# Audit of TELMoS12

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Report prepared for Transport Scotland

LATIS Lot 4: TELMoS Audit - TS ref. A7788323

| Version | Date | Author | Notes |
|---|---|---|---|
| 1.0 | 29/8/2016 | Ian Williams | |

## *Contents*

## *LIST OF TABLES*



## *LIST OF FIGURES*

## *EXECUTIVE SUMMARY*

This report is in two parts combining together the documentation of the two main tasks carried out in this WSP/SIAS audit of the 2012 version of TELMoS. Part A documents the analysis of the results for the reference case and two land use sensitivity test scenario runs of the TELMoS12 and TMfS12 models for the period 2012-2037. Part B documents the analysis of the interface between TELMoS12 and its associated transport model TMfS12.

Due to the nature of audit activity, this report is already historic in some respects because the most recent version TELMoS14 has already addressed some of the aspects that are documented below. The audit chronology was as follows. At the Inception stage the main audit tasks were agreed. Then these tasks were completed by the auditor through analysing the results from commissioned scenario runs of TELMoS12 carried out by the model developer DSC. The resulting audit findings for TELMoS12 were transmitted to DSC in two notes that provide the contents of Parts A and B of this report. Then DSC as part of their ongoing TELMoS14 development tasks were able to address some of these points immediately in this next version of the model and such updates, based on the more recent DSC response to the two audit notes, have been appended below as footnotes. Other responses from DSC to these earlier notes have also been included as footnotes together with further comments from the auditor, where relevant.

In part A, the three scenario runs were defined as follows:

- Reference Case (**BQ**) - the current reference case run against which the outcomes from sensitivity tests can be compared in a consistent fashion;
- Sensitivity Test 2 (**HU**) - **Commercial Planning permission changes** such that 100% of the permissible commercial development land added during the period within the City of Edinburgh zones in the reference case has instead been transferred out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years;
- Sensitivity Test 3 (**IQ**) - **Commercial and residential planning permission changes** such that all (100%) of both the permissible commercial and the residential development land added during the period within the City of Edinburgh zones has been transferred out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years.

This analysis has been implemented by creating a set of trend charts that present the pattern of growth through time in the main variables for each of the three model runs. These charts have been set up to show results at the level of the 32 local authorities (LAs) because this spatial level appears to provide the best compromise between ease of interpretation of the results presentation, while retaining adequate spatial detail between areas that are competing for new developments.

The general conclusion from the analysis of the model runs is that most of the key responses of the model appear to match to the main a priori expectations. This suggests that TELMoS12 is functioning broadly as expected and that it provides plausible future trends at the LA level, the spatial scale at which the model results were analysed.

The two sensitivity tests were shown to be implemented in the form that had been specified and they proceeded in their forecasts of activity levels to generate major changes that were generally in the locations and with the broad magnitudes that had been expected.

Nevertheless as now summarised, there remain some potential issues where further checking and validation is needed in order to ascertain whether specific mechanisms or parameter values within the model may need to be adjusted in order to improve the realism of its forecasts. *The paragraphs in italics below indicate updates since the original recommendations were supplied to DSC.*

Most aspects of the forecasting within the model of the linked components of population, of households and of residential rents and floorspace development have performed in a plausible fashion. The main associated query relates to some of the local changes in household sizes that are forecast in the reference case and in the sensitivity tests.

> **AR1**: Validate the realism of the mechanisms in the model that have generated the more extreme forecast local differences in household size trends and then adjust these mechanisms if necessary.

*DSC have re-calibrated the migration model for TELMoS14 to address these issues.*

Within the reference case, the temporal trends in the employment totals and the resident worker numbers vary greatly over time between LAs, including particularly significant absolute short term changes from 2011 to 2012. Moreover, employment declines by -18% in Clackmannanshire even though this is the LA with the highest population growth rate of +36%.

> **AR2:** Understand which mechanisms in the model generate such spatial and temporal variations in the employment and resident worker numbers and then confirm that these variations have a rational foundation, rather than being erratic random effects that might add instability to the resulting forecasts from the model. Adjust the model mechanisms if necessary to damp down unrealistic volatility.

*The 2011-12 discontinuity arose for historic reasons that have been resolved in TELMoS14. A wider exploration for Clackmannanshire of how the local employment decline mechanism aligns with the local forecast 36% growth in population would still be instructive.*

While within the reference case the retail and hotel floorspace growth trajectories appear plausible, in contrast for office and industrial floorspace for many LAs much of their growth is concentrated just in the first 1 or 2 years after 2012 and subsequently the floorspace volume declines gently at a constant rate thereafter.

> **AR3:** Validate the realism of the mechanisms in the model that have generated these angular office and industrial floorspace growth patterns and then adjust them if necessary.

Within the reference case the commercial floorspace rents for each floorspace type tend often to be high in the more remote areas and in the Islands but to be much lower in the cities of Glasgow, Aberdeen and Edinburgh.

> **AR4:** Validate the realism of this forecast pattern of differential commercial rent levels and of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

*Subsequent adjustments to TELMoS14 appear to have made significant progress in resolving the recommendations AR3 and AR4 above.*

Within sensitivity test 3 the added changes to residential planning permissions, in addition to the commercial floorspace permission changes originally in sensitivity test 2, lead to significant local forecast changes in floorspace construction in offices and industrial but not in retail.

> **AR5:** Validate the realism of this forecast pattern of no retail response to significant changes in residential patterns and the soundness of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

*The further discussion and information provided by DSC explains that this lack of change in retail is due to the absence of un-used permissible development for retail by the later years. The speed and completeness of this exhaustion mechanism may merit further consideration as to its plausibility.*

In both sensitivity tests there is an unexpected systematic pattern of relative increases in commercial floorspace rents in East and Midlothian, in response to the relative increases in floorspace volumes there, whereas in Edinburgh and West Lothian the responses are that rent changes are in the reverse direction from floorspace changes, i.e. in line with expectations.

> **AR6:** Validate the realism of this forecast pattern of mixed rent response and of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

*The further discussion and information provided by DSC explains why this mixed rent response pattern has occurred, and has indicated that the future introduction of an employment distance deterrence function, in place of the closed travel to work areas, would be expected to alleviate these issues.*

In both sensitivity tests the forecast residential rental changes exhibit considerable short-term fluctuations that would appear to be due more to noise within the system than to real world influences.

> **AR7:** Investigate how to introduce a mechanism to the model that would damp down somewhat the short term fluctuations in residential rents.

There are also a variety of other aspects raised regarding the model and its results. These also require further scrutiny to ensure that the assumptions made about them are valid and that they do not point to further lurking issues within the model.

In part B the audit focused on the model interfaces and first examined the functioning of the car ownership mechanism in TELMoS as this has a major influence on car travel demand patterns in the transport models. It then examined the formulation and segmentation of the interfaces and examined the effectiveness of their operation in practice through analysing inputs and outputs from relevant policy test runs.

Much of this analysis has been illustrated by creating a set of trend charts that present the pattern of growth through time in the main variables for each of the model runs of interest. These charts have been set up to show results at the level of the 32 council areas because this spatial level appears to provide the best compromise between ease of interpretation of the results presentation, while retaining adequate spatial detail between areas with different transport characteristics.

The main recommendations for future actions and enhancements to TELMoS are summarised here based on the findings of the model audit analyses.

A wide variety of distinct source documents have needed to be utilised to develop a clear picture of the operation of the data processing and data flows relating to the interface between TELMoS12 and TMfS12. This proliferation of documentation sources makes it difficult to grasp the exact functioning of the interface and it increases the chances of misinterpretation of its operation.

> **BR1:** Reorganise and unify the documentation of the interface into a single, updated and complete description.

An analogous document could also be produced to document the interface used between TELMoS and CSTM.

*The auditor and model developer agree on the benefits that would accrue from this extra documentation.*

The car ownership patterns produced by TELMoS are a very important input to the forecasts in TMfS. Although there is a very close match in TELMoS to the observed household numbers in total for 2011, because of the data availability at the time this task was carried out there are consistent and significant differences from the observed values in the car ownership composition of these households in 2011 both at the council area level and at the overall national level for Scotland.

> **BR2:** The methodology that was adopted to create the COZN file for 2011 should be revisited to ensure that an improved match to the observed 2011 household car ownership shares is achieved across all zones.

*For TELMoS14, the starting point has adopted specially commissioned tables of 2011 Census outputs on household car ownership that have been used to resolve this issue.*

The realism of the forecasts that are made of the car ownership categorisation of households was checked, which has identified a very wide range of trajectories both over time and between council areas. These trajectories rarely match observed previous trends in their particular area and in some cases they appear to reverse them. There may be behavioural evidence that can be assembled that justifies both the specific major deviations from the average trajectories and the reversals of the previous trends presented for particular areas**.**

> **BR3:** However, if such evidence is not forthcoming it would be wise to reorganise the forecasting model:
>
> - to match the observed base year spatial pattern of household car ownership rates;
> - to then forecast a zonal pattern of change in these household car ownership rates that is less extreme in its differentiation between areas and that does not present radical reversals from past local trends except where there is evidence to support them.
>
> To achieve such improvements to forecasting performance it is likely that significant changes will need to be made to the current household car ownership model structure and/or parameters and suggestions have been provided on how this might be achieved.

The manner in which the results output from TELMoS are used to generate the trip ends within TMfS was examined. The provision of the planning data from TELMoS for use in the trip end estimation and car ownership segmentation within TMfS is carried out in an effective fashion throughout; it maintains a suitably high degree of segmentation in a consistent manner. This data is then used in tandem with the trip rates input from NTEM in a suitable fashion to generate the required zonal trip productions, segmented by trip purpose and car ownership category. A few suggestions have been provided for minor enhancements to the procedures in order to further improve its overall performance.

The files for the trip end model for the final year 2037 for the reference case run BQ and alternative scenario ER (Low population, Low economic growth), together with the standard yearly zonal activity output files from TELMoS have been examined to understand the impact of TELMoS land use changes on TMfS trip generation patterns. This indicates, as expected that there is a strong relationship within the parameters governing trip rates in NTEM between high car ownership levels and high mechanised trip rates. In general the comparisons suggest that the trip production mechanism works in practice in the form that is expected from the underlying methodology. The comparison also highlights the crucial role that accurate car ownership forecasting should play in determining the future level of mechanised travel demand.

The next step in the audit examined the reverse direction of the interface, in which the transport costs and characteristics output from TMfS are used to influence the forecast location pattern of floorspace, households and employment within TELMoS. The zone to zone transport supply characteristics that are output from TMfS are segmented by mode and time period and are then transformed into zonal accessibility measures segmented by trip purpose for origins and destinations for use within TELMoS. This transformation mirrors the analogous transport model stages of mode and destination choice carried out in TMfS. On theoretical grounds it would be expected that consistent choice hierarchies and parameter values should be applied within the analogous choice stages common to TELMoS and TMfS but this consistency is not present, presumably due to historic differences in their model development trajectories. The use of conflicting choice hierarchies between them is particularly unhelpful as it may imply conflicting rates of responses to mode or destination zone specific policy measures.

> **BR4:** There is now a strong case for removing unnecessary differences between their choice hierarchies and parameter values in the next round of updates and enhancements to TMfS and TELMoS.

*The recommendations B4 and B5 are the only issue of substance on which there is a disagreement of principle between the auditor and the model developer. Some scenario test runs have been outlined by the auditor that if run in the future could ascertain whether or not this difference in structure and in parameters between TELMoS and TMfS would be likely to create consistency issues when forecasting.*

This should then ensure that the scale of their responses to policy and investment measures would be consistent across them, because the choice hierarchy and its parameter values have already been directly calibrated within TMfS using procedures that are based on observed behaviour.

> **BR5:** It seems appropriate that the choice hierarchy and its parameter values should be ported across from TMfS for direct use within TELMoS, thus adopting the TMfS approach when resolving any differences. The only exception is that the inclusion of the walk mode within TELMoS should be replicated within TMfS.

This proposal for the inclusion of car and cycle in TMfS is because of the continuing importance of both the walk and cycle modes within the denser urban areas, particularly in and around Edinburgh, where observed growth in car ownership rates has been low or negative and where alternatives to car have increased their competitiveness.

The test runs PQ/PR (do-minimum) and PS/PU (A9 Perth–Inverness scheme) were analysed to demonstrate the impact of TMfS cost changes resulting from the A9 scheme on the TELMoS forecasts of household and employment location patterns and then through to the associated trip end estimates from 2027 onwards. The percentage change impact for households that is forecast from the scheme is tiny at the council area level, with growth increases by 2037 of around 0.07% for Highlands, Moray and Perth.

The percentage impact on employment from the A9 scheme that is forecast by 2037 is considerably greater than that for households, though it is still small. There are small employment gains in Highlands (0.7%) and in Perth (0.4%) and no change in Moray, a magnitude and pattern that is plausible. Surprisingly, there are rather larger forecast percentage gains and losses in employment in areas that are distant from the A9 scheme so that the underlying reason for these latter scheme-induced employment changes is not clear. The growth and decline trends in these distant areas are too large and too consistent through time to be likely to be just a result of minor random model noise**.**

> **BR6:** Accordingly, the operation of the underlying accessibility mechanism in influencing the location of individual employment sectors requires further investigation.

*Investigations to date on this topic remain inconclusive.*

These unexpected employment impacts in areas remote from the scheme may simply be a manifestation of the inconsistencies in land use responses that could be generated due to the lack of consistency in the choice hierarchy and parameters between TELMoS and TMfS, as raised in recommendation BR4 above, so that removing these inconsistencies may be a good starting point for investigation.

This opportunity to examine and audit the functioning of the interface from TELMoS to TMfS and its reverse has proved to be informative. It has demonstrated the critical importance to both models of having an accurate and reliable car-ownership forecasting mechanism and has highlighted an urgent need for improvement in this mechanism. For many of the interchanges of data between models, the current procedures appear to be working well. However, some of the employment location responses to transport supply changes seemed implausible and this highlights the need for consistency between the models in choice model representation, whenever there is duplication in functionality between the models.

> **BR7:** In future audits, the analysis of the effectiveness of the operation of the interfaces between the individual models should be allocated to one of the auditors of the individual models. This would ensure that important aspects within the modelling system as a whole do not get left aside without proper scrutiny.

*Significant progress appears to have been achieved in progressing most of the recommended tasks above. A future audit of their combined impacts within TELMoS14 would provide confirmation of the degree of success of these enhancements.*

# 1 INTRODUCTION TO PART A

## 1.1 OVERVIEW

1.1.1 Part A documents the analysis of the results that were provided by DCS on 25/8/2015 for the reference case and two land use sensitivity test scenario runs of the TELMoS12 and TMfS12 models for the period 2012-2037. These three runs were defined as follows:

- Reference Case (**BQ**) - the current reference case run against which the outcomes from sensitivity tests can be compared in a consistent fashion – see Section 2 for the detailed analysis of the results;
- Sensitivity Test 2 (**HU**) - **Commercial Planning permission changes** such that 100% of the permissible commercial development land added during the period within the City of Edinburgh zones in the reference case has instead been transferred out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years– see Section 4;
- Sensitivity Test 3 (**IQ**) - **Commercial and residential planning permission changes** such that all (100%) of both the permissible commercial and the residential development land added during the period within the City of Edinburgh zones has been transferred out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years– see Section 5.

1.1.2 The main findings from the analysis of these runs are summarised in Section 6, together with a set of recommendations for further checking, validation and improvements to the mechanisms within the model. In Appendix 1 a set of corrections to the standard results summary spreadsheet of DSC is proposed.

## 1.2 BACKGROUND

1.2.1 These sensitivity tests are a follow up to the residential planning permission test that was carried out in the previous audit of TELMoS07. In that test all *residential* planning policy inputs of zones in East Lothian, West Lothian and Midlothian were transferred instead to City of Edinburgh zones, noting that the direction of the transfer then was the reverse of that adopted in the new sensitivity tests.

1.2.2 The main conclusions drawn from the model results from this original residential test (Demonstration Test 1) were:

- "It is not immediately obvious why in Table 4.2 all authorities other than the City of Edinburgh should exhibit relative reductions (albeit small) in new residential floorspace. The reverse would be expected on the basis of the risk of oversupply in Edinburgh. Does this imply a logical issue within the residential development model? Presentation of information on the changes in rents might help to understand the processes in operation.
- The spatial pattern of change of households and population in Figures 4.2 and 4.3 appears plausible, with an increased need to commute in from outside around

the Lothian areas that have lost residences, and a loss of commuters to Edinburgh from elsewhere due to more labour now residing within the City. It is not obvious why the City of Glasgow and its surrounds have lost employment despite having gained population and households. Is there an explanation for this employment loss there? Overall the 2% increase in employment in Edinburgh appears very low when compared against the 19% increase in population and 23% increase in households." …

- "It would be interesting to also explore a similar test of the sensitivity to changes in planning policy inputs for commercial land. In the investigations of the forecasts, there was a wider range of queries relating to the performance of the commercial development models than to that for residential development."

1.2.3 The two sensitivity tests are designed to inform this conjecture in the context of the current version of TELMoS.

# 2 Characteristics of the Reference Case (BQ)

## 2.1 Introduction

2.1.1 In preparation for the analysis of the responses in the model to the sensitivity tests, a review has been carried out of some of the main results over time from the current reference case run (BQ). The main findings are summarised below in this Section. The aims of this analysis are:

- to ensure that no obvious deterioration in the plausibility and consistency of the model results has arisen due to the changes that were introduced to TELMoS12 subsequent to the previous audit of TELMoS07 to either the model structure, the reference case assumptions or the input data values;
- to provide a clear background understanding of the main trends over time in the spatial pattern of the model results in order to provide the context that is needed to inform our understanding of the responses to the sensitivity tests.

2.1.2 This reference case review has been implemented by introducing a set of trend charts into the spreadsheet "ITabs Analysis HU-BQ_INW.xlsm" which is based on the original spreadsheet provided from DCS. These charts present the pattern of growth both in absolute values and as 2012-based indices through time in the main variables. These charts have been set up to show results at the level of the 32 local authorities (LAs) because this spatial level appears to provide the best compromise between ease of interpretation of the results presentation, while retaining adequate spatial detail between areas that are competing for new developments. Because the subsequent sensitivity tests are applied at the LA level it is this spatial level that is of particular interest for analysis.

## 2.2 Trends in population and households

2.2.1 The national **population growth** rate over the period from 2012 through to 2037 is 10% and most LAs grow by between 4% and 18%. The main exceptions are:

- Angus declined by -4%, while East Ayrshire (1%), Falkirk (2%) and East Lothian (3%) also have low growth rates;
- Midlothian (23%), Sterling (25%) and Clackmannanshire (36%) have the fastest growth.

These estimated temporal patterns of population growth over time do not exhibit major erratic variations so the overall pattern appears to be plausible.

2.2.2 The national **household growth** rate over the period from 2012 through to 2037 is 22% and most LAs grow by between 11% and 34%. The main exceptions are:

- The City of Edinburgh (6%) and East Lothian (6%) have the lowest growth rates;
- Fife (38%), Sterling (39%), West Lothian (40%) and Falkirk (50%) have the fastest growth.

These estimated temporal patterns of household growth over time avoid major erratic variations so the overall pattern appears to be plausible, other than a query regarding **why Falkirk is estimated to show a 50% increase in household numbers but only a 2% increase in population!**[1]

2.2.3 The spatial pattern of the trends in the number of **persons per household** was analysed within a new sheet <HHSize ref>, with results summarised in Figure 1. This analysis indicated that the household size rates in 2012 at the LA level ranged from 2.1 to 2.4 (1.45 to 2.9 at the zonal level) with an average of 2.21, whereas in 2037 it ranged from 1.5 to 2.4 (1.3 to 3.0 at the zonal level) with an average of 2.0. The greatest local reduction over the period 2012 to 2037 was -32% at LA level for Falkirk from 2.27 to 1.52 (-43% at the zonal level in the Falkirk zone 377) and the greatest local increase at the LA level was 3% for Clackmannanshire (58% at the zonal level in the Edinburgh zone 107).

2.2.4 Other than the peculiarly large reduction in Falkirk, the remaining overall household size trends and results appear plausible, noting that the small number of more extreme changes at the zonal level has largely been smoothed out at the LA level.

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[1] Response from DSC: *We have been back and looked again at the forecasts for Area 6, which contains Falkirk and the drivers that affect those forecasts. We note that the Migration modelling is drawing high numbers of single person households to that Area. We have been exploring whether this is realistic and/or whether adjustments are required to the Migration modelling. In TELMoS14 (and the SESPLAN Cross Boundary Study reference case) we have re-calibrated the Migration model in the light of this work.*

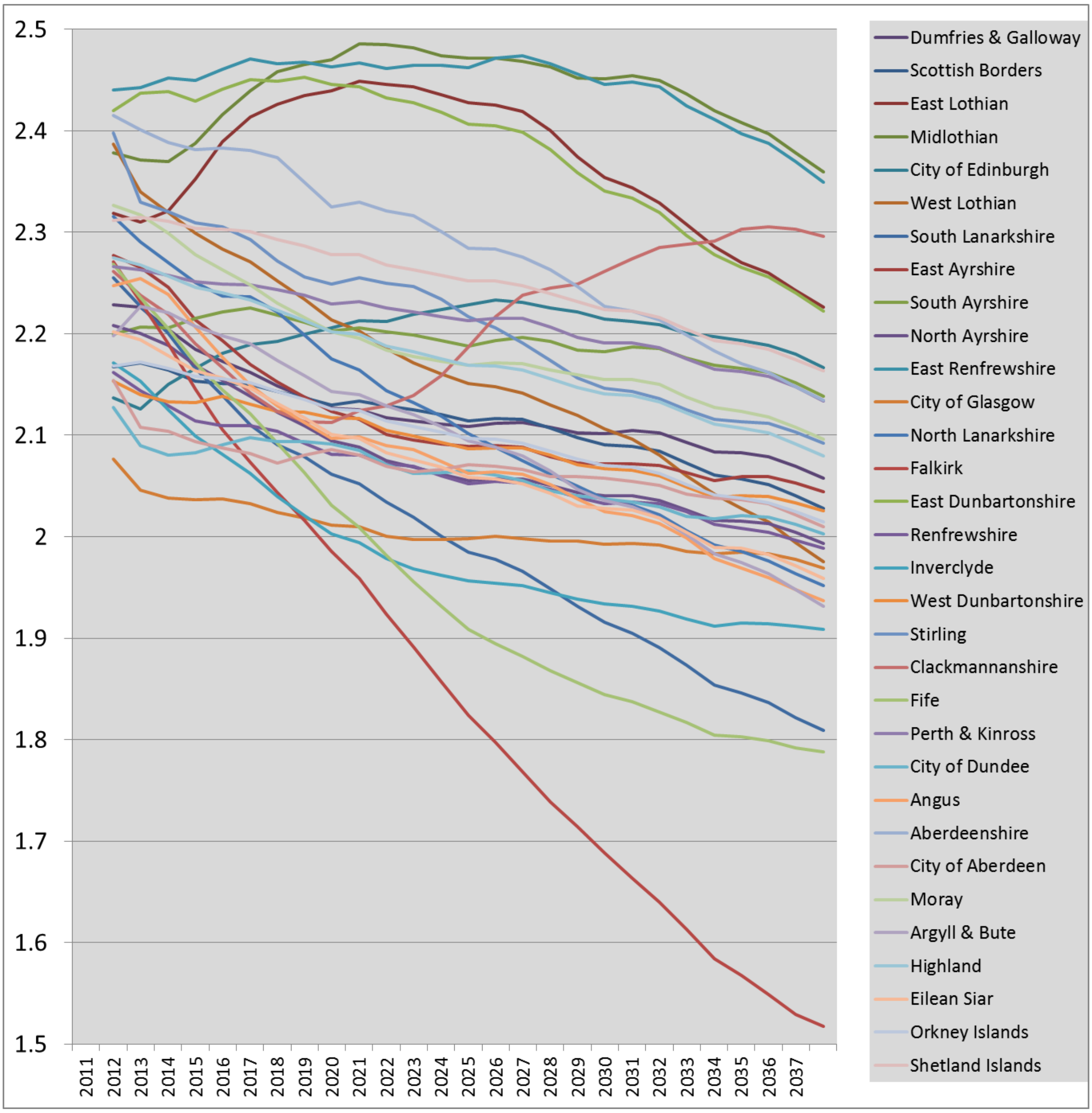


**Figure 1 Estimated household size trends by local authority for reference case (BQ)**

## 2.3 TRENDS IN WORKERS AND EMPLOYMENT

2.3.1 The national **resident worker growth** rate over the period from 2012 through to 2037 is 6% and most LAs grow by between -7% and 22% as indicated by the growth indices presented in Figure 2. The main exceptions are:

- Angus (-14%), East Ayrshire (-14%), East Dunbartonshire (-13%) and East Lothian (-11%) have the lowest growth rates;
- The Cities of Dundee (26%) and Glasgow (29%) have the fastest growth.

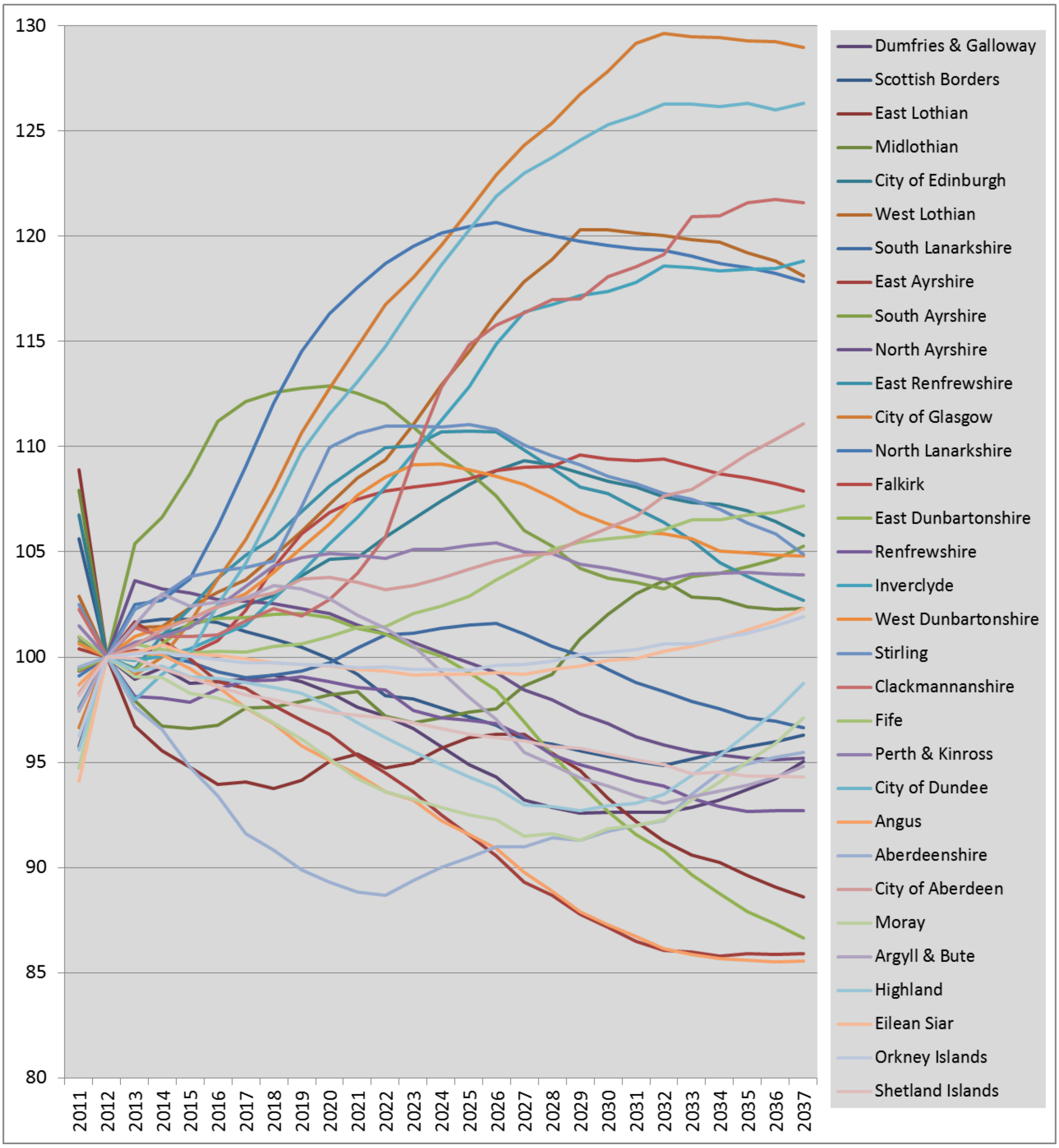


**Figure 2 Index (2012=100) of resident worker trends by local authority, reference case (BQ)**

2.3.2 The temporal trends in the resident worker numbers in Figure 2 vary greatly over time between LAs. **It would be important to understand which mechanisms in the model generate such spatial and temporal variations and then to confirm that these have a rational foundation, rather than**

**being erratic random effects that might add instability to the resulting forecasts from the model**.[2]

2.3.3 The significant absolute short term change from 2011 to 2012 in resident worker numbers indicated in Figure 2 for many LAs, particularly the large losses in the City of Edinburgh (-6%), East Lothian (-8%) and Midlothian (-7%), also merits further checking and explanation.[3]

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[2] Response from DSC: *The processes that influence the number of resident workers are set out in the model description report.*
*The Regional Economic Model forecasts change in economy at the Area or Macro zone level. These are based upon the 2001 Travel to Work Areas. The level of growth at the national level is calibrated to be consistent with the economic scenario provided by Transport Scotland.*
*Changes in the economic performance of different Areas are modelled in the REM and are influenced by the mix of economic sectors, levels of investment, patterns of trade and Area accessibility calculations.*
*The Migration model models the processes by which households with people of working age (and dependents) move from areas with relatively low employment opportunity to areas of relatively high opportunity.*
*In addition to these long distance moves, the residential location model models the processes by which a proportion of households will look to move in any one year. Their moves will be influenced by the availability of residential floorspace, rent levels and accessibility.*
*The employment location model models similar processes for employment within an Area.*
*The residential location modelling includes a distance deterrence function that allows for moves across Area boundaries, the employment location modelling in TELMoS12 does not.*
*It is worth re-iterating that the Area boundaries are based upon TTWAs. They are not necessary contiguous with local authority boundaries. The modelling of location can result in movement between local authority areas (within the same Area) or between local authority areas (where the distance deterrence modelling permits movement between Areas).*
*The Employment Status model determines the proportion of working age adults in work in each zone.*
*Clearly the outputs that are described in this section are the outcome of several modelled processes. As mentioned in an earlier response to an Audit Technical Note, it would be possible to switch off different processes in a systematic way in order to understand the impact of each process upon the forecasts*
**Auditor response**: I think that this systematic investigation of the impacts of individual mechanisms would be a useful exercise as part of the future model development and testing for resident workers and for each of the other main location mechanisms within TELMoS.
To provide a robust foundation for policy testing, it is important to confirm, perhaps using time series charts similar to those here, that each of the individual behavioural mechanisms, as well as the combined set of mechanisms, all respond sensibly to policy measures in all locations throughout all years.

[3] Response from DSC: *The TELMoS base is 2012. The creation of that base year dataset involved two steps. Firstly creating a preliminary 2011 dataset using the initial census material and other published statistics, then (secondly) running the model for 12 months to create a 2012 base.*
*At the time when TELMoS12 was being developed there was a requirement from the travel demand model developers that we generate 2012 planning data for their model. This was required for their model development.*
*During the subsequent development of the model, a problem was discovered with the trade distance values input to the regional economic model. The model was not converging with the set*

*of trade coefficients distances as originally input and used for 2011-12. The standard procedure in this case is to re-calibrate the trade distances. In this case the trade distances were re-calibrated for the years 2012- 2037. They were not re-calibrated for the year 2011-2012. The rational for this decision was that the forecast period was 2012-2037, the planning inputs for 2012 had already been sent to (and used by) the transport demand modellers, there was a tight timetable for model delivery that did not allow going back to 2011 and we had understood that a new reference case would be prepared at some point soon that would allow the trade values for 2011-2 to be recalibrated too. In the event, there was no new reference case of TELMoS12 commissioned, rather the focus switched to developing TELMoS14.*
*This problem was corrected in TELMoS 14*

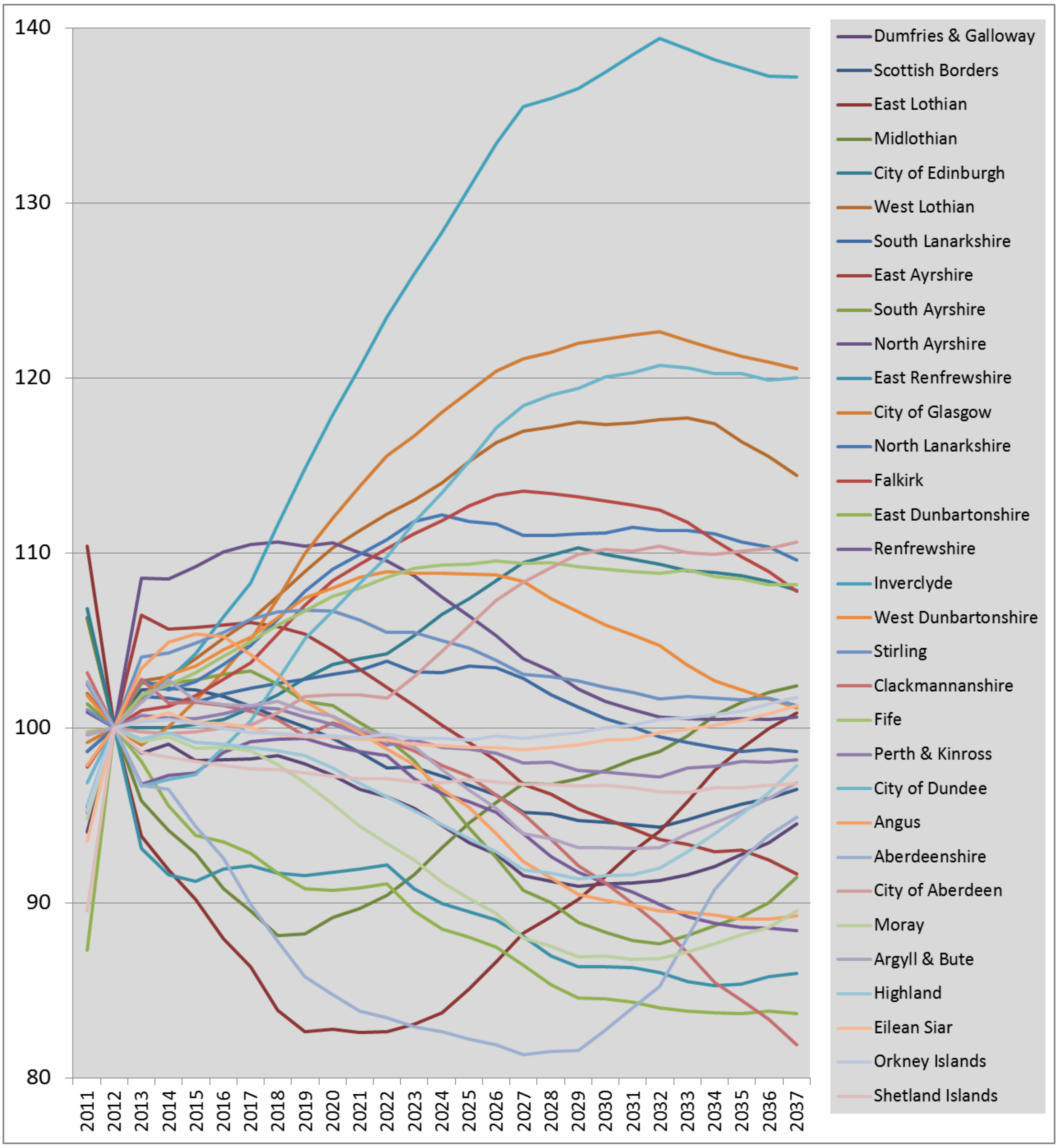


**Figure 3 Index (2012=100) of employment trends by local authority, reference case (BQ)**

2.3.4 The national **employment growth** rate over the period from 2012 through to 2037 is 6% and most LAs grow by between -12% and 11% as indicated by the growth indices presented in Figure 3. The main exceptions are:

- East Renfrewshire (-14%), East Dunbartonshire (-16%) and Clackmannanshire (-18%) have the lowest growth rates;
- West Lothian (14%), the Cities of Dundee (20%) and Glasgow (21%) as well as Inverclyde (37%) have the fastest growth.

2.3.5 The scale of the % changes from 2011 to 2012 in the number employed within these zones is yet greater than that for resident workers, varying from +15% East

Dunbartonshire to -9% East Lothian. Figure 3 indicates that **there are some sharp fluctuations over the first few years, with increasing divergences among LAs between growth and decline trends until the mid-2020**s. After this the broad trends settle down so that most LAs then tend to revert back towards a more common growth rate. **The major employment decline of -18% in Clackmannanshire in the period from 2012 to 2037 merits further checking and explanation, particularly because this is the LA with the highest population growth rate of +36%**.[4]

## 2.4 TRENDS IN FLOORSPACE AND RENTS

2.4.1 The spatial pattern of growth in population and in employment is heavily dependent on the availability of floorspace, which in turn is dependent on the availability of land for development across the zones of the model. Accordingly, in this Section we review the trends in floorspace growth and in rent levels for each of the sectors residential, retail, office, industrial and hotel in turn.

