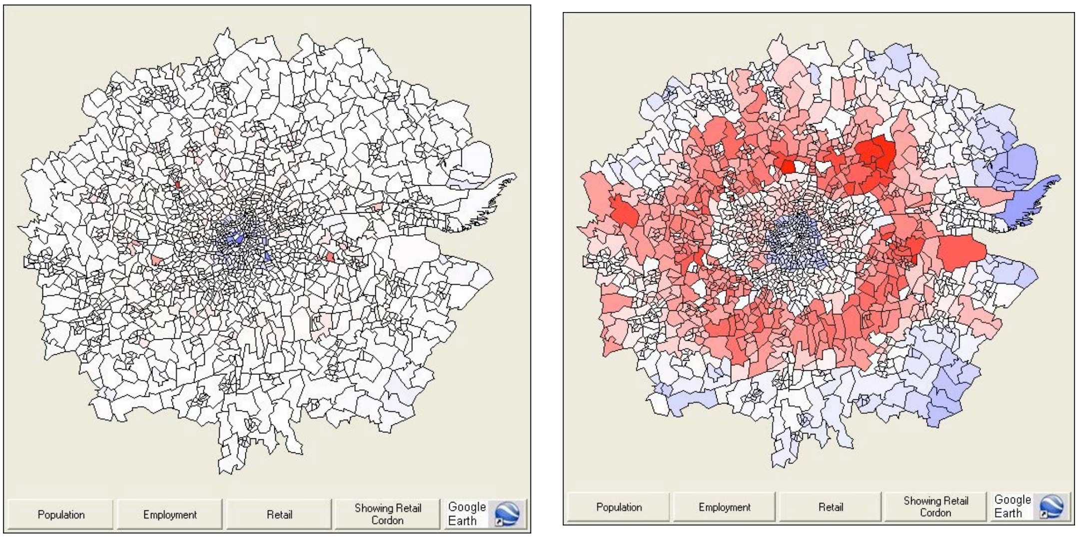


Figure 4: Retailing and Commerce: Deviations from the Baseline Model Predictions

Retailing Counts S_j Retailing Counts S'_j

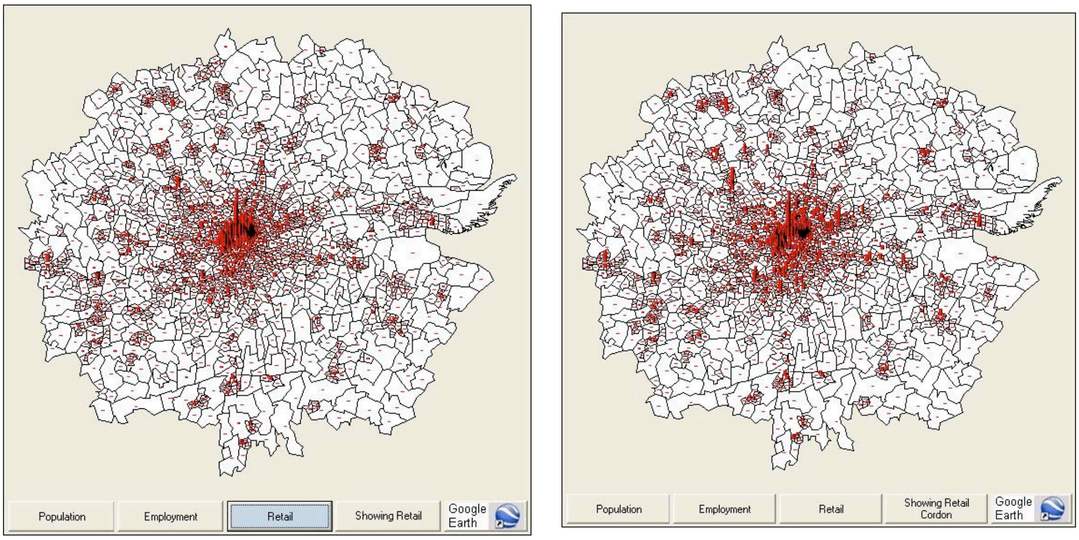


Figure 5: Retailing and Commerce: Baseline and Cordon Model Predictions

Displacements by Cordon Zone

To get a clearer aggregate picture of the displacements of population and retail activity we need to consider the total activity change by cordon zone and in Table 4, we summarise all these measures for both activities.

Table 4: Changes in Activity by Cordon Zone

Cordon Zone Ω_k	Zone 1	Zone 2	Zone 3	Zone 4	Total
Pop Baseline $\sum_{j\in\Omega_k} P_j$	3780878	2439937	5071750	5539070	13428845
Pop Prediction $\sum_{j\in\Omega_k} P'_j$	339319.4	2294511	4946105	5848915	13428845
Deviations $\sum_{j\in\Omega_k} (P_j - P'_j)$	-38768	-145426	-125645	309846	6
$\zeta_k = \sum_{j\in\Omega_k} \lvert P_j - P'_j \rvert / \sum_{j\in\Omega_k} P_j$	-0.103	-0.060	-0.025	0.056	n/a
Retailing Baseline S_j	142745	246047	582291	667883	1638966
Retailing Prediction S'_j	132743	212074	594418	699594	1638966
Deviations $\sum_{j\in\Omega_k} (S_j - S'_j)$	-10003	-33973	12128	31712	-137
$\sigma_k = \sum_{j\in\Omega_k} \lvert S_j - S'_j \rvert / \sum_{j\in\Omega_k} S'_j$	-0.070	-0.138	0.021	0.047	n/a

The biggest population shifts are in Zone 4 where over 50% of the total displacement takes place – with an increase in these suburban-ex-urban areas. In terms of the local displacement, some 10% of population is lost in Zone 1, with 6 % and 2% in Zones 2 and 3, and nearly 6% is added in Zone 4. All these statistics bear out the fact that the impacts are greatest in terms of proportionate switch towards the centre but greatest in absolute terms towards the periphery of the region. The displacement for service jobs is more extreme than population in that the largest loss percentage wise locally is in Zone 2 followed by Zone 1, but then the growth in Zone 3 and Zone 4 mean there are positive shifts in the periphery. These are entirely consistent with our comments about the zonal distribution of these changes from the maps shown in Figures 2 and 3.

We can examine the same sort of changes with respect to densities as we illustrate in Table 5. Zone 4 without any road pricing regulations covers nearly 90% of the region while Zone 1 where most of the jobs are located covers only 0.2% of the region. Clearly densities are very high there and fall dramatically as one moves from the centre to the periphery. Again as with travel times, the relative distribution of densities depends on the unit of measure but densities in the central Zone 1 are more than 25 times those of the outer Zone 4. With the changes generated by the road pricing policies, the population densities in Zone 1 fall by 10% and increase by some 5% in the outer area. The changes in retail densities are a little more muted but are entirely consistent with all our comments so far: falls in retail density in Zones 1 and 2 and slight rises in Zones 3 and 4.

Our last analysis relates to average trip lengths and the amount of travel activity generated by these policies. At the aggregate level of small zones, the redistributions of activity that are illustrated in Figure 3 and 4 are clear enough but they do represent an aggregation of much more detailed interzonal trip distributions. It is well known that one can have many different trip distributions that are consistent with a single activity pattern. For example, if the pattern were, say uniform, the same volume of activity in each zone could be generated by having no trips to each zone or by an even number of trips between every zone and every other. In short, the activity pattern that we see does not reveal the underlying movement that is generated from it. To see what this movement is, we need to examine it at the level at which it is predicted.