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[4] Response from DSC: *Clackmannanshire is within the Stirling and Alloa Area or Macrozone. This Area also covers Stirling and parts of Perth and Kinross.*
*Employment in the Stirling and Alloa area decreases by 5% over the period 2012-37. Within the Area there is some variation in employment growth. In Stirling employment increases by 1%, whilst in Clackmannanshire as is reported by the Auditor employment declines by 18%.*
*We have commented previously that employment location can be influenced by availability of commercial floorspace and accessibility.*
*If we look at office and industrial floorspace (the main employment floorspaces) we see that, for office floorspace whilst at the Macrozone level office floorspace increases by 13%, office floorspace in Stirling increases by 18% and in Clackmannanshire by 3%. Similarly for industrial floorspace whilst at the macro-zone level industrial floorspace declines by 1%, in Stirling the amount of this floorspace increases by 1% and in Clackmannanshire industrial floorspace is forecast to decline by 4%.*
*The changes in employment level appear broadly consistent with the changing distribution of commercial floorspace.*
**Auditor response**: While this -18% reduction in employment might perhaps be consistent with these local commercial floorspace changes, the discussion should also note that retail floorspace is forecast in Figure 6 to grow by 138% in Clackmannanshire.
A wider exploration for Clackmannanshire of how the local employment decline mechanism aligns with the local forecast 36% growth in population would be instructive.

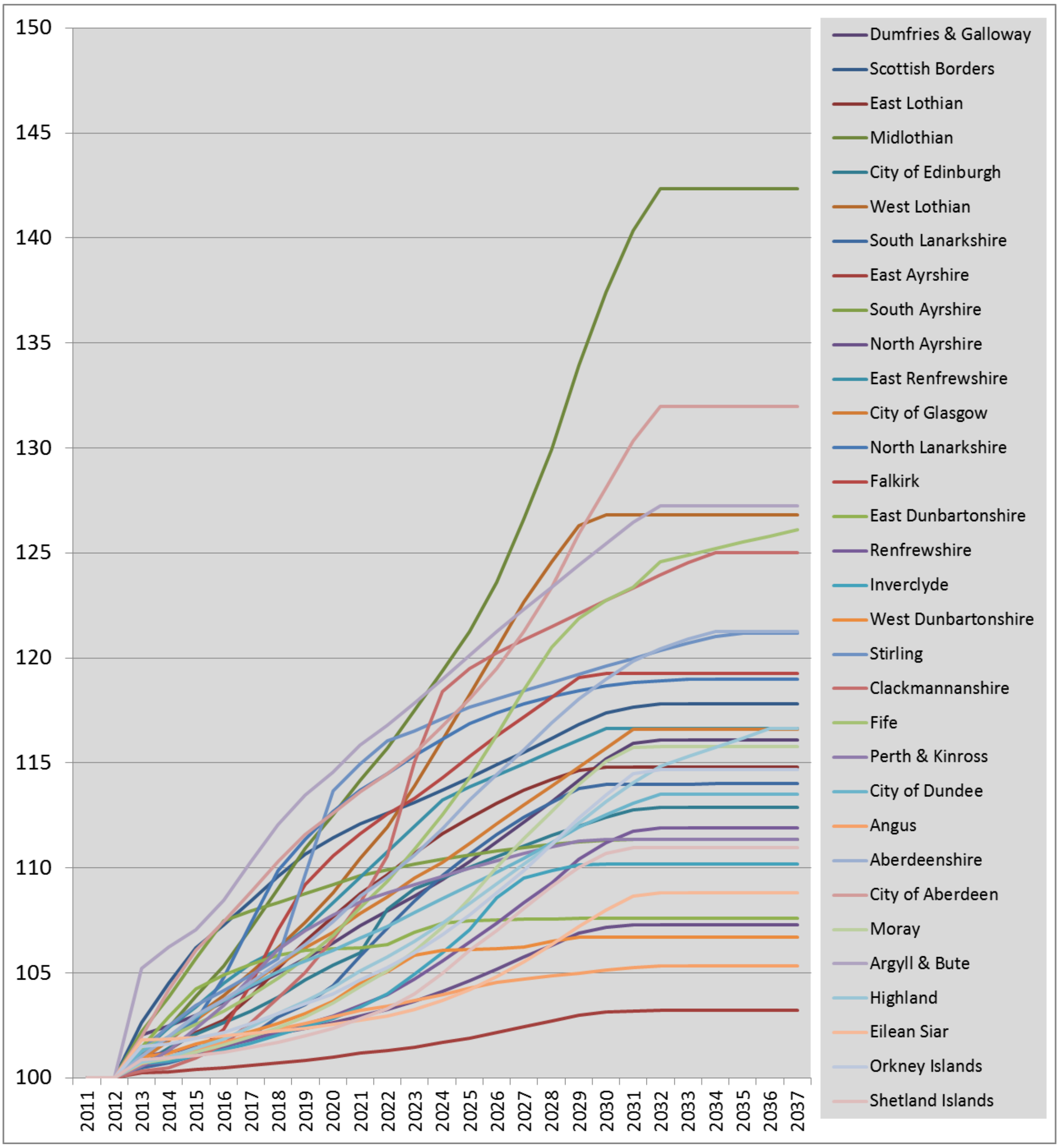


**Figure 4 Index (2012=100) of residential floorspace trends by local authority, reference case (BQ)**

2.4.2 The growth from 2012 to 2037 in **residential floorspace volumes** presented in Figure 4 is smooth over time and varies from 4% in East Ayrshire to 42% in Midlothian, presumably as a function of planning permission availability and of local demand differences. In most local authorities there is no growth after 2031, presumably because no land as yet has been allocated that far ahead for new housing.

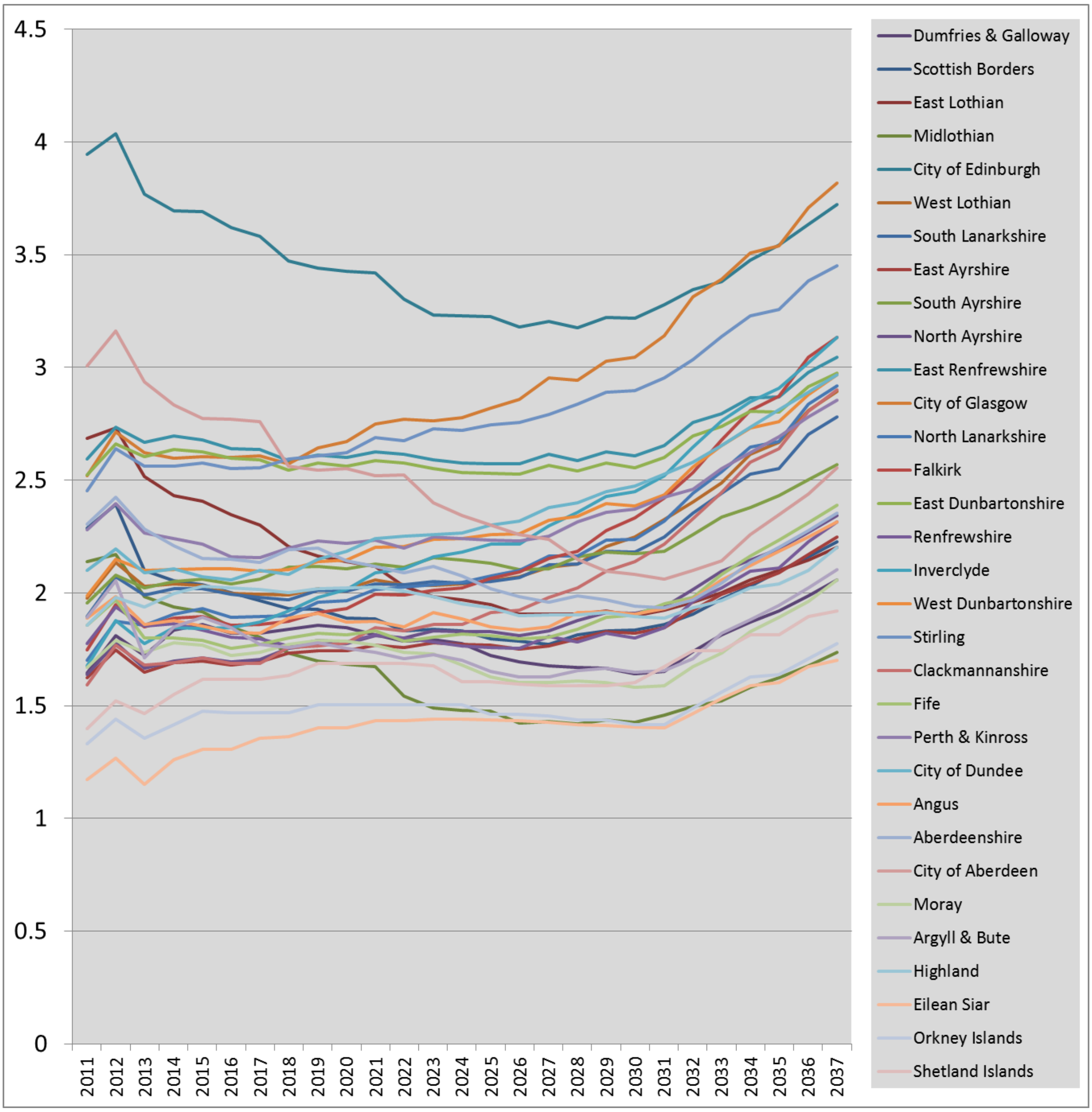


**Figure 5 Residential floorspace rents (£/m²/week) by local authority, reference case (BQ)**

2.4.3 The pattern of weekly **residential rents** per square metre of floorspace is presented in Figure 5. In 2012 the highest rents were in the City of Edinburgh (£4.04) and City of Aberdeen (£3.16), whereas by 2037 the highest rents are forecast to be in the cities of Glasgow (£3.82) and Edinburgh (£3.72) and in Stirling (£3.45), with the Aberdeen rent having dropped to £2.55. In the early years rents generally are decreasing but they start to grow strongly in later years, presumably because relatively little land has been allocated as yet for new housing development in this later period. In most LAs there is a temporary significant upward increase in rents in 2012. The realism of this blip should be validated or it should be removed otherwise.[5]

2.4.4 The trends over time both in residential rents (other perhaps than the significant temporary upward blip in 2012) and in the volumes of new residential development avoid erratic fluctuations and generally appear to be plausible.

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[5] Response from DSC: *2012 is the base year. The blip relates to the trade distance issue described above. The decline in the period post 2012 relates to the relatively large quantity of planned development in this period*

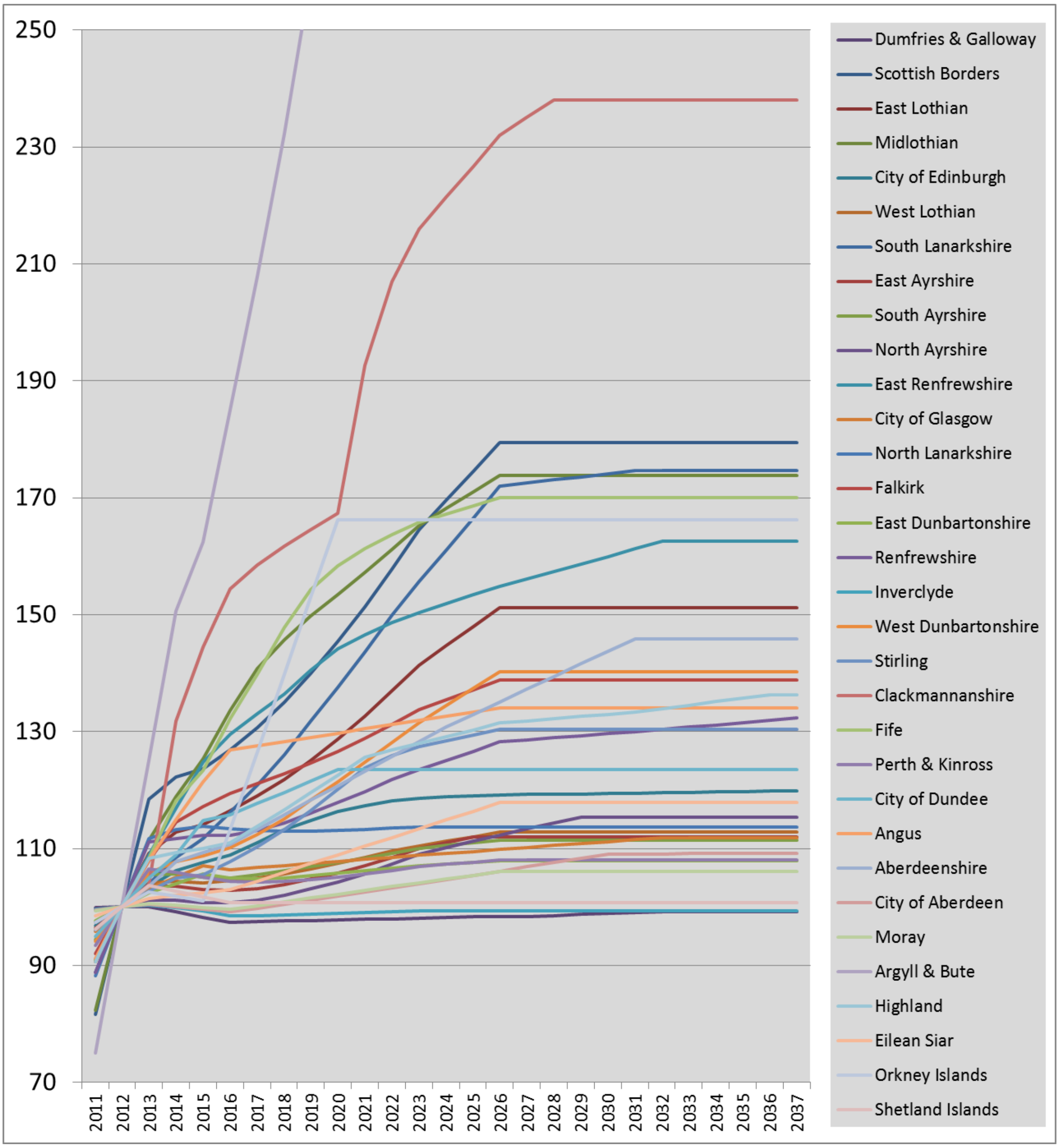


**Figure 6 Index (2012=100) of retail floorspace trends by local authority, reference case (BQ)**

2.4.5 The growth from 2012 to 2037 in **retail floorspace volumes** presented in Figure 6 varies from 0% in Inverclyde, the Shetlands and Dumfries and Galloway to 138% in Clackmannanshire and 204% in Argyll & Bute. In most local authorities there is no growth after 2026, presumably because no land as yet has been allocated that far ahead for new retail developments.[6]

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[6] Response from DSC: *We believe that the increase in floorspace in the first two model years (ie 2012-14) may reflect the fact that planned commercial development in these years was treated as exogenous and not as permissible. The assumption, behind this approach, was that the*

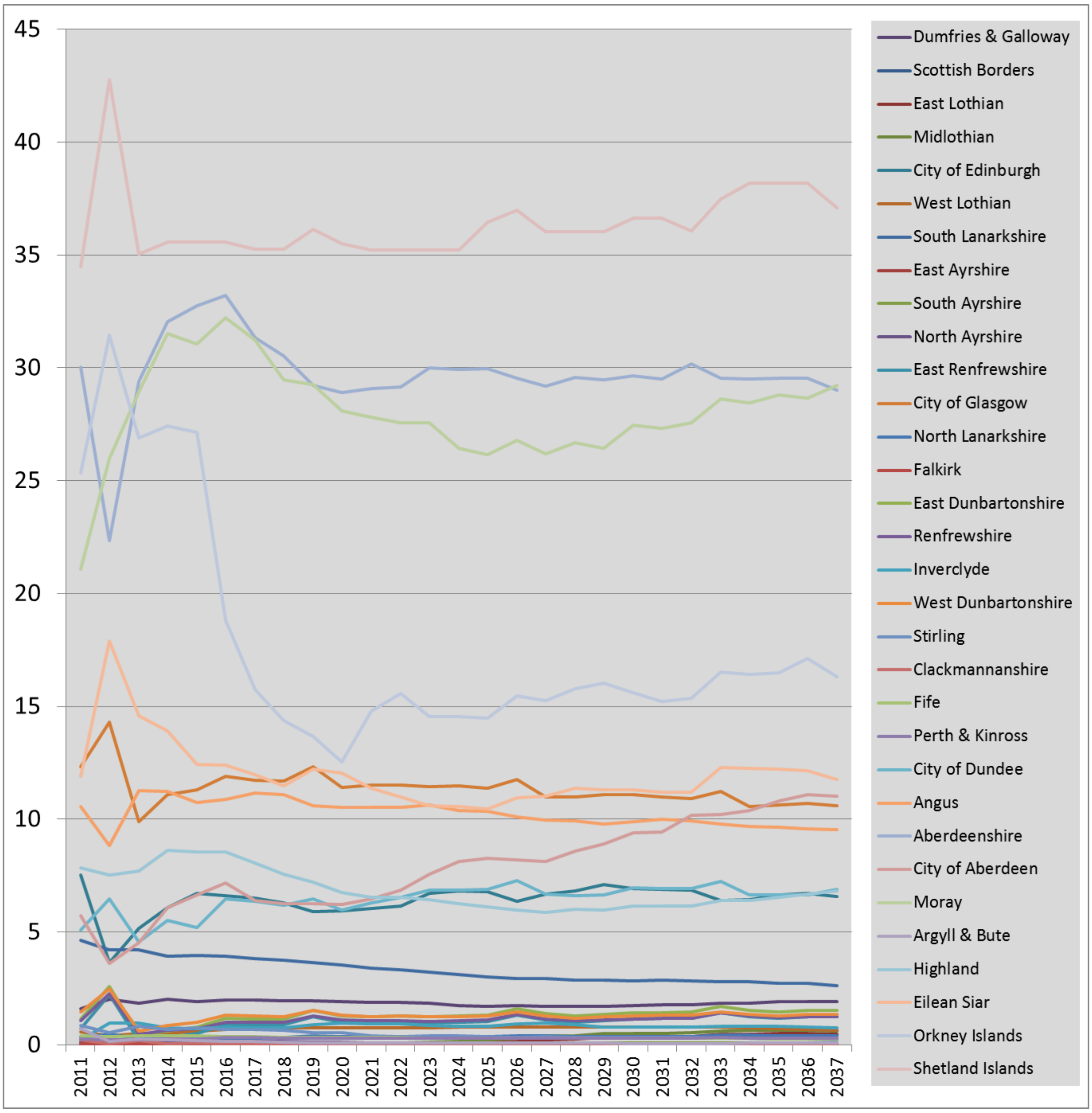


**Figure 7 Retail floorspace rents (£/m²/week) by local authority, reference case (BQ)**

2.4.6 The pattern of weekly **retail rents** per square metre of floorspace is presented in Figure 7. In 2012 the highest rents were in the more remote areas such as the Shetland Isles (£43), the Orkneys (£31) and Moray (£26), whereas those

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*commercial sites that were expected to come forward in the short term (ie the first two years) would presumably have a high degree of commitment and that the decision to go ahead with the development had already been taken.*
*In TELMoS14 we have refined the approach. We have constrained floorspace change, in the first two years, to be consistent with the growth in demand for floorspace.*

for the cities of Glasgow (£14), Aberdeen (£6) and of Edinburgh (£4) are much lower.[7] In the early years, particularly in 2012, the retail rents fluctuate significantly and then they tend to stabilise in the longer term back to a level similar to their initial value in 2011. **This odd spatial pattern of retail rents and of early rapid fluctuations is not what would be expected and so merits further investigation and validation**.

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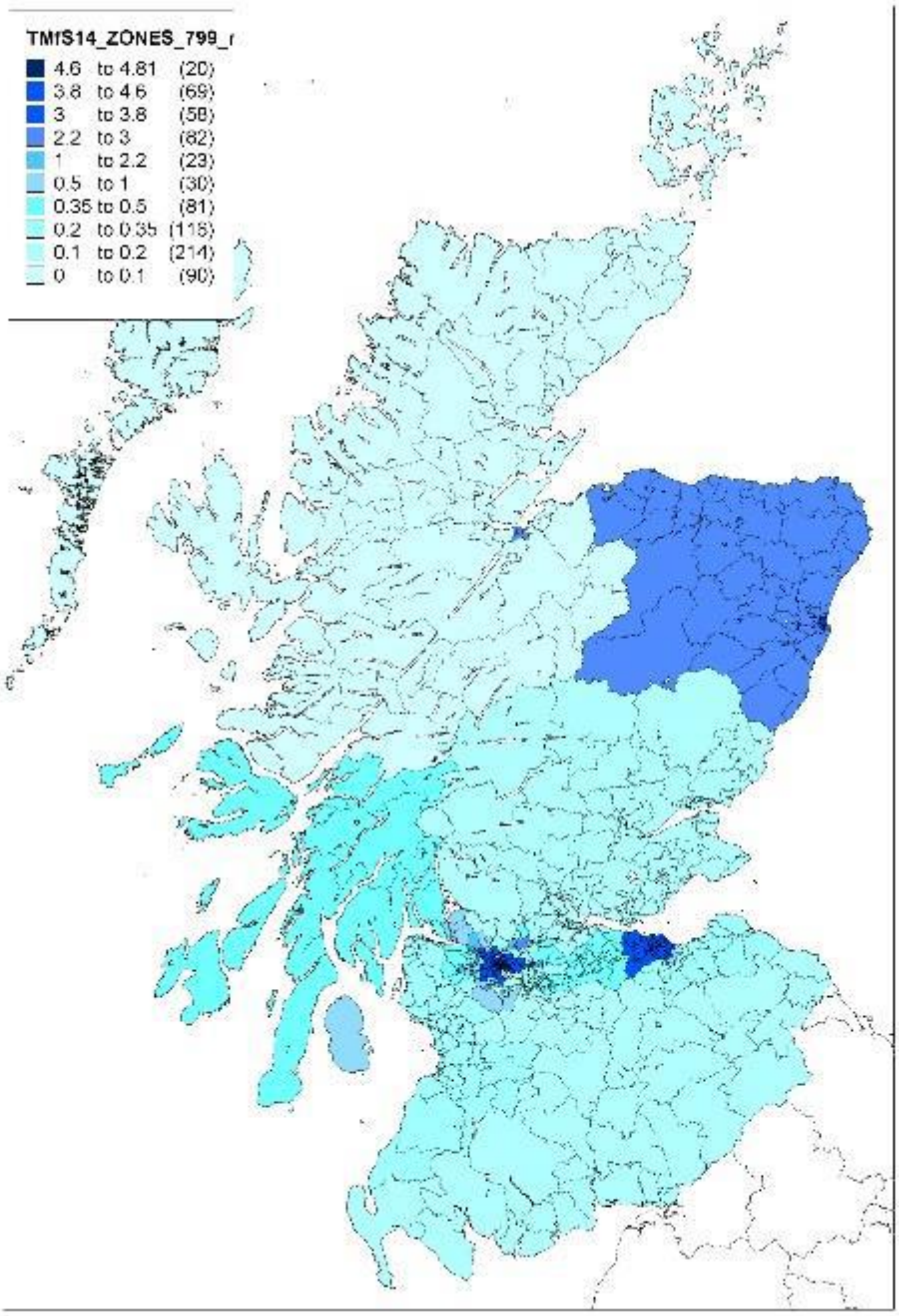
[7] Response from DSC: *We have reviewed retail rents in the base year in TELMoS14. The attached map shows the 2014 base year distribution*




**Auditor response:** This pattern appears much more plausible

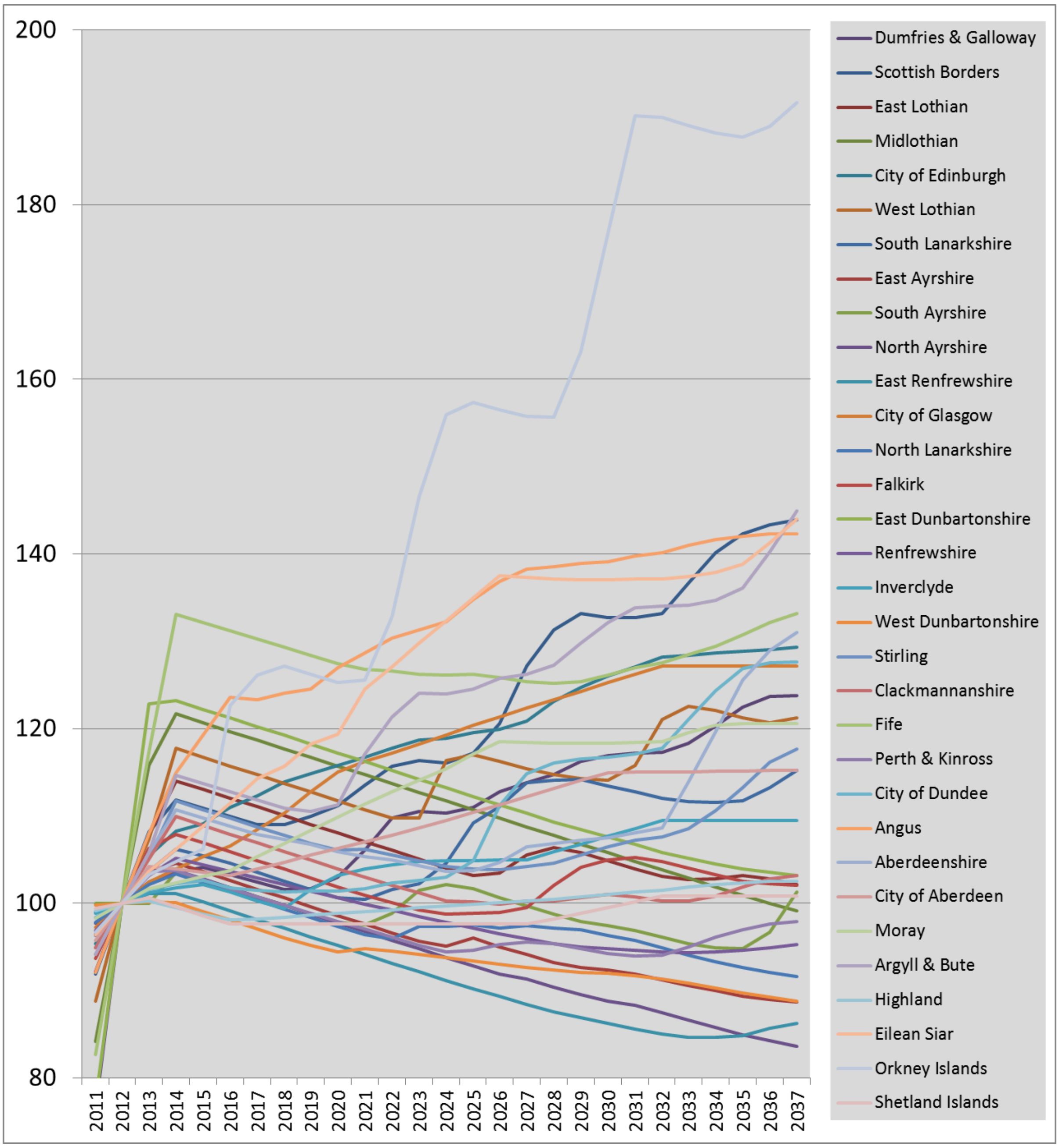



**Figure 8 Index (2012=100) of office floorspace trends by local authority, reference case (BQ)**

2.4.7 The growth from 2012 to 2037 in **office floorspace volumes** presented in Figure 8 varies from -14% in East Renfrewshire and -16% in North Ayrshire to around 43% in Eilean Siar, the Scottish Borders, Angus and Argyll & Bute and up to 92% in the Orkneys. Other LAs have growth rates in office volumes of less than 34%. For many LAs the growth appears to be concentrated just in the first 1 or 2 years after 2012 and subsequently the office floorspace volume declines gently at a constant rate thereafter. **This angular trend pattern, as well as the major fluctuations in volumes between 2012 and 2014 merit further checking and validation**.

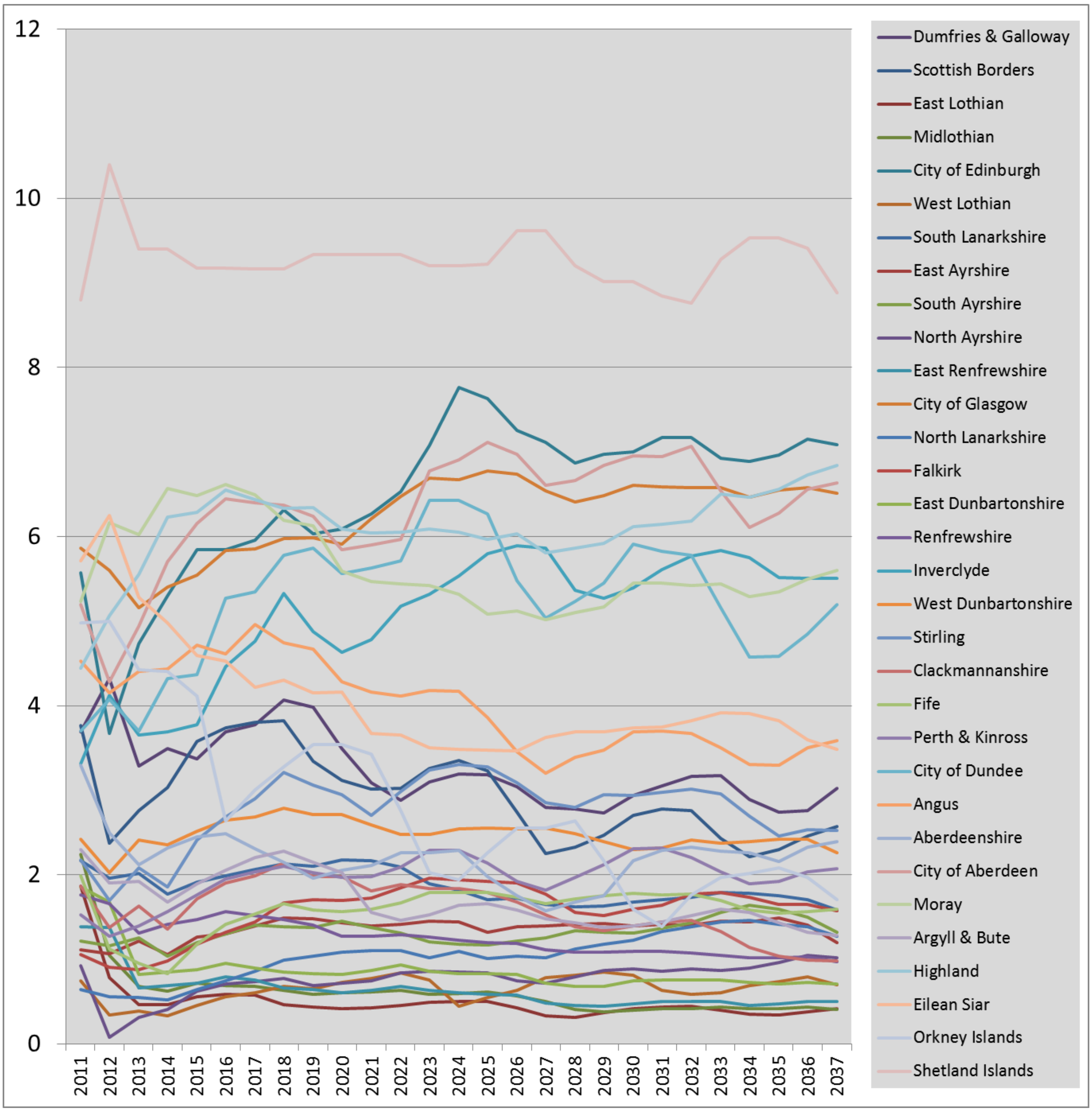



**Figure 9 Office floorspace rents (£/m²/week) by local authority, reference case (BQ)**

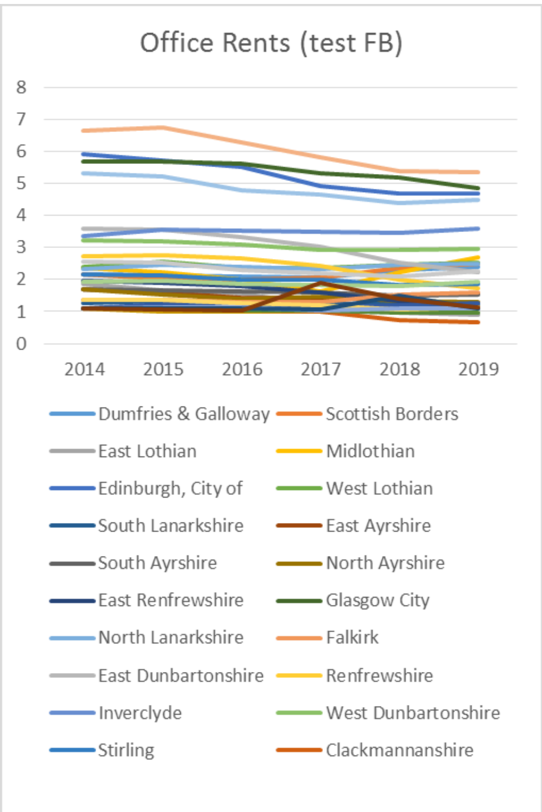
2.4.8 The pattern of weekly **office floorspace rents** per square metre is presented in Figure 9 and has broad similarities in pattern to that of retail rents. In 2012 the highest rents again are often in the more remote areas such as the Shetland Isles (£10.4), Eilean Siar (£6.3) and Moray (£6.2), while those for the cities of Glasgow (£5.6), Aberdeen (£4.3) and of Edinburgh (£3.6) are lower and the lowest rents are in North Ayrshire (£0.1) and West Lothian (£0.3). In the early years, particularly in 2012, the retail rents fluctuate greatly and then they tend to reduce the size of these cyclic variations in the longer term. **This odd base year spatial**

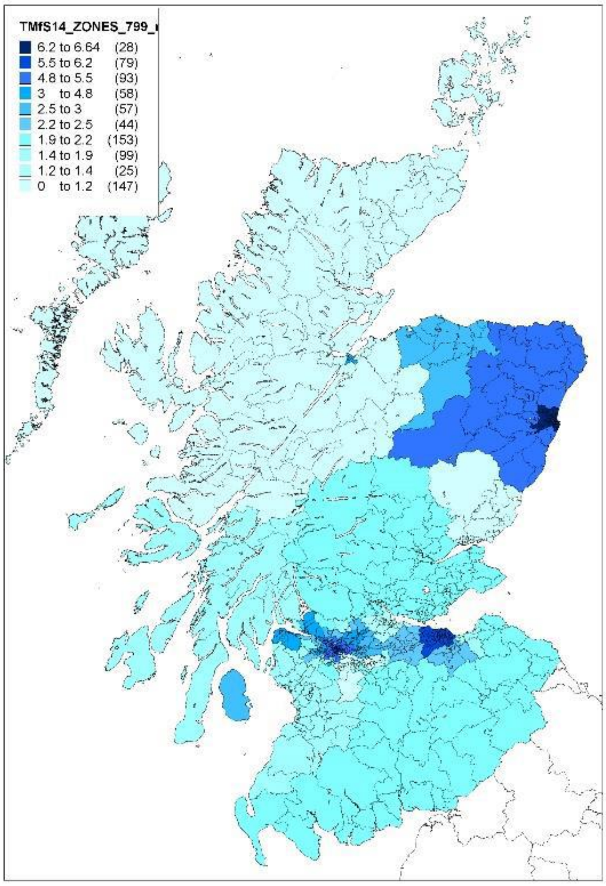
**pattern of office rents and of early rapid fluctuations is not what would be expected and so merits further investigation and validation**[8].

---

[8] Response from DSC: *The Change in office rents for 2014-2019 in TELMoS14 are shown below. We believe they have addressed this issue.*
*Again the base year office rents for TELMoS14 are shown below. We believe these reflect the (limited) available rent data.*

**Auditor response:** The base year map and the rent trend change patterns now both appear to be much more plausible



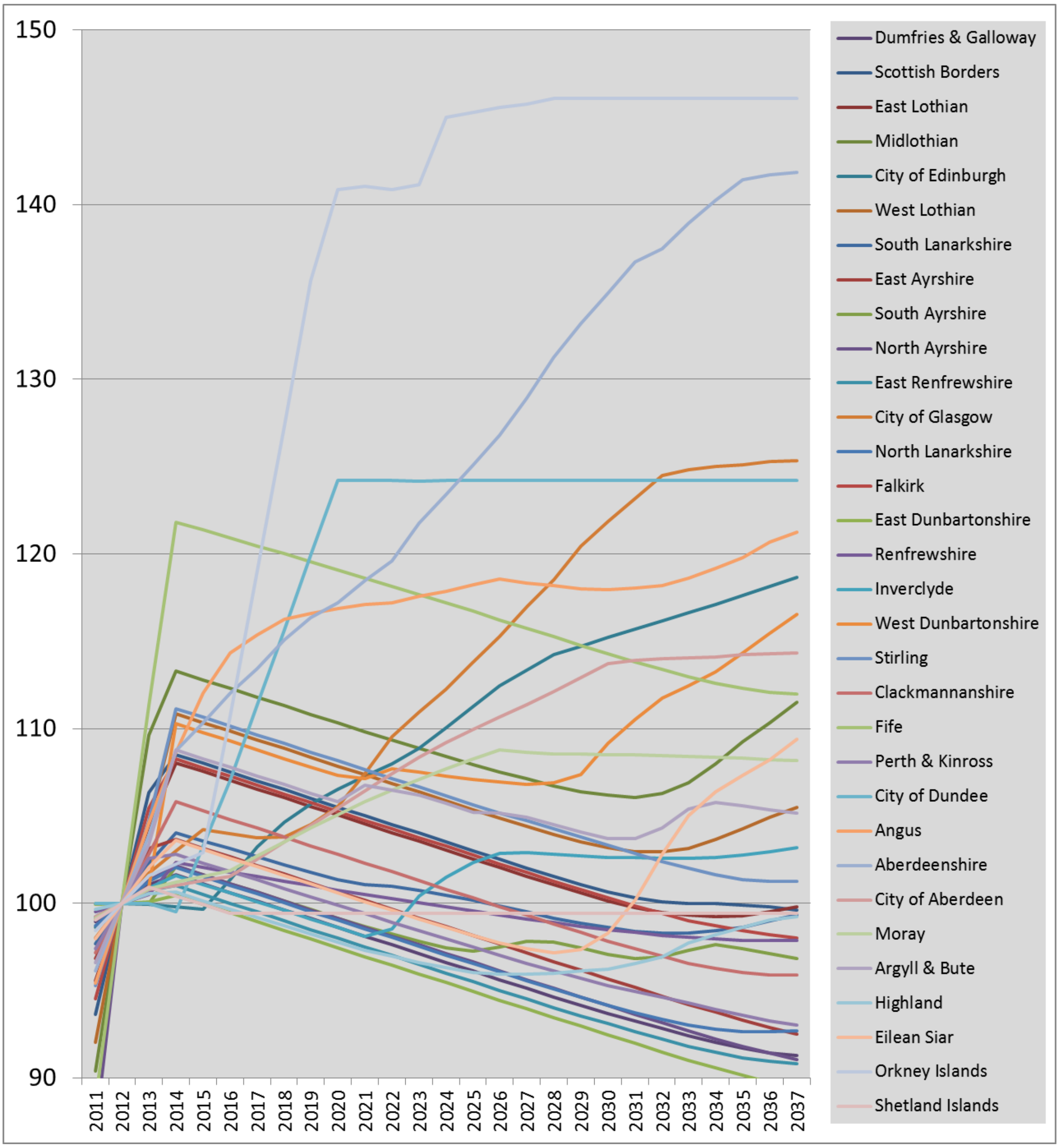



**Figure 10 Index (2012=100) of industrial floorspace trends by local authority, reference case (BQ)**

2.4.9 The growth from 2012 to 2037 in **industrial floorspace volumes** presented in Figure 10 varies from -11% in East Dunbartonshire and -9% in North Ayrshire, Dumfries & Galloway and East Renfrewshire, up to 42% in Aberdeenshire and 46% in the Orkneys. Other LAs have growth rates in industrial volumes of less than 26%. Following a similar pattern to that for office floorspace, for many of the same LAs the growth appears to be concentrated just in the first 1 or 2 years after 2012 and subsequently the office floorspace volume declines gently at a constant rate thereafter. **This angular trend pattern, as well as the major fluctuations in volumes between 2011 and 2014 merit further checking and validation**.

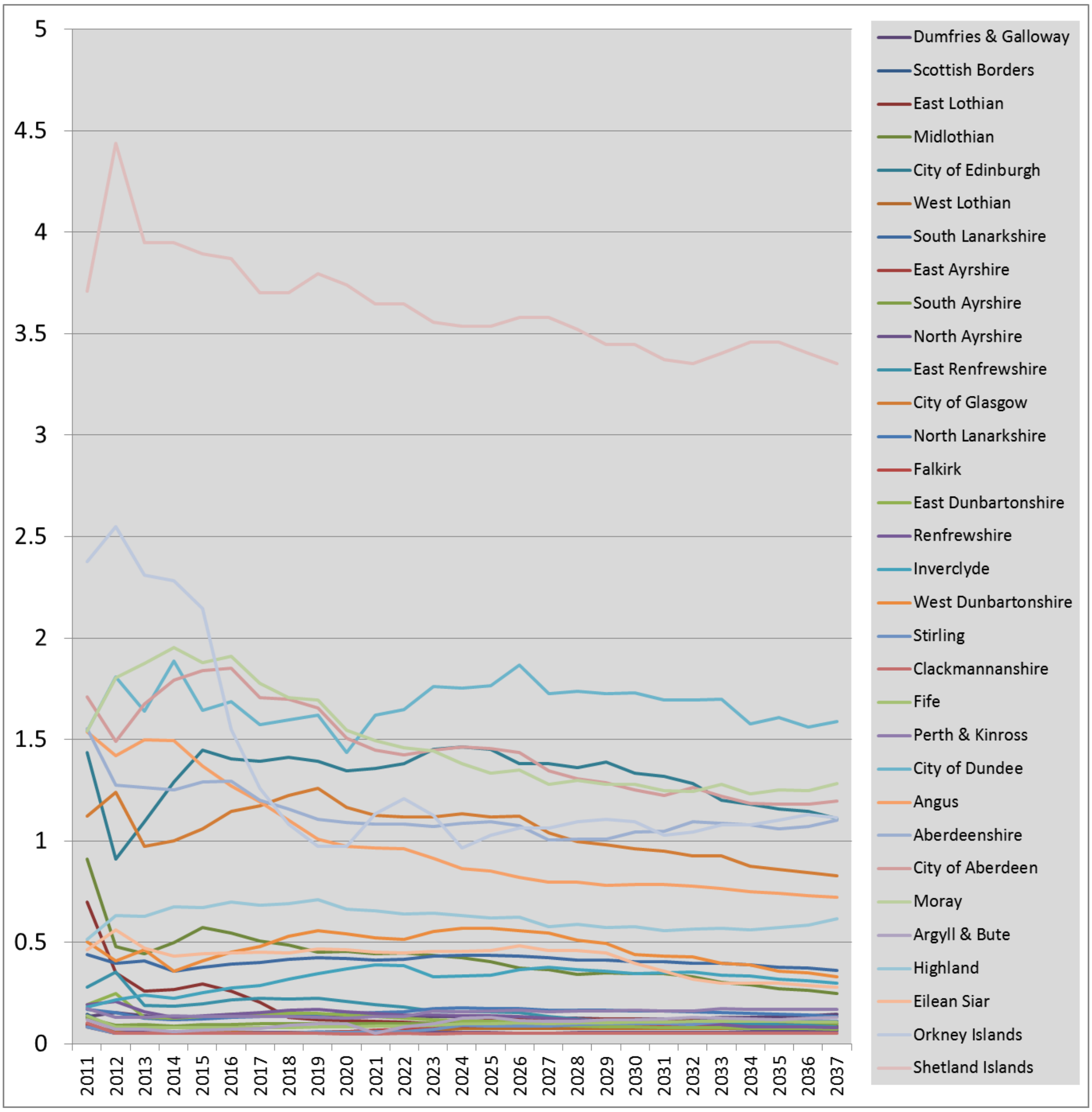



**Figure 11 Industrial floorspace rents (£/m²/week) by local authority, reference case (BQ)**

2.4.10 The pattern of weekly **industrial floorspace rents** per square metre is presented in Figure 11 and has broad similarities in pattern to that of retail and office rents. In 2012 the highest rents again were often in the more remote areas such as the Shetland Isles (£4.4), Orkneys (£2.5) and Moray (£1.8), while those for the cities of Glasgow (£1.2), Aberdeen (£1.5) and of Edinburgh (£0.9) are lower, while the rents in half of the LAs are below £0.2. In the early years, particularly in 2012, the industrial rents fluctuate greatly and then they tend to stabilise in the longer term back to a more constant level close to their original 2012 value. **This odd base year spatial pattern of industrial rents and of early rapid fluctuations is not what would be expected and so merits further investigation and validation**.

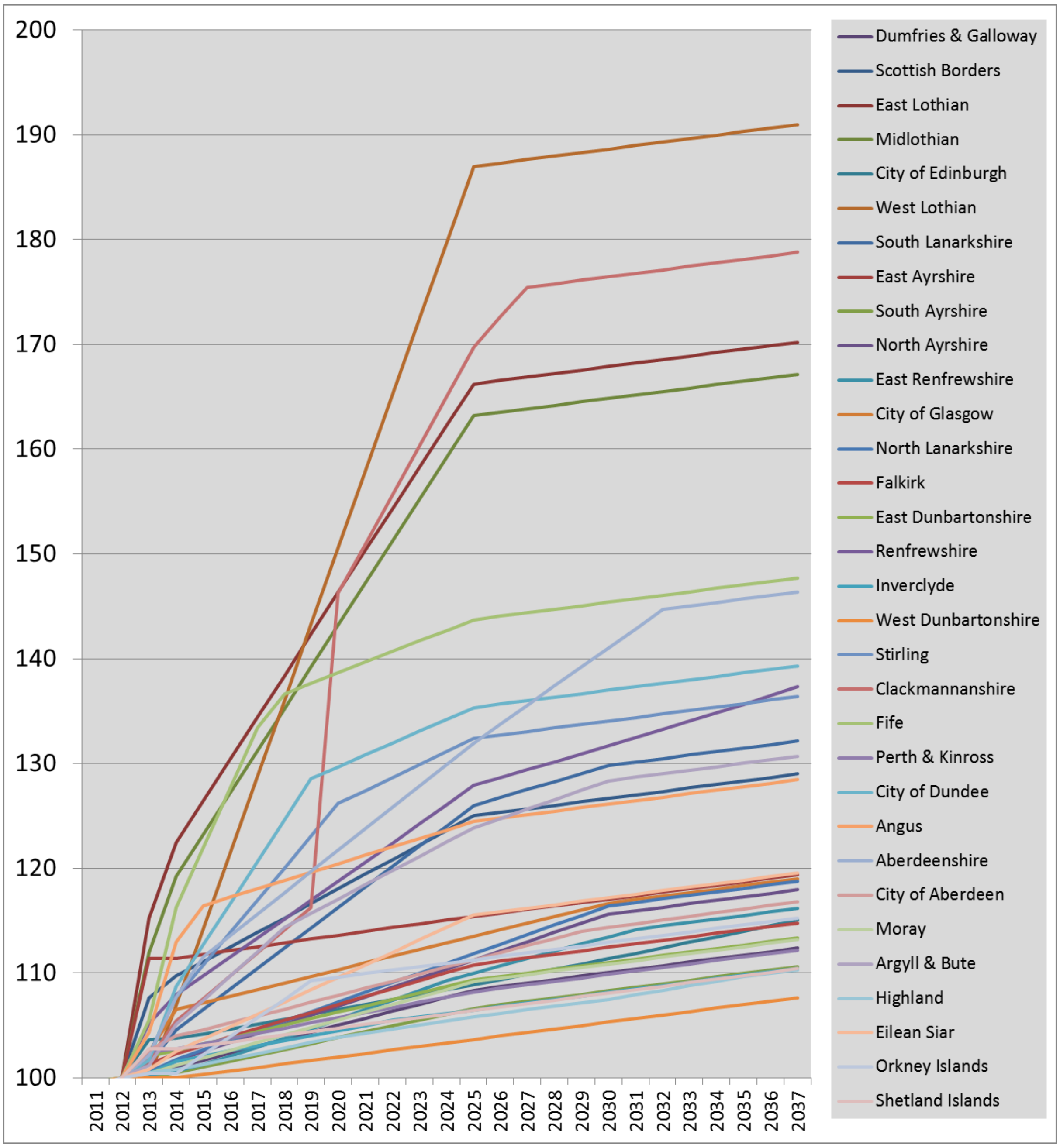



**Figure 12 Index (2012=100) of hotel floorspace trends by local authority, reference case (BQ)**

2.4.11 The growth from 2012 to 2037 in **hotel floorspace volumes** presented in Figure 12 varies from 8% in West Dunbartonshire up to 67% in Midlothian, 70% in East Lothian, 76% in Clackmannanshire and 91% in West Lothian. Other LAs have growth rates in hotel volumes of less than 48%. Following a similar pattern to that for retail floorspace, in most local authorities there is relatively slow growth in hotel floorspace volume after 2026.

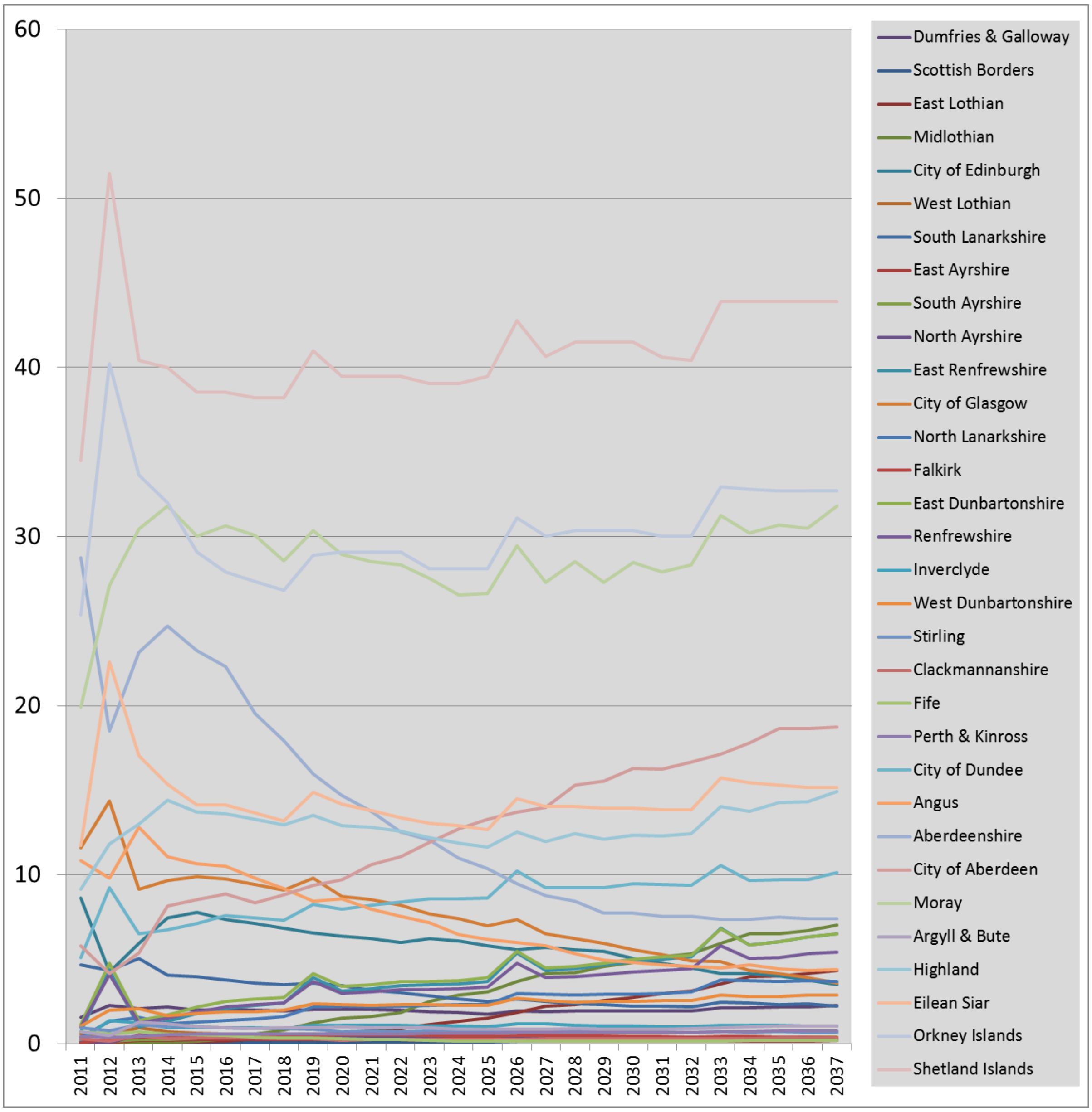



**Figure 13 Hotel floorspace rents (£/m²/week) by local authority, reference case (BQ)**

2.4.12 The pattern of weekly **hotel rents** per square metre of floorspace is presented in Figure 13. In 2012 the highest rents were in the more remote areas such as the Shetland Isles (£51), the Orkneys (£40) and Moray (£27), whereas those for the cities of Glasgow (£14), Aberdeen (£4) and of Edinburgh (£4) are much lower. In the early years, particularly in 2012, the hotel rents fluctuate significantly and then they tend to stabilise in the longer term. **This odd base year spatial pattern of hotel rents and of early rapid fluctuations is not what would be expected and so merits further investigation and validation**.

## 2.5 SUMMARY OF MAIN FORECAST TRENDS

2.5.1 The plausibility at the local authority level of the forecast trend results from 2012 to 2037 for the reference case BQ differs considerably between sets of activities.

2.5.2 Other than the peculiar results in Falkirk, which forecast a 50% increase in household numbers but only a 2% increase in the associated population, the remaining broad population and household trends appear plausible at the local authority level.

2.5.3 The patterns of change for employment and resident workers are somewhat erratic, particularly in the early years, so their stability and plausibility appear less secure. Their temporal trends vary greatly over time between LAs. In particular, the major employment decline of -18% in Clackmannanshire in the period from 2012 to 2037 merits further checking and explanation, especially because this is the LA with the highest population growth rate of +36%. It would be important to understand which mechanisms in the model generate such spatial and temporal variations and then to confirm that these have a rational foundation, rather than being erratic random effects that might add instability to the resulting forecasts from the model.

2.5.4 The trends over time both in residential rents (other perhaps than the significant temporary upward blip in 2012) and in the volumes of new residential development avoid erratic fluctuations and appear generally to be plausible, with the highest rents tending to occur in the large cities.

2.5.5 For many LAs the floorspace growth for office and industrial floorspace appears to be concentrated just in the first 1 or 2 years after 2012 and the floorspace volume declines gently at a constant rate thereafter. This angular trend pattern, as well as the major fluctuations in volumes between 2011 and 2014 merit further checking and validation. In most local authorities there is no growth after 2026 in retail floorspace and only slow growth in hotel floorspace, presumably because no land as yet has been allocated that far ahead for new retail or hotel developments.

2.5.6 For the various types of commercial floorspace (retail, office, industrial and hotel) that have been analysed, the estimated rents in 2012 in the remote LAs of Scotland (e.g. the Shetland and Orkney Isles, Eilean Siar and Moray) in many cases greatly exceed those in the major cities of Glasgow, Edinburgh and Aberdeen, sometimes by a factor of 10. This spatial rent pattern does not appear to be credible. Furthermore, there is frequently an initial short period of major fluctuations in rents between LAs, before they later stabilise to a less erratic pattern.

2.5.7 The subsequent improvements within TELMoS14 to address a number of the issues raised above appear to have led to significant improvements in the model's performance.

# 3 THE BEHAVIOUR TO BE EXPECTED FROM SENSITIVITY TESTS 2 AND 3

3.1.1 The main aims of the sensitivity tests are to understand the functioning of TELMoS12 with respect to:

- how severe restrictions on employment growth within one city would permeate through the system;
- how the dynamics of the model might operate over time in and around a major city within which there is limited scope for growth in the stock of floorspace;
- whether combining the switching of both the commercial and the residential floorspace growth accelerates or offsets their individual effects.

3.1.2 This section has been compiled prior to actually reviewing the model's results produced from implementing the sensitivity tests. The aim is to use practical experience in other cities to first document the broad real world economic behaviour and resulting location trends that would be expected in practice from the application of these (admittedly somewhat extreme) sensitivity test scenarios. It is not expected that these *a priori* assumed behavioural patterns and trends would be matched exactly in all of the locations listed but if the modelled outcomes turn out to differ strongly from them, then doubts may arise over the plausibility of its internal model behavioural relationships or parameter values.

3.1.3 The main results expected *a priori* from the **Commercial sensitivity test** 2 scenario are as follows:

a) Within **Edinburgh** itself –a much **smaller growth** over time **in employment** compared to the base year. Such growth as occurs should be achieved through the intensification of use of the commercial land available in the base year. A major corresponding increase in commercial land prices compared to the reference case run is expected.
b) Within **the three Lothian LAs** – substantially **higher growth** rates in **employment** through each future year than in the reference case, due to the major increase in commercial land available there and to its absence from Edinburgh. A decline might be expected in most commercial land prices compared to the reference case run due to the increased local land supply.
c) Within the **other major cities** (Glasgow, Aberdeen, Dundee) that might potentially compete with Edinburgh for some city centre service activities, a **small increase** might arise over the values in the reference case run **in their employment levels and commercial land prices**. This would result from Edinburgh's reduced ability to compete with them.
d) Within the **lower density areas adjacent to Edinburgh and the Lothians** (i.e. Fife, Clackmannanshire, Falkirk, North Lanarkshire, South Lanarkshire, Scottish Borders) a **small decrease** over the values in the reference case run might arise **in employment levels and in commercial land prices** due to greater land availability in their adjacent zones.

3.1.4 The main results expected *a priori* from the **Commercial and Residential sensitivity test** 3 scenario are as follows:

e) Within **Edinburgh** itself –much **smaller growth over time in population, households and employment** compared to the base year. Such growth as occurs should be achieved through the intensification of use of the land available in the base year. A major corresponding increase in residential and commercial land prices compared to the reference case run is expected.
f) Within **the three Lothian LAs** – substantially **higher growth rates in population, households and employment** through each future year than in the reference case due to the major increase in land available there and to its absence from Edinburgh. A decline is expected in residential and commercial land prices compared to the reference case run due to the increased local land supply.
g) Within the **other major cities** (Glasgow, Aberdeen, Dundee) that might potentially compete with Edinburgh for some city centre service activities, a **small increase** over the values in the reference case run might arise **in their population, households and employment levels and in their residential and commercial land prices**. This would result from Edinburgh's reduced ability to compete with them.
h) Within the lower density areas adjacent to Edinburgh and the Lothians a **small decrease** over the values in the reference case run might arise **in population, households and employment levels and in residential and commercial land prices** due to greater land availability in their adjacent zones.

3.1.5 In subsequent sections we explore how closely the estimated sensitivity test results match to these *a priori* expectations.

# 4 Sensitivity Test 2 (HU): Commercial Planning Permission Changes

## 4.1 Introduction to the sensitivity test

4.1.1 In sensitivity Test 2 (HU) the commercial planning permission is changed such that 100% of the permissible commercial development land (retail, office, industrial, and hotel floorspace categories[9]) added within the City of Edinburgh zones in the reference case during the period has instead been transferred out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years.

4.1.2 More specifically the "Edinburgh commercial planning input for test BQ was aggregated over Edinburgh zones, in each forecast year, and redistributed among East Lothian, Midlothian and West Lothian zones in accordance to the distribution of all commercial floorspace within East Lothian, Midlothian and West Lothian in

[9] Health and Education floorspace types are not counted as being part of commercial floorspace and so their inputs were not adjusted.

the model base year, 2012." (DSC, PN33). All other commercial planning policy inputs outside of Edinburgh, East Lothian, Midlothian and West Lothian zones remain the same as they were in reference case BQ.

4.1.3 Sensitivity tests 2 and 3 are variants of TELMoS12 reference case BQ. They are a land use and transport interaction (LUTI) model run. The required planning policy inputs for each test were included in the runs of TELMoS12 for each future year from 2013 to 2037. The resulting outputs provided the necessary files to run the transport model in each transport year. The transport model, TMfS is run in years 2017, 2022, 2027 and 2032. Transport costs were sent back from TMfS for input to TELMoS12 for each transport year and the land use database was run forward to the next transport year.

4.1.4 This review of this sensitivity test has been implemented by introducing a set of trend charts into the spreadsheet ."ITabs Analysis HU-BQ_INW.xlsm" in the tabs <xxx % test-ref> and/or <xxx ABS test-ref>. For clarity, the results for the sensitivity tests in these charts are presented using distinct line patterns (but without modifying the line colour specific to each LA) that indicate the main groups of LAs for which similar types of responses are expected:

- the three Lothian LAs which gain permissions are presented as "■";
- Edinburgh which loses permissions is presented as "▲";
- the other major cities Glasgow, Aberdeen and Dundee are presented as "✶";
- the six lower density LAs surrounding the Lothians are presented as "✚";
- the remaining LAs are presented as in the reference case charts as simple lines without patterns.

## 4.2 EMPLOYMENT RELATED RESULTS

4.2.1 The first step in this review is to confirm the success of the implementation of the sensitivity test 2 in the form in which it had been specified.[10]

[10] Response from DSC: *Retail: increase in East Lothian, Midlothian and West Lothian +159,666m2 decrease in Edinburgh* 159,685m2
*Office: increase in East Lothian, Midlothian and West Lothian +333,493m2, decrease in Edinburgh 776,241m2*
*Industrial : increase in East Lothian, Midlothian and West Lothian +117,883m2 decrease in Edinburgh 169,989m2*
*leisure: increase in East Lothian, Midlothian and West Lothian +115,807m2, decrease in Edinburgh 114,811m2*
**Auditor response:** This substantially higher total decrease in Edinburgh office volume than the corresponding increase elsewhere is consistent with the higher construction density at which offices are likely to be built there than outside.
Such density differences are less likely to occur for other floorspace types, which is why the losses and gains are close to cancelling out. Accordingly these totals appear appropriate.

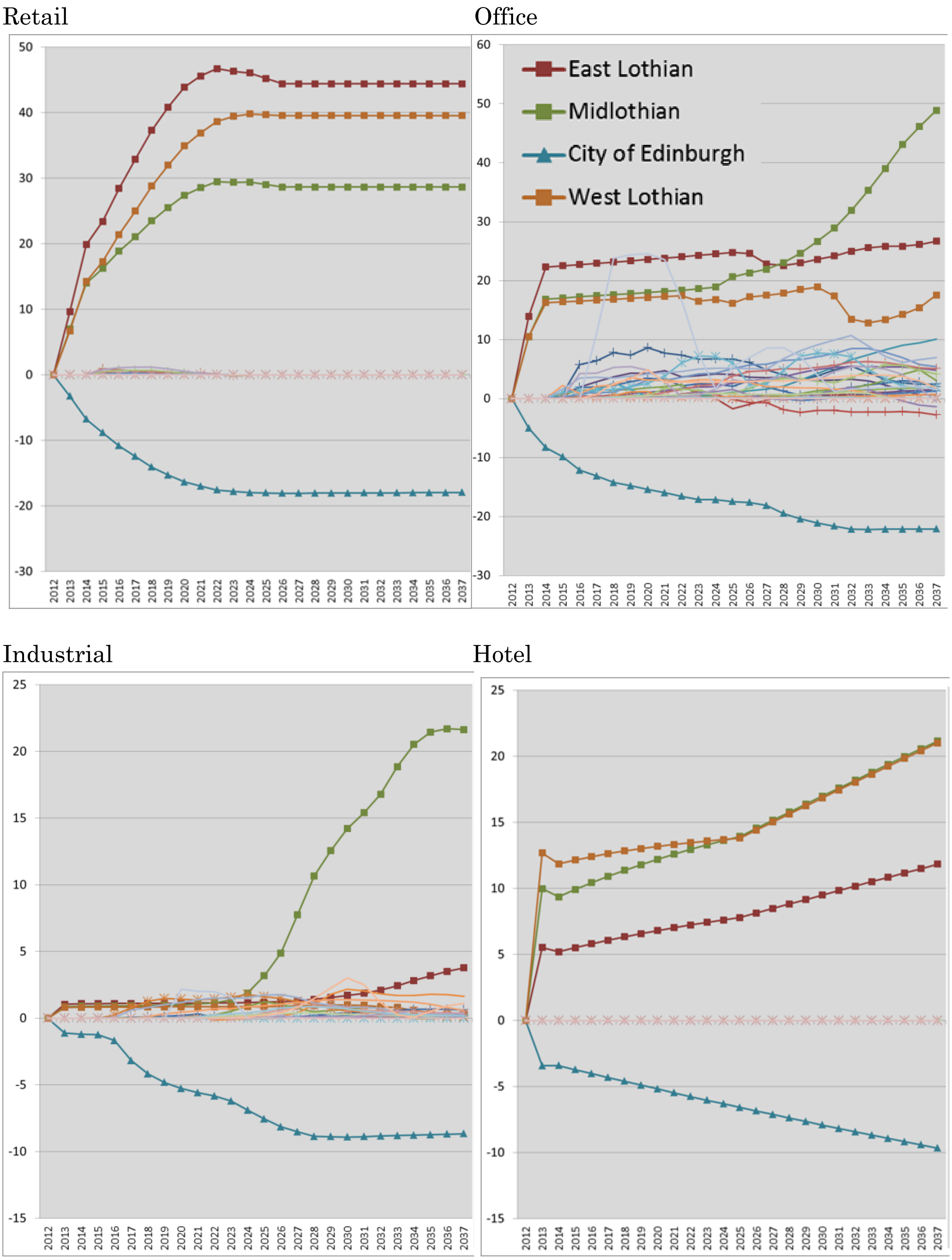



**Figure 14 Percentage change in commercial floorspace volumes by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.2.2 The annual percentage increase in **commercial floorspace volume** in the sensitivity test 2 relative to the reference case volume is presented in Figure 14 for retail, office, industrial and hotel floorspace types for the period 2012 to 2037. Relative to the reference case, the three Lothian LAs exhibit major percentage increases of up to 50% by 2037 (except for industrial floorspace which has minimal growth in West Lothian and under 5% in East Lothian). There is a relative decrease of -10% to -20% for the various floorspace types in the City of Edinburgh. As expected, within the other 28 LAs there is relatively little change from the reference case for the retail, industrial and hotel floorspace volumes. The exception is office floorspace which does present significant temporary fluctuations of up to 10% in many LAs and an increase of 25% for the years 2018 to 2021 for the Orkney Islands **Except for these few peculiarities, these charts otherwise suggest that the design of the sensitivity test has been correctly implemented within the model structure**.

4.2.3 The next step is to examine how these commercial floorspace changes impact in turn on the LA patterns of employment and of resident worker numbers.

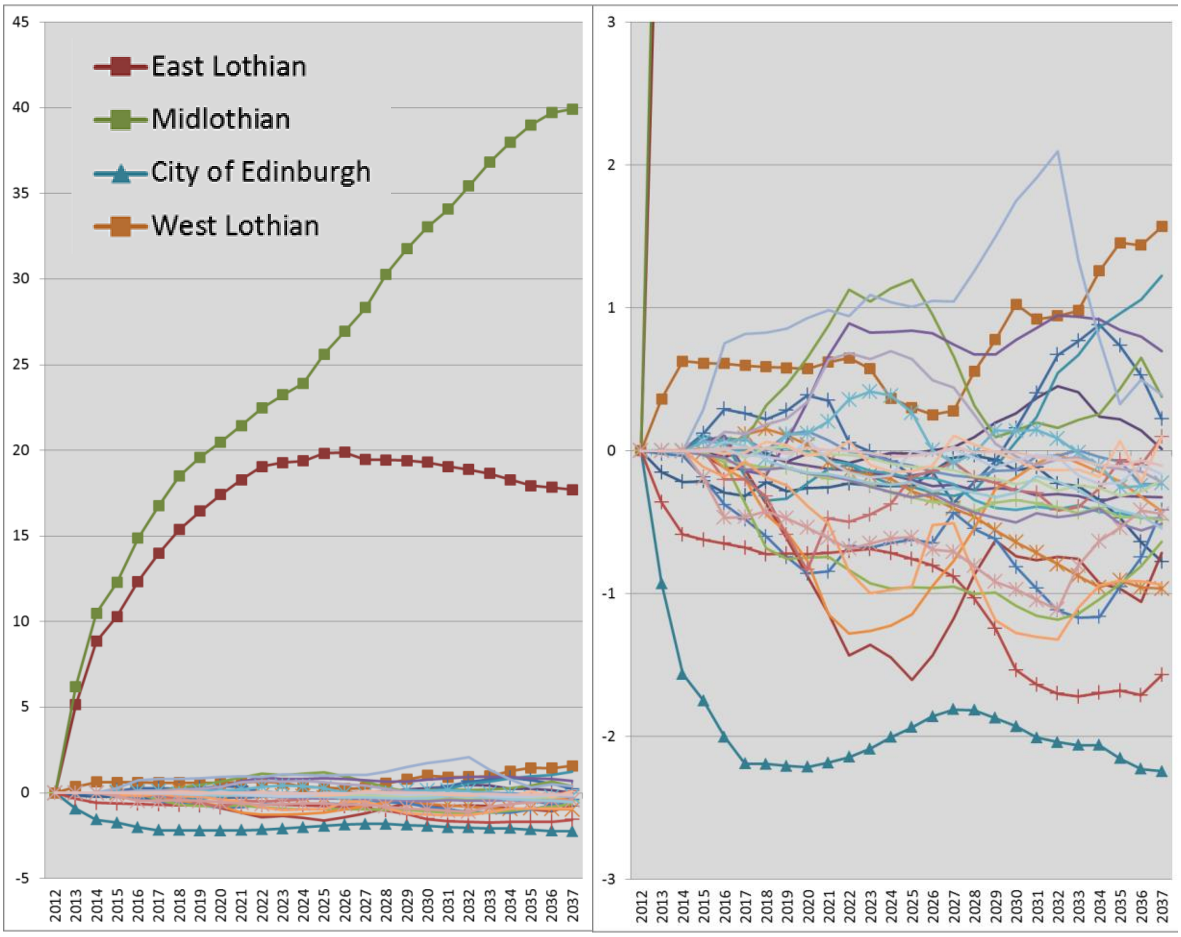



**Figure 15 Percentage change in employment by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.2.4 The annual percentage increase in **employment numbers,** aggregating all employment types together, in the sensitivity test 2 relative to the reference case volume is presented in Figure 15 for the period 2012 to 2037. Relative to the reference case: East Lothian (18%) and Midlothian (40%) exhibit major percentage increases; West Lothian has increased only by 2%; while there is a relative decrease of -2% for the City of Edinburgh. The directions of these employment changes are what would be expected in response to the changes in floorspace volumes indicated above in Figure 14, though the percentage reduction of just -2% in employment in the City of Edinburgh is small compared to the relative reductions of at least 10% in floorspace there.  Likewise, the percentage increase of just 1.5% in employment in the West Lothian is small compared to the relative increases of over 20% in the retail, office and hotel floorspace there.[11]

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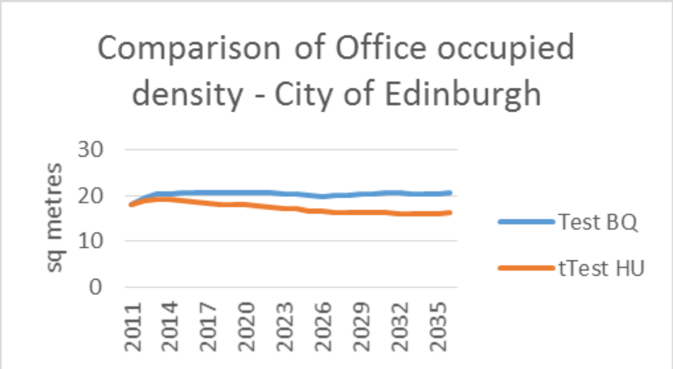
[11] Response from DSC: *Within TELMoS there is a rent mechanism operating, if demand exceeds supply then rents are likely to rise and the amount of floorspace occupied (per worker) may lessen.*
*Looking at office floorspace within Edinburgh (ie major employment land use) then in Test HU, with a constrained supply, office densities are around 4 square metres per worker lower in 2037 in Test HU. This reduction in density (and changes in other authorities) explains the apparent discrepancy between change in floorspace and change in employment.*




*To understand the rent responses it is helpful to consider the development and location processes and how they are modelled within TELMoS.*
*The planning policy inputs are an input to the Development model. Within TELMoS12 the development model models two processes, one by which floorspace is brought forward at national level, one by which floorspace is brought forward at Area (or Macrozone) level. Of these the national process is the one that produces the largest change in floorspace.*
*Within this sensitivity test planning policy inputs are constrained in Edinburgh. This is part of TELMoS Area ( Macrozone) 1; an area that covers most of Edinburgh, East Lothian and Midlothian and approximates to the Edinburgh 2001 Travel to work area. It is an area where there is demand for floorspace, with most sites being brought forward and developed in the Do-Minimum Reference Case BQ.*
*In the sensitivity test HU where inputs are constrained in Edinburgh. We'd expect the development model would built in other areas of demand. Some of these would be in other parts of Area 1, some would be elsewhere within Scotland.*
*The employment location model models the processes by which employment is located in available floorspace. It operates within TELMoS Areas ( Macrozones). Despite the constraint on employment floorspace, introduced in the Sensitivity Test, there is still a demand for employment within TELMoS Area ( Macrozone) 1. Employment has to compete for a reduced supply of commercial floorspace and rents increase. This is seen in both Edinburgh and, to a lesser extent, in those parts of Midlothian and East Lothian that lie within TELMoS Area ( Macrozone) 1.*
*In contrast, West Lothian lies mainly within Area 6. This area is based upon the Livingstone and Bathgate TTWA. This area sees some additional development (from the processes described above). However there is relatively little employment relocation across the border of TELMoS Areas ( Macrozones) 1 and 6. For this reason the demand does not grow sufficiently to result in an increase in rents in this Area.*

4.2.5 There are temporary fluctuations for other more distant LAs with the greatest being +2% for Aberdeenshire in 2032 and -1.6% for East Ayrshire in 2025. Closer in, there is a consistent employment decline in Falkirk down by -1.6% by 2037 but little systematic change elsewhere.