Table 5: Changes in the Density of Activity by Cordon Zone

Cordon Zone Ω_k	Zone 1	Zone 2	Zone 3	Zone 4	Total
Pop Base Density $\sum_{j\in\Omega_k} P_j / \Delta_j$	12.322	10.653	3.799	0.476	1.014
Pop Pred Density $\sum_{j\in\Omega_k} P'_j / \Delta_j$	11.058	10.018	3.705	0.502	
Ret Base Density $\sum_{j\in\Omega_k} S_j / \Delta_j$	4.652	1.074	0.436	0.057	0.124
Ret Pred Density $\sum_{j\in\Omega_k} S'_j / \Delta_j$	4.326	0.926	0.445	0.060	
Area $\sum_{j\in\Omega_k} \Delta_j$	30684	229028	1335008	11643420	13238140
% Area $\sum_{j\in\Omega_k} \Delta_j \Big/ \sum_j \Delta_j$	0.002	0.017	0.101	0.880	1

For each of our four zones, we can thus produce an aggregate matrix of trips that shows the relative dependence of each zone on the other three; we have this for the original model baseline run and we also have it for the new model run which is based on adding the transport costs associated with the cordon policies. To examine how the cordon policies impact on the system at the level of this higher level aggregate dependence, we need to compare each cell of the aggregate baseline model matrix to the cordon matrix. Let us define the flows between each of Zones 1, 2, 3, 4 as follows. For the baseline flows we compute the flows from the basic trips T_{ij} as

$$T_{k\ell} = \sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T_{ij} \quad , \quad i, j \in \Omega$$

where we have four zones, and this we have a total possible of 16 aggregated trips. We form the same aggregate zones for the cordon policies as

$$T'_{k\ell} = \sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T'_{ij} \quad , \quad i, j \in \Omega$$

We are also able to compute the time travelled for each of these 16 flows as

$$t_{k\ell} = \sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T_{ij} t_{ij} \quad , \quad \text{and} \qquad t'_{k\ell} = \sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T'_{ij} t'_{ij} \quad ,$$

and each of these can be associated with mean trip lengths as

$$C_{k\ell} = \frac{\sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T_{ij} t_{ij}}{\sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T_{ij}} \quad , \quad \text{and} \quad C'_{k\ell} = \frac{\sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T'_{ij} t'_{ij}}{\sum_{i\in\Omega_k} \sum_{j\in\Omega_\ell} T'_{ij}} \quad .$$

We are also able to compute these statistics for the retail model.

Table 6: Absolute Changes in Trip Volumes for the Residential and Retail Models

Predicted Cordon Trips $\{100T'_{k\ell}/\sum_k\sum_\ell T'_{k\ell}\}$ $\{100S'_{k\ell}/\sum_k\sum_\ell S'_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	1.6	7.8	6.1	1.6	**17.0**
2	0.7	6.4	6.2	1.7	**15.1**
3	0.2	2.2	16.5	7.4	**26.3**
4	0.1	0.7	8.1	32.8	**41.6**
Total	**2.5**	**17.1**	**36.9**	**43.5**	**100.0**

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.7	0.5	0.2	0.0	**1.5**
2	4.4	6.8	3.9	0.7	**15.7**
3	2.4	4.4	22.6	6.9	**36.3**
4	0.7	1.2	9.6	35.0	**46.6**
Total	**8.1**	**13.0**	**36.3**	**42.6**	**100.0**

Baseline Trips $\{100T_{k\ell}/\sum_k\sum_\ell T_{k\ell}\}$ $\{100S_{k\ell}/\sum_k\sum_\ell S_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	1.8	7.7	6.3	1.3	**17.0**
2	0.7	6.3	6.7	1.4	**15.1**
3	0.2	3.3	16.6	6.2	**26.3**
4	0.1	0.9	8.3	32.3	**41.6**
Total	**2.8**	**18.2**	**37.8**	**41.2**	**100.0**

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.7	0.5	0.2	0.0	**1.5**
2	4.1	6.7	4.4	0.6	**15.7**
3	3.0	6.1	21.5	5.6	**36.3**
4	0.9	1.7	9.5	34.5	**46.6**
Total	**8.7**	**15.0**	**35.6**	**40.7**	**100.0**

Trip Differences $\{100(T'_{k\ell}-T_{k\ell})/\sum_k\sum_\ell T_{k\ell}\}$ $\{100(S'_{k\ell}-S_{k\ell})/\sum_k\sum_\ell S_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	-0.21	0.09	-0.24	0.35	**0**
2	0.00	0.14	-0.47	0.32	**0**
3	-0.06	-1.06	-0.07	1.20	**0**
4	-0.02	-0.26	-0.16	0.43	**0**
Total	**-0.29**	**-1.08**	**-0.93**	**2.31**	**0**

Zones	*1*	*2*	*3*	*4*	*Total*
1	-0.03	0.02	0.00	0.01	**0**
2	0.26	0.11	-0.48	0.11	**0**
3	-0.65	-1.73	1.07	1.31	**0**
4	-0.19	-0.48	0.15	0.51	**0**
Total	**-0.61**	**-2.07**	**0.75**	**1.94**	**0**

We will deal with the implications of these changes in order. First we look at the changes in absolute volumes for the residential and retail trip distributions and we show the aggregated matrices $T_{k\ell}$, $T'_{k\ell}$ and $T'_{k\ell}-T_{k\ell}$ in percentage terms in Table 6 where the percentages for each link $k\ell$ are computed as proportions of the total flow. For the baseline model trips, this is $100T_{k\ell}/\sum_k\sum_\ell T_{k\ell}$ and all other variables are treated in the same way. The model baseline and cordon predictions are shown in Table 6(a) and (b) and it is immediately clear for the residential trips that the dominance of the flows from a Zone to itself is clear with nearly 60% of all trips falling into this category. Table 6(c) shows that the impact of the cordons is such that the central Zone 1 loses trips – but Zone 2 gains while Zone 3 loses marginally and Zone 4 gains substantially probably because there are no cordon policies present there. In terms of interzonal flows, Zone 3 and Zone 4 all lose trips that flow to Zones 1, 2, and 3 illustrating significant decentralisation, while Zone 3 loses to Zone 4. These flows are more or less mirrored in the retailing sector with Zones 3 and 4 gaining most significantly, In these zones, 56% of all retailing activity takes place at the baseline and this increases to nearly 58% with the cordon policies. These do not seem to be very dramatic but when once converts these into the numbers involved, this is 2% of all trips and is over 200,000 persons. We illustrate a useful summary of the baseline flows in Figure 6 that reveal the salient characteristics of the metro region.

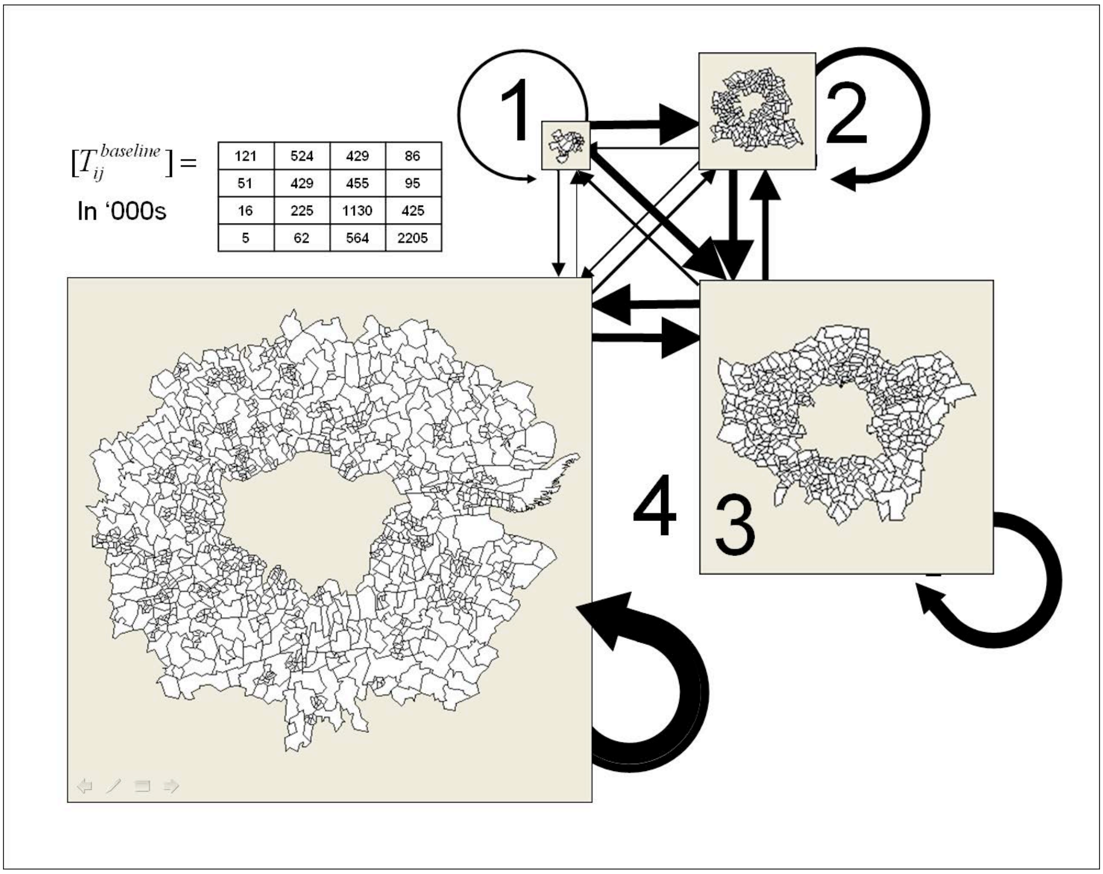


Figure 6: Baseline Flows Between the Aggregated Cordon Zones

Our next set of measures deals with shifts in total travel time due to this reconfiguration of trips. For the residential and retail service sectors, we can compute the total travel times associated with the 4x4 matrix of aggregated zones for the baseline and for the cordon scenario and these are shown in Table 7. These shifts are not dissimilar for those revealed from the total trip distributions pictured above, except of course that there are big additions in travel time posed by the cordon scenario because we add 20 minutes and 10 minutes to all travel times associated with Zones 1 and 2, and Zone 3. The relative distribution of all these times however mirrors the relative distribution in trips. A lot more travel time is captured by the outer zones and lost from the inner zones and this reflects these redistributions in all the results so far. A slightly more muted version of this pattern is reflected in the distributions of retailing trips also shown in Table 7.