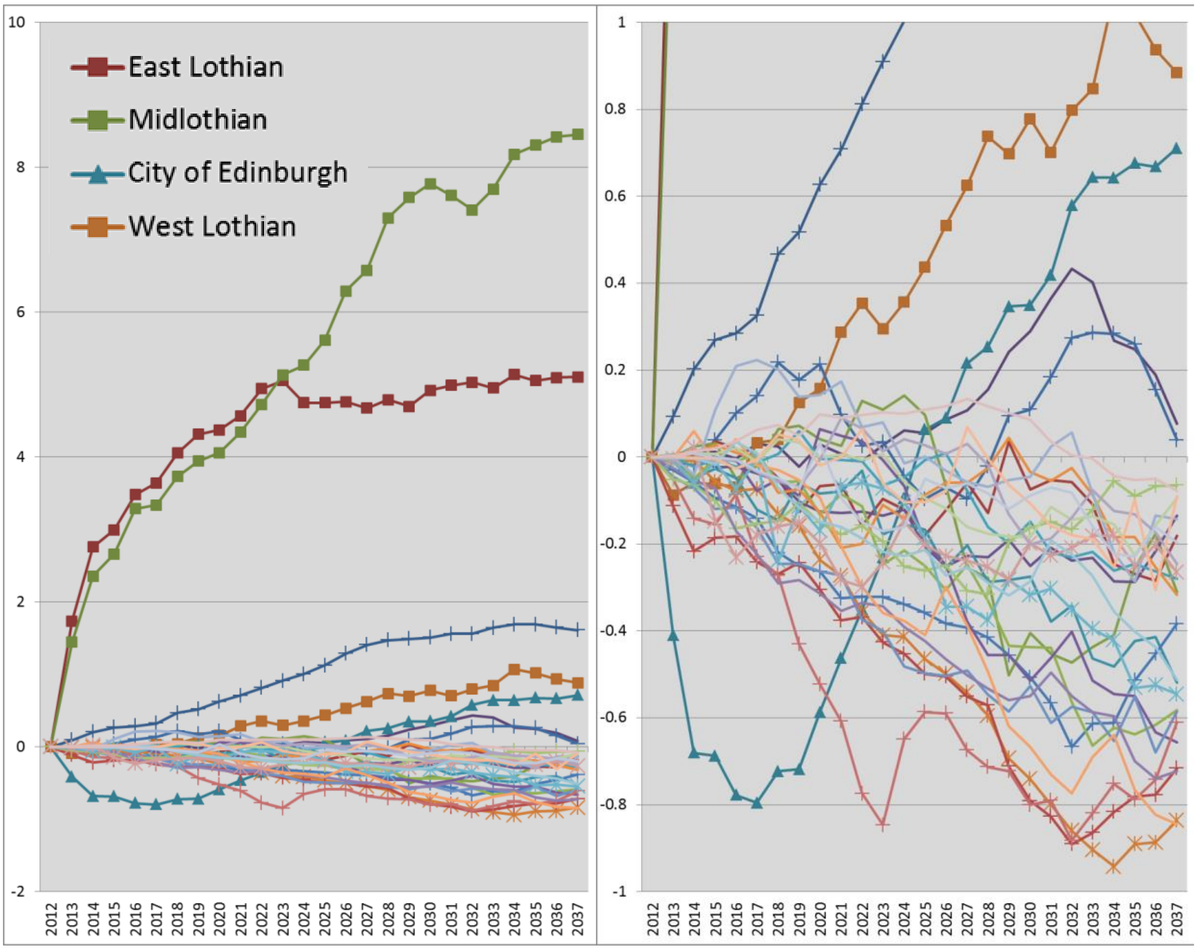



**Figure 16 Percentage change in resident workers by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.2.6 The annual percentage increase in **resident workers** in the sensitivity test 2 relative to the reference case volume is presented in Figure 16 for the period 2012 to 2037. Relative to the reference case: East Lothian (5%) and Midlothian (8%) exhibit significant percentage increases but West Lothian has increased only by 1%. Although there is a relative decrease of 1% for the City of Edinburgh prior to 2020, this subsequently gradually reverses leading to a 0.7% increase by 2037.

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*For TELMoS14 we did propose to introduce an employment distance deterrence function. Despite the term 'distance deterrence' this would actually permit employment to relocate across an Area border as part of the employment location modelling.*
*This enhancement was not pursued by Transport Scotland.*
**Auditor response:** This enhancement is worth reconsidering as assumptions on closed travel to work areas that are invariant through time, have limitations for the reasons discussed in the DSC comments above and indicated by the model's results.

4.2.7 There is a sustained increase of 1.6% in Scottish Borders. In most other LAs there are minor fluctuations over the years leading generally to small declines by 2037, with the greatest declines of -0.8% being in City of Glasgow and in Angus.

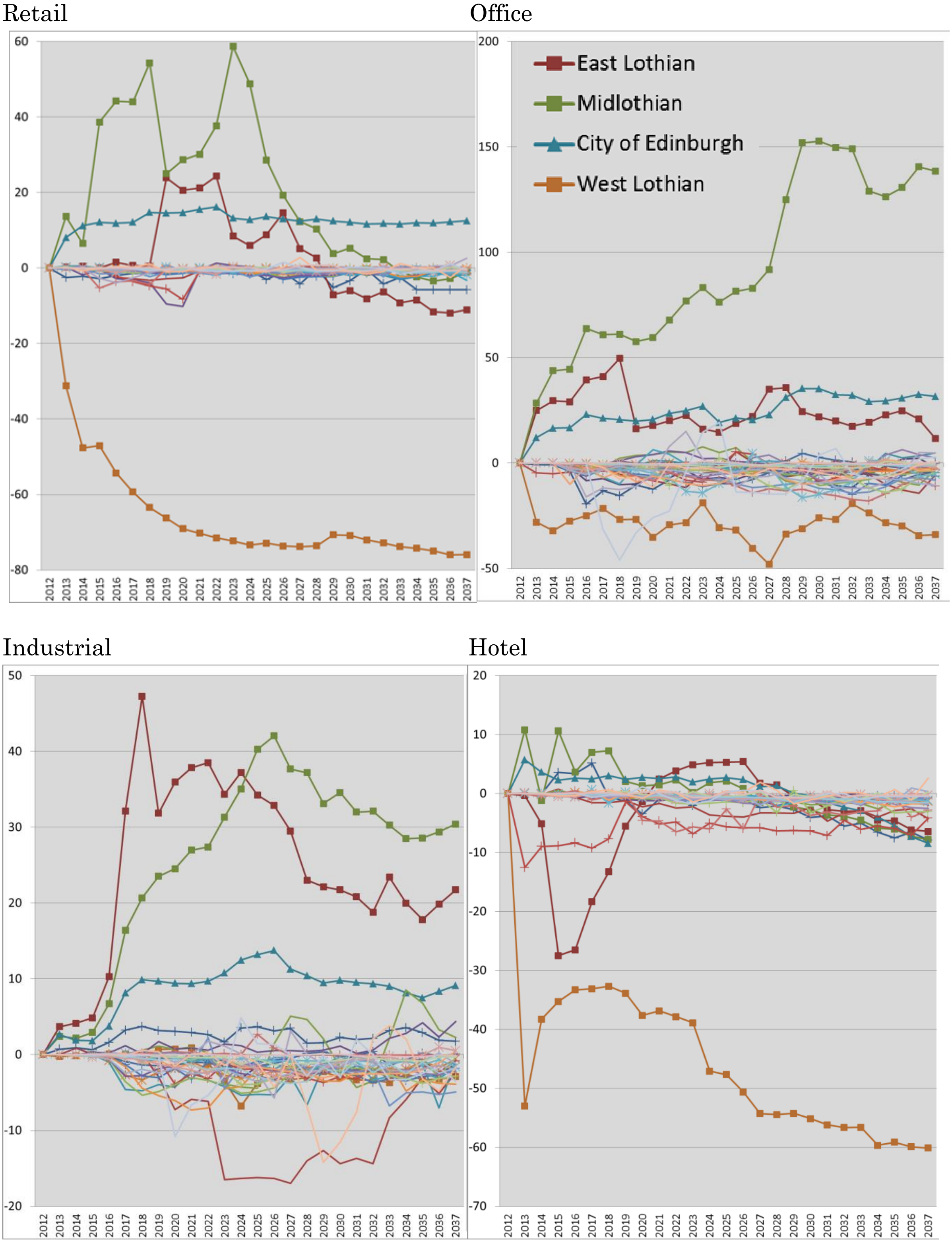



**Figure 17 Percentage change in commercial floorspace rents by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.2.8 The annual percentage increase in **commercial floorspace rents** in the sensitivity test 2 relative to the reference case volume is presented in Figure 17 for retail, office, industrial and hotel floorspace types for the period 2012 to 2037. The expected economic response to switching all land that is available for new commercial development from Edinburgh to the Lothian LAs is that rental values would increase relatively within Edinburgh due to the increase in competition. This is what the model predicts for retail, office and industrial floorspace through to 2037 and for hotel floorspace, though through only until 2029.

4.2.9 Correspondingly, rents would be expected to reduce relatively for the three Lothian LAs due to their land supply increase via the associated increase in their floorspace volume that is illustrated above in Figure 14. A consistent rent decrease for all commercial floorspace types is predicted by TELMoS only for West Lothian. In contrast, rent increases rather than decreases are predicted throughout the period for East and Midlothian for both office and industrial floorspace and rent increases are predicted there until the 2030s for retail floorspace[12]. For hotel floorspace, rent increases are predicted for Midlothian until 2026 and for East Lothian from 2021 to 2028.

4.2.10 This unexpected systematic pattern of relative increases in floorspace rents in East and Midlothian, in response to the relative increases in floorspace volumes there, requires further analysis in order to confirm that the causal mechanisms within TELMoS are operating in the expected manner.

## 4.3 POPULATION RELATED RESULTS

4.3.1 Only the commercial planning permissions were relocated for this sensitivity test 2, those for residential were left unchanged until within sensitivity test 3. However, in response to the significant employment location changes, the densities of residential developments could be adjusted by developers over time, while households could relocate and densify within the existing residential floorspace. This section reviews these residential responses for the activities: population, households, residential floorspace volumes and rents.

[12] **Auditor comment:** In the case of office floorspace, the (originally unexpected) increase in rents in the Lothians, now appears reasonable in the light of the net reduction in total office floorspace in the area overall, as indicated above in the scenario description in the footnote at the start of Section 4.2 .
However, for other commercial floorspace types, the rent increases in East and Midlothian are likely to be a side-effect of the use of closed TTW areas, as discussed in comments above.

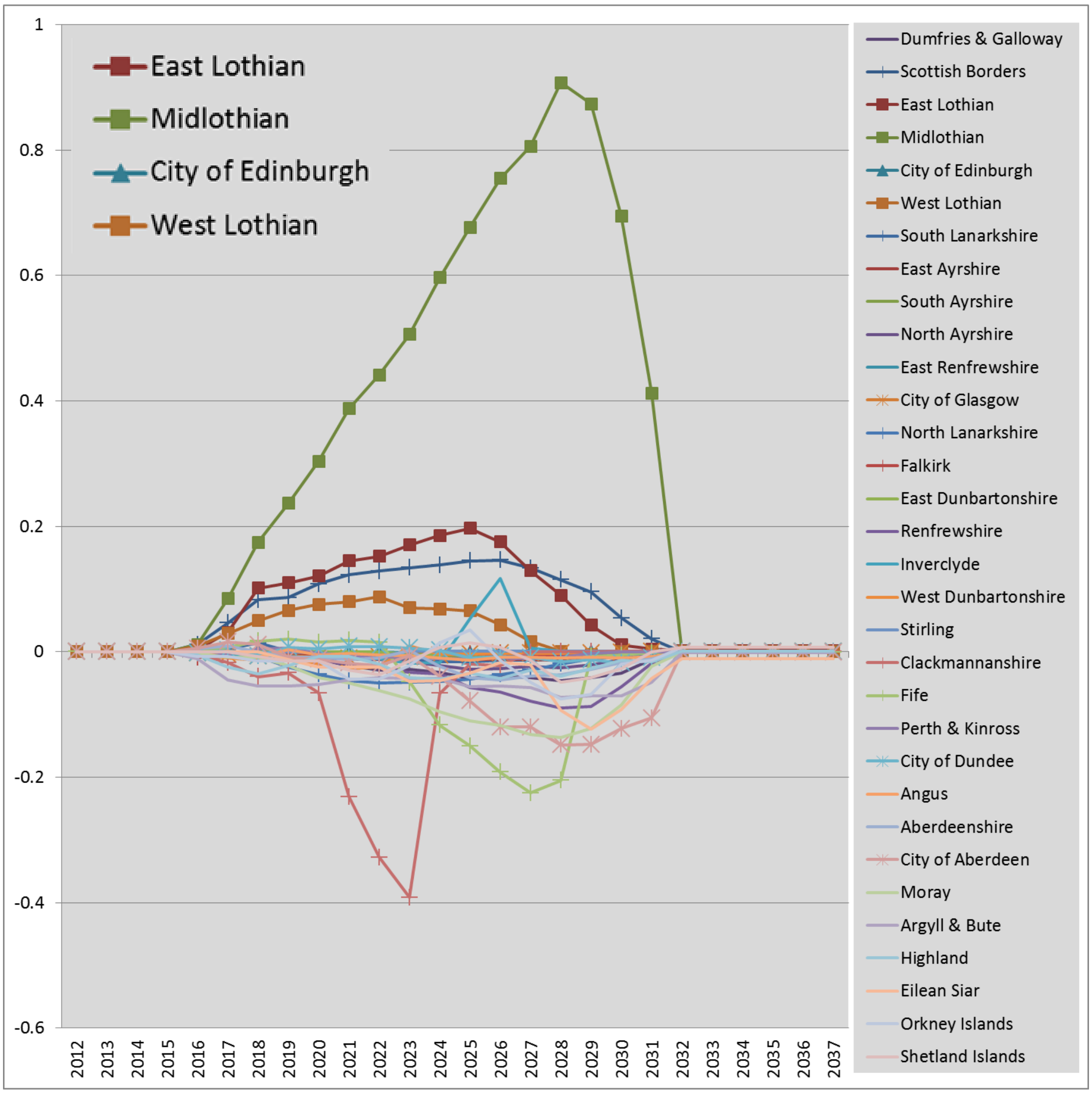



**Figure 18 Percentage change in residential floorspace by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.3.2 The annual percentage increase in **residential floorspace volume** in the sensitivity test 2 relative to the reference case volume is presented in Figure 18 for the period 2012 to 2037. Relative to the reference case, the three Lothian LAs exhibit maximum percentage increases of 0.1% to 0.9% during the 2020s whereas there is virtually no change throughout for the City of Edinburgh, though Clackmannanshire (-0.4%) and Fife (-0.2%) do have minor relative decreases in residential floorspace, whereas Scottish Borders increases by 0.15%.

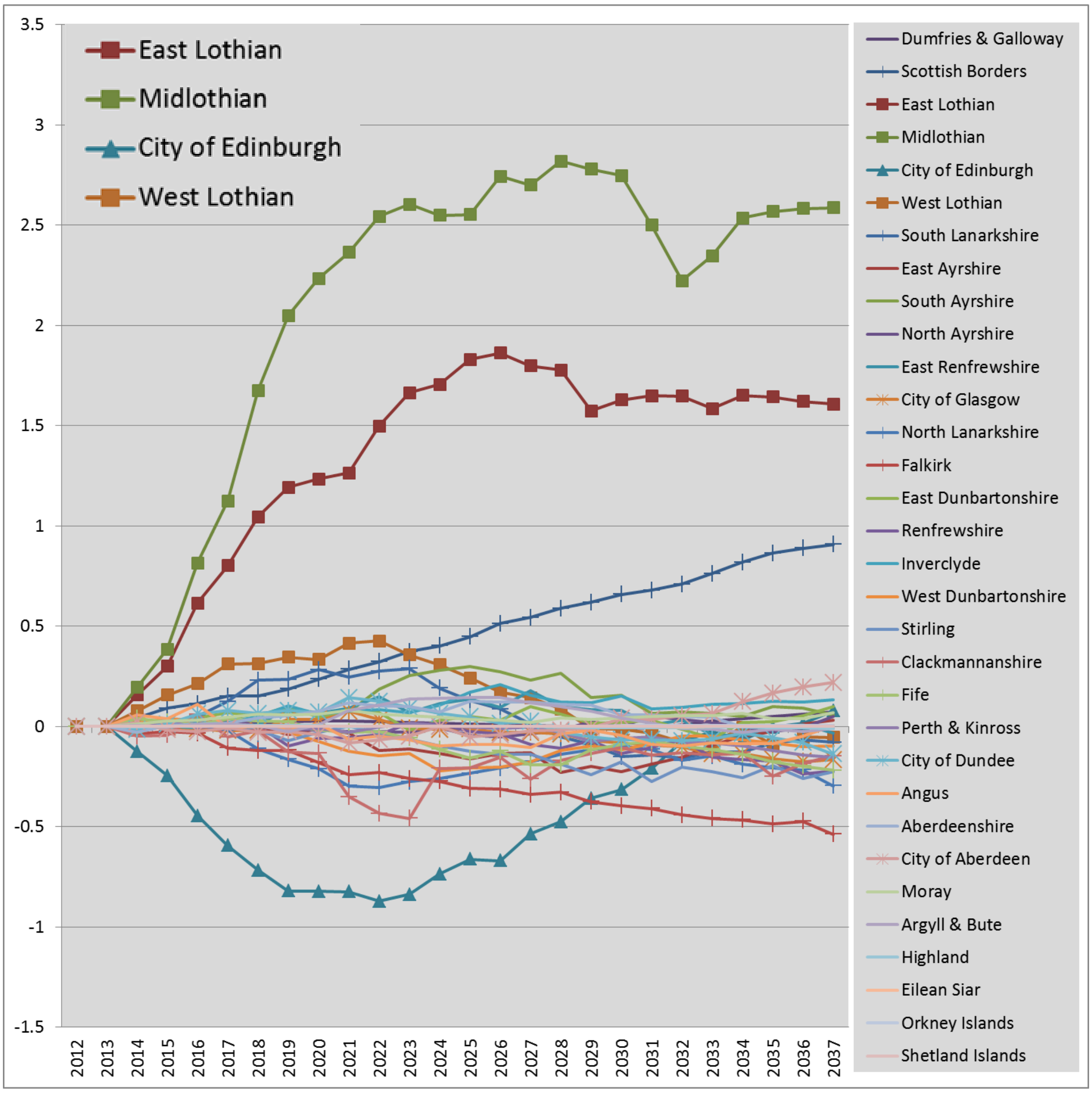



**Figure 19 Percentage change in households by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.3.3 The broad spatial pattern of relative increases in household numbers illustrated in Figure 19 broadly matches that previously shown in Figure 18 for residential floorspace development. However, the scale of the relative percentage increases in household numbers: e.g. Midlothian (2.5%), East Lothian (1.5%), Scottish Borders (1%) is substantially greater than the corresponding 0.9%, 0.2%, 0.15% increases in residential floorspace volumes. This implies greater densification of households within such LAs and as we will see below, corresponding increases in rents per square metre of residential floorspace.

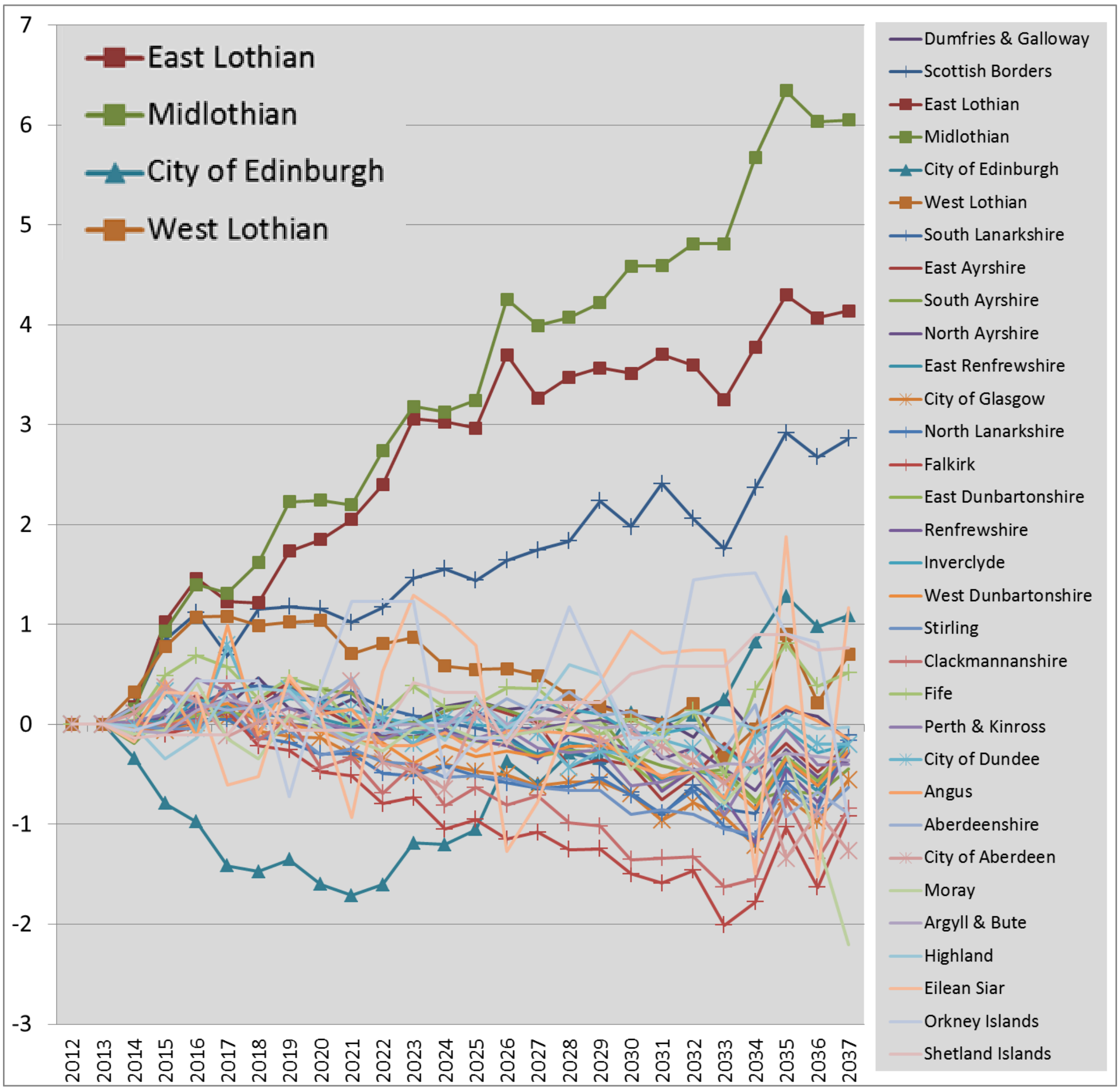



**Figure 20 Percentage change in residential floorspace rents by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

4.3.4 The spatial and temporal patterns of relative changes in rents per square metre of residential floorspace, illustrated in Figure 20, match broadly to the underlying demand pattern of relative change in the number of households that is illustrated above in Figure 19. **This rental pattern is what would be expected from a model of households competing to locate in the floorspace**. The scale of the relative percentage increases in rents: e.g. Midlothian (6%), East Lothian (4%), Scottish Borders (3%) is substantially greater than the corresponding 2.5%, 1.5%, 1% increases in household numbers. However, the rental values exhibit considerable short-term fluctuations which would appear to be due more to noise within the system than to real world influences and so **it would be helpful to damp down these short-term rent fluctuations**.

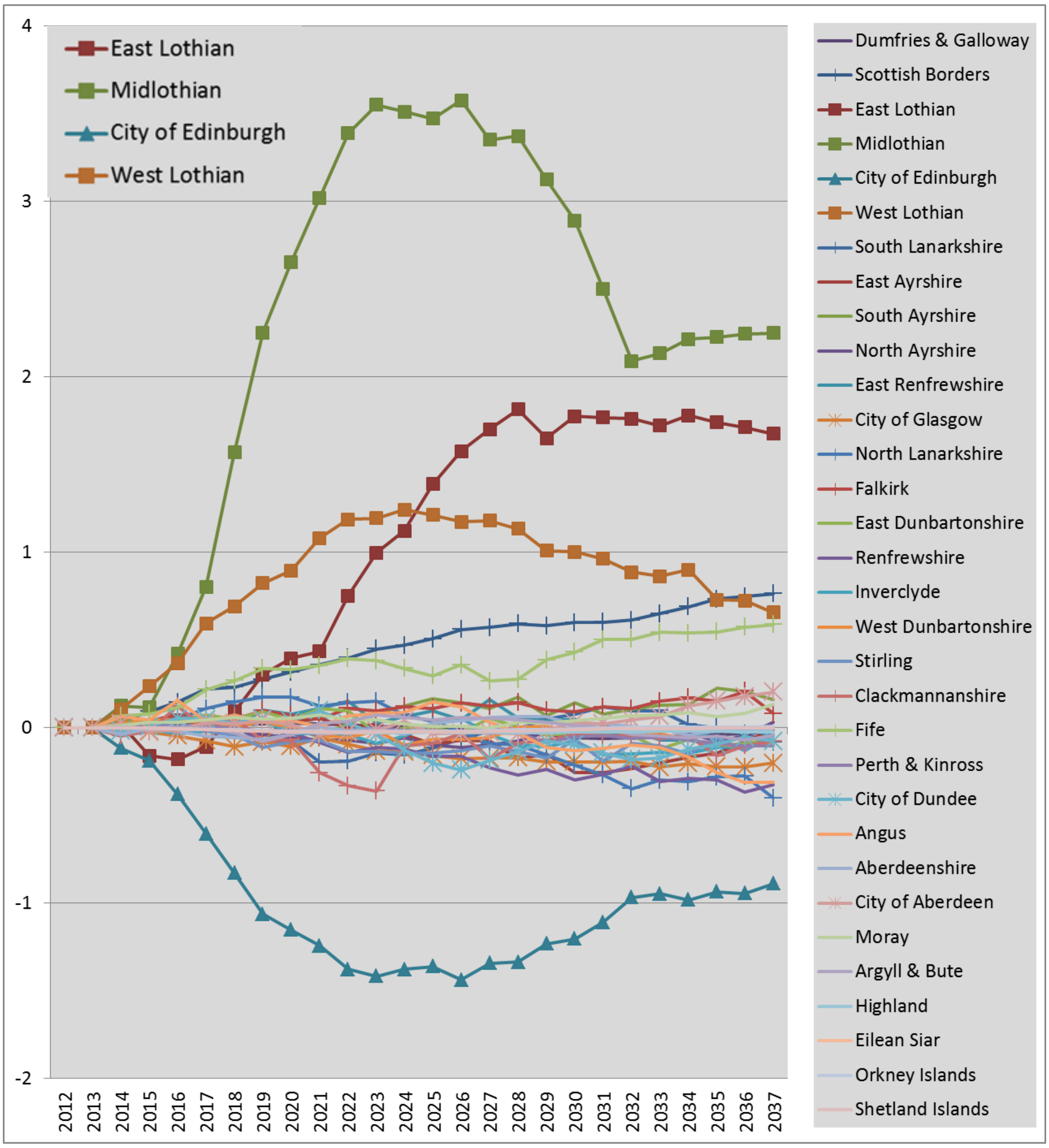



**Figure 21 Percentage change in population by local authority 2012-2037, Sensitivity Test 2 minus the ref. case (HU-BQ)**

**4.3.5** The broad spatial pattern of relative increases in population numbers illustrated in Figure 21 matches that previously shown in Figure 19 for household numbers for many LAs (e.g. Midlothian, East Lothian, Scottish Borders and Edinburgh). However, the growth pattern of population in West Lothian, Falkirk and Fife for example is not matched by the corresponding trend in household numbers. **It would be helpful to validate the realism of the mechanisms in the model that have generated these differences in trends.**

# 5 Sensitivity Test 3 (IQ): Commercial and Residential Planning Permission Changes

## 5.1 Introduction to the sensitivity test

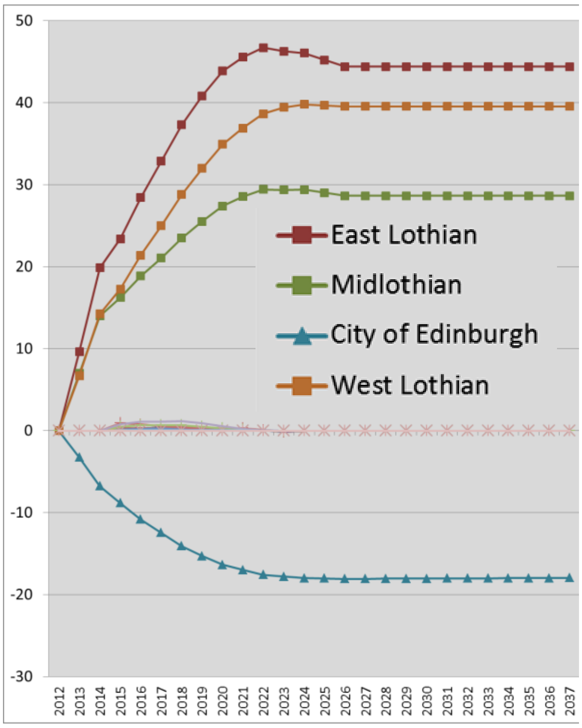
5.1.1 In sensitivity test 3 (**IQ**) which builds on test 2, the residential planning permission is changed in addition to the changes in commercial planning permissions such that all (100%) of both the permissible commercial and the residential development land added during the period within the City of Edinburgh zones has been transferred instead out pro-rata to East Lothian, West Lothian and Midlothian zones in all future years. The same implementation approach for the residential land was adopted as that previously described for sensitivity test 2 above in Section 4.

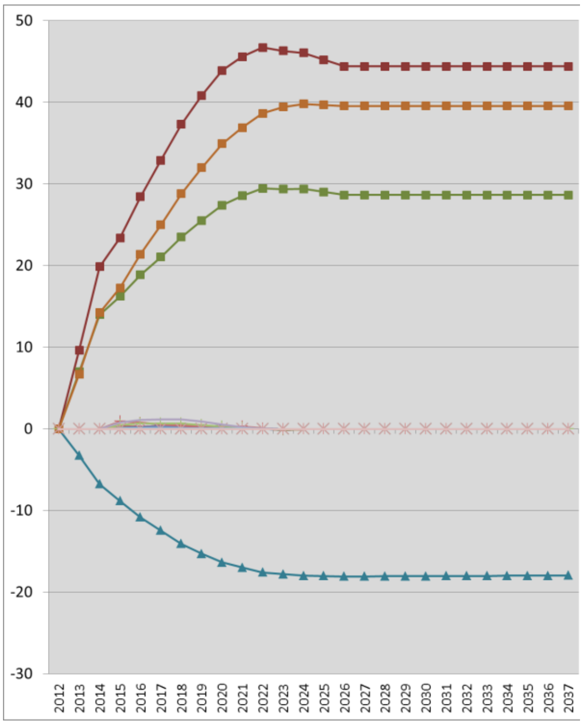
5.1.2 The order of presentation of the sensitivity test 3 results, first the employment related and then the residential population related results, is the same as that adopted above in Section 4. However, in the figures below to aid comparisons we generally present both the chart for test 3 on the left and the reference chart for test 2 on the right, which is adjusted where helpful to present the same common axis scales for both tests.

## 5.2 Employment related results

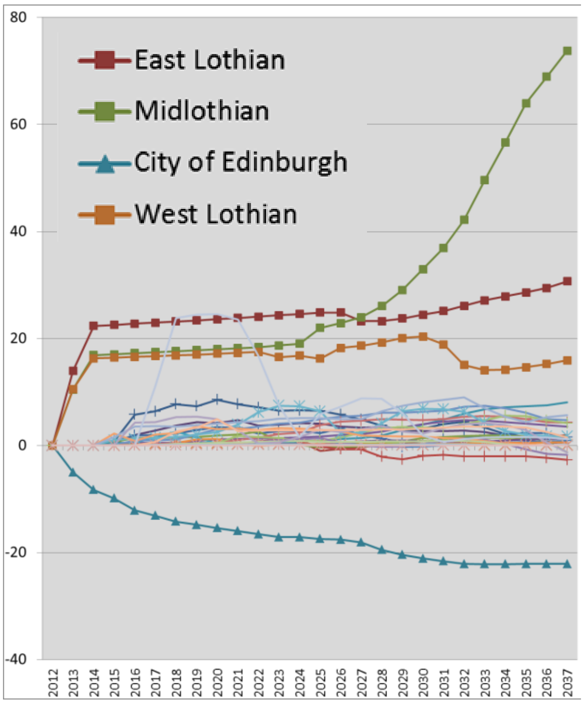
5.2.1 The first step in this review is to confirm the success of the implementation of the sensitivity test 3 in the form in which it had been specified.

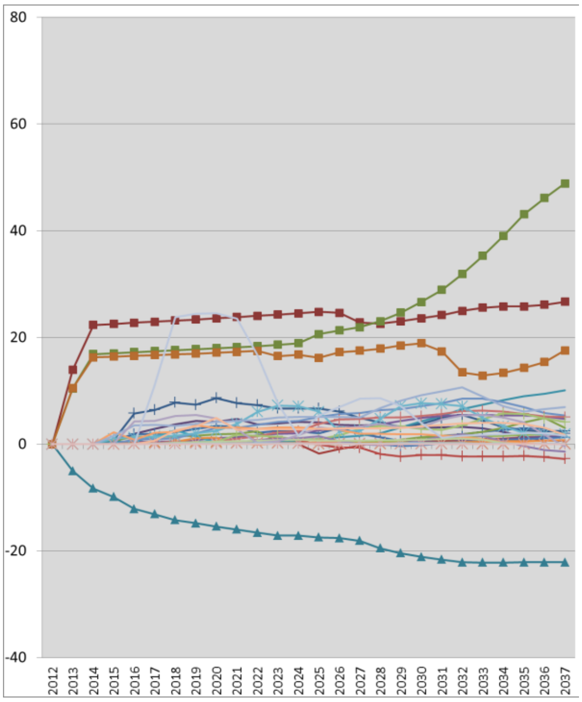
Retail



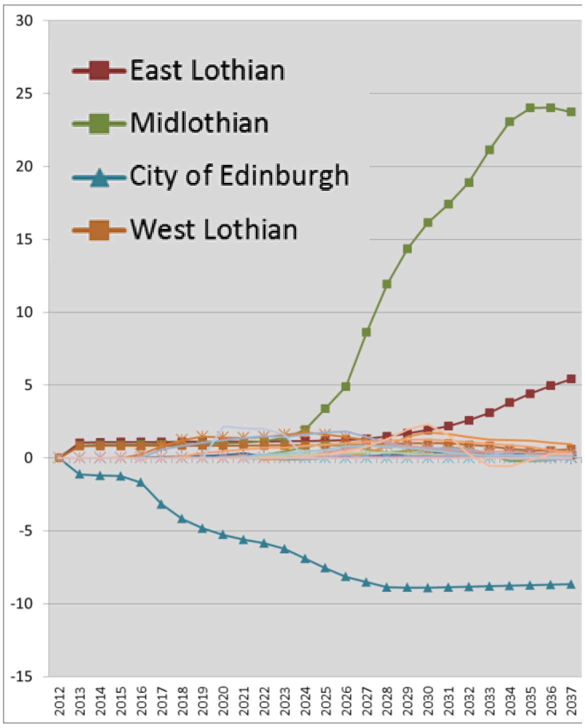



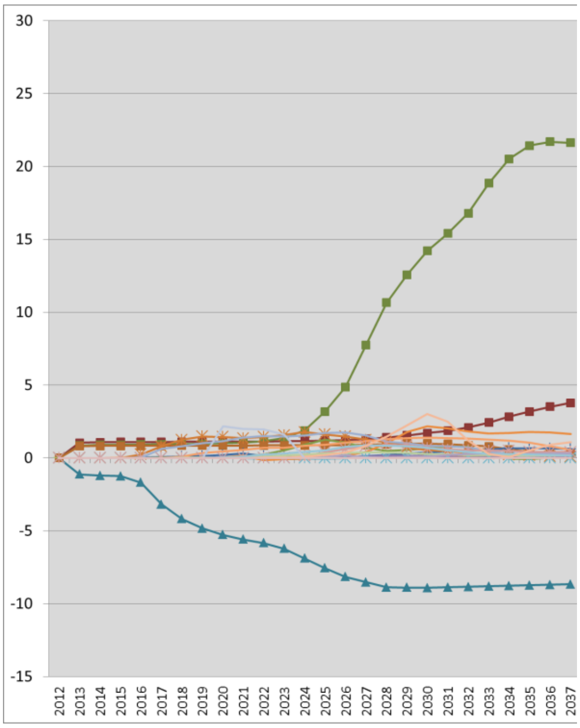
Office




Industrial



Hotel

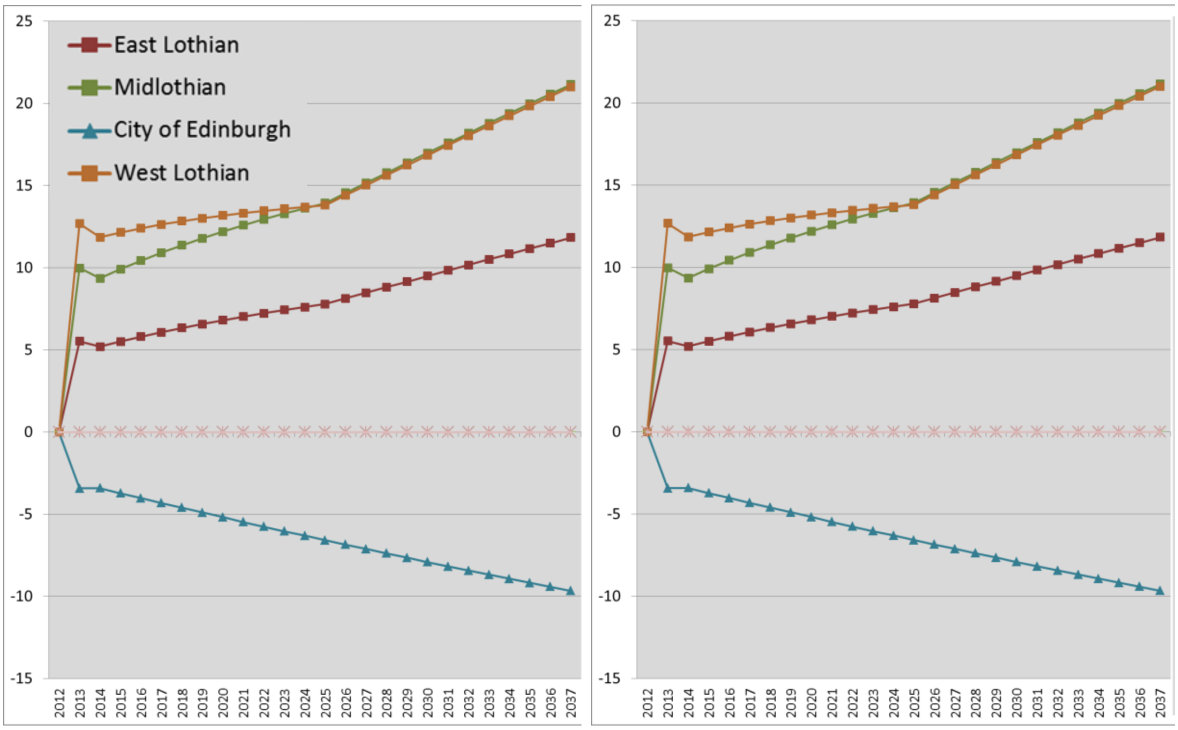



**Figure 22 Percentage change in commercial floorspace volumes by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.2.2 The annual percentage increases in **commercial floorspace volume** in the sensitivity tests 3 and 2, relative to the reference case volume, are presented in Figure 22 in turn for retail, office, industrial and hotel floorspace types for the period 2012 to 2037. For retail floorspace there is generally a miniscule difference (<0.01%) between the results from the two sensitivity tests, while for hotel floorspace both tests give exactly identical results throughout. In contrast for office floorspace both East (31% vs 27%) and Midlothian (73% vs 49%) have somewhat greater gains by 2037 in sensitivity test 3 than in test 2, relative to the reference case, with some increased gains also exhibited in these two LAs for industrial floorspace[13]. For the City of Edinburgh for each type of floorspace the relative reductions appear very similar across the two tests.

[13] Response from DSC: *The different response of retail floorspace as compared to office and industrial floorspaces is due to the relative supply of permissible development (of each land use) that is input in the planning policy inputs.*
*The supply of retail permissible development is all brought forward and developed within Test BQ and Test IQ. There are no significant quantities of un-used permissible development at the end of the forecast period.*
*In contrast the supply of office and industrial permissible development exceeds the demand and not all the inputs are modelled as developed by 2037.*

5.2.3 It is not obvious in the real world, why in sensitivity test 3 the addition of changes to residential planning permissions to the commercial floorspace permission changes originally in sensitivity test 2, should lead to significant local changes in floorspace construction in offices and industrial but not in retail. **It might be expected that retail floorspace should be the floorspace type most likely to respond by relocating to serve the redistributed households. The mechanisms in the model should be re-examined to consider this response**.[14]

5.2.4 The next step is to examine how these commercial floorspace changes impact in turn on the LA patterns of employment numbers.

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*The availability of undeveloped permissible development allows additional floorspace to be brought forward and developed in parts of Midlothian, East Lothian and West Lothian. In contrast for retail there is no un-used permissible development available to respond to the changing residential distribution in the way that is suggested.*

**Auditor response:** See comments in next footnote.

[14] **Auditor response:** The explanation above regarding the rapid exhaustion of local retail permissions, clarifies the operation of the mechanism that is queried here.

The speed and completeness of this exhaustion mechanism merits further consideration as to its plausibility.

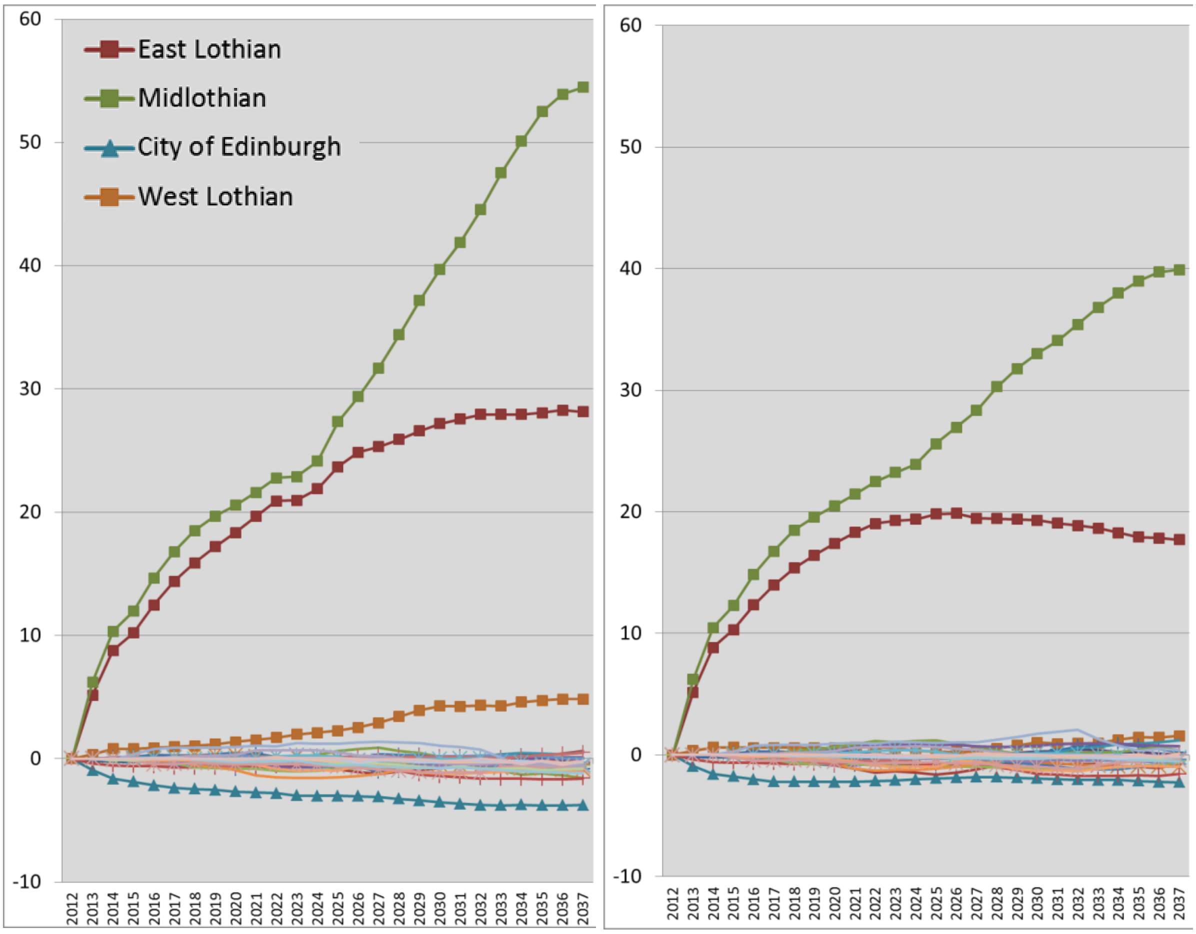



**Figure 23 Percentage change in employment by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.2.5 The annual percentage increases in **employment numbers,** aggregating all employment types together, in the sensitivity tests 3 and 2 relative to the reference case volume are presented in Figure 23 for the period 2012 to 2037. Sensitivity test 3 compared to test 2 exhibits increased percentage increases relative to the reference case for each of East Lothian (28% vs 18%), Midlothian (54% vs 40%) and West Lothian (5% vs 1%). There is also a greater relative decrease of -4% vs -2% for the City of Edinburgh. These employment changes are broadly what would be expected in response to the changes in floorspace volumes indicated above in Figure 22.

5.2.6 In sensitivity test 3 the ability of employment to relocate to fill the changed commercial floorspace locations appears to be amplified in response to the residential population having similar flexibility in relocation. This model response seems quite plausible.

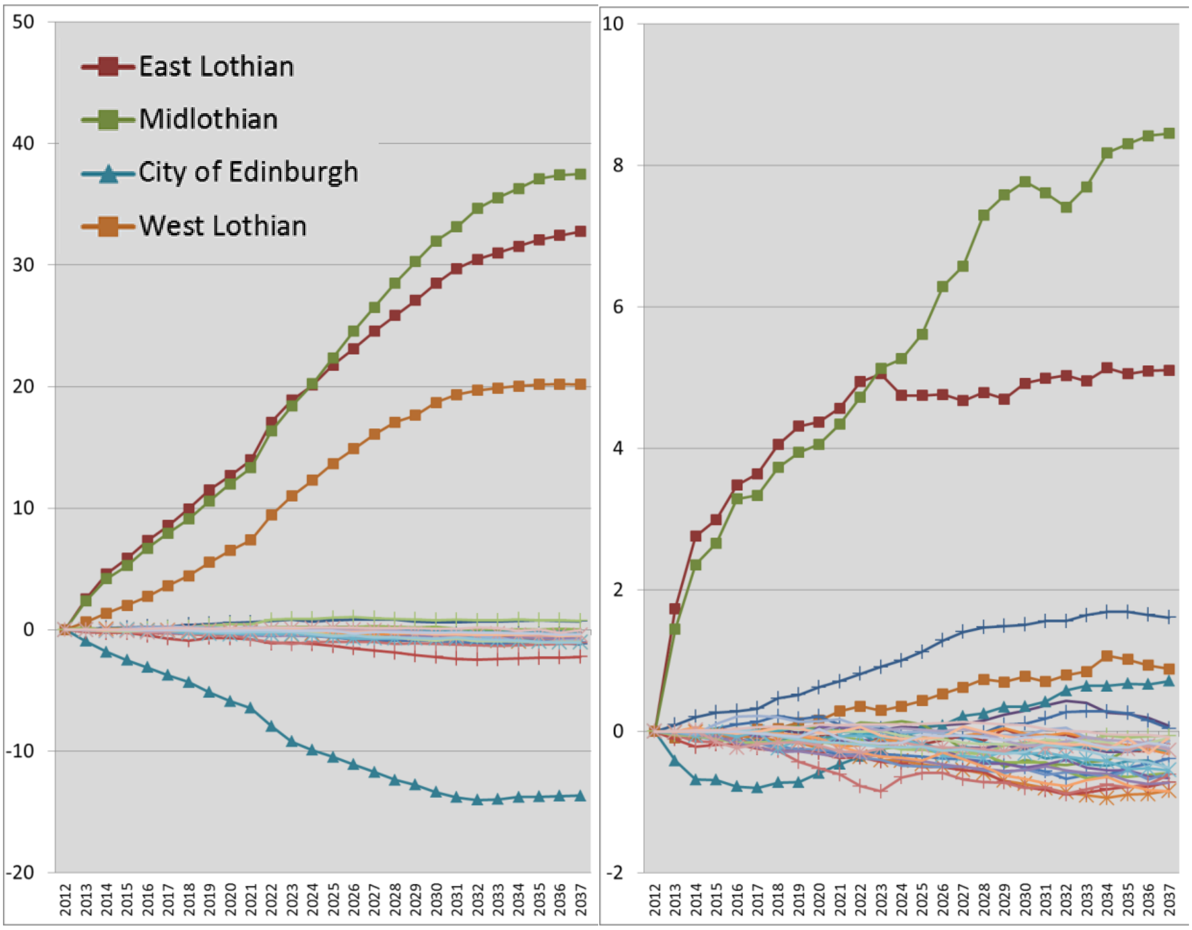
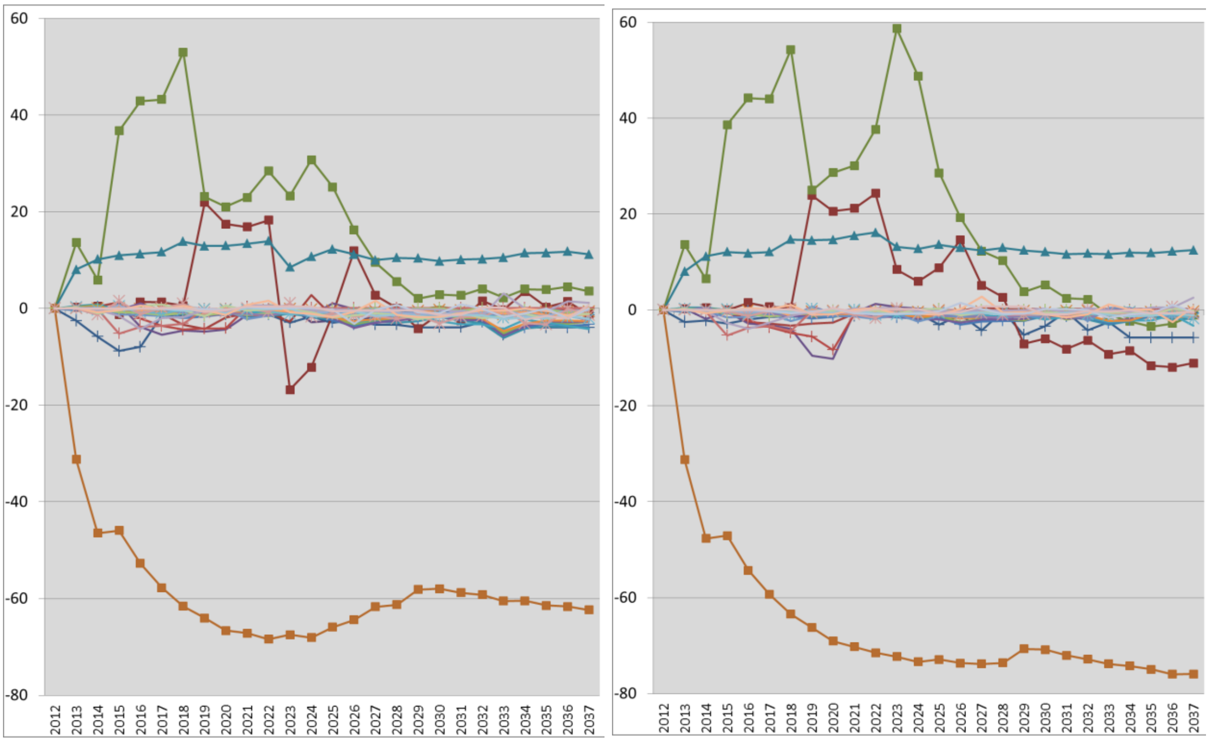



**Figure 24 Percentage change in resident workers by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

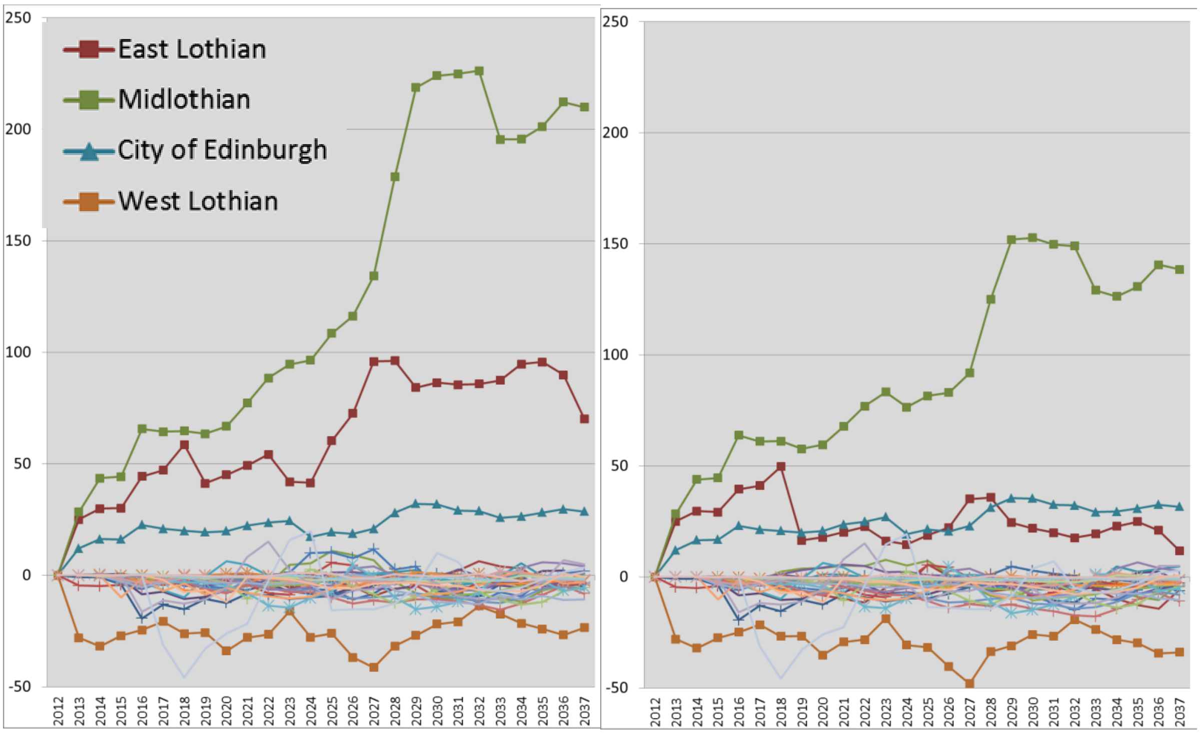
5.2.7 The annual percentage increases in **resident workers** in the sensitivity test 3 and 2 relative to the reference case volume are presented in Figure 24 for the period 2012 to 2037. Because of the modified pattern of residential planning permissions, there are some major resulting variations in the percentage changes from the reference case for sensitivity test 3 compared to for test 2. The Lothian LAs in sensitivity test 3 increase by between 20% and 38% as opposed to between 1 % and 8% in sensitivity test 2. Likewise in sensitivity test 3 the -14% reduction in the number of resident workers in the City of Edinburgh reverses the 0.7% increase by 2037 of sensitivity test 2.

5.2.8 In sensitivity test 3 there are small increases of 0.7% in Scottish Borders and Fife. In most other LAs there are minor fluctuations over the years leading generally to small declines by 2037, with the greatest decline of -2.2% being in Falkirk.

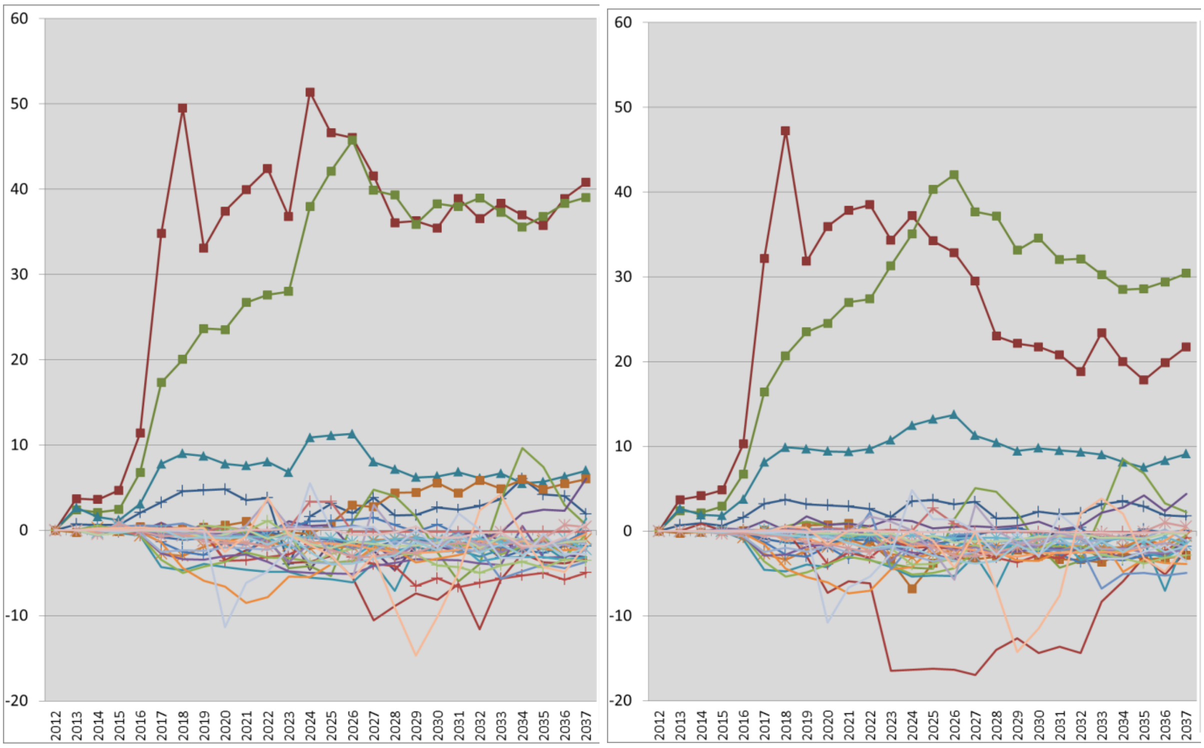
## Retail



## Office



Industrial



Hotel

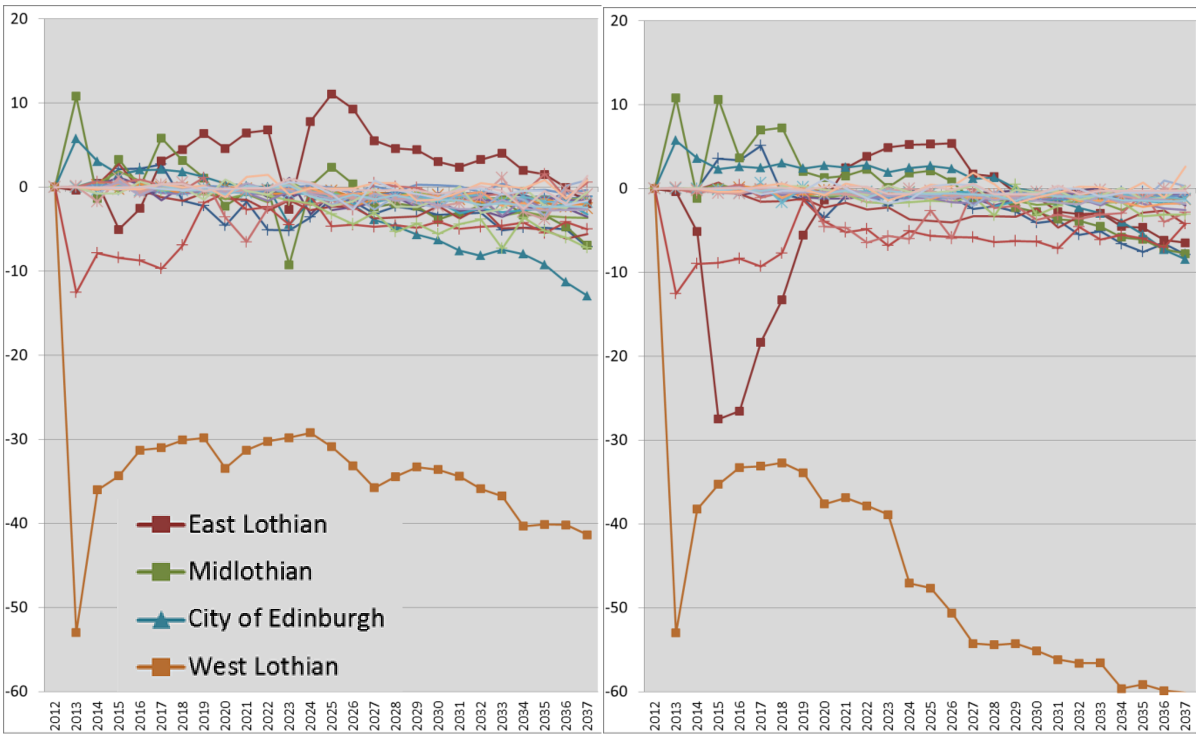



**Figure 25 Percentage change in commercial floorspace rents by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.2.9 The annual percentage increases in **commercial floorspace rents** in the sensitivity tests 3 and 2 relative to the reference case volume are presented in Figure 25 for retail, office, industrial and hotel floorspace types for the period 2012 to 2037. There are broad similarities in the rent change trends over time between both sensitivity tests, though those for sensitivity test 3 tend to be slightly less pronounced over time for retail and hotel floorspace but more pronounced for office and industrial.

5.2.10 The unexpected systematic pattern of relative increases in floorspace rents in East and Midlothian, in response to the relative increases in floorspace volumes there, that was noted for sensitivity test 2 continues to occur for sensitivity test 3.

## 5.3 Population related results

5.3.1 While the commercial planning permissions were relocated for sensitivity tests 2 and 3, those for residential were changed only within sensitivity test 3, so its implications are examined next for the activities: population, households, residential floorspace volumes and rents.

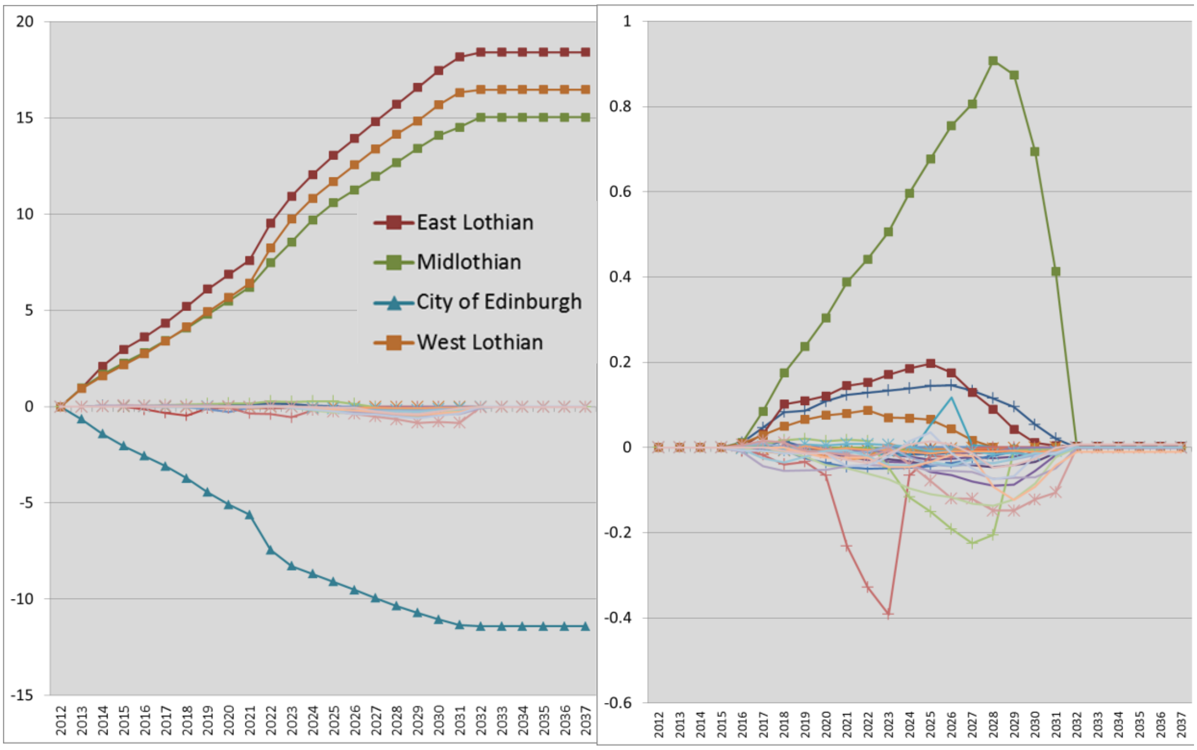



**Figure 26 Percentage change in residential floorspace by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.3.2 The annual percentage increases in **residential floorspace volume** in the sensitivity tests 3 and 2 relative to the reference case volume are presented in Figure 26 for the period 2012 to 2037. As expected, sensitivity test 3 shows major relative increases of 15% to 18% in the Lothians and a decrease of -11% in the City of Edinburgh, in contrast to the changes of less than 1% found in sensitivity test 2. **This suggests that both tests have been implemented correctly.**

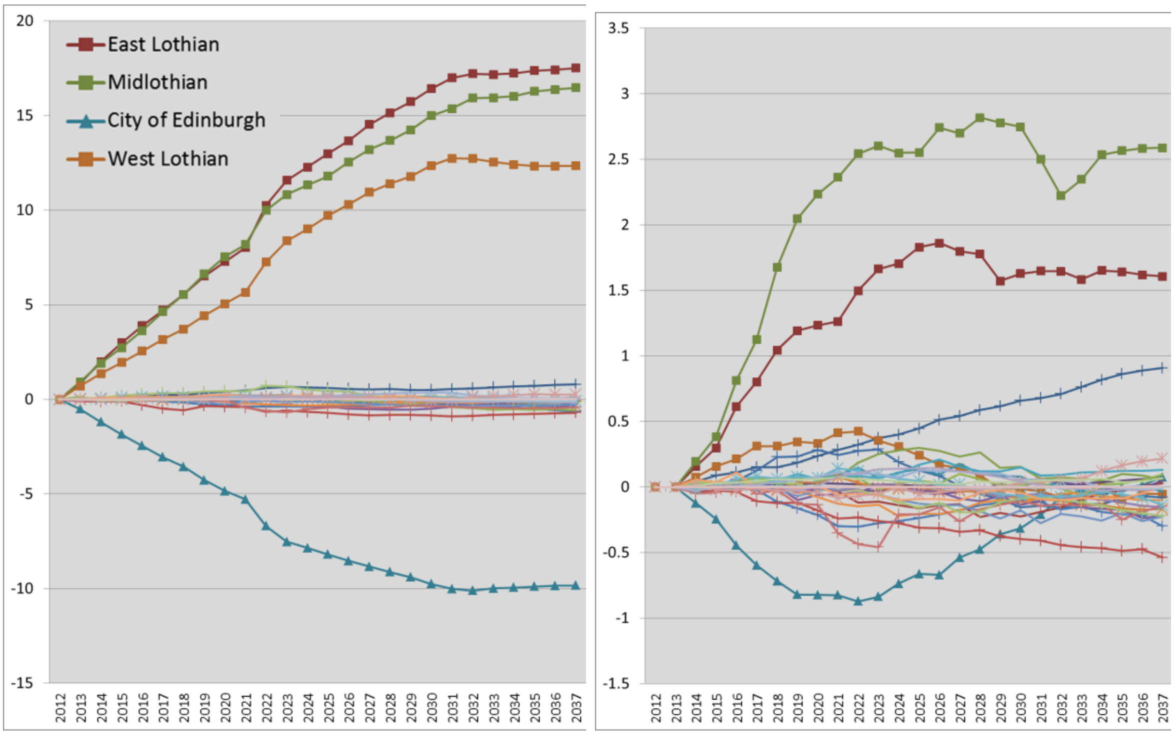



**Figure 27 Percentage change in households by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.3.3 For sensitivity test 3 the trends of relative increases in household numbers illustrated in Figure 27 match closely but often at a slightly reduced scale to those previously shown in Figure 26 for residential floorspace development. More specifically, the household % growth in Midlothian is a little higher than the floorspace growth, that in West Lothian is 4% points lower than the floorspace growth and the household decrease in Edinburgh is a -10% compared to -11% for floorspace. In contrast to the major differences in household numbers between the two sensitivity tests for the Lothians and Edinburgh, there are only small changes in household numbers between them in the other LAs. **These estimated relationships all appear to be plausible.**

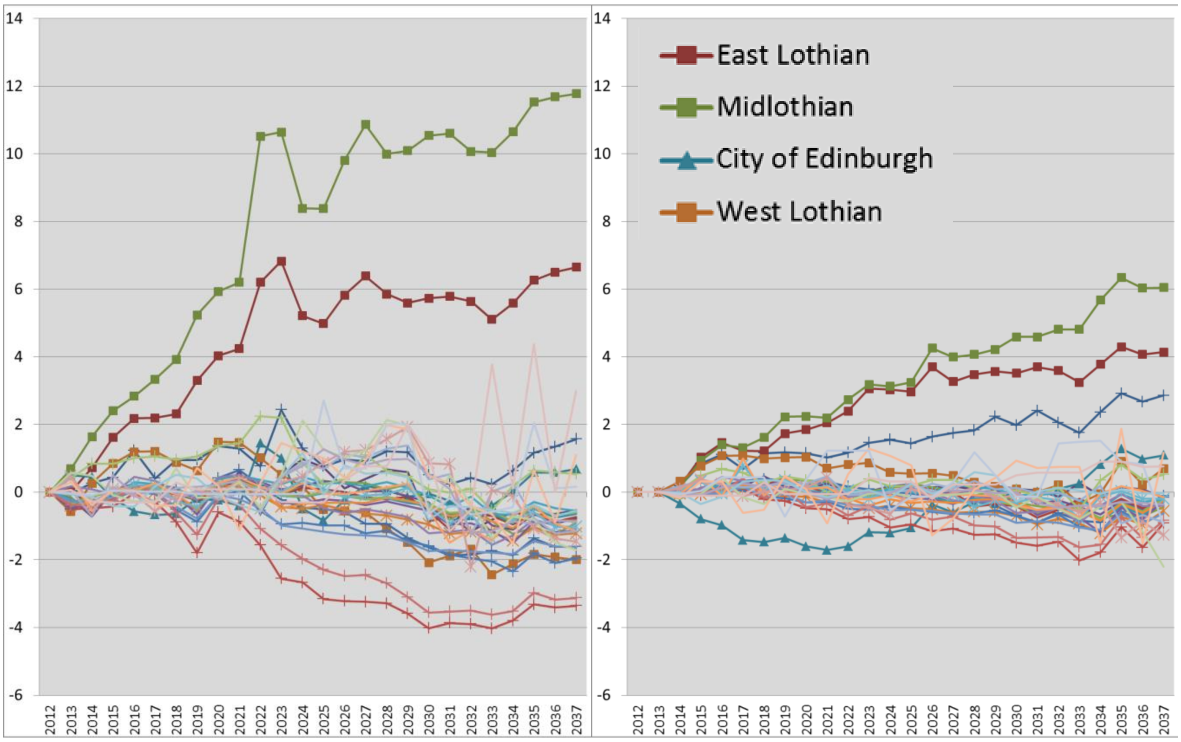



**Figure 28 Percentage change in residential floorspace rents by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.3.4 The spatial and temporal patterns of relative changes in rents per square metre of residential floorspace are illustrated in Figure 28 for sensitivity tests 3 and 2. The greatest rent % increase is for Midlothian, which is consistent with this being the LA that has its % increase in household numbers outstripping that for residential floorspace volume. Analogously, there is little rent increase in West Lothian which is consistent with household % gains being less than the increase there in residential floorspace. **Other than the considerable short-term fluctuations in values, this residential rental pattern is what would be expected from a model of households competing to locate in the floorspace**.

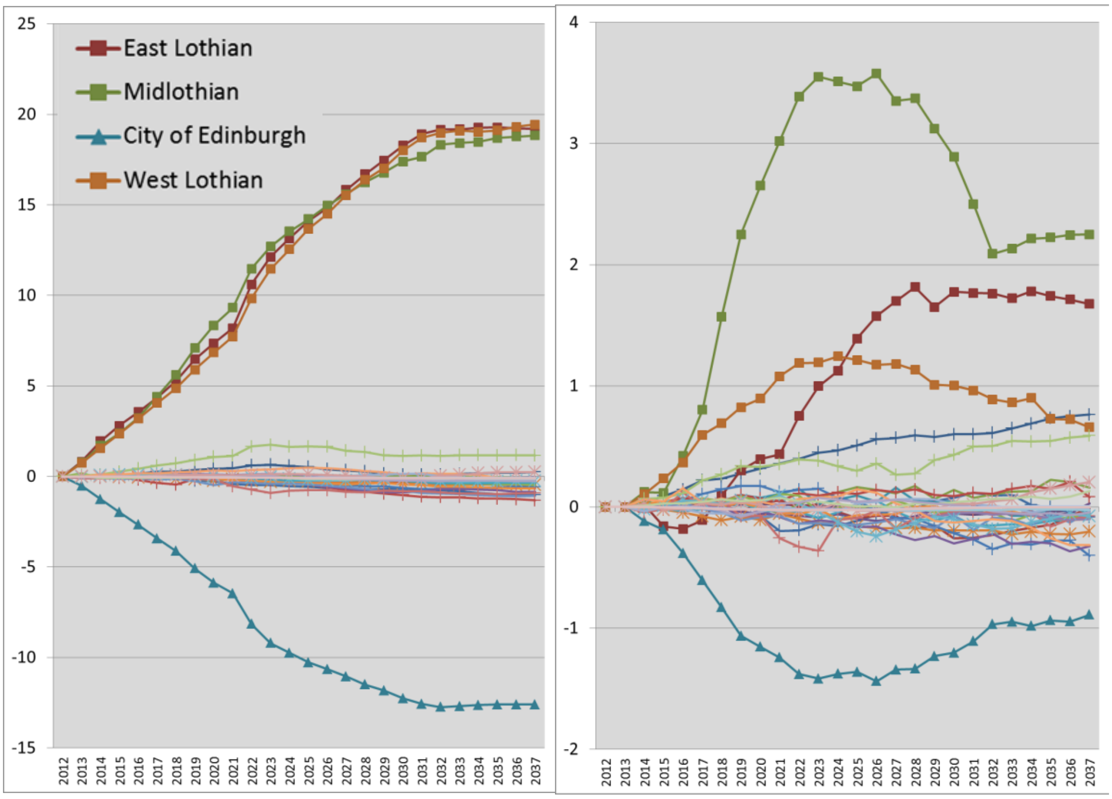



**Figure 29 Percentage change in population by local authority 2012-2037, Sensitivity Tests 3 (left, IQ-BQ) and 2 (right, HU-BQ) minus the ref. case**

5.3.5 For sensitivity tests 3 the broad spatial pattern of relative increases in population numbers illustrated in Figure 29 is more uniform between the Lothian LAs than that previously shown in Figure 27 for household numbers. Fife gains 1% in population by 2037 despite no increase in household numbers. Falkirk loses -1.3% in population in tandem with a -0.7% decrease in households. These relationships suggest that there are significant differential changes in numbers of persons per household between LAs.