Table 7: Changes in Total Trip Distances for the Residential and Retail Models

Predicted Cordon Trips

$\{100T'_{k\ell}t'_{k\ell} / \sum_k \sum_\ell T'_{k\ell}t'_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.7	5.9	8.4	2.7	**17.7**
2	0.5	4.3	7.4	2.6	**14.7**
3	0.3	3.6	12.7	8.1	**24.7**
4	0.1	1.8	12.0	28.9	**42.9**
Total	**1.6**	**15.6**	**40.5**	**42.3**	**100.0**

$\{100S'_{k\ell}t'_{k\ell} / \sum_k \sum_\ell S'_{k\ell}t'_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.3	0.4	0.3	0.1	**1.0**
2	3.3	4.6	4.6	1.0	**13.5**
3	4.3	7.1	16.4	7.1	**34.8**
4	2.1	3.6	14.6	30.4	**50.7**
Total	**9.9**	**15.6**	**35.9**	**38.6**	**100.0**

Baseline Trips $\{100T_{k\ell}t_{k\ell} / \sum_k \sum_\ell T_{k\ell}t_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.8	6.5	8.5	3.3	**19.1**
2	0.6	5.1	7.7	3.2	**16.6**
3	0.2	2.8	12.9	9.2	**25.1**
4	0.1	1.3	11.0	26.9	**39.3**
Total	**1.7**	**15.6**	**40.1**	**42.6**	**100.0**

$\{100S_{k\ell}t_{k\ell} / \sum_k \sum_\ell S_{k\ell}t_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.4	0.4	0.3	0.1	**1.2**
2	3.9	5.6	4.9	1.3	**15.7**
3	3.5	5.8	18.0	8.6	**36.0**
4	1.6	2.6	14.1	28.8	**47.2**
Total	**9.4**	**14.4**	**37.3**	**38.8**	**100.0**

Trip Differences

$\{100(T_{k\ell}t_{k\ell} - T'_{k\ell}t'_{k\ell}) / \sum_k \sum_\ell T'_{k\ell}t'_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.13	0.60	0.05	0.62	**1.41**
2	0.07	0.81	0.35	0.61	**1.84**
3	-0.07	-0.84	0.20	1.12	**0.41**
4	-0.04	-0.53	-1.05	-2.04	**-3.66**
Total	**0.09**	**0.04**	**-0.44**	**0.31**	**0.00**

$\{100(S_{k\ell}t_{k\ell} - S'_{k\ell}t'_{k\ell}) / \sum_k \sum_\ell S'_{k\ell}t'_{k\ell}\}$

Zones	*1*	*2*	*3*	*4*	*Total*
1	0.09	0.08	0.03	0.02	**0.21**
2	0.61	1.03	0.28	0.25	**2.17**
3	-0.72	-1.27	1.64	1.52	**1.17**
4	-0.50	-1.00	-0.54	-1.51	**-3.55**
Total	**-0.52**	**-1.16**	**1.41**	**0.27**	**0.00**

Our last analysis is the most controversial in that it deals with changes in the mean trip travel times. Our method for adding to the travel costs is to convert the additional travel charge into minutes. When we plug these new values into the travel time matrices, each link is added by a factor of 0, 10, 20, or 30 minutes. With all the redistribution that takes place, the average mean trip time increases by 40% from 68 to 96 minutes and this must be due to the dominant orientation of the system to the centre of London which has some half the jobs of the whole metro area. Note that in fact travellers would not actually travel on average 96 minutes but they would essentially pay the equivalent of travelling for this length of time given the existing travel times in the 2001 baseline system. In Table 8, we show these values where it is clear that as we travel through the central Zone 1 to 2 then 3 and finally the non cordon Zone 4, the average travel time decreases relative to the baseline from something like 1.7 the value of the intrazonal trips in Zone 1 to about 1.2 in Zone 3. The same ratios are found for the retail trips. In terms of absolute values, the mean trip length inside Zone 1 is 29 and this increases to 50 whereas in Zone 4, this is 68 which increases to 79. Clearly the interzonal trips are the key determinants of the increased value of travel time to 96 minutes.

Table 8: Changes in Mean Travel Times for the Residential and Retail Models

Predicted Cordon Trips

$$C'_{k\ell} = \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} T'_{ij}t'_{ij} \Big/ \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} T'_{ij}$$

$$CS'_{k\ell} = \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} S'_{ij}t'_{ij} \Big/ \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} S'_{ij}$$

Zones	*1*	*2*	*3*	*4*
1	50	80	135	198
2	71	76	120	181
3	134	119	76	119
4	203	192	131	79

Zones	*1*	*2*	*3*	*4*
1	51	71	132	190
2	81	74	113	173
3	135	119	72	112
4	206	192	132	74

Baseline Trips $C_{k\ell} = \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} T_{ij}t_{ij} \Big/ \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} T_{ij}$

$$CS_{k\ell} = \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} S_{ij}t_{ij} \Big/ \sum_{i\in\Omega_k}\sum_{j\in\Omega_\ell} S_{ij}$$

Zones	*1*	*2*	*3*	*4*
1	29	58	102	162
2	49	52	84	142
3	100	83	58	98
4	167	153	110	68

Zones	*1*	*2*	*3*	*4*
1	30	49	98	154
2	58	49	76	134
3	103	84	55	92
4	171	154	112	64

Trip Differences $C'_{k\ell} - C_{k\ell}$

$CS'_{k\ell} - CS_{k\ell}$

Zones	*1*	*2*	*3*	*4*
1	21	22	33	36
2	23	25	36	39
3	33	36	17	21
4	36	39	20	11

Zones	*1*	*2*	*3*	*4*
1	21	22	34	36
2	22	25	37	39
3	32	35	17	20
4	35	38	20	10

Trip Travel Time Ratio $C'_{k\ell}/C_{k\ell}$

$SC'_{k\ell}/SC_{k\ell}$

Zones	*1*	*2*	*3*	*4*
1	1.72	1.38	1.33	1.22
2	1.46	1.48	1.43	1.27
3	1.33	1.44	1.30	1.21
4	1.22	1.25	1.18	1.17

Zones	*1*	*2*	*3*	*4*
1	1.69	1.46	1.34	1.23
2	1.38	1.50	1.48	1.29
3	1.31	1.42	1.30	1.22
4	1.21	1.25	1.18	1.16

Case Study 2: The Impact of CrossRail 1 on Travel Times and the Distribution of the Employed Population

What is Crossrail?

Crossrail 1 is a high speed transit line which is designed to improve the east-west accessibility and travel times for many groups of travellers in Greater London. It is also designed to connect up key stations that are not connected to Heathrow at present, in particular Euston-St. Pancras-Kings Cross and Liverpool Street which are mainline stations serving the north and east of the UK, including Scotland. It is the first of these lines with a second (Crossrail 2) being planned to run northeast-southwest under London's centre, and with High Speed 2 which is the new line being planned to link the south and north of the UK. Connectivity is the main focus of these lines as the stations they are linked to are hubs in their own right as shown in Figure 7 below.

Figure 7: Schematic of Crossrail 1 with Key Hubs Shown

The line is 118-kilometre (73-mile) with "42km of new tunnels under London to Shenfield and Abbey Wood in the east. The project is building 10 new stations and upgrading 30 more, while integrating new and existing infrastructure. The £14.8 billion Crossrail project is currently Europe's largest infrastructure project. Construction began in 2009 at Canary Wharf, and is now almost 75% complete. It is being delivered on time and within funding. The new railway will be known as the Elizabeth line when services begin in 2018" (at http://www.crossrail.co.uk/). In Figure 8, we show the physical route of the line.