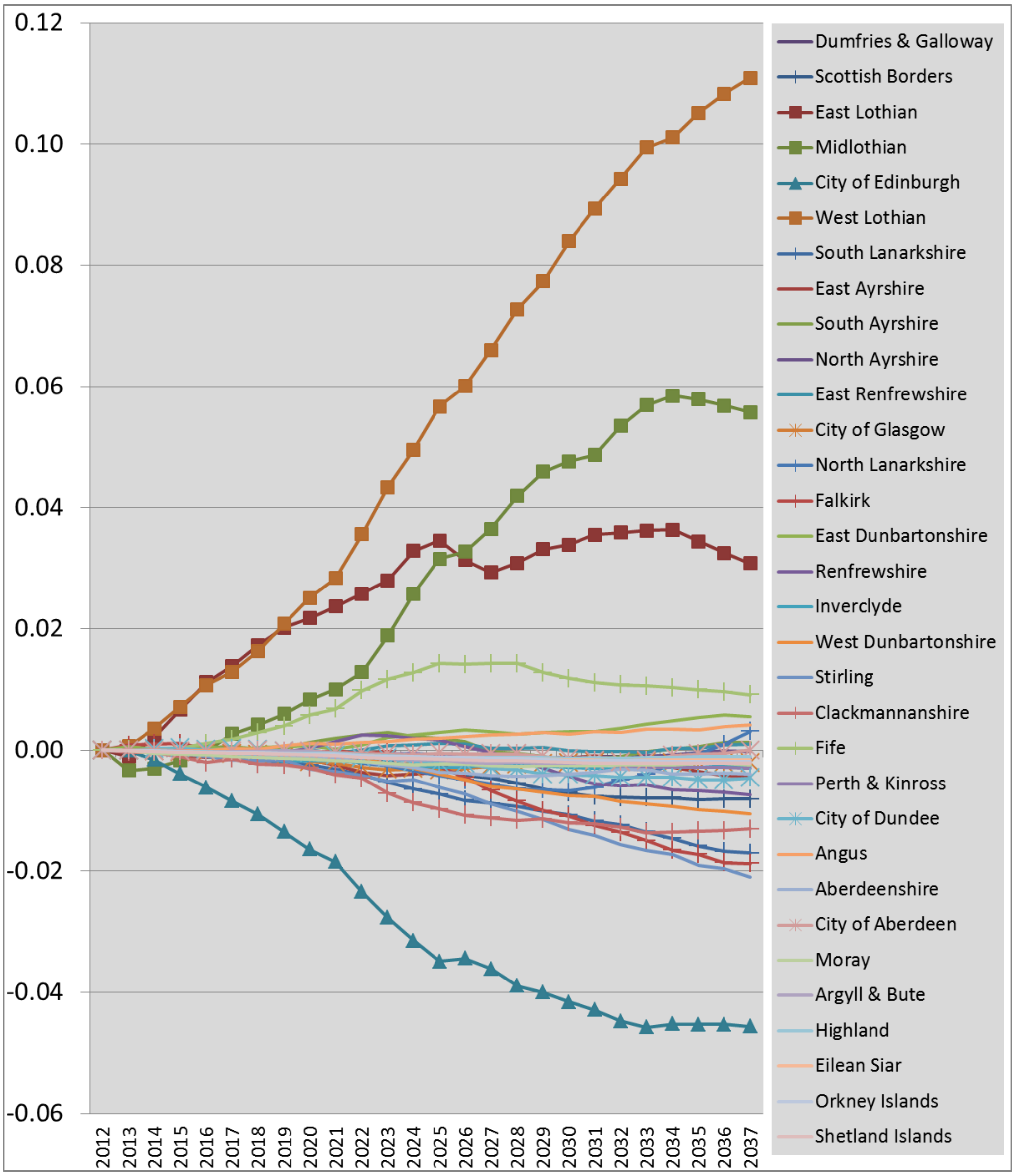



**Figure 30 Absolute change in household size by local authority 2012-2037, Sensitivity Test 3 minus the ref. case (IQ-BQ)**

5.3.6 This is confirmed in Figure 30 which presents the change in household size in sensitivity 3 from the reference case. It illustrates the Lothian LAs all increase in household size, while the City of Edinburgh declines. **It would be helpful to validate the realism of the mechanisms in the model that have generated these differences in household size trends.**

# 6 Summary and Assessment of Findings from Runs

## 6.1 The reference case run (BQ)

6.1.1 The first task in this audit was to ensure that no obvious deterioration in the plausibility and consistency of the model results has arisen due to the changes that were introduced to TELMoS12 subsequent to the previous audit of TELMoS07. Happily, no major deteriorations in performance have been found.

6.1.2 The plausibility at the local authority level of the forecast trend results for the reference case BQ differs considerably between sets of activities. The main findings from the examination at the local authority level of the **reference case trends** in the various activities from 2012 to 2037 are summarised as follows.

a) Both the **population** and the **household** growth trends appear individually to be plausible at the LA level.
b) The **average household size** reduces by 11% nationally through to 2037, reducing gradually in most LAs. However there were some odd cases such as a 3% increase in Clackmannanshire and a 32% decline in Falkirk. It would be helpful to validate the realism of the mechanisms in the model that have generated these local differences in household size trends.
c) The temporal trends in the **resident worker numbers** vary greatly over time between LAs. It is important to understand which mechanisms in the model generate such spatial and temporal variations and then to confirm that these variations have a rational foundation, rather than being erratic random effects that might add instability to the resulting forecasts from the model. The significant absolute short term changes from 2011 to 2012 in resident worker numbers for many LAs merit further checking and explanation, particularly the large losses forecast in the City of Edinburgh (-6%), East Lothian (-8%) and Midlothian (-7%).
d) There are some sharp fluctuations over the first few years in **employment** totals by LA, with increasing divergences among LAs between growth and decline trends until the mid-2020s. The major employment decline of -18% in Clackmannanshire in the period from 2012 to 2037 merits further checking and explanation, particularly because this is the LA with the highest population growth rate of +36%.
e) The growth rates of **residential floorspace** volumes are smooth over time but very greatly between LAs, which would be reasonable provided that this is a function of local planning permission availability and of local demand differences. In most LAs there is no growth after 2031, presumably because no land as yet has been allocated that far ahead for new housing.
f) The trends over time in **residential rents** (other perhaps than the significant temporary upward blip in 2012) appear plausible.as does the rent level differentiation between LAs.
g) The growth in **retail floorspace volumes** varies from 0% in various LAs up to 138% in Clackmannanshire and 204% in Argyll & Bute. In most local authorities there is no growth after 2026, presumably because no land as yet has been allocated that far ahead for new retail developments.
h) The **retail rents** per square metre of floorspace are highest in the more remote areas and are much lower in the cities of Glasgow, Aberdeen and Edinburgh. . In the early years, particularly in 2012, the retail rents fluctuate significantly and then they tend to stabilise in the longer term back to a level similar to their initial value in 2011. This odd spatial pattern of retail rents and of early rapid

fluctuations is not what would be expected and so merits further investigation and validation. Similar issues arise with the patterns of **office, industrial and hotel rents**.

i) For many LAs the growth in **office floorspace volumes** appears to be concentrated just in the first 1 or 2 years after 2012 and subsequently the office floorspace volume declines gently at a constant rate thereafter. This angular trend pattern, as well as the major fluctuations in volumes between 2011 and 2014 merit further checking and validation. Similar issues arise with the pattern of **industrial floorspace volume** growth.

j) The growth in **hotel floorspace volumes** varies between a low of 8% up to 67% to 91% for the Lothian LAs and Clackmannanshire. Other LAs have growth rates in hotel volumes of less than 48%. Following a similar pattern to that for retail floorspace, in most local authorities there is relatively slow growth in hotel floorspace volume after 2026.

## 6.2 THE SENSITIVITY TESTS 2 (HU) AND 3 (IQ)

6.2.1 This Section summarises the main findings from the examination from 2012 to 2037 at the local authority level of the changes from the reference case in the **sensitivity tests 2 and 3** trends resulting from the relocation of the commercial planning permissions (plus the residential permissions in test 3) from Edinburgh to the Lothian LAs.

a) Except for a few minor possible peculiarities, the pattern of the location and scale of the **commercial and residential floorspace volumes** suggest that the designs of the sensitivity tests 2 and 3 have been correctly implemented within the model structure.

b) It is not obvious in the real world, why in sensitivity test 3 the addition of changes to residential planning permissions to the commercial floorspace permission changes originally in sensitivity test 2, should lead to significant local changes in floorspace construction in offices and industrial but not in retail. It might be expected that **retail floorspace** should be the floorspace type most likely to respond by relocating to serve the redistributed households. The mechanisms in the model should be re-examined to consider this response.

c) The directions of the **employment** changes in sensitivity tests 2 and 3 are what would be expected in response to the forecast changes in floorspace volumes, though noting that the relative percentage changes in the City of Edinburgh and in West Lothian are small compared to the relative changes there for floorspace. The spatial pattern of change in **resident workers** by LA likewise is in line with expectations, being small in test 2 and considerably larger in test 3 in response to its changes in residential floorspace availability.

d) The pattern of **commercial floorspace rent** changes is often broadly similar in the two tests. It evolves as expected in Edinburgh where it increases in response to a relative reduction in floorspace supply and in West Lothian, which has reduced rent in response to increased supply. However, the unexpected systematic pattern of relative increases in floorspace rents in East and Midlothian, in response to the relative increases in floorspace volumes there, requires further analysis in order to confirm that the causal mechanisms within TELMoS are operating in the expected manner.

e) Within test 2, there is, as expected, relatively little change in the location of **new residential floorspace** but within the overall residential stock there are small increases in the number of **households** in the Lothians and reductions in Edinburgh. The corresponding increases and decreases in **population** are a little larger, due in part to changes in **household size** in these and other LAs. The realism of these household size changes needs to be validated.

f) Within test 3, there are major increases in **new residential floorspace** in the Lothians and decreases in Edinburgh and as expected the changes in the number of **households** there follow a very similar pattern but at a slightly reduced scale except for Midlothian. The pattern of change in **population** matches less closely to the spatial pattern of household change, again suggesting that resulting from the policy test there are significant systematic differential changes in numbers of persons per household between LAs, the realism of which needs to be validated.

g) The local changes in the **residential rental pattern** are broadly what would be expected from a model of households competing to locate in the available floorspace. However, these residential rental values exhibit considerable short-term fluctuations which would appear to be due more to noise within the system than to real world influences and so it would be helpful to damp them down somewhat.

## 6.3 RECOMMENDATIONS

6.3.1 The general conclusion is that most of the key responses of the model appear to match to the main *a priori* expectations listed above in Section 3. This suggests that TELMoS12 is functioning broadly as expected and that it provides plausible future trends at the LA level, the spatial scale at which the model results were analysed.

6.3.2 The two sensitivity tests were shown to be implemented in the form that had been specified and they proceeded in their forecasts of activity levels to generate major changes that were generally in the locations and with the broad magnitudes that had been expected.

6.3.3 Nevertheless as now summarised, there remain some potential issues where further checking and validation is needed in order to ascertain whether specific mechanisms or parameter values within the model may need to be adjusted in order to improve the realism of its forecasts.

6.3.4 Most aspects of the forecasting within the model of the linked components of population, of households and of residential rents and floorspace development have performed in a plausible fashion. The main associated query, as discussed above in paras 2.2.2 onwards, 4.3.5 and 5.3.5 onwards, relates to some of the local changes in household sizes that are forecast in the reference case and in the sensitivity tests.

**AR1**: Validate the realism of the mechanisms in the model that have generated the more extreme forecast local differences in household size trends and then adjust these mechanisms if necessary.

6.3.5 DSC have re-calibrated the migration model for TELMoS14 to address these issues.

6.3.6 Within the reference case, the temporal trends in the employment totals and the resident worker numbers vary greatly over time between LAs, including particularly significant absolute short term changes from 2011 to 2012. Moreover, employment declines by -18% in Clackmannanshire even though this is the LA with the highest population growth rate of +36%.

**AR2:** Understand which mechanisms in the model generate such spatial and temporal variations in the employment and resident worker numbers and then confirm that these variations have a rational foundation, rather than being erratic random effects that might add instability to the resulting forecasts from the model. Adjust the model mechanisms if necessary to damp down unrealistic volatility.

6.3.7 The 2011-12 discontinuity arose for historic reasons that have been resolved in TELMoS14. A wider exploration for Clackmannanshire of how the local employment decline mechanism aligns with the local forecast 36% growth in population would be instructive.

6.3.8 While within the reference case the retail and hotel floorspace growth trajectories appear plausible, in contrast for office and industrial floorspace for many LAs much of their growth is concentrated just in the first 1 or 2 years after 2012 and subsequently the floorspace volume declines gently at a constant rate thereafter.

**AR3:** Validate the realism of the mechanisms in the model that have generated these angular office and industrial floorspace growth patterns and then adjust them if necessary.

6.3.9 Within the reference case the commercial floorspace rents for each floorspace type tend often to be high in the more remote areas and in the Islands but to be much lower in the cities of Glasgow, Aberdeen and Edinburgh.

**AR4:** Validate the realism of this forecast pattern of differential commercial rent levels and of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

6.3.10 Subsequent adjustments to TELMoS14 appear to have made significant progress in resolving the recommendations AR3 and AR4 above.

6.3.11 Within sensitivity test 3 the added changes to residential planning permissions, in addition to the commercial floorspace permission changes originally in sensitivity test 2, lead to significant local forecast changes in floorspace construction in offices and industrial but not in retail.

> **AR5:** Validate the realism of this forecast pattern of no retail response to significant changes in residential patterns and the soundness of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

6.3.12 The further discussion and information provided by DSC explains that this lack of change in retail is due to the absence of un-used permissible development for retail by the later years. The speed and completeness of this exhaustion mechanism may merit further consideration as to its plausibility.

6.3.13 In both sensitivity tests there is an unexpected systematic pattern of relative increases in commercial floorspace rents in East and Midlothian, in response to the relative increases in floorspace volumes there, whereas in Edinburgh and West Lothian the responses are that rent changes are in the reverse direction from floorspace changes, i.e. in line with expectations.

> **AR6:** Validate the realism of this forecast pattern of mixed rent response and of the underlying mechanisms in the model that have generated it and then adjust them if necessary.

6.3.14 The further discussion and information provided by DSC explains why this mixed rent response pattern has occurred, and has indicated that the future introduction of an employment distance deterrence function, in place of the closed travel to work areas, would be expected to alleviate these issues.

6.3.15 In both sensitivity tests the forecast residential rental changes exhibit considerable short-term fluctuations that would appear to be due more to noise within the system than to real world influences.

> **AR7:** Investigate how to introduce a mechanism to the model that would damp down somewhat the short term fluctuations in residential rents.

6.3.16 There are also a variety of other aspects raised, as summarised above in the Sections 6.1 and 6.2, regarding the model and its results. These also require further scrutiny to ensure that the assumptions made about them are valid and that they do not point to further lurking issues within the model.

6.3.17 Significant progress appears to have been achieved in progressing most of the recommended tasks above. A future audit of their combined impacts within TELMoS14 would provide confirmation of the degree of success of these enhancements

# 7 APPENDIX 1: REVISIONS AND CORRECTIONS

7.1.1 This Section lists topics where suggestions are made for improvements or corrections to the analysis of the outputs from the model.

7.1.2 In file “ITabs Analysis HU-BQ.xlsm” a number of corrections have been identified, which generally also occur in file “ITabs Analysis IQ-BQ.xlsm”.

a) The values in rows 714 (zone 709: City of Edinburgh) to 717 (Zone 712: City of Aberdeen) appear strange for many sheets.
b) The formulae in rows 841 (Clackmannanshire) to 844 (rest of Fife) should refer to the next column in order to be consistent with the year specified in row 831 and the values in rows 832 to 839 for many sheets.
c) The names of the sheets < RENT ABS test-ref> and < RENT % test-ref> were changed to < RENT3 ABS test-ref> and < RENT3 % test-ref> so as to be consistent with the overall naming convention.
d) In sheets <POPNTT % test-ref>, <HHLDTT % test-ref>, <RWKRTT % test-ref>, <FLSP1 % test-ref> to <FLSP7 % test-ref> at least, the formulae from row 722 onwards all referred to sheets "EMPLTT" rather than to "POPNTT", "HHLDTT", "RWKRTT", "FLSP1_", etc.
e) In <RENT1 % test-ref>, <RENT2 % test-ref> the formulae were corrected to refer to the current rather than previous row.

# 8 INTRODUCTION TO PART B

## 8.1 OVERVIEW

8.1.1 Part B, reports on the audit Task 3 'Performance of the Interface'. It documents the analysis of the current interfaces between TELMoS12 and its associated transport model TMfS12. It first examines the functioning of the car ownership mechanism in TELMoS as this has a major influence on car travel demand patterns in the transport models. It then examines the formulation and segmentation of the interfaces and examines the effectiveness of their operation in practice through analysing inputs and outputs from relevant policy test runs.

8.1.2 It includes both directions of the interface:

- the annual zonal planning data (population, households and employment) that is provided by TELMoS for input to the transport model TMfS;
- the matrices of transport costs that are provided by the transport model TMfS for input to TELMoS.

8.1.3 The analysis of the O-D matrices of light and of other goods vehicle produced by TELMoS for assignment within the transport models has not been within the scope of this audit task.

8.1.4 The main findings from the analysis are summarised in Section 11, together with a set of recommendations for further checking, validation and improvements to the interfaces between TELMoS and its associated transport model.

## 8.2 SCOPE OF TASK

8.2.1 The interface between TELMoS and TMfS was not included within the aspects covered in the Audit of TMfS12 by AECOM in 2014, so that there is no duplication of effort across the set of model audit tasks in LATIS. Nor were the interfaces audited in detail in the TELMoS07 Audit, though a number of potential issues related to interfaces became apparent during this audit and so were recommended for future investigation.

8.2.2 The specification of this audit of interfaces task was first outlined in in the TELMoS Auditor's Inception Report, Technical Note TN001 (final version issued 4th September 2014). Its Section 5 outlined our then understanding of the model interfaces and of the issues that might usefully be examined during the audit. The scope of this task was defined in its Section 6.4 as follows.

> "6.4.1 The effectiveness of the performance of the interfaces that connect between TELMoS and the transport models TMfS and CSTM is as important an element as the performance of these individual models themselves. Accordingly, it needs to be audited. There is already a specification by DSC in the MDP for Task 6 which outlines how improvements to consistency of the interfaces with other models could be achieved through a better matching across models when disaggregating from larger to smaller model zones. We understand that further technical notes on the interfaces will also be requested from DSC shortly. We

would include review of all these documents in line with other proposed enhancements as outlined in section 1.1 above.

6.4.2 There were a number of aspects relating to the interface that were raised previously in the audit of TELMoS07 but that had not progressed far since then, including:

- The benefits of greater harmonisation of the segmentation definitions between models in order to avoid unnecessary aggregation errors when transferring data between them.
- The benefits of consistency between the behavioural response rates / elasticities for mechanisms such as the home-work relationship that is common to both TELMoS and the transport models.
- Investigating the difference in the forecast results between running the full land use/transport cycle at a 1 or 2 year frequency as an alternative to the standard LATIS 5 year interval. Any such increase in run frequency has more significant impacts on the operation of TMfS than of TELMoS because of the much longer run times of the former than the latter, so this will need to be considered when devising any tests.
- Investigating where parking responses fit best within the modelling system.

6.4.3 We would comment further on these design aspects of the model, but focus mainly on the clarification and auditing of the data exchange between TELMoS and the transport models. This will involve exchanges in both directions:

- Conversion of Land Use information from TELMoS into Trip Ends for the Transport Model: We have received documentation of the Trip End Model, some implications of which have been outlined in Chapter 5.
- Conversion of transport costs into accessibility information within TELMoS: We have yet to receive documentation or other evidence of this stage of the model process.

6.4.4 We would seek to obtain data extracts from TELMoS and the respective transport models which confirm:

- How changes in land use within the TELMoS model (e.g. population or employment) are transformed into trip ends within the transport models;
- How changes in transport connectivity or cost are reflected as accessibility inputs to TELMoS.

6.4.5 We would seek existing scenarios which are capable of illustrating these changes: carefully selected comparators are likely to be needed, though it seems likely that some suitable scenarios would be present in existing runs.

6.4.6 Making subsequent changes to the modelling system to address these issues would require model development resources for both TELMoS and TMfS/CSTM so as part of our audit of the interfaces we would consult with the developers and auditors of these models to understand better their views on how the interfaces could be improved.

6.4.7 The main steps within this overall task are therefore as follows:

- Clarify processes and review further documentation provided;

- Request example data input/output from existing runs. This will also include clarification and consideration of the Task 6 proposal in the MDP;
- Review the above data to ensure reasonable correspondences between inputs/outputs and sensitivity to land use changes. Ascertain if further bespoke runs are needed to test the correspondence (if so, we will aim to combine these within the sensitivity tests request in the future forecast review of Section 6.3 above);
- Discuss with DSC and CSTM model developers the issues relating to running TELMoS and CSTM together, and in particular the transport cost data exchange, again, in light of MDP proposal for improved interfaces.
- If appropriate, propose improvements/alterations to the approach."

## 8.3 INITIAL WORK

8.3.1 The initial analysis of the interfaces was progressed through work that has been documented in the Auditor's Technical Note TN002, Transport Model Interfaces (v1.1 of 25/11/2014). It reviewed ten documents that had been supplied that contained some discussion on the model interfaces. It then identified some aspects of the documentation of the interface methodology that still remained unclear and outlined the need for some indicative model runs that would enable the operation in practice of the interface to be audited more systematically.

8.3.2 DSC's responses: to this TN002; to the discussions that were held relating to that note, both in person at the meeting on 26th November 2014; and subsequently by email, are compiled in the DSC Project Note PN20(v1 of 18/2/2015). This provides further information about the files and their contents that are transferred between the models within the interface procedure.

8.3.3 PN 20 also outlines:

- the reference case BQ and alternative scenario ER (Low population, Low economic growth) that will provide the data files that are to be analysed to demonstrate the impact of TELMoS land use changes on TMfS trip generation;
- the tests PR (do-minimum) and PU (A9 scheme) to be used to demonstrate the impact of TMfS cost changes on TELMoS activity location patterns.

8.3.4 Since then DSC and SIAS have provided the auditors with sets of input and output files from these model runs to enable the operation in theory and in practice of the interface to be examined in greater depth.

## 8.4 TASK SUMMARY FOR THE AUDIT OF INTERFACES

8.4.1 We now summarise each of the individual tasks that is contained in the Section 6.4 of the Auditor's Technical Note TN001 that has been reproduced above. For each we indicate where the audit work that has been completed on this task is documented below within this report.

a) Review the relevant reports and project notes produced by DSC, MVA or SIAS that document the interfaces, particularly :PN 75 and the TMfS:07 Trip End Model User Manual for TELMoS07; the Model Development Report (MDR, v1.3 Nov. 2013), PN17 and PN18 for TELMoS12; and Task 6 of the TELMoS12 Model

Development Programme Report(MDP). These and other documents are reviewed in Section 10.1 for the TMfS interface, building on the earlier material in the TELMoS Auditor's Technical Note TN002 and in the response to it in the DSC Project NotePN20.

b) The progress achieved and the continuing relevance of the set of recommendations regarding interfaces originally made in the TELMoS07 Audit are discussed in Section 9 relating to the car ownership forecasting mechanism.
c) The analysis of the mathematical formulation and of the practical operation of the conversion of TELMoS land use information into trip end volumes for the transport models TMfS is presented in Section 10.2.
d) The analysis of the trip production results generated by this procedure is presented in Section 10.3.
e) The analysis of the mathematical formulation and of the practical operation of the conversion of the OD matrix of transport costs from TMfS into TELMoS zonal accessibility measures is presented in Section 10.4.
f) The analysis of the accessibility impact generated by this procedure is presented in Section 10.3.
g) The initial draft set of recommendations on potential improvements/alterations to the interfaces is presented in Section 11. These can subsequently be refined and finalised once they have been discussed with Transport Scotland and with the TELMoS and TMfS model developers.
h) The audit of the interfaces between TELMoS and CSTM has not been included within this phase of audit work.

# 9 CAR OWNERSHIP FORECASTING

## 9.1 INTRODUCTION

9.1.1 The car ownership patterns produced by TELMoS are a very important input to the forecasts in TMfS since they are a major determinant of the spatial pattern and of the overall level of demand for car travel. Accordingly, the effectiveness of the forecasting of household car ownership rates is one of the mechanisms in TELMoS that was examined in the previous audit. In this Section we revisit and extend that analysis.

9.1.2 In Section 9.2 the zonal pattern of household car ownership rates is compared in 2011 between the Census and the model outputs for the reference case run BQ. Then in Section 9.3 the realism of the forecasts of car ownership rates is examined in two ways. Firstly, the short term forecast trends from 2011-2021 are compared with the observed Census trends from 2001-2011. Then the longer term trajectory for car ownership rates is charted to check its plausibility. The results of these comparisons are assessed in Section 9.4.

## 9.2 BASE YEAR VALIDATION

9.2.1 To validate the starting point for the mechanism that forecasts car ownership tends, the spatial pattern of household car ownership rates is compared between the 2011 Census and the model values in the year 2011. Note that TELMOS12 does not report on 2011 car ownership because its base year is 2012 but the spatial pattern of household car ownership rates in 2012 in the model has changed little from 2011. The results at the council area level are presented in Table 1, which shows the percentage difference of the model estimate from that observed in the Census for the number of households with no, 1 or 2 or more cars and for household numbers in total[15].

**Table 1 Census 2011 number of households and percentage difference from Census, by household car/van ownership class, by council area for run BQ**

| | All HHs | % diff from observed | | | |
|---|---|---|---|---|---|
| **Council Area** | **(000)** | **No car** | **1 car** | **2+ cars** | **All HHs** |
| **City of Aberdeen** | **103.4** | **3.3%** | **5.2%** | **-14.2%** | **0.00%** |
| Aberdeenshire | 104.7 | 22.6% | 23.5% | -27.9% | 0.00% |
| Angus | 51.6 | 8.4% | 12.6% | -22.9% | 0.01% |
| Argyll & Bute | 40.1 | 11.3% | 8.5% | -21.0% | 0.01% |
| Clackmannanshire | 22.7 | 8.0% | 13.2% | -23.9% | -0.02% |
| Dumfries & Galloway | 68.0 | 7.2% | 13.4% | -23.2% | 0.00% |
| **City of Dundee** | **69.2** | **10.5%** | **-1.1%** | **-22.5%** | **0.00%** |
| East Ayrshire | 53.9 | 15.8% | 8.1% | -26.8% | 0.00% |
| East Dunbartonshire | 43.5 | 7.2% | 15.2% | -20.9% | 0.02% |
| East Lothian | 42.9 | 8.1% | 13.1% | -23.4% | 0.01% |
| East Renfrewshire | 37.2 | 4.6% | 18.6% | -21.8% | -0.04% |
| **City of Edinburgh** | **223.1** | **-3.9%** | **5.5%** | **-4.6%** | **0.00%** |
| Eilean Siar | 12.6 | 25.8% | 9.9% | -31.7% | 0.03% |
| Falkirk | 68.7 | 14.7% | 9.1% | -23.8% | 0.00% |
| Fife | 161.0 | 8.1% | 10.0% | -21.3% | 0.00% |
| **City of Glasgow** | **285.7** | **6.9%** | **-4.4%** | **-15.0%** | **0.00%** |
| Highland | 102.1 | 15.9% | 11.6% | -26.2% | 0.00% |
| Inverclyde | 37.4 | -0.9% | 15.0% | -23.5% | 0.02% |
| Midlothian | 35.0 | 2.8% | 9.7% | -16.0% | 0.01% |
| Moray | 40.1 | 23.3% | 11.4% | -30.1% | -0.01% |
| North Ayrshire | 62.5 | 8.0% | 5.9% | -20.0% | 0.00% |
| North Lanarkshire | 146.0 | 9.7% | 8.7% | -25.1% | 0.00% |
| Orkney Islands | 9.7 | 6.9% | 10.7% | -17.2% | 0.05% |
| Perth & Kinross | 64.8 | 8.4% | 9.8% | -17.6% | 0.00% |
| Renfrewshire | 80.9 | 2.1% | 10.2% | -19.3% | 0.01% |
| Scottish Borders | 52.5 | 4.5% | 10.7% | -16.8% | 0.00% |
| Shetland Islands | 10.0 | 1.8% | 12.9% | -15.0% | 0.00% |

[15] Values coloured red denote the greatest percentage differences for that category and those coloured blue denote the least differences.

| | All HHs | % diff from observed | | | |
|---|---|---|---|---|---|
| **Council Area** | **(000)** | **No car** | **1 car** | **2+ cars** | **All HHs** |
| South Ayrshire | 51.3 | 10.7% | 10.1% | -23.7% | 0.01% |
| South Lanarkshire | 139.2 | 8.7% | 10.1% | -22.7% | 0.00% |
| Stirling | 37.6 | 0.6% | 13.9% | -16.4% | 0.01% |
| West Dunbartonshire | 42.2 | 6.7% | 2.8% | -18.1% | 0.01% |
| West Lothian | 73.4 | 8.9% | 11.1% | -21.2% | 0.00% |
| **Scotland** | **2372.8** | **6.9%** | **8.5%** | **-20.8%** | **0.00%** |

Source: 2011 Census Table KS404, and TELMoS12 reference case run BQ, year 2011.

9.2.2 This Table indicates a very close match in the model to the observed household numbers in total for 2011 but it also highlights consistent differences in the car ownership composition of these households both at the council area level and at the overall national level for Scotland.[16]

9.2.3 For Scotland as a whole in 2011, there is a 6.9% overestimate in the model for the **no car households** with this excess being greater than 20% in Aberdeenshire, Eilean Siar and Moray. In contrast the City of Edinburgh undershoots by -3.9%.

9.2.4 There is an 8.5% overestimate in the model for the **one car households** for Scotland as a whole, with this excess being greater than 15% in Aberdeenshire, Inverclyde and East Renfrewshire. In contrast the City of Glasgow undershoots by -4.4%.

9.2.5 The greatest difference in the model from Scotland as a whole is the -20.8% underestimate for the households with **two or more cars**. This shortfall is greater than -25% for Aberdeenshire, East Ayrshire, Eilean Siar, Highland, Moray and North Lanarkshire, whereas only the city of Edinburgh with a -4.6% underestimate is not at least -14% below the observed number of households.

9.2.6 These substantial deviations in TELMoS from the 2011 observed rates of household car ownership are likely to have a detrimental impact in later model

[16] Response from DSC: *TELMoS12 was commissioned before detailed results from the 2011 Census, relating to levels of car ownership by different household types were available.*
*In creating the 2012 base year data, two steps were taken:*

- *Creation of an interim 2011 profile. This drew upon three sources of data. Firstly the preliminary 2011 Census district level summary data for households, secondly Scottish Transport Statistics Table T1.20 which reports on national proportion of hhlds with 0, 1 and 2 plus cars (based upon Scottish Household Data) and thirdly the TELMoS07 forecasts of the probability of households of each type in each zone having 0,1 or 2plus households. The first two of these were used as controls the third to provide the spatial disaggregation.*
- *The second step was to forecast forward to 2012 and the TELMoS12 base year.*

*This approach made use of the 'best' data on car ownership that was available at the time.*
*The table shows firstly that the number of households in 2011 is consistent with the Census but that the proportions of no, 1 and 2 plus cars differs. At a national level this difference reflects differences between the SHS-based statistics and the Census, at a local level the discrepancy may also reflect differences in mix of households assumed.*

years on the accuracy of the representation in TMfS of the spatial pattern of demand for car travel.

9.2.7 Section 5.4 of the TELMoS12 MDR explains the creation of the car-ownership database (COZN file) that contains zonal estimates of the number of households with no, one or two cars or more for 2011. It states:

> "5.4.5 District level data from the 2011 Census has then been used to create an interim 2011 Car Ownership database. The Census values having been used to scale the TELMoS07 2011 car ownership database."

9.2.8 It is not obvious from this description, why the significant disparity from the observed 2011 Census car ownership shares would have arisen. **The methodology that was adopted to create the COZN file for 2011 should be revisited to ensure that an improved match to the observed 2011 household car ownership shares is achieved across all zones.**[17]

## 9.3 REALISM OF FORECASTS

9.3.1 The next task is to explore the realism of the forecasts[18] that are made of the car ownership categorisation of households. This involves three separate checks documented in turn below:

- A broad comparison of the forecasts from 2007 to 2031 against the outturn Census trends from 2001 to 2011 but using the earlier TELMoS07 model runs rather than the current TELMoS12 model runs;
- A comparison of the short term forecasts from 2011 to 2021 from the TELMoS12 reference case run BQ, again against the outturn Census trends from 2001 to 2011;
- A long term review of the TELMoS12 forecast trends through to 2037.

9.3.2 The DSC TELMoS07 PN80 "Car ownership changes over time" (v1, May, 2009) describes for the earlier TELMoS07 model runs the forecast pattern of car ownership changes over the period 2007 to 2031 within Scotland and more specifically within the Glasgow and Edinburgh regions. It forecast:

> "that overall non car owning households are decreasing over the period. This tendency is more intensely observed within zones in central Glasgow and central Edinburgh"
>
> "significant percentage increases in the number of households owning two or more cars in the centre of Glasgow and Edinburgh with a few zones showing 50% plus increases."

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[17] Response from DSC: *For TELMoS14, the starting point has been the specially commissioned tables of 2011 Census output. This should provide a more consistent base (when compared with the Census).*
**Auditor response:** It would be instructive to repeat the Table 1 above for inspection as part of the checking of TELMoS14. Major local changes in car ownership rates would not generally be expected in practice over the short 3 years from 2011 to 2014.

[18] The mathematical formulation of the car ownership forecasting model is documented in Chapter 17 and in Appendix A10 of the TELMoS12 Model Development Report.

9.3.3 To provide some evidence on the potential short-term realism of these forecast trends from TELMoS07 for the major urban areas, the observed household car ownership changes from 2001 to 2011 were examined using Census data. This indicated the following.

- Glasgow city overall had a -5.4 percentage point reduction in the proportion of households with no car, which was greater than the Scottish national average reduction of -3.7. However, Glasgow city only had an increase of +3.0 percentage points in the proportion of households with two or more cars, which was below the national average of a +4.8 percentage point increase.
- Edinburgh city overall had very different to trends from the rest of Scotland. The proportion of households with no car *increased* by +0.4 percentage points, whereas all other council areas had percentage point declines of between -1.2% and -7%. The proportion of households with two or more cars also increased by just +0.4 percentage points, whereas all other council areas had percentage point increases of between 2.9% and 8.9%.

9.3.4 Overall, this analysis suggests that the TELMoS07 forecasts of future trends from 2007 for the largest cities were not in line with the observed recent car ownership trends within the two largest cities. It is likely that further spatial subdivision of these two cities may indicate that within denser, more central areas the observed rate of change in in the proportion of households with no cars is strongly negative – a recent feature common to many central areas of cities in the rest of the UK and one not picked up successfully by DfT's existing version of the National Car Ownership (NATCOP) model.[19]

9.3.5 A new version of NATCOP produced by Rand is in the process of being released by DfT at present. This endeavours to improve the representation of car ownership trends in dense urban areas (similar to Inner Edinburgh) through including this as one of its extra explanatory variables. This new NATCOP version should be considered as a potential resource to improve TELMoS car ownership forecasting in the large urban areas, provided it has been shown to validate well over time for such areas.

9.3.6 The next step was to check whether the subsequent short-term 2011-21 forecasts from the current TELMoS12 reference case BQ run, provided a closer match to the observed car ownership trends identified by the Census. The results for each of the three car ownership categories are presented in Figure 31 in the form of scatter graphs of the 2001-11 observed versus the forecast 2011-21 percentage point increase in the number of households in the specified household car ownership category.

[19] Response from DSC: *Note : The car ownership forecasting model applied in TELMoS is based upon the DfT's NATCOP model.*
*A re-calibrated version of the NATCOP model was released in 2009(???). This contained new co-efficients. TELMoS07's car ownership model was based upon the old (pre-2009) coefficients, TELMoS12 took account of the new coefficients.*

9.3.7 From the outset it should be stressed that there is no expectation that the observed car ownership trends from 2001 to 2011 should persist unchanged for each individual council area through the next decade, so that we would not expect to find all of the scatter graph points exactly on the 45 degree line for each of the three categories.

9.3.8 To examine how closely the 2011-21 forecasts retained the observed 2001-11 trend in each individual council area a regression of the forecast versus the observed % point growth was run separately for each car ownership category. For the no car households the resulting R squared value for this trend line in Figure 31 was 1% and for the one car households it was 4%, each of which implies that the past trend provides no substantial explanation of the forecast trend.

9.3.9 For households with 2 or more cars, although the R squared value indicates that 30% of the variation in the forecast growth can be explained by past observed trends, the negative slope of the regression line implies that the relationship is reversed so that past growth implies future declines and vice versa.