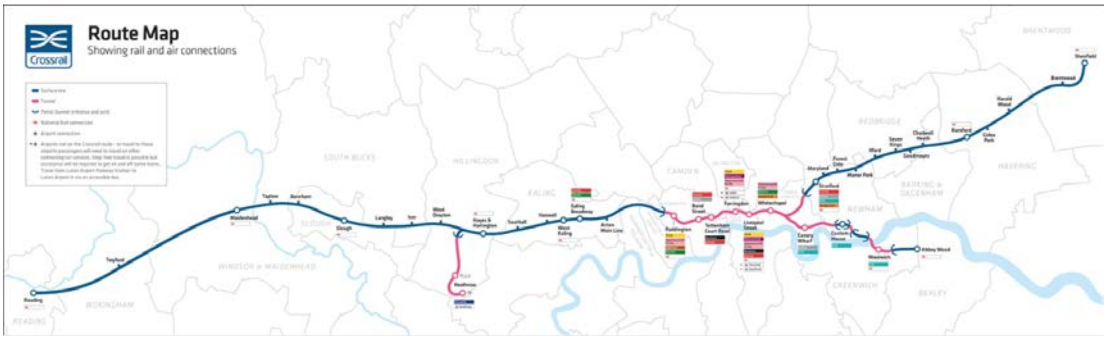


Figure 8: The Actual Crossrail 1 Line

Here we will develop two key elements of the scenario. We have very detailed modal networks for rail, bus and road for the UK (excluding Northern Ireland). We have a baseline scenario from **Quant** and we have entered the new travel time matrix for rail into the model which includes the detail of Crossrail. The model will redistribute trips from bus and road to rail and in doing do, it will change the distribution of population. We will call trips by rail T_{ij}, the relevant travel times t_{ij} and the population generated at the zonal level (MSOA) P_j. We are interested in the shift from $P_j^{baseline}$ to P'_j where we will plot $\Delta_j = P'_j - P_j^{baseline}$. There are several measures of impact that we will thence compute and plot.

Defining Measures of Impact

We start with a shortest route network measured between zone centroids i and j which is defined in terms of travel time as t_{ij}. These zones are those in **Quant** which are MSOAs – middle level superoutput areas – which are the top level at which the model works. The networks are at a much finer level – in the case of roads at the level of street junctions and in terms of buses at bus stop level. Rail is at the level of stations and the connections between station and MSOA centroids is at the road level. When we add new segments to rail, the new travel time matrix is defined as t'_{ij}. All these times will be the same or shorter than the original matrix, that is $t'_{ij} \le t_{ij}$ and our first measure simply counts for any pair of nodes, whether the travel time is shorter or not, that is

$$if\ t'_{ij} \le t_{ij}\ then\ n_{ij} = 1,\ otherwise\ n_{ij} = 0$$

The first measure of impact is simply a sum of these changes for every node which gives the number of changes in travel time from any node to all the other 7201 nodes in the system, where these nodes are all the middle layer superoutput areas (MSOAs) in England and Wales. Then the measure for each node i is defined as

$$n_i = \sum_j n_{ij}$$

and in percentage terms this is simply $\rho_i = n_i / 7201$.

The second measure is to use travel times directly. We do not count whether or not a link has been improved – shortened – but accumulate the travel times for a node to all other nodes. That is we first define the travel time difference as

$$\Delta_{ij} = \left| t'_{ij} - t_{ij} \right| \ge 0 \quad .$$

We need to form some indices of total change in travel time for each node of the system where the nodes are the MSOA centroids. So first for any node i we compute the total changes in travel time as

$$\delta_i = \sum_j \Delta_{ij} = \sum_j \left| \left(t'_{ij} - t_{ij} \right) \right| \quad .$$

This is an index of simple counts of the reduction in travel times for each node to every other in the system. Spatially it reveals what nodes are impacted most by the changes in the network. It is a measure of how much reduction in travel time an individual traveller would gain if they visited every place (MSOA centroid) in the country from any particular centroid as the starting point. We can also compute percentage changes but we will not do this here.

Our third index weights the travel times differences by trips – this is a measure of the total number of people affected by the change where we measure the trips which we observe before the travel time change takes place as T_{ij}. Then the formula is

$$\tau_{ij} = T_{ij} \left| \left(t'_{ij} - t_{ij} \right) \right| \ge 0$$

and the total amount of travel time saved – the number of trip makers and the time they could potentially save where all these tripmakers to travel from a centroid i to all others in the system – is

$$\tau_i = \sum_j T_{ij} \left| \left(t'_{ij} - t_{ij} \right) \right| \quad .$$

We can also express this in percentage terms as $\tau_i = \tau_i \Big/ \sum_i \sum_j T_{ij} \left| \left(t'_{ij} - t_{ij} \right) \right|$. We can find overall indices of system impact from these measures by summing and then normalising them. For example all we need to do is express the number of changes in travel times as a percentage of all possible changes, the total change in travel time for individuals as a percentage of all travel times, and the same for the number of trips weighted by travel times. These measures from the three above are given below. First the total number of travel time changes is

$$N = \sum_i n_i = \sum_i \sum_j n_{ij}$$

and in percentage terms this is simply $\nu = \sum_i n_i \big/ 7201^2$. What this shows out of a total of $7201^2 = 51{,}854{,}401$ possible travel times ν are improved. The second measure computes this in terms of the time saved. The total travel time saved δ is thus

$$\delta = \sum_i \delta_i = \sum_i \sum_j \Delta_{ij} = \sum_i \sum_j \left| \left(t'_{ij} - t_{ij} \right) \right| \quad .$$

Our last travel time measure computes this in terms of trips. From the total amount of time saved from the third measure above which is based on the trips, we simply divide this total by the total time spent by all trip makers before the network changes. Then the total amount of time saved from all trips from each node is

$$\tau = \sum_i \tau_i = \sum_i \sum_j T_{ij} \left| \left(t'_{ij} - t_{ij} \right) \right| \quad .$$

Another significant measure relates to the distribution of population. There is no guarantee that changing travel times will increase population near to the points where such times are decreased for the model simply redistributes that which is already there. The measure that we generate is a simple difference

$$\Delta_j = P'_j - P_j^{baseline} \text{ where } \sum_j (P'_j - P_j^{baseline}) = 0$$

We can also look at absolute differences $\left| \Delta_j \right|$ but in the case of changing travel times we are interested in where populations are increased (as well as decreased),

Generating the Impacts

Our first impacts are simply in terms of counts n_i. For every one of the 7201 MSOAs in England and Wales, there are 7201 shortest routes, all of which have the potential to be affected by Crossrail. In fact only 450 of these links – some 6% – are unaffected by

Crossrail. One might think that if you are travelling from anywhere to anywhere, then at some point you must use Crossrail but it is entirely possible for a traveller to come down from the north to the far south and pass through London across Crossrail but not use the line at all. In some respects this requires much further analysis for it shows the impact is extensive. To show what the impact is, we show the impact in London and the south east in Figure 9 as:

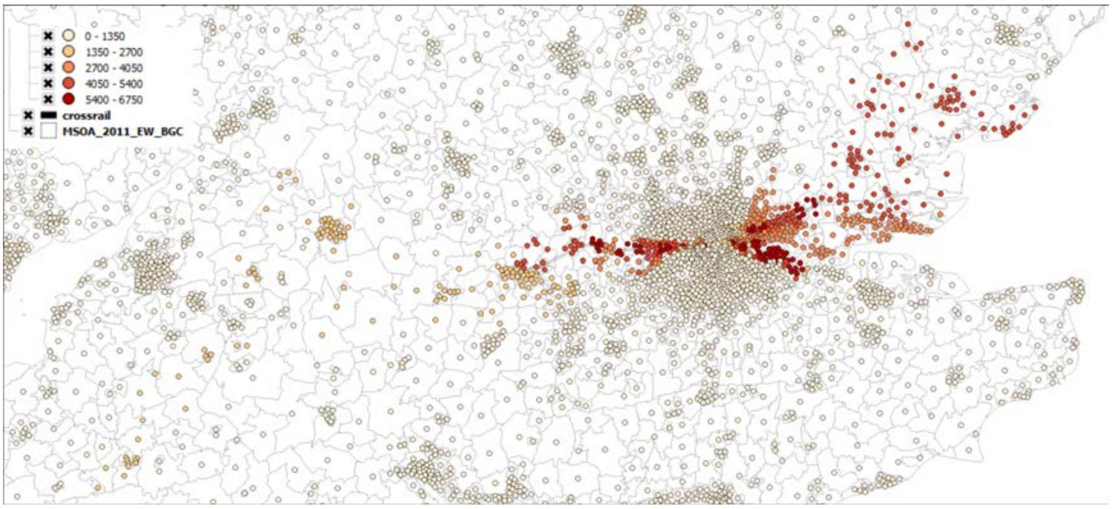


Figure 9: MSOAs with More Than 1350 Changes in Travel Time

Figure 9 is by far the clearest statement of the impact which is more extensive than one imagines. It is easy to see that the really big changes to travel times are along the line but to the east and west of the centre of London. In fact it is in the east towards Stratford and the south east spur line to Woolwich and Abbey Wood (as well as Canary Wharf) that are most affected – probably because the connectivity is so poor in these areas relative to other parts of London. What is of interest as the fact that the big centres to the west – Reading, Swindon, Bath and Bristol are picked out as having improved travel times overall and it is surprising to see such diffusion which is greater than we anticipated. In fact if we look at the UK in general and we can do this in **Quant**, we see that many urban areas in the North and in South Wales are affected by Crossrail. However once we move to other measures then these impacts will become less significant for it is the amount of travel time and the number of trip makers need to be identified.