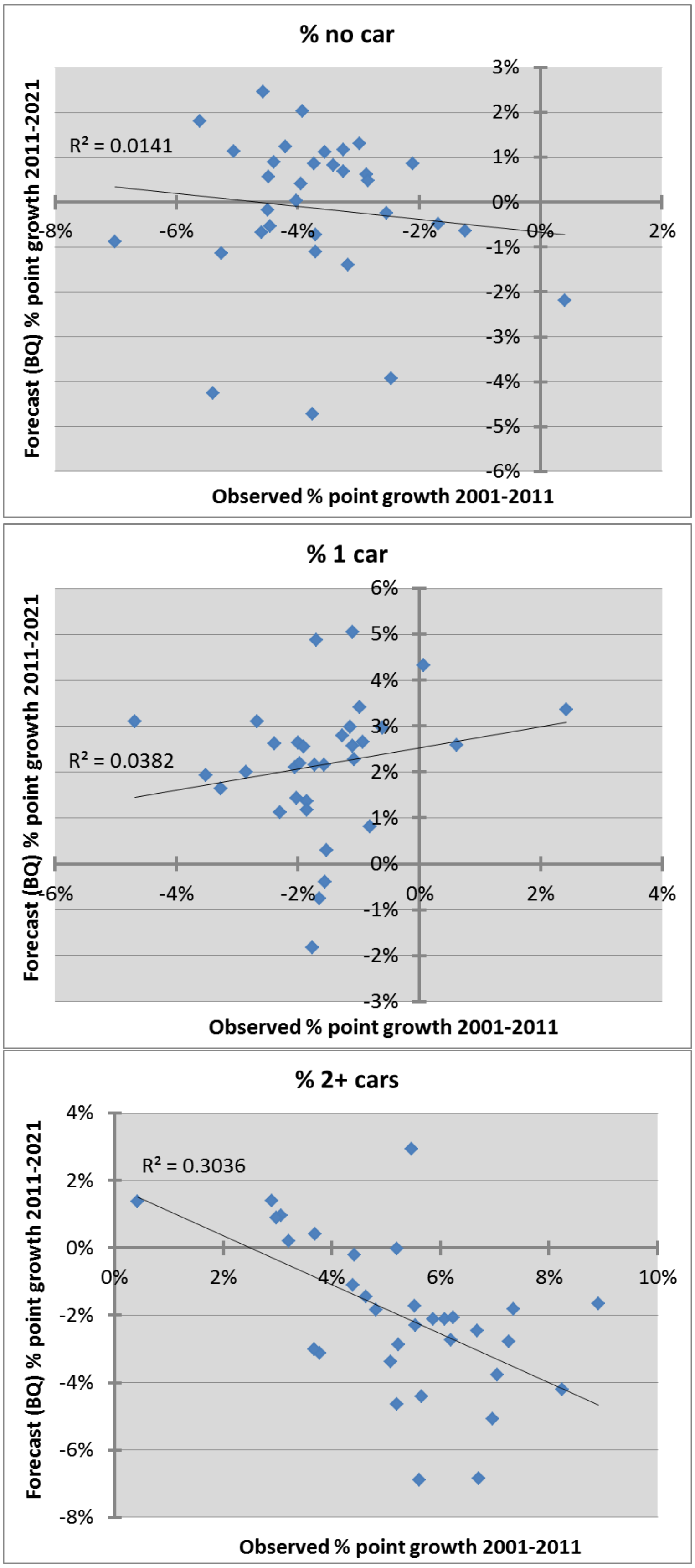


**Figure 31 Forecast 2011-2021 Versus the observed 2001-2011, % point growth for households with no, 1 or 2 or more cars, by council area**
Source: Census Tables KS404(2011), KS17(2001), and TELMoS12 reference case run BQ, years 2011 to 2021.

9.3.10 These comparisons do not inspire confidence that the forecasting of short-term car ownership trends has a strong behavioural basis in TELMoS12.[20] Our default expectation is that there should be a substantial positive relationship between past and future trends except where there is a sound behavioural explanation as to why this should be overridden for certain periods or for certain types of zone.

9.3.11 We have further analysed below, using the charts presented in Figure 32 to Figure 34, the longer term forecasts of household car ownership rates for the reference case run BQ over the period 2011 to 2037. The aim is to review their general spatial evolution and stability aiming to ascertain whether differentials between council areas are maintained in a plausible fashion.

[20] Response from DSC: *We note the concern. The approach taken in TELMoS12 predicts household car ownership as a function of household structure, income and licence holding trends. The household forecasts are constrained to be consistent with NRS household forecasts (in terms of broad category of household type), the licence holding reflects Scottish Transport Statistics Table 1.16, the incomes are derived from TELMoS' Regional Economic Model (which in turn is calibrated so as to be consistent with an independent economic forecast provided by Transport Scotland).*
*For TELMoS14 we have taken on board this concern and introduced an additional constraint whereby the total number of cars is calibrated to be consistent with NTEM forecasts.*
**Auditor response**: see also the discussion in para. 9.3.5 on using the new NATCOP version.

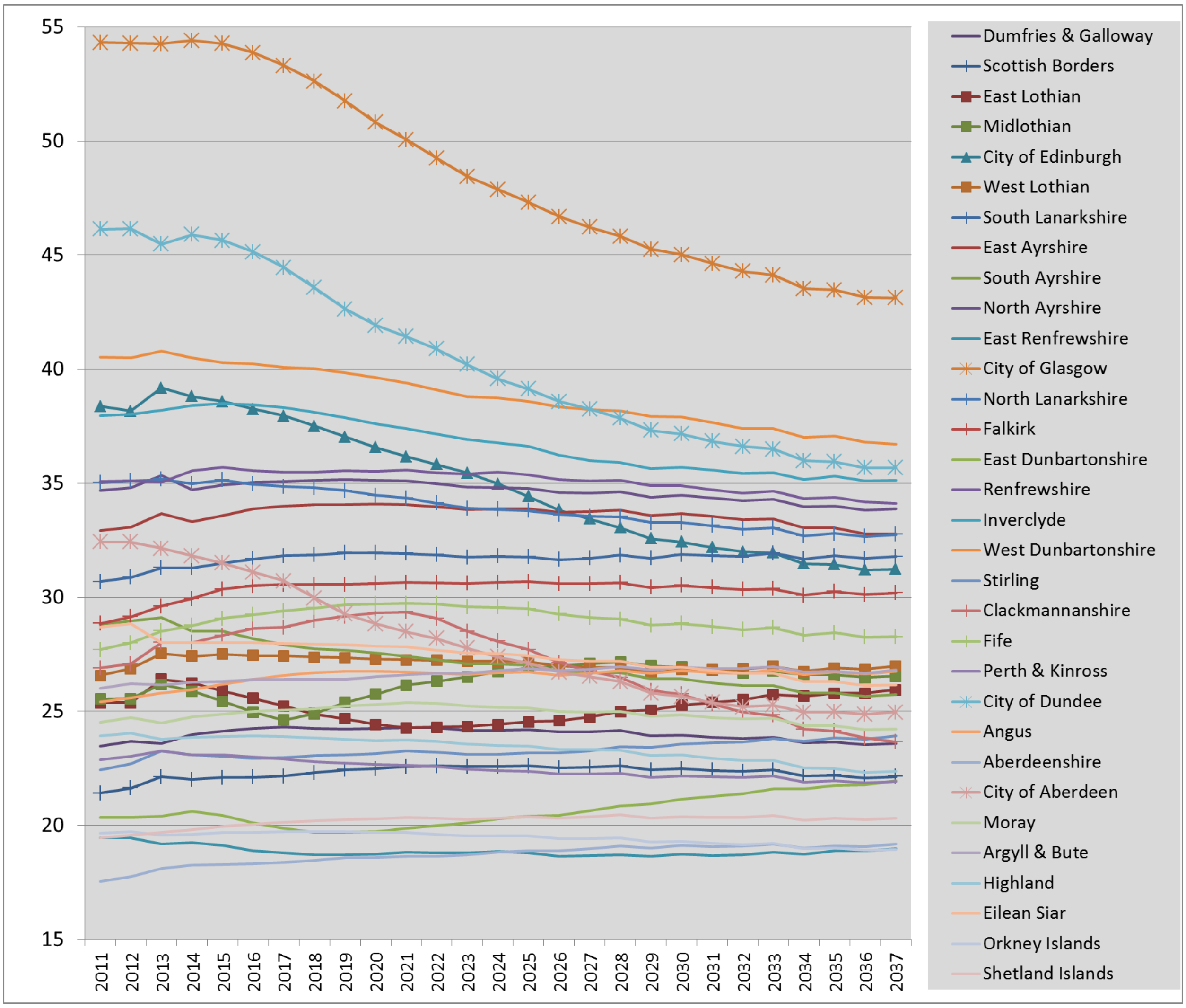


**Figure 32 Forecast percentage of households with no car, by council area, 2011-2037, reference case (BQ)**

9.3.12 Figure 32 presents the forecast percentage of **households with no cars** for each council area over the period 2011-2037. For most areas that start with high proportions of households with no cars there are small reductions over the period, whereas there is broad stability over time for most of other areas. However the trend for the four main cities is rather different to the other areas in that, independent of their starting percentages, these cities each exhibit major reductions over time in the proportion of households with no car, ranging from Glasgow reducing from 54% down to 43%, through to Aberdeen reducing from 32% down to 25%.

9.3.13 These major -7 to -11 percentage point reductions that are forecast for the cities are in sharp contrast to the much smaller changes in the range of +1 to -3 percentage points typically forecast for most other areas. With the possible exception of Glasgow, which despite the 5 percentage point reduction over 2001 to 2011, still had a very high 55% proportion of households with no car in 2011, there would need to be some compelling behavioural explanation to justify the mechanism causing the cities to radically change their future behaviour from that of the past.[21]

[21] Response from DSC: *As explained above, the car ownership takes account of change in income. The change in average income 2012-2037 by local authority (Test BQ) is shown below. The largest increases in income are in Glasgow, Dundee and Aberdeen. The response of the car ownership model to this change (ie increase in proportion of households with a car) does not seem unreasonable. This may also explain the increase in two plus car owning households described below:*

| | |
|---|---|
| Dumfries & Galloway | 111% |
| Scottish Borders | 111% |
| East Lothian | 106% |
| Midlothian | 108% |
| City of Edinburgh | 122% |
| West Lothian | 109% |
| South Lanarkshire | 104% |
| East Ayrshire | 107% |
| South Ayrshire | 121% |
| North Ayrshire | 108% |
| East Renfrewshire | 120% |
| City of Glasgow | 129% |
| North Lanarkshire | 114% |
| Falkirk | 99% |
| East Dunbartonshire | 109% |
| Renfrewshire | 111% |
| Inverclyde | 117% |
| West Dunbartonshire | 112% |
| Stirling | 105% |
| Clackmannanshire | 120% |
| Fife | 104% |
| Perth & Kinross | 117% |
| City of Dundee | 131% |
| Angus | 109% |
| Aberdeenshire | 106% |
| City of Aberdeen | 130% |
| Moray | 114% |
| Argyll & Bute | 104% |
| Highland | 113% |
| Eilean Siar | 116% |
| Orkney Islands | 113% |
| Shetland Islands | 108% |

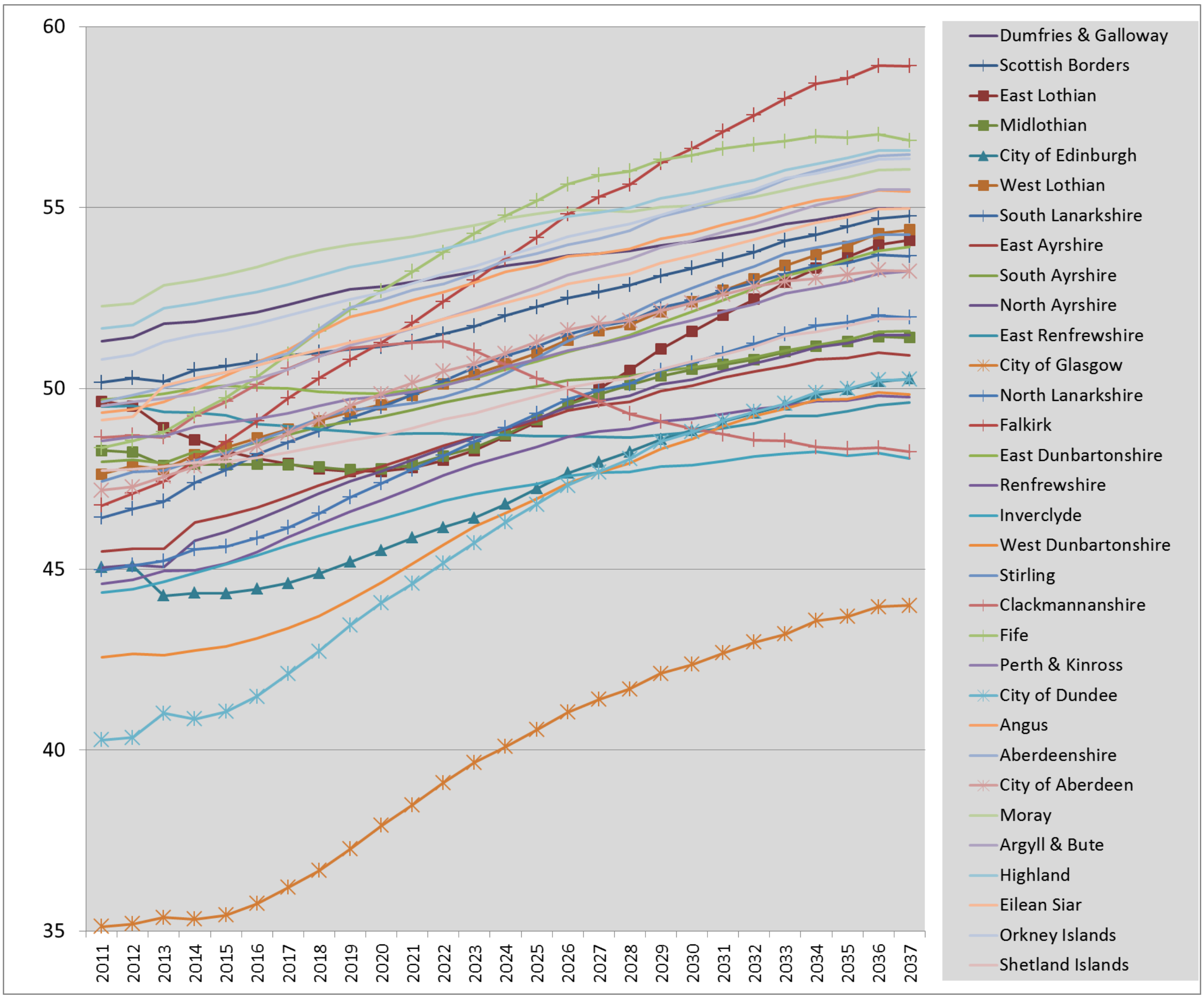


**Figure 33 Forecast percentage of households with one car, by council area, 2011-2037, reference case (BQ)**

9.3.14 It is complex to interpret the forecast trend in Figure 33 for the proportion of **households with 1 car** because this trend is the outcome of the balance of two other distinct trends: households with no car; and in those with two or more cars. Accordingly we focus primarily instead on interpreting these other two car ownership categories because their trajectories are simpler to understand individually.

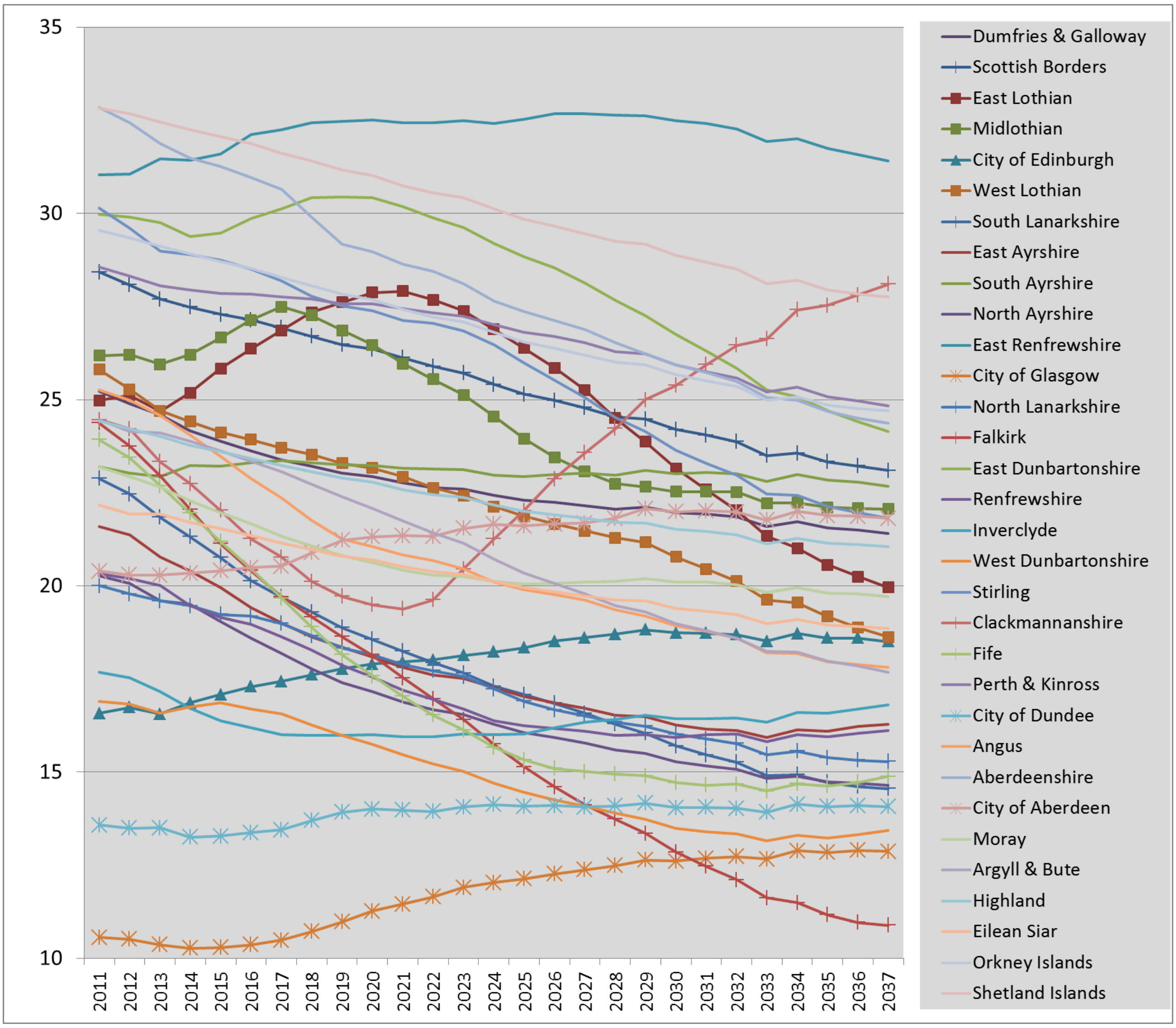


**Figure 34 Forecast percentage of households with two or more cars, by council area, 2011-2037, reference case (BQ)**

9.3.15 Figure 34 presents the forecast percentage of **households with two or more cars** for each council area over the period 2011-2037. Amongst the council areas there are a wide range of very different trajectories over time so these variations require some behavioural justification. There is an average decline of -4 percentage points across Scotland overall. But Falkirk reduces from 24% to 11%, whereas the four cities all increase their proportions with 2 or more cars. For East Lothian and Midlothian there is strong growth in the early years, followed by substantial later declines. In contrast Clackmannanshire declines initially from 24% down to 19% by 2021 but then rises subsequently to 28% by 2037.

## 9.4 Assessment

9.4.1 The spatial differentiation in car ownership forecast trends must be captured in a behaviourally correct fashion within TELMoS12 to ensure that it can provide realistic forecasts of future car transport demand. However, the review above of the forecast household car ownership trends in Figure 32 to Figure 34 has identified a very wide range of trajectories both over time and between council areas. These trajectories rarely match previous trends in their particular area and in some cases appear to reverse them.[22]

**9.4.2** There may be behavioural evidence that can be assembled that justifies both the specific major deviations from the average trajectories and the reversals of the previous trends presented for particular areas**. However, if such evidence is not forthcoming it would be wise to reorganise the forecasting model:**

- **to match the observed base year spatial pattern of household car ownership rates;**
- **to then forecast a zonal pattern of change in these household car ownership rates that is less extreme in its differentiation between areas and that does not present radical reversals from past local trends except where there is evidence to support them.**

9.4.3 **To achieve such improvements to forecasting performance it is likely that significant changes will need to be made to the current household car ownership model structure and/or parameters**. Some suggestions for particular topics that should be reconsidered are now outlined.

9.4.4 In the TELMoS12 MDR Chapter 17 it states that the design and many of the parameter values of the car ownership model are based upon the UK Department for Transport's national car ownership model, NATCOP, which has then been adapted and converted into a zonal and incremental form for use in the DSC DELTA software on which TELMoS is run. However, the forecasts of car ownership changes that were published some years back from this NATCOP model via the TEMPRO system have not matched well to the observed Census changes from 2001 to 2011 in the denser urban areas in England. Accordingly, some of the issues raised above regarding the realism of forecast car ownership trends in the cities

[22] Response from DSC: *We note the concerns over the ability of NATCOP to forecast change 2001 to 2011. Does this concern relate to the NATCOP version whose coefficients were applied in TELMoS07 or to the 'recalibrated' version whose coefficients were applied in TELMoS12? Either way we would share some of the concerns expressed regarding NATCOP and have had some preliminary discussions with other (non LATIS) clients as to alternative approaches*.
**Auditor response:** My concerns regarding dense urban areas relate to both previous versions of NATCOP. As I have not yet seen a validation of results of the soon to be released newest NATCOP version, I cannot provide confirmation that its introduction of urban density relationships is sufficient in practice to capture the observed lower patterns of growth in such areas in recent years. Accordingly, some explicit backcasting of local car ownership trends, say to 2001, should be part of the TELMoS development task.
I am certainly not arguing that the relationship between income growth and car ownership growth is less relevant today. My point is that in some rich dense urban areas, other urban influences are stronger than the income effects that will still exist there. This point has been confirmed for Inner London in a recent paper: Clowes J (2015) *Rising Population, Falling Traffic: Why Has Car Ownership Fallen While London Has Prospered?* European Transport Conference, 2015, Barcelona. http://abstracts.aetransport.org/paper/index/id/4547/confid/20

may not be peculiar to the application to the Scottish cities but might require a more radical restructuring of the NATCOP based structure or of its input parameter values.

9.4.5 A quick examination of the household car ownership model parameters in Table 17-4 and 17-5, suggested that the main differentiation in their values was between zone groups, which is as expected. However, there was little variation in coefficient values for the ownership of 1+ cars / household between 1 adult and 2+ adult households and no difference at all by household size for the saturation level parameters for either 1 car or 2+ car households. These parameter value relativities may benefit from being reconsidered.

9.4.6 Para. 17.3.7 of the TELMoS12 MDR states:

> "Note that the NATCOP design and calibration included variables relating to company car ownership; these can also be included in the DELTA version. However the DfT inputs used for NTEM 6.2 assume no change in the company car ownership inputs. Variables that do not change over time add zero to the linear predictor term. The company car ownership terms are therefore irrelevant to the working model, and for simplicity have been omitted."

9.4.7 The "On the Move Study (LeVine & Jones, 2012) deduced from its examination of National Travel Survey data prior to 2007 for Great Britain that a significant part of the reduction from the previous high growth rate for car travel was a result of changes in the taxation of company car purchases and use. This suggests that the changing role of company car use might also be considered as part of the refresh of the car ownership forecasting methodology.

# 10 INTERFACE OF TELMOS12 TO TMFS12

## 10.1 DOCUMENTATION

10.1.1 Our understanding of the form of operation of the interface for data going in both directions between TELMoS12 and TMfS12 has been built up using various documents that are described in this Section.

10.1.2 The TMfS:07 Trip End Model User Manual (TEMUM, v1.2, May, 2011) outlines in its Section 2.3 the use of TELMoS planning data in tandem with NTEM trip rates to generate zonal trip ends. Our understanding is the trip end methodology used for TMfS12 is virtually the same other than that that the Base year changed to 2012 and the final forecast year changed to 2037 for the TMfS12 version. It also describes the goods vehicle O-D matrices for LGVs and HGVs sent from TELMoS to TMFS.

10.1.3 The TELMoS12 MDR covers the following topics.

- Chapter 23 provides an overview of the Interface Definition File and a brief introduction to the other three data files sent from TELMoS to TMfS, which are:

  - zonal totals for persons segmented by person and household type (TMFS<><>.CSV[23]);
  - zonal totals for households and for employment by type (TAV_<><>.CSV);
  - zone pair data on synthesized freight vehicle movements for each of light goods vehicles and other goods vehicles (TRFL<><>.CSV).
- Sections 12.1.1 and 12.1.2 discuss the processing of the generalised costs provided by TMfS and the creation of two datasets of accessibilities, within TELMoS. as follows:

  "12.1.1 The Accessibility sub-model takes the generalised costs that are generated by the transport model and calculates:
    - accessibility for each measure (i.e. commuting, shopping, business trip etc)
    - accessibility for each household and employment type.

  *12.1.2* The outputs from the model are:
    - a set of origin accessibilities for household and employment activities
    - a set of destination accessibilities for households and employment activities."

10.1.4 This interface has subsequently been documented in greater detail by DSC in TELMoS12 PN17 "The TELMoS TMfS interface" (27 August 2014 v1.0), which provides:

- an overview of the interface between TELMoS and TMfS;
- a description of the data passed from TELMoS to TMfS;
- a description of the data passed from TMfS to TELMoS.

10.1.5 The use of the TELMoS output zonal planning and car ownership data to estimate home-based trip productions within the TMfS trip end model is described in Chapter 9 and Appendix L of the TMfS Demand Model Development Report (DMD, 2nd Feb. 2015). The estimation of reverse and non-home-based trips is briefly outlined there in Chapter 6. The introduction to TMfS of the TELMoS estimated goods vehicle matrices is described there in Section 10.8.

10.1.6 The DSC Project Note PN20 answered some remaining queries about the segmentation and organisation of the data within the interface files.

## 10.2 CONVERSION OF LAND USE INFORMATION INTO TRIP ENDS

10.2.1 Aggregation errors can potentially arise whenever data categories are aggregated or sub-divided in order to ensure consistency between component parts of a modelling system that differ in their native categorisations in use. Accordingly, we now examine the uniformity of the segmentations in use across the various stages of the transmission of the TELMoS planning data through to the TMfS trip end model. We start by providing a summary of our understanding of the sequence

[23] The documentation "File<><>" denotes that in practice the model year and the specific scenario being run are included in each file name, e.g. "avzn37bq" indicates the output file AVZN for the final run year 2037, of the reference case scenario BQ.

of operations through which the data that is output from TELMoS feeds into and then is used within TMfS.

10.2.2 The zoning system currently used is identical for TELMoS12 and TMfS12. This is beneficial as it should avoid the generation of spatial aggregation errors when interchanging data between the models.

10.2.3 Once a TELMoS test run has been completed, the tabulation program ITMFS (MDR, Chap. 23) as documented in PN20, uses the model output data in the files AVZN<><>.CSV and COZN<><>.CSV, together with the interface definition file TMFS<><>.inp (partially documented in DSC PN20) to create two zonal CSV files (illustrated in Figures 2.1 and 2.2 of TEMUM) that are subsequently input to TMfS for use within the trip end calculations:

- TAV_<><>.CSV contains the number: of resident households; of total persons employed (jobs) in the zone; and of those employed there within 6 particular economic sectors;
- TMFS<><>.CSV contains population data comprising the number of resident persons in each zone, disaggregated into 9 person types (by age, sex, working status) that are further cross-classified by 8 household type size and car ownership combinations.

10.2.4 PN20 states, referring to this TMFS file structure, that:

> "*1.2.07* The information that populates this table is based upon:
> - Avzn – activity database which contains the number of households of each type, including the number of children, resident working adults, non-working adults and retired
> - Cozn – car ownership database which contains the proportion of each household type in each of the three car ownership categories, no car, one car and two plus cars

10.2.5 These two files are documented more precisely in Chapter 4 of the MDR, as follows:

> "*4.2.2* For household activities, the Block AVZN01 records the numbers of persons by type (children, working adults, non-working adults and retired persons) *within households of each activity* in each zone."
>
> "*4.5.1* The car ownership database file, COZN<year><test>.dat contains zone-level data on the proportion *of each household activity* within each of the three car ownership categories: no car, 1 car and 2+ cars (see Table 3-9). The three values always sum to one." *(italics added)*

10.2.6 This MDR documentation appears to clarify that the segmentation into household activity types[24] remains common across the AVZN and the COZN files.

[24] The 20 **household activity type** categories used in COZN are based upon a mixture of age, composition and employment status, further disaggregated by socio-economic level and are listed in Table 3-4 of the MDR. In the AVZN file 58 denotes the highest numbered employment activity.

Accordingly, the step within the ITMFS routine that subdivides the resident population numbers between household car ownership categories will have access to this relevant intermediate household activity information. Based on information from DSC, the specification of how this subdivision of resident persons is implemented is as follows. Within each specific zone and household activity category combination, firstly, all person types are split identically using the relevant car ownership split that was input from COZN. These persons are then aggregated from the 20 TELMoS household activity types into the 8 TMfS household groups. Table 5 of PN20 lists for each of the twenty TELMoS *household activity types*, the TMfS *household group* to which it is allocated.[25]

10.2.7 The four TELMoS person types (children, non-workers, workers and retired) are defined in Table 3-5 of the MDR. In TELMoS12 PN17 it states:

> "3.05 Firstly, TELMoS does not model male and female adults separately. The data output to TMfS is based on the application of proportions (that are input exogenously in each transport model year) to TELMoS' calculation of the numbers of adults
>
> 3.06 Secondly, the employment sector data that is transferred do not represent a comprehensive sectoral disaggregation of employment - the sectors used in the interface are more aggregate than those in TELMoS itself."

10.2.8 Table 3 of PN20 appears to indicate that when creating the TMFS file of population numbers, as well as splitting each of the non-working adult and the retired person categories between males and females, the ITMFS routine also splits the working adult category into four sub-categories: specifically, between male and female by part- and full-time work. The set of factors for splitting to male and female is a model input in each transport year. It would be possible to change the proportions over time, however no such change has been implemented in the TELMoS12 Do-Minimum. At present there is no provision to vary the split of male/female by either zone or household type.

10.2.9 **The approach described above for supplying the detailed planning data from TELMoS to TMfS for use in its trip end estimation procedure appears to be sound and to avoid unnecessary aggregation errors**.

10.2.10 The trip end model operates as a standalone procedure that is documented in detail for TELMoS07 in TEMUM and in outline more recently within Chapter 9, Appendix A.8 and Appendix L of the TMfS12 Demand Model Development Report (DMDR, Feb. 2015).

[25] Response from DSC: *NB for TELMoS14 the process is a little more complex because the household types do not aggregate so simply to the TMfS household groups*
**Auditor response:** I appreciate that developing two models separately may create strong reasons for divergences between models in their segmentation definitions. However, such differences can create long term reductions in the accuracy of the joint system due to the aggregation / disaggregation errors that they tend to create. Accordingly, such divergences should be avoided by design whenever possible.

10.2.11 It is an incremental model which pivots from the set of files used within the base year model. It acts entirely as a ratio model. Growth rates for each modelled zone are calculated using a combination of changes in planning data (number of households, population and employment forecast over time) and a series of trip rates. These rates of growth are then applied to TMfS base year trip ends to create forecast year trip ends.

10.2.12 The estimation of zonal trip end totals within TMfS applies NTEM trip rates to the number of persons in each of 88 person type categories within the zone. This approach is only used for trip productions for the from-home trip purposes. The to-home trip ends and non-home-based trip ends are created in a separate process.

10.2.13 The 88 person types distinguished in NTEM are listed in DMDR appendix L as 11 person types combined with the 8 household groups discussed above for the TMFS<><>.CSV file. This file only contains 9 person types, so that the remaining two categories of male and female students aged 16-64 are generated as follows:

> "the student data set is extracted from the non-working column using a set of factors, which are 0.2794 for Males and 0.2453 for Females." (TEMUM, Chap. 2)

10.2.14 This apparent use of a universal set of factor values for generating the student population appears overly simplistic. In the vicinity of universities the ratio is likely to be much higher whereas elsewhere it would be correspondingly lower. **The switch to a set of student factors that are differentiated by zone or by broad groups of zone types should lead to a minor improvement in model performance.** These zonal factors could be calculated initially from the 2011 Census and then scaled over time in line with expected changes in national student numbers.

10.2.15 Three NTEM home-based purposes: work, employers business and education are explicitly represented within TMfS, whereas the remaining five NTEM home-based purposes are combined together to form the home-based other (HBO) purpose within TMfS.

10.2.16 The files tmfs37_AER.csv for trip productions and tav_37_AER.csv for trip attractions are output from the trip end model for use in the pivoting procedure. These *output* files have the naming convention TAV_<>_<>.CSV and TMFS<>_<>.CSV. They should not be confused with the slightly differently named planning data *input* files TAV_<><>.CSV and TMFS<><>.CSV to the trip end model that are described above in para. 10.2.3 These output files have the following usage and content:

> "Examples of the 'tav_XX_SS.csv' and 'tmfsXX_SS.csv' files are shown in Figures 3.10 and 3.11. These are used in future year pivoting. The TAV file contains the relevant planning data file multiplied by the trip attraction rates and then combined into Work (HW), Employers Business (HE), Other (HO) and Education (HS) purposes. This data is then used in conjunction with a similar file from a

forecast year to produce attraction growth factors. In this case the factors are the same for all time periods, modes and household types.

Similarly, the 'tmfsXX_SS.csv' file contains the relevant planning data multiplied by the trip rates described in section 2. It is used in conjunction with a file for a future year scenario to produce production growth factors. Different values are produced by time period, mode and household type. These are designated in the column headers by A, I and P for the time periods; C11, C12, C2 and C0 for the household types; C and P for car and PT and W, E, O and S (Work, Employers Business, Other and Education) for the purposes." (page 30, TEMUM)

10.2.17 The headings on the 64 columns of the TMFS<>_<>.CSV output file are coded as "PTM Cnn", as explained above, where the codes denote.

- P person type: W, O, E, S
- T period: A, I - but no PM peak period P is included
- M mode: C= car; P = public transport
- Cnn HH size / car ownership: C0 = no car; C11 = 1 car + 1 adult; C12 = 1 car + 2+ adults; C2 = 2 or more cars.

10.2.18 The NTEM trip rates for car and public transport only are applied within TMfS but the NTEM trip rates for walk and cycle are excluded because these active modes are not included within the TMfS modelling although they are included within TELMoS.

10.2.19 TEMUM, Chap. 2 states:

"Note that for the purposes of TMfS, 'Area Type 5' (Urban Medium) trip rates are applied as this was considered to be the most appropriate assumption or average set of trip rates for the TMfS coverage area." …

"The car driver and car passenger trip rates are combined to produce car person trip rates. Similarly, bus and rail trip rates are combined to produce general public transport trip rates."

10.2.20 Initially the auditor considered recommending that consideration should be given to refining the use of the NTEM procedure by switching from the use of a common area type for all of Scotland to make use instead of the NTEM metropolitan area type values for the cities of Glasgow and Edinburgh. Although within NTEM the trip rates as a whole for a specific person type do not vary greatly between area types, their modal composition does vary. The research underpinning NTEM identified significant differences between area types (ME&P, 2000, Table 4.3) in mode split for car versus public transport. For example, the proportion of public transport trips increases strongly in denser urban areas, whereas the proportion of car trips is greatest in the most rural low density areas. In practice a large part of this spatial differentiation is automatically picked up by the strong differences between area types in car ownership patterns and their associated modal choices. This car ownership differentiation is already represented in detail within the segmentation used in the trip end model of TMfS. Accordingly, other than for car owners in Inner London, the variation between area types in walk mode share is not pronounced, provided that the major influence of car availability is explicitly and accurately represented. Drawing these various strands of evidence together suggests that there may in practice be no overriding need to complicate the modelling by the introduction of trip rates specific to the major cities. However, this analysis does provide yet another reason why the accuracy of the forecasts of the spatial pattern of car ownership rates discussed above in Section 9.4 is of high importance.

10.2.21 In summary, **the provision of the planning data from TELMoS for use in the trip end estimation and car ownership segmentation within TMfS is carried out in an effective fashion throughout; it maintains a suitably high degree of segmentation in a consistent manner. This data is then used in tandem with the trip rates input from NTEM in a suitable fashion to generate the required zonal trip productions, segmented by trip purpose and car ownership category**. A few suggestions have been provided for minor enhancements to the procedures in order to further improve its overall performance.

## 10.3 EXAMINATION OF TRIP END RESULTS

10.3.1 In their Note TN002, the auditors requested

> "that DSC and SIAS provide analysis of a set of TELMoS and TMfS runs which confirm:
>
> 1) How the absolute numbers of productions and attractions in TELMoS zones correspond with the absolute numbers of trip ends produced by TMfS. We understand that TELMoS trip end forecasts are used to scale TMfS base year trip ends. Therefore this comparison should be supplied for both models in the Base Year (where the trip ends are independent), and for the future year, showing the original TELMoS forecast and the resulting TMfS input trip ends. The figures should demonstrate:
>
> a. That no bias is introduced due to any differences between the TELMoS and TMfS base trip ends;
>
> b. That the absolute figures in the future year TMfS model correspond well with the TELMoS figures, including variations across segments.
>
> 2) The future year information should be provided for at least two scenarios with Land Use inputs to TELMoS varied, with changes to both residential and employment data, applied both in urban and rural areas. The comparison of TELMoS and TMfS future year trip ends should show sensible changes in TMfS which correspond to the TELMoS inputs."

10.3.2 DSC has provided the auditor with the input files AVZN and COZN and the output files TAV and TMFS for the trip end model for the final year 2037 for the reference case run BQ and alternative scenario ER (Low population, Low economic growth). These files, together with the standard yearly zonal activity output files from TELMoS have been examined to understand the impact of TELMoS land use changes on TMfS trip generation patterns.

10.3.3 The general results from the reference case scenario BQ have already been summarised by SIAS in the Do-Minimum Forecasts October 2013 (DMFO, Dec. 2013). We understand that there is a draft of the Alternative Forecasting Scenarios report that includes the ER scenario, which if available to the auditor would provide useful contextual information to inform the discussion below. We now provide a brief overview of the main ER scenario trend outcomes relative to the reference case BQ in order to provide the context for the subsequent analysis of trip end changes.