The next measure is the total cumulative sum of travel time changes δ_i which assumes that a person travelling from an MSOA to any other would receive the benefits of these reduced travel times. We plot this below in Figure 10 and it is quite clear that the impact is much more narrowly defined along the path of the rail line. This is also a good picture of wider impact but we have left out all MSOAs that have less than ~210,000 minutes of travel savings – note that this is only an average for one route of a saving of 29 minutes – and the maximum savings is 8.25 million minutes saved. This can easily be achieved for example if we had 30,000 persons from an MSOA using Crossrail and travelling far enough to save 30 minutes. There are 2 million plus persons who work in the area immediately affected by Crossrail. In Figure 10, it is interesting the way the impact follows the coastline rail lines in the east into East Anglia and into South Wales and Cornwall.

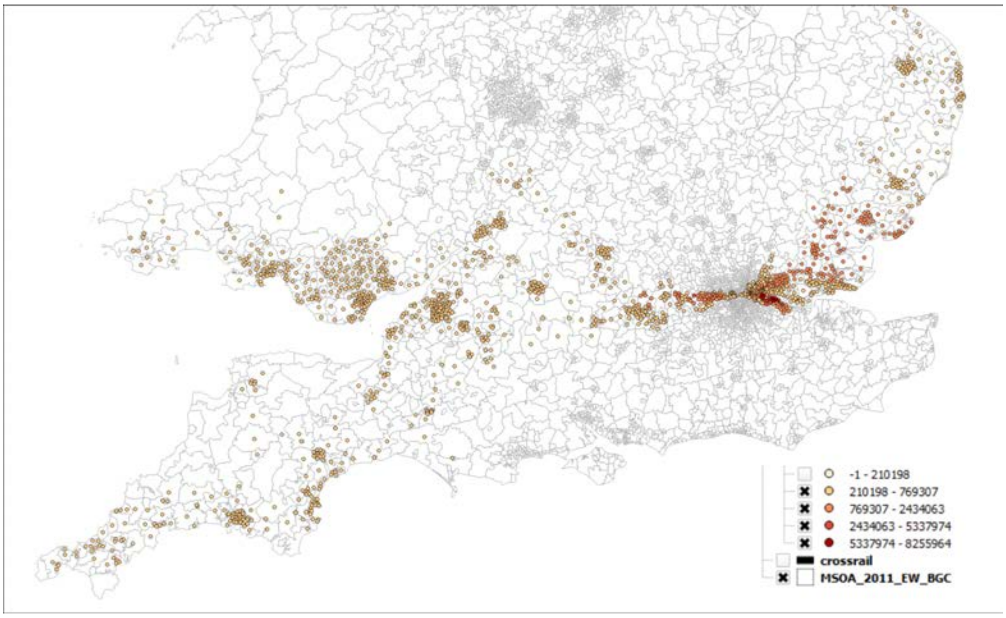


Figure 10: MSOAs with More Than ~210,000 Minutes Savings in Travel Time

The last measure is much more focussed on the real impact for this weights the travel time savings by the number of 'potential' trips in each MSOA. By potential trips, we mean the observed trips from any MSOA but this includes trips that are made by modes other than rail. To get a better estimate we first just use rail trips or rather then new predicted set of rail trips generated by the model. We show the total trip time savings in Figure 11. These scale up to a maximum of 68 million minutes of travel time in the MSOA with the biggest savings and in this figure, we have not plotted any savings less than 25857 minutes. Note however that many of the trips from one MSOA to another are zero because of the confidentiality issues in the Census trip distribution data set where values have been set equal to zero. It is easy to see that the distribution of these travel time savings is much more extreme than any of the other two distributions. In fact we will plot these distributions below for each of the measures comparing these to the distribution of differences in population which we will now examine.

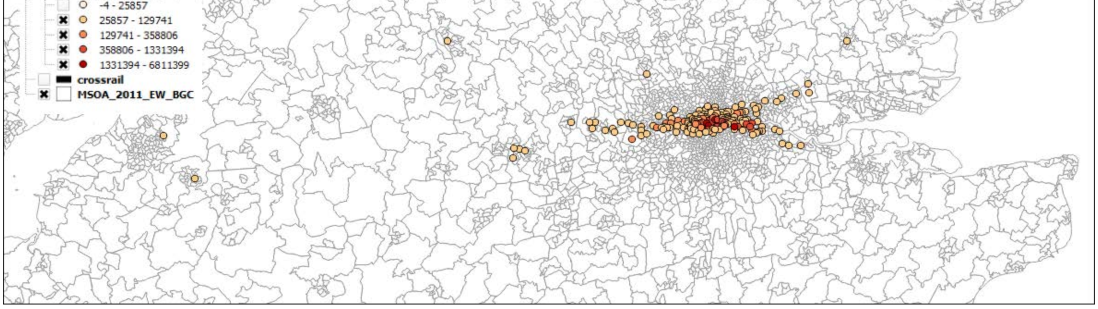


Figure 11: MSOAs with More Than 25,857 Minutes Savings in Trip Travel Time

Our last analysis looks at the distribution of population displaced from the baseline due to the impact of the new railway line. This to an extent is an extension of the last analysis except here we are summing over the trip distribution matrices with respect to the destinations of the trips. Moreover these changes are entirely occasioned by the new travel time matrix. If we write the changes in population in terms of the trip distributions, we can see the relation. Then the baseline and predicted populations are

$$P_j^{baseline} = \sum_i T_{ij(rail)} + \sum_i T_{ij)road)} + \sum_i T_{ij(bus)}^b$$
$$P_j' = \sum_i T_{ij(rail)}' + \sum_i T_{ij)road)}' + \sum_i T_{ij(bus)}'$$

and the differences that we plot for each MSOA are as defined earlier as $\Delta_j = P_j' - P_j^{baseline}$. Note that as usual, $\sum_j \left(P_j' - P_j^{baseline}\right) = 0$. We show these in Figure 12 where the red scale relates to places where population is gained from the impact of travel changed by the line and the blue scale population loss that is effected by the line.

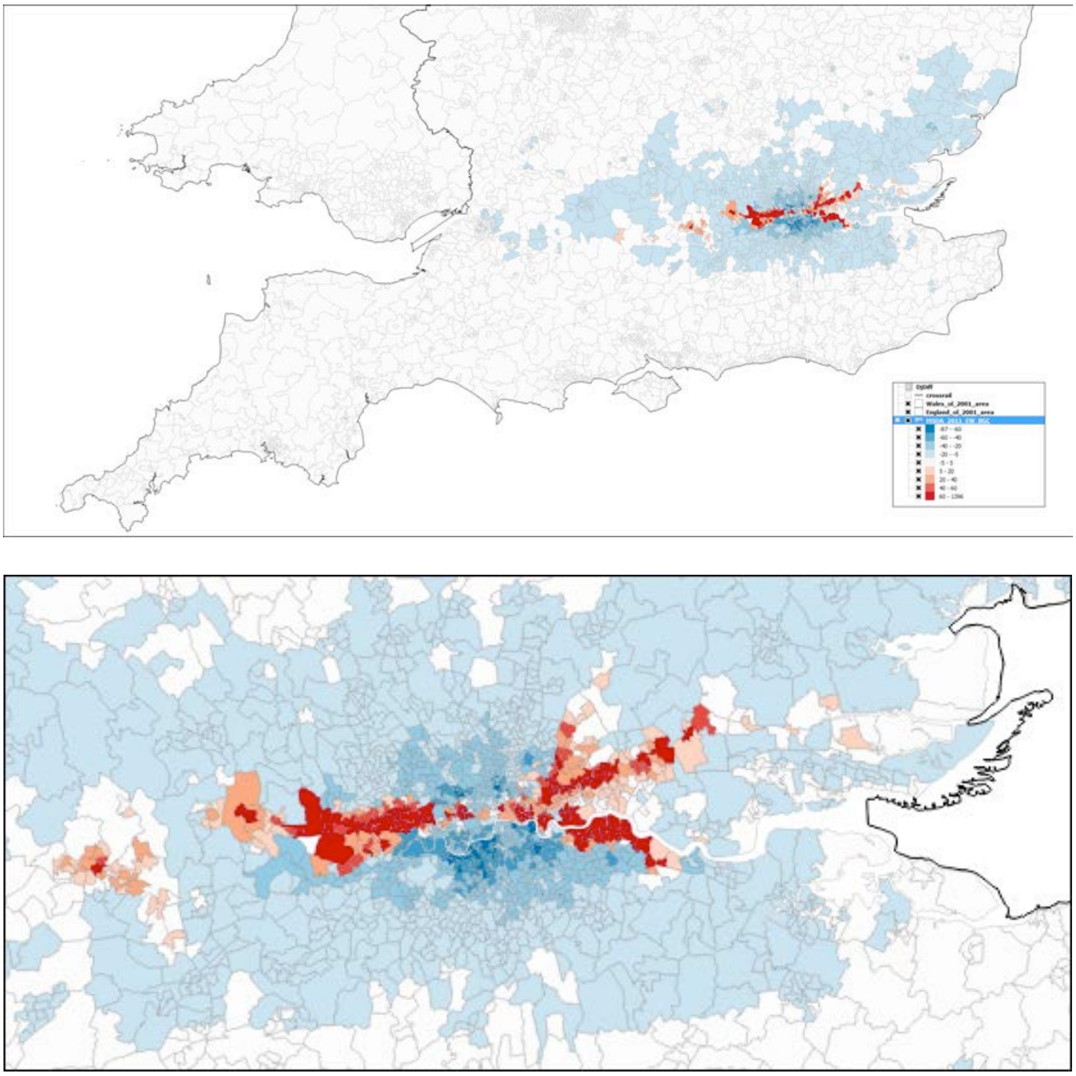


Figure 12: All Mode Shifts in Employed Population along Crossrail for London & the SE

In Figure 13, we will simply plot the population change associated with the rail split, that is, associated with

$$P_{j(rail)}^{baseline} = \sum_i T_{ij(rail)} \text{ and } P'_{j(rail)} = \sum_i T'_{ij(rail)}$$

as $\Delta_{j(rail)} = P'_{j(rail)} - P_{j(rail)}^{baseline}$ which is always positive for all the shortest routes for the Crossrail times are shorter than the baseline and this will occasion a positive switch. The results are as follows in Figure 13: note that the lightest colour in this figure is the shift from 4 to 18 people while the non-coloured (white shading) is below 4 people. The biggest shift in population in an MSOA is 1431 persons which is substantial given that the average population of an MSOA in the England and Wales is 7787 persons. However the MSOAs in the Crossrail area are substantially higher in population terms.

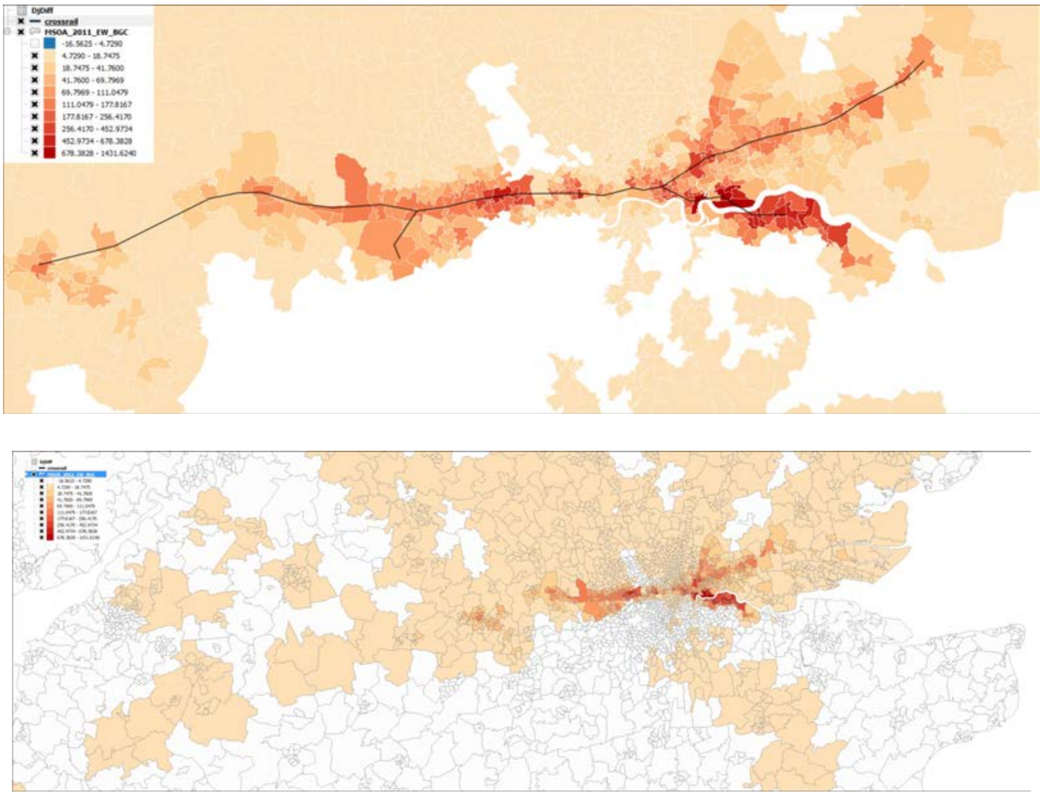


Figure 13: Rail Mode Shifts in Employed Population along Crossrail for London- the SE

An Analysis of the Changed Travel Time Distributions

The travel time displacements mapped above are close to one another in terms of the visual impact; that is, the measures indicate the fan-like diffusion of the impacts from around the 118km line, with interesting impacts across the whole of southern Britain. However the measures are a little different in that once we add trips to the mix, then these do not bear any obvious relation to the line. In other words, we can have big impacts in travel times – reductions – in places that have few trips whereas small impacts in areas with big trips. Thus the n_i and δ_i statistics do not have any associated trip volumes whereas τ_i measures the predictions of trips with respect to travel time. The population difference measures are also another twist on the concatenation of trips dealing only with the modal shift of population caused by rail.

If we rank order the statistics and produce a rank-size plot, these will invariably display the fact that in city systems, there are a few really large impacts and a very large number of small impacts, following the ubiquitous power law or something like it. We show these measures all collapsed onto each other (by normalising with respect to their means and standard deviations) in Figure 14 and it is clear that the travel time measure δ_i is much less discriminating than the count or trip travel measures. This is in terms of the numerical distribution, not their spatial incidence that can only be captured by the visualisations shown earlier. The population differences in fact are reasonably classic in profile, closest to a power law but both the trip measures τ_i and $\Delta_{j(rail)}$ indicate that the largest impacts represent a slightly different regime. We have not explored this but undoubtedly this would be the areas related to the line of the railway.

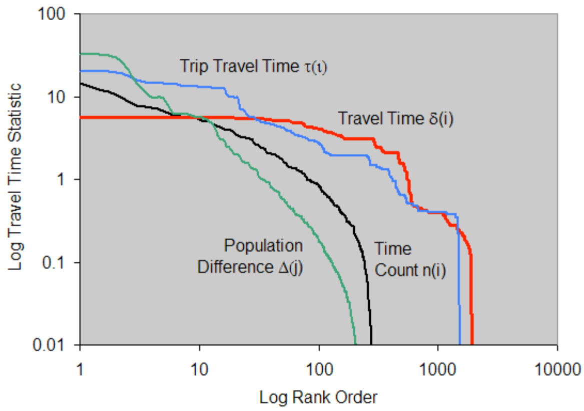


Figure 14: Rank Ordered Statistical Measures of Travel Time Displacement

stats	n_i	δ_i	τ_i	$\Delta_{j(rail)}$
n_i	1			
δ_i	0.761	1		
τ_i	0.042	0.076	1	
$\Delta_{j(rail)}$	0.532	0.777	0.209	1

Table 9: Correlations of the Key Displacement Measures

Last but not least, Table 9 shows the correlations and it is clear that the trip travel times τ_i are the least correlated with the other measures. Primarily this is due to the fact that the trip data does not measure travel time in any sense for it relates to the historic development of residential locations and these do not coincide with changes in travel times per se.

In conclusion to this case study, there is much *post-hoc* analysis yet to do in tying specific results of impact to the impact of the line and to other land use activities such as the distributions of jobs and retailing.

Case Study 3: The Impact of Employment Growth and the Role of the Green Belt in the Heathrow Airport Area

Additional Airport Infrastructure and Employment in the Heathrow Area

Airport capacity in southeast England is severely limited. Heathrow, the major UK and London airport, has been developed in a piecemeal fashion. It is located in one of the most prosperous areas of the UK and the pressures on growth are extreme. The airport currently sits on the edge of the greenbelt which constrains growth of population (and jobs) for the UK greenbelts are the most contentious of planning instruments inhibiting growth and preserving open landscape. In the long standing debate about a purpose-built major airport for London, it is probably the easiest to expand with a minimum of cost although it would require massive new connectivity to make it link to the western and northern regions. Its expansion would do little to address London's imbalance of east versus west and it would do nothing for any regional policy in the country which might involve expanding places such as Manchester airport.

Nevertheless, the current proposal which has been accepted as the best alternative by the Airport Commission (Davies, 2015) is to build a third runway in the north west of the area between the current airport and the M4 motorway. Various proposals suggest that the number of new jobs that would be created would be in the order of 40,000 to 70,000 locally over the next 30 years (Heathrow The Right Choice, 2015). In fact the jobs in the Heathrow area have expanded from some 100,000 to 150,000 over the last 15 years and this is without a third runway. What we have done here is to locate 50,000 jobs in five boroughs around the airport – the Berkshire borough of Slough, the west London boroughs of Hillingdon, Ealing, and Hounslow, and the Surrey borough of Spelthorne (which includes Staines). These boroughs are the least affected by the Green Belt in the Heathrow area.

We have located these jobs in the five boroughs in question by increasing the jobs there by some 15% pro rata to the jobs in each of the MSOAs in each borough. We show this increase in Figure 15 and it quite clear that the biggest increase is in the Heathrow MSOA itself which is at the centre of the increase. Note the spur out to the north west of the airport which is into the greenbelt.

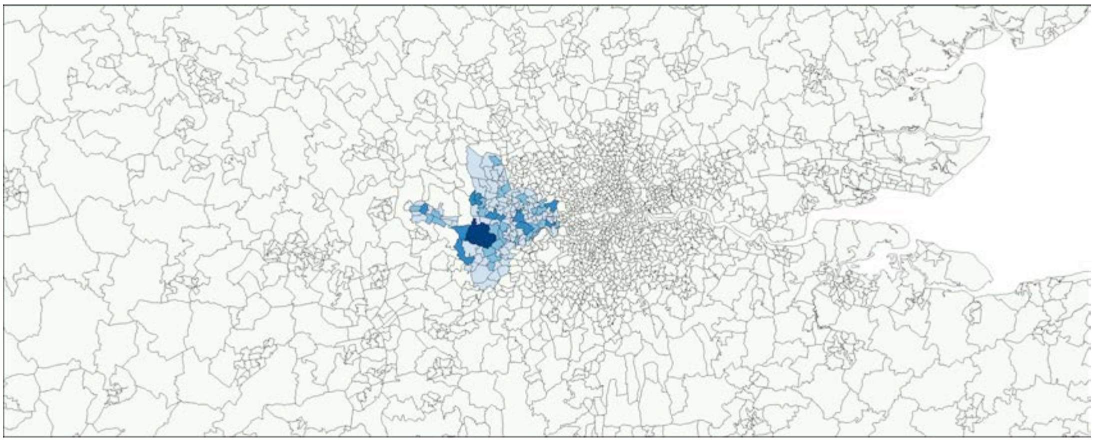


Figure 15: 15% Increase in Jobs to ~50.000 in Five Boroughs Near Heathrow Airport's Third Runway Extension

It is worth focussing for a moment on the effect of the green belt because this is the key issue in many urban development problems in the UK. There are only green belts in England but there are very strongly protected cordons around many towns and cities in Scotland and it has been widely accepted that green belts to stop sprawl combined with tight development control have avoided the worst excesses of uncoordinated urban development as is seen in many developing countries and some parts of North America. The problem with greenbelts is that they appear to have constrained the housing market from delivering acceptable products to the populations and have caused land prices and housing prices (and in turn rents) to increase to astronomical levels in places like London.

The green belt extent around London is shown in Figure 16 and it is clear that this is a very sharp boundary on development. As the model (**Quant**) works at the level of allocating activities to MSOAs (middle layer super output areas), we need to code the green belt to the areas and what we have done is to specify the percentage coverage of each MSOA by green belt. These range from zero coverage to 25% to 50% to 75% shown on a 3 point scale in Figure 17.

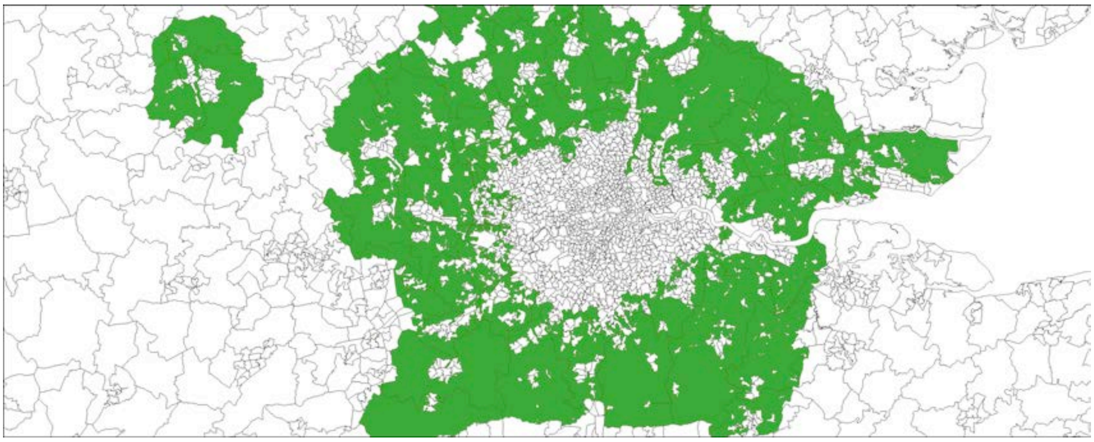


Figure 16: The London and Oxford Green Belts

Figure 17: Coding the Green Belt as Percentage Coverage of Each MSOA

Testing the Impact of the Additional 50,000 Jobs
When we add 15% of existing employment to the MSOAs shown in Figure 15, this adds 52575 jobs in total. In fact of the 7201 MSOAs in England and Wales, there are some 1989 where one or more person is added, some 1072 where more than 10 employed residents are added and some 99 were more than 100 employed residents are added. This follows a typical power law of distribution but it is fairly flat. In using the **Quant** model, we have made two runs to predict where the employment will reside. The first applies the residential location model with constraints on location posed by the green

belt. If population is allocated to zones with excess of the 50% threshold in the calibration run, the model is constrained; that is factors are introduced to make sure the population allocated to these green belt zones is constrained to the maximum totals. If we call the total predicted resident employed population P_j, then if the zone in question is a green belt zone, we figure out the maximum population Z_j it can take if the area is covered by more than 50% of greenbelt designated land. Then if $P_j > Z_j$ we introduce a weight on the zone called B_j which is determined iteratively such that when the system is balanced, $P_j \leq Z_j$ for all zones. This we call the constrained model.

The first model runs take new jobs and input them into the model that has been calibrated at the base data which is constrained to this cross section. This is what we refer to as the unconstrained prediction. If we are adding jobs, then it is likely that some of the green belt zones will be infringed and if they are, then we simply examine what the predicted distribution is. Note that this may include zones whose populations have been fixed to the green belt limits at calibration. This prediction is shown in Figure 18. and notice how it covers a roughly circular area around the airport and five boroughs in question with a slight bias back towards central London where there is more attractivity to locate and better transport links.

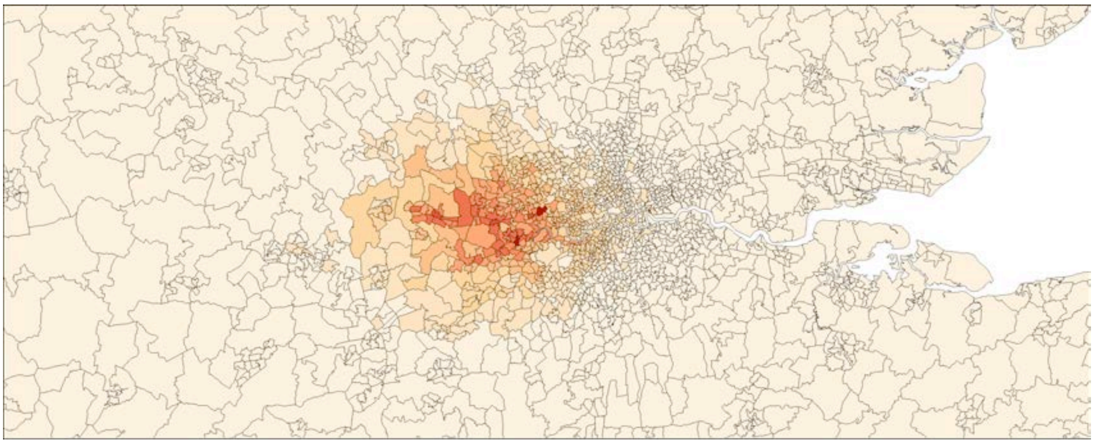


Figure 18: Increase in Employed Residential Populations Ignoring Constraints on the Green Belt

We can now run the model once again and invoke the constraints and as expected a very different picture emerges with the green belt being invoked rigorously in all those areas where the designated control is greater than 50% of the area of the zone. We show this pattern in Figure 19 and to reinforce the impact of the green belt we also show in Figure 20 the green belt imposed on the prediction This shows that zones that do not gain in population are affected by the green belt and the population is accordingly constrained. The green belt thus inhibits – in fact stops – further development to the west of the airport. Note how the borough of Slough receives the greatest increases although there is a tendency for the major growth to occur back across the Greater London Authority boundary where there is no imposition of a green belt.

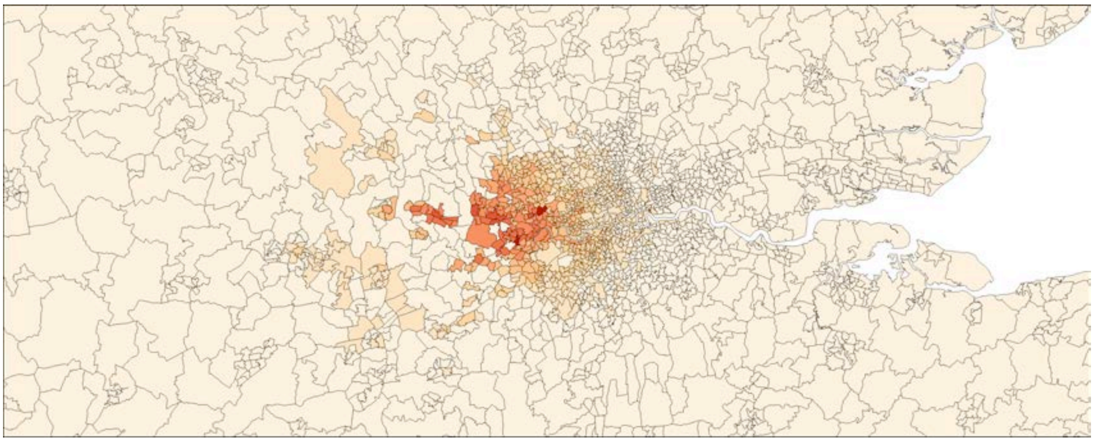


Figure 19: Increase in Employed Residential Populations with Constraints Imposed by the Green Belt

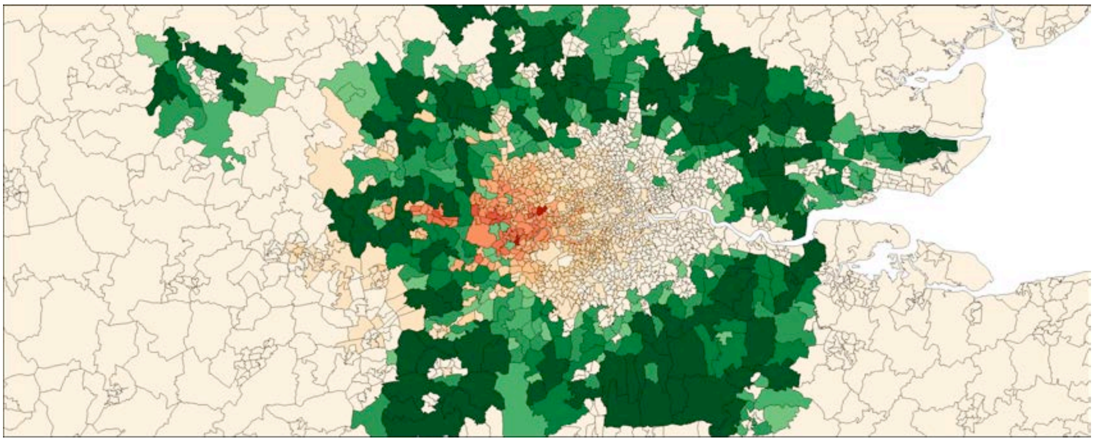


Figure 20: Impact of the Green Belt on Additional Employed Residential Population

Strictly speaking we should now evaluate this strategy of locating new jobs by examining the changes in travel costs and trip volumes that are of course predicted from the model runs. We can look at changes in density and changes in the activity rates all of which vary spatially in these kinds of prediction but we will leave these for future analysis. As **Quant** and **Simulacra** are both models that deal with trip movements, we can generate many measures of impact such as those that we explored for the road pricing and the impact of Crossrail 1 previously.

To conclude, we will examine the pattern of differences posed by the unconstrained and constrained predictions. Essentially what we are showing in Figures 18 to 20 are the positive differences $[P_j^{predicted} - P_j^{calibrated}]$ and we can analyse their distribution as we indicated earlier. If we graph the differences between the baseline and unconstrained prediction $[P_j^{unconstrained-pred} - P_j^{calibrated}]$and the baseline and the constrained prediction $[P_j^{constrained-pred} - P_j^{calibrated}]$, if these were the same then we would get a straight-line on the scatter graph. In fact when we do this we get a near straight-line except that the zones that are constrained by the greenbelt show up as zero value of difference for the comparison. Figure 21 shows this quite graphically as we illustrate below where the dark blue scatter are the unconstrained zones and the red points are those that are constrained – with zero differences. You can see the straight-line scatter is not perfect but close due to the fact that in the constrained run, some zones which are still unconstrained gain greater shares of the new population due to some zones receiving zero. In Figure 21, we graph all zones in England and Wales as **Quant** is applied as we have already noted for the whole country.

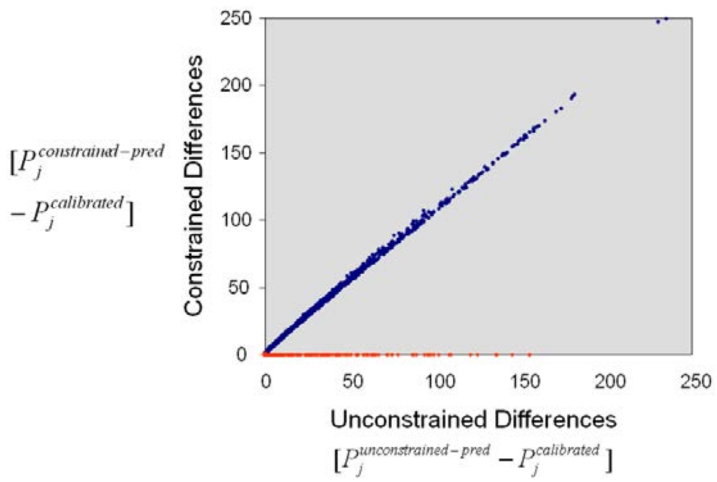


Figure 21: Unconstrained and Constrained Zonal Population Differences

Conclusions: Next Steps in Evaluating Policy Constraints Using Simulacra and Quant

In our three case studies, we have approached the evaluation of changes in population and transport flows in an informal manner. In the models, the next steps are to embody formal evaluation mechanisms and measures such as consumer surplus/consumer benefit into the analysis. We have not yet extended the models in this manner but it is a simple step.

We also need to produce a much better translation in these models between distance, travel time and travel cost, so that we can freely translate road pricing and cordon tolls into other equivalent measures. In fact the networks that we now have in **Quant** are very detailed as we have seen in examining Crossrail impacts on travel time as they are formed from public transport timetabling data which is the best available for measuring travel times on public transport. Travel times on the road system are much more problematic but progress is being made on adding flow and capacity to ensure that these are appropriate.

We need better measures of density and land supply in these models especially as many possible scenario tests relate to housing and land and we need to define our green belt constraints in terms of population and density limits. In fact green belt are developed as spatial/aerial instruments and usually these are not generalised to administrative units but simply related to actual land plots. There needs to be more work in this area. Last but not least, we need a more formal framework for evaluation. The three case studies – transport cordon pricing policies, the impact of fast urban rail, and the allocation of jobs in areas of extreme pressure on land –have several elements in common and we need a comprehensive formal set of evaluation measures. to adapt our model predictions to the different policies that we seek to test. There are underway in other projects

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