10.3.4 The forecast differences between the ER scenario and the reference case by 2037 in the national population of children, working adults, non-working adults and retired persons are presented in Table 2 which indicates a -4.6% lower total population, with the greatest reduction being the -11.8% reduction in working adults.

**Table 2 Forecast 2037 population components for runs BQ and ER**

| Run | Total* | Children | Working adults | Non-working adults | Retired |
|---|---|---|---|---|---|
| ER | 5,506,742 | 892,965 | 2,104,874 | 1,224,879 | 1,284,023 |
| BQ | 5,773,064 | 920,455 | 2,385,834 | 1,116,487 | 1,350,288 |
| ER-BQ | -266,323 | -27,491 | -280,960 | 108,393 | -66,265 |
| %ER-BQ | -4.6% | -3.0% | -11.8% | 9.7% | -4.9% |

*Note: this population total excludes the 84,930 students over 16 that are common to both scenarios

Source: Files avzn37er.CSV, avzn37bq.CSV, activities 1 to 20.

10.3.5 In the low growth ER scenario through to 2037 the Scottish total population grows only by 5.6% rather than the 10.6% growth in the reference case. There is a corresponding reduction in the growth in the number of households down to 18% from the 23% growth that is forecast in the reference case. The slower relative population growth occurs in all areas, as illustrated in Figure 35 but differs substantially in its scale both over time and across areas.

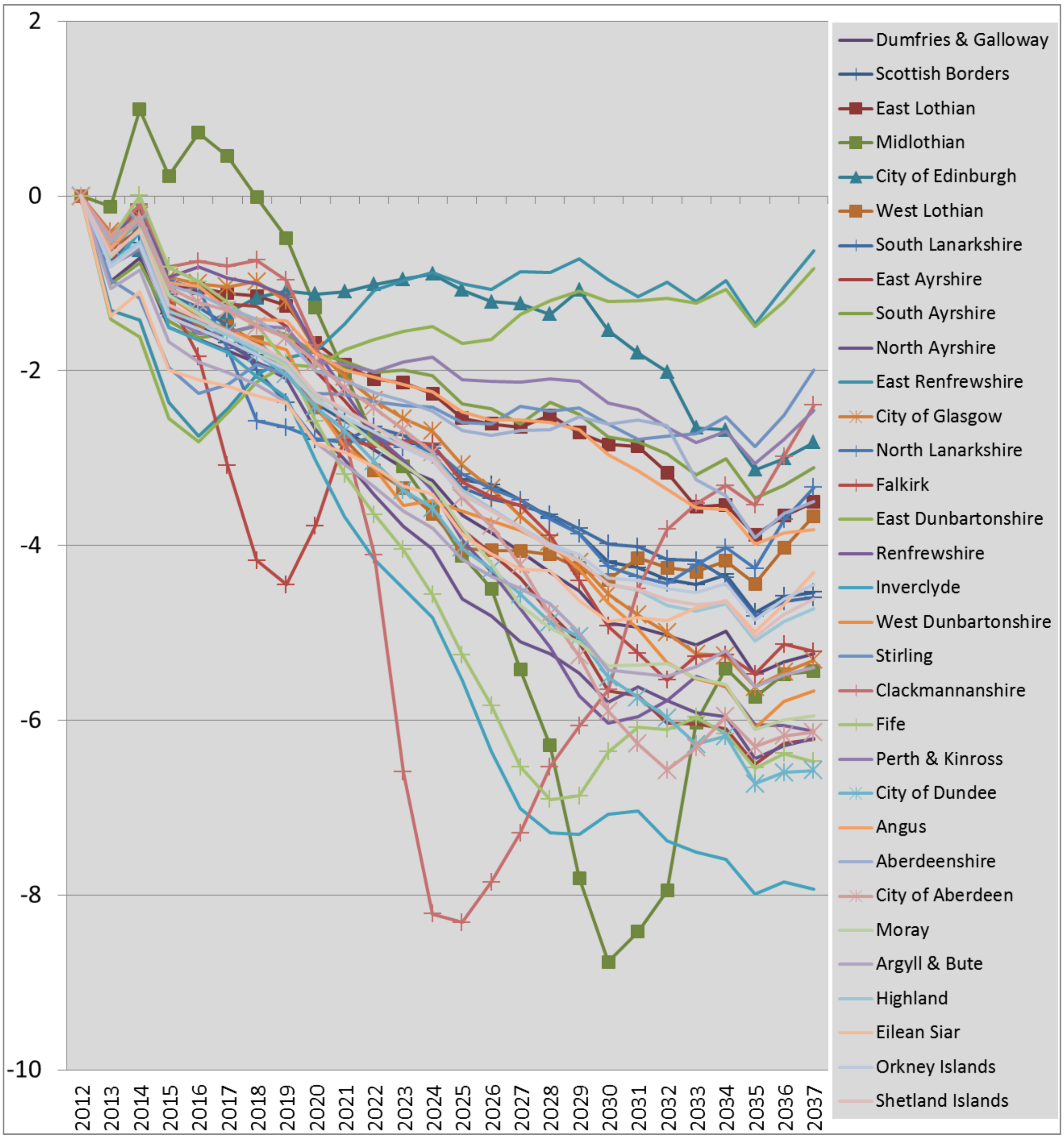


**Figure 35 Percentage difference in population, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.6 For East Dunbartonshire and East Renfrewshire there is an early reduction of around -2.5% in the population growth for the scenario ER relative to the reference case, which then gradually eases back to around -1% by 2037. At the other extreme, Inverclyde declines consistently down to -8% relative to the reference case, while the cities of Dundee (-6.6%) and of Aberdeen (-6.1%) also have strong relative declines. Figure 35 also indicates that some areas such as Falkirk, Clackmannanshire and Midlothian have quite unstable patterns of difference through time, in which major declines are then followed by major recoveries. We show below that these cyclic patterns are closely tied in with the representation in the model of the growth trajectory for residential floorspace and of the influence on it of the local availability in each year of land for residential development.

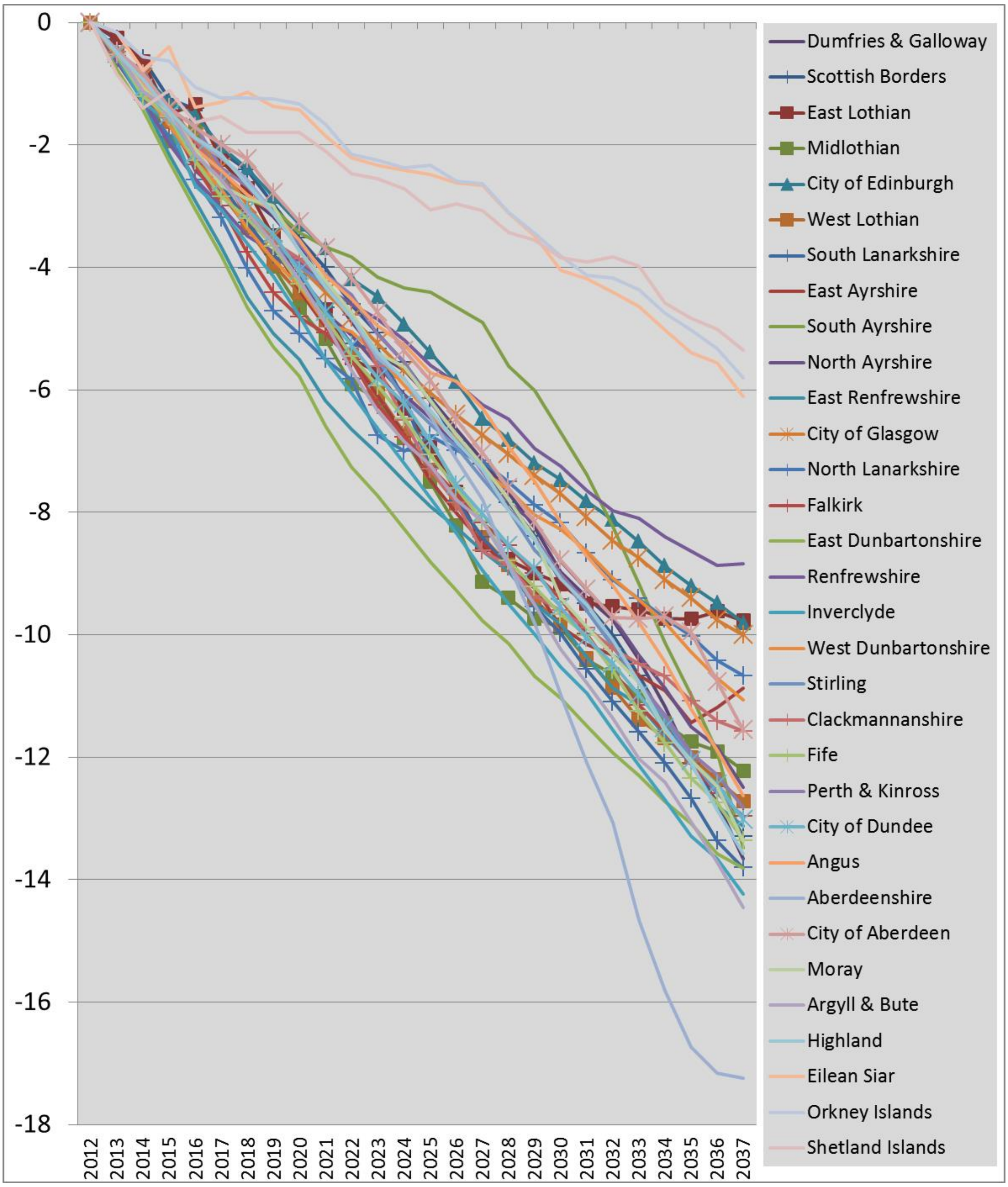


**Figure 36 Percentage difference in employment (jobs), by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.7 The slower relative growth in employment occurs consistently in all areas in the scenario ER, as illustrated in Figure 36. The Islands have relative declines of around -6% by 2037, while most other areas decline consistently down to between -9% and -14%, with only Aberdeenshire as an outlier with a decline of -17%.

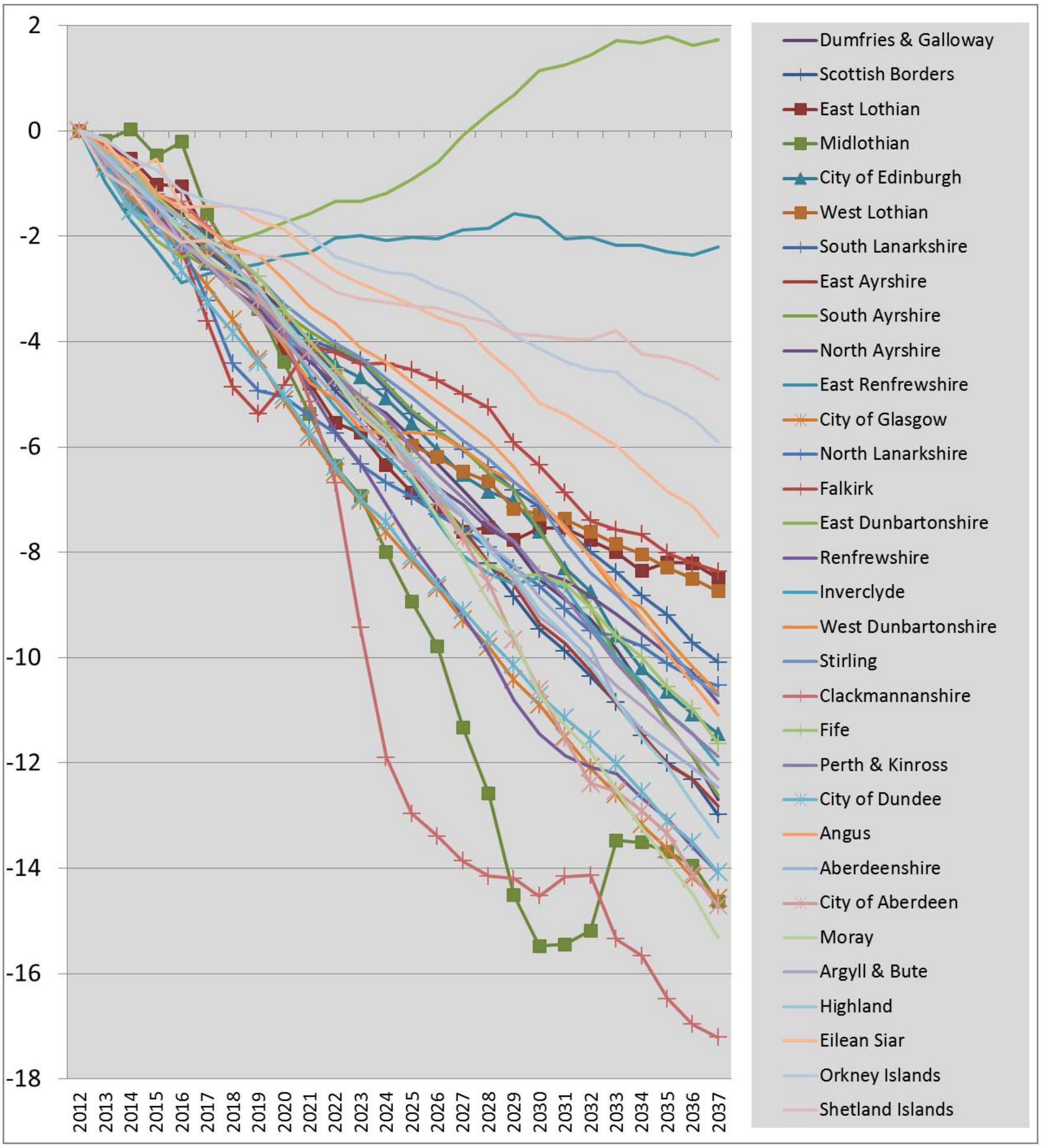


**Figure 37 Percentage difference in resident workforce, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.8 The slower relative growth in employment in turn leads to a slower relative growth in the workforce resident in almost all areas in the scenario ER, as illustrated in Figure 37. However, in this case the spatial distribution of the trend in relative declines is less uniform at the home end than that at the workplace end, as illustrated previously in Figure 36. East Dunbartonshire and East Renfrewshire exhibit relative growth from 2016 onwards, whereas Clackmannanshire and Midlothian exhibit very steep relative declines until the mid-2020s and erratic growth thereafter.

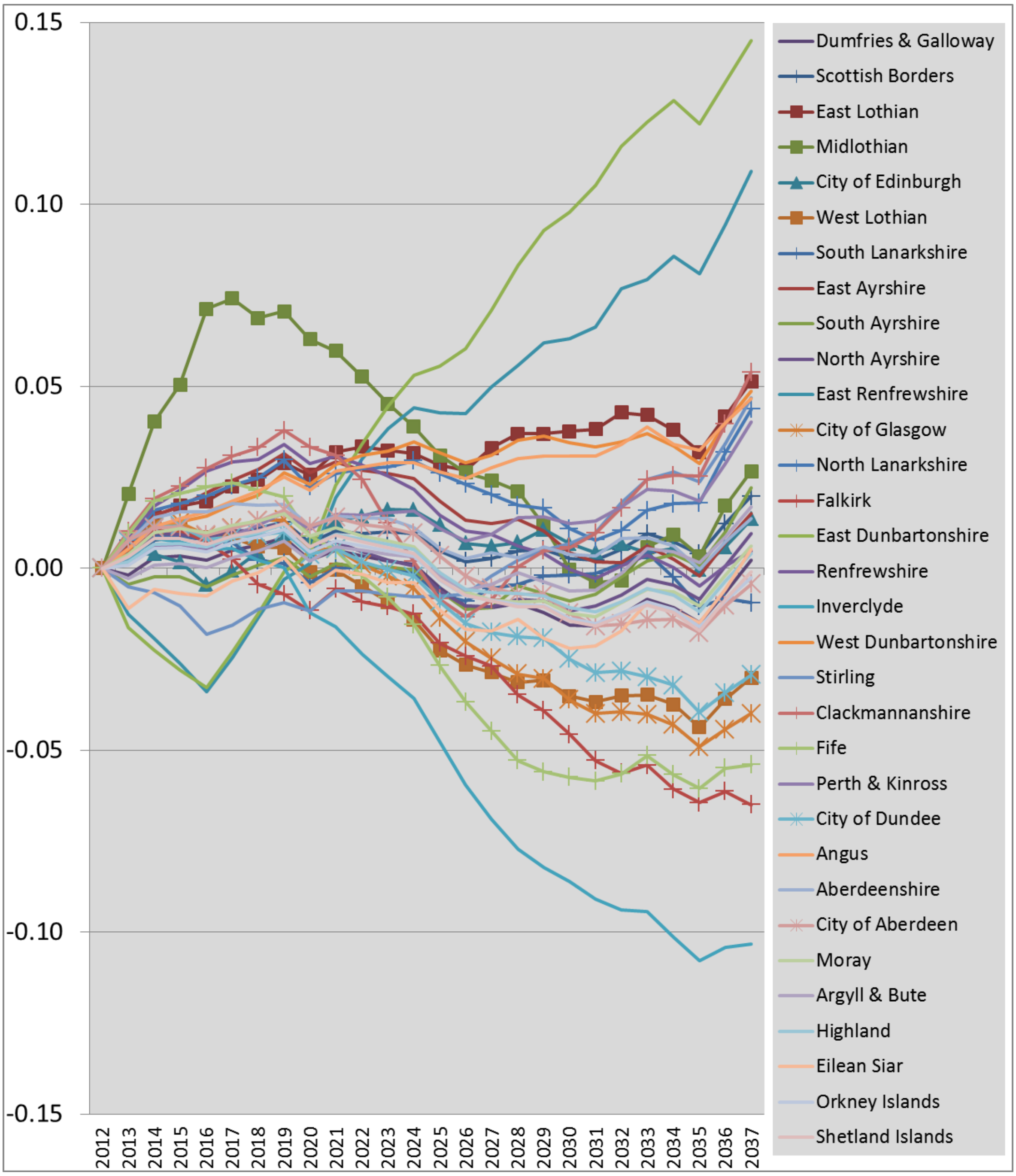


**Figure 38 Absolute difference in household size, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.9 At the national level the 10% decline from 2.2 to 2.0 in average household size occurred at similar rates in the low growth scenario ER as in the reference case BQ. However, Figure 38 indicates that areas such as East Dunbartonshire, East Renfrewshire, Midlothian and East Lothian, which were among the areas with the largest initial household sizes in 2011, declined less in the scenario ER than in the reference case. In contrast, Inverclyde declined significantly more rapidly in the scenario ER than in the reference case.

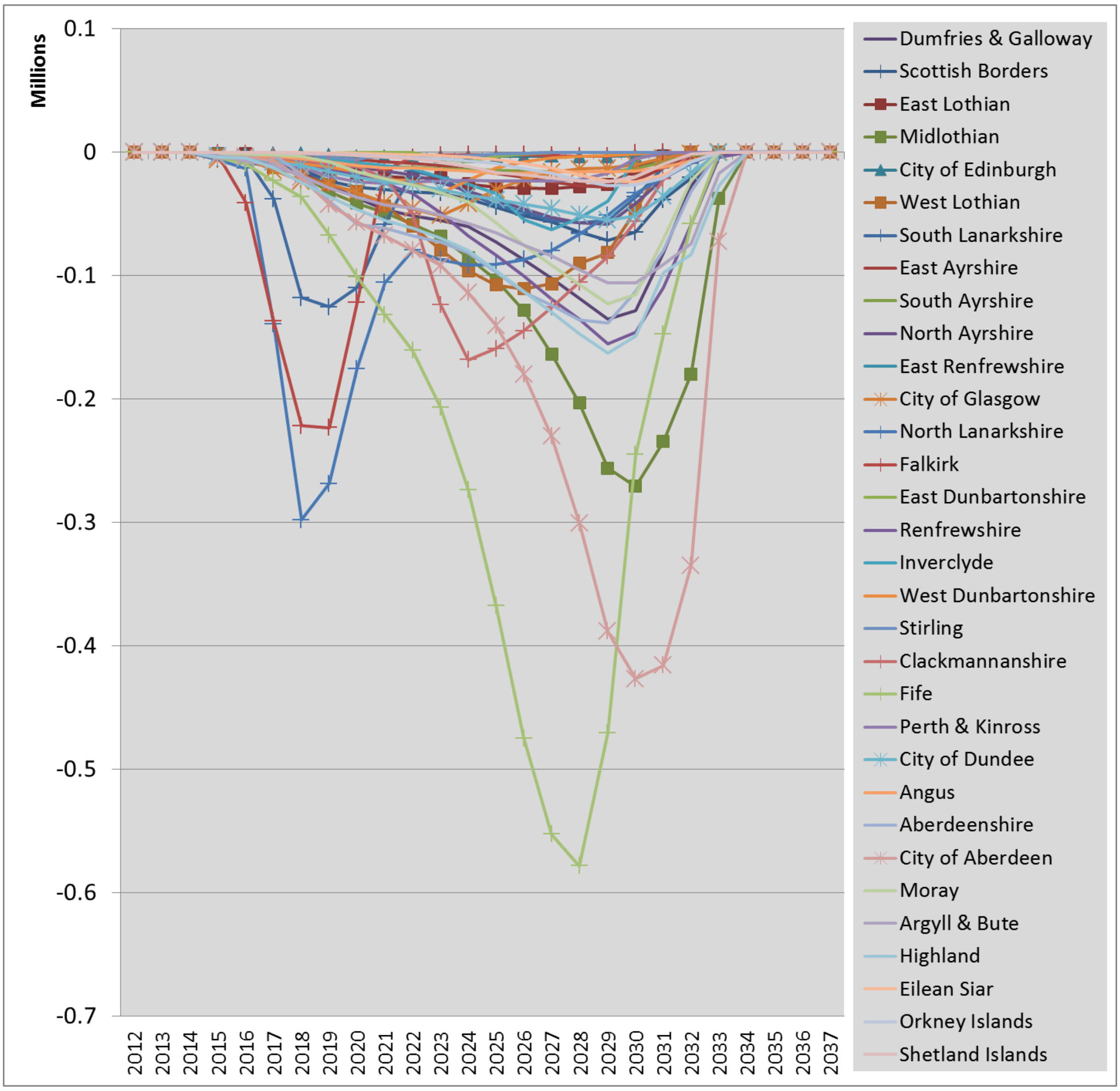


**Figure 39  Absolute difference in residential floorspace volumes, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.10 Figure 39 shows significantly lower volumes of residential floorspace for the scenario ER for some areas but only during the middle period from 2017 to 2033. At the start and end of the period the volumes are identical throughout all areas. This indicates that in the low growth scenario ER, the developable land is taken up significantly more slowly in councils such as, North Lanarkshire, Fife and City of Aberdeen. However, all of the available land zoned for residential development has been exhausted by the early 2030s, so that even these less popular locations will also have been filled up by this time.

10.3.11 The commercial floorspace growth for the scenario ER, relative to the reference case, produces relative reductions that:

- for retail are between 0 and -1% in all areas but only during the period 2015 to 2025, after which in each year the scenarios have identical volumes;
- for office the reductions start showing up from 2019, increasing gradually to -8% to -14% for a number of areas by 2037;

- for industrial the reductions by 2037 have grown to -3% to -6% for a number of areas.

There is zero difference between the runs throughout the period in the zonal floorspace volumes for the hotel, education and health activities. Their growth pattern appears not to be influenced by economic or demographic developments.

10.3.12 An important implication of the identical values across the two test runs in the later period for the forecasts for their residential and for their retail floorspace volumes is that it effectively removes the long term influence of planning policy on residential and retail locations in the model's responses. It also helps to explain some of the more substantial cyclic relative increases followed by reductions in the population differences illustrated previously in Figure 35.

10.3.13 For all residential and commercial floorspace types there is a continuing decline over time in the rent level for run ER relative to the reference case. This rent decline is what would be expected to occur as a result of the lower rate of population and employment growth in this scenario.

10.3.14 The charts above have provided an overview of the demographic and economic impacts across both time and space forecast by TELMoS for the low growth scenario ER. They provide the context for the next stage of the analysis below which examines how these impacts feed through to influence the zonal trip end volumes within TMfS, starting by examining the trends in household car ownership.

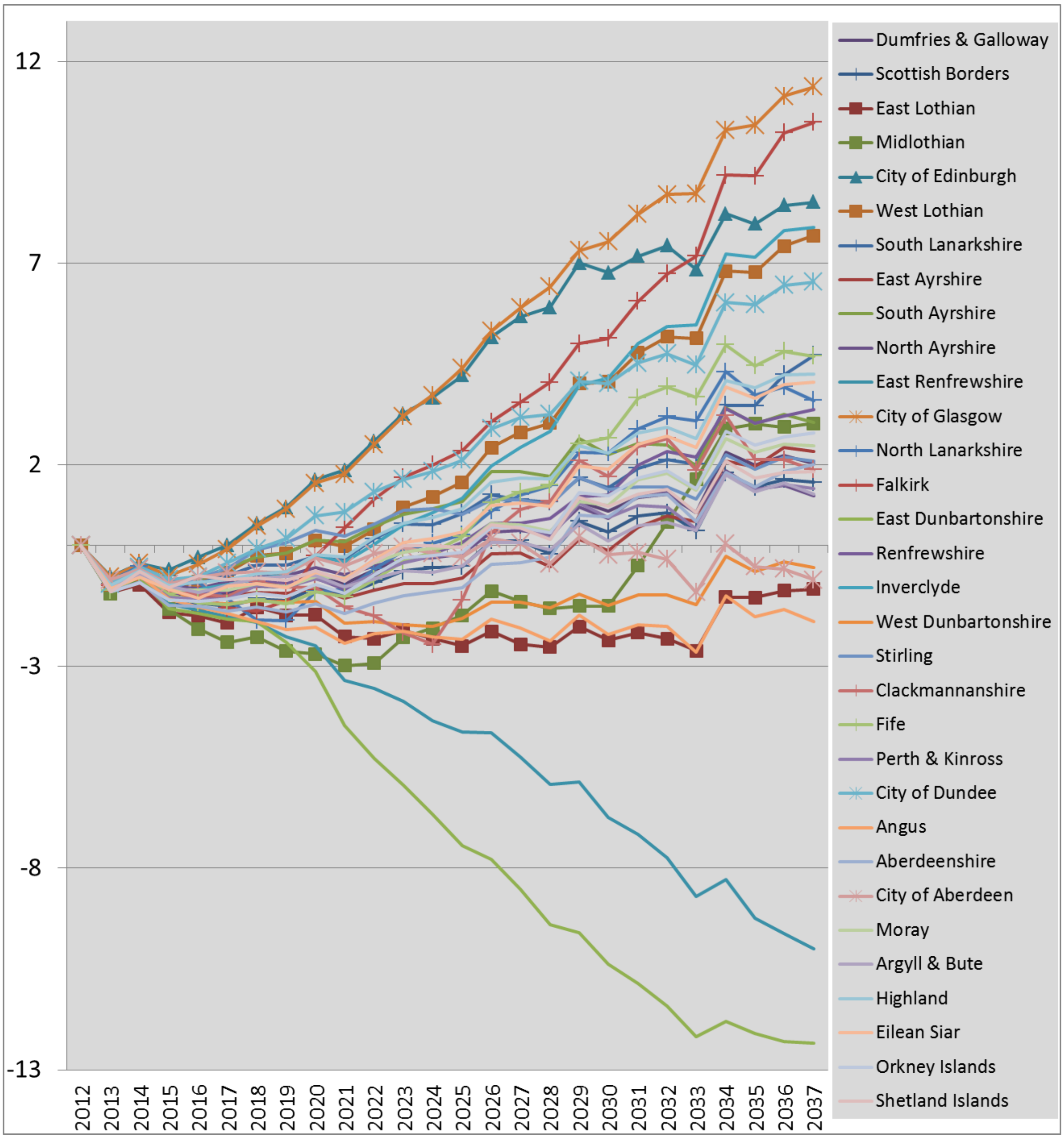


**Figure 40 Percentage difference in households with no car, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.15 Figure 40 indicates a gradual percentage growth over time for most areas in the number of no car households in the low growth scenario ER, relative to the reference case run. East Dunbartonshire (-12%) and East Renfrewshire (-10%) are the only council areas that exhibit major declines in the relative number of households with no cars. For Scotland overall, the households with no cars increase over the period by 17% in scenario ER but only by 11% in the reference case. This forecast is consistent with expectations regarding scenario ER that its lower economic growth should reduce the number of households that have cars available.

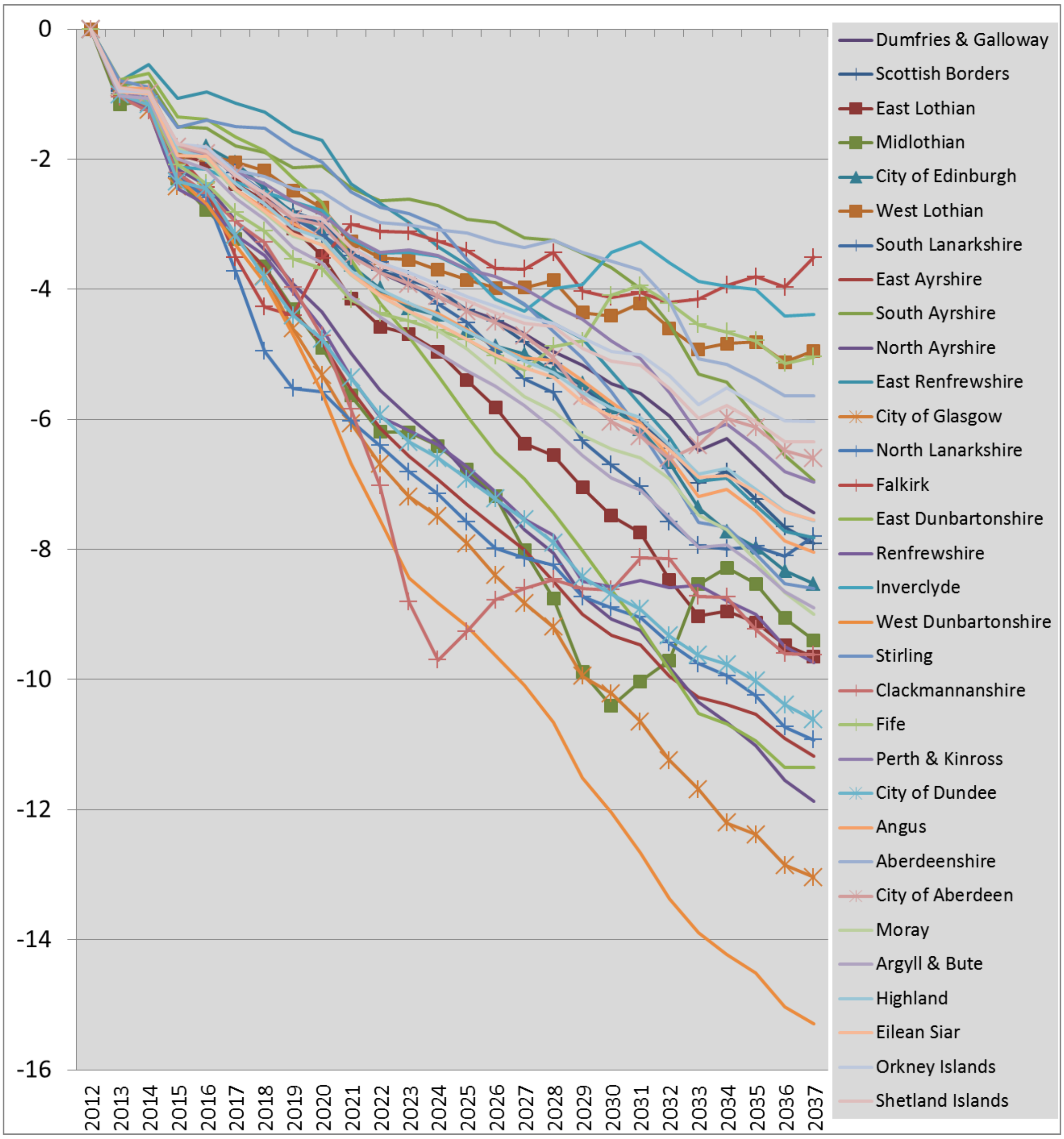


**Figure 41 Percentage difference in households with one car, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.16 Figure 41 indicates a consistent percentage decline over time for all areas in the number of one car households in the low growth scenario ER, relative to the reference case run. For Scotland overall, the number of households with one car increases over the period by 27% in scenario ER but by 39% in the reference case. This reduction in scenario ER is due to a mixture of fewer households overall, as well as to fewer with cars due to lower economic growth.

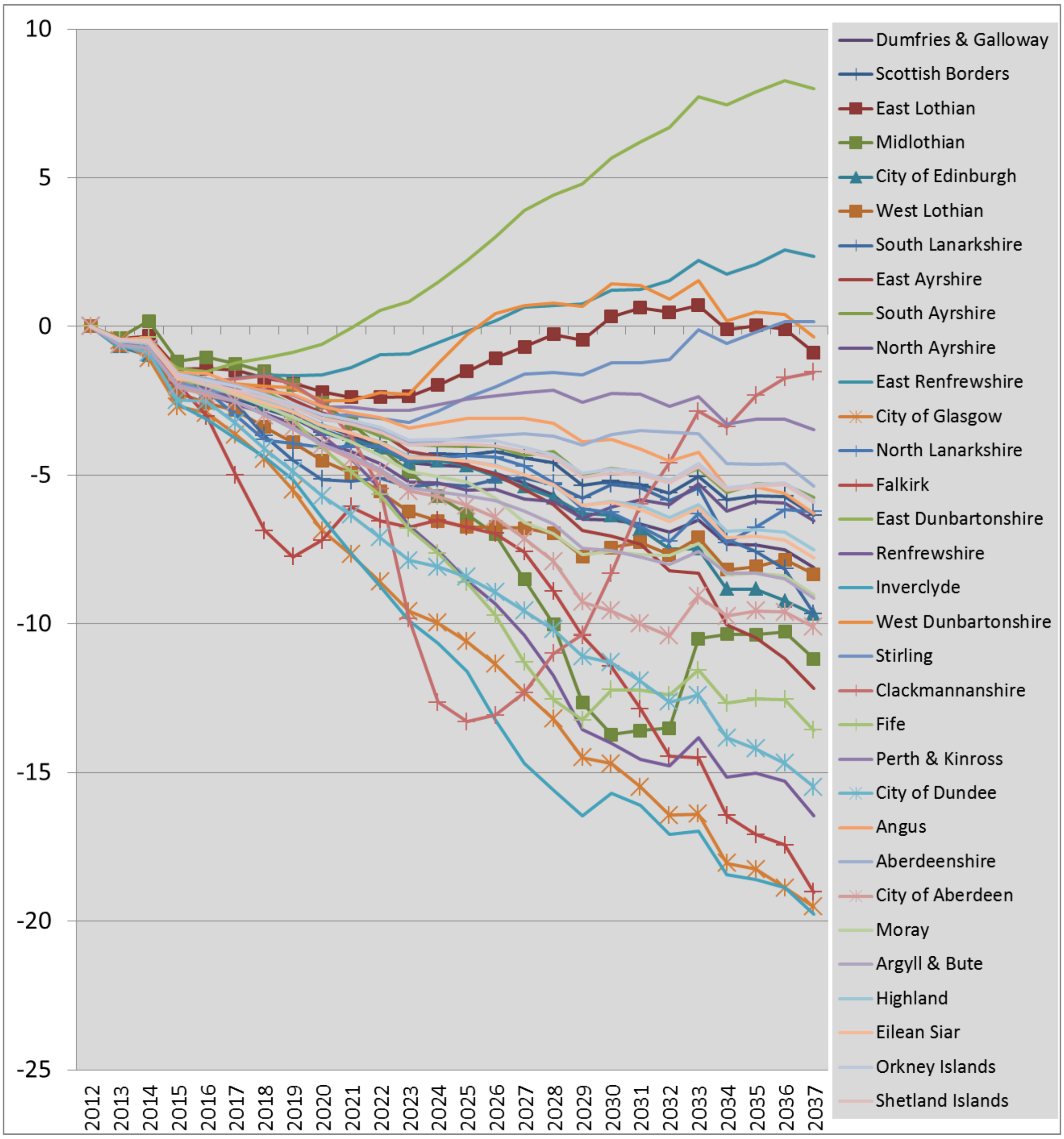


**Figure 42 Percentage difference in households with two or more cars, by council area, 2012-2037, Scenario ER minus reference case (BQ)**

10.3.17 Figure 42 indicates a spatially varied percentage change over time for the number of households with two or more cars in the low growth scenario ER, relative to the reference case run. For Scotland overall, the households with two or more cars increase by 2% over the period in the reference case but reduce by -7% in scenario ER. This reduction is a combination of both fewer households and lower incomes in the scenario. There are however increases for scenario ER relative to the reference case for East Dunbartonshire (8%) and East Renfrewshire (2%), in contrast to the relative reductions of almost -20% in Falkirk, Inverclyde and the city of Glasgow and of over -15% for Renfrewshire and the city of Dundee..

10.3.18 The reason why we have focused in detail here on car ownership patterns is because in NTEM the car ownership level has a major impact on the estimated trip rates for mechanised modes. Those in households without cars make many more trips by walk/cycle and by public transport modes and correspondingly fewer by car. Those households with as many cars as adults make the highest proportions of mechanised trips (Table, 4.2, ME&P, 2000). Accordingly, the analysis of the file cozn37er[26] indicates that a major cause of the forecast reduction in trip making within TMfS is due to the low growth scenario ER having a larger proportion of its population within households with no cars than that in the base case.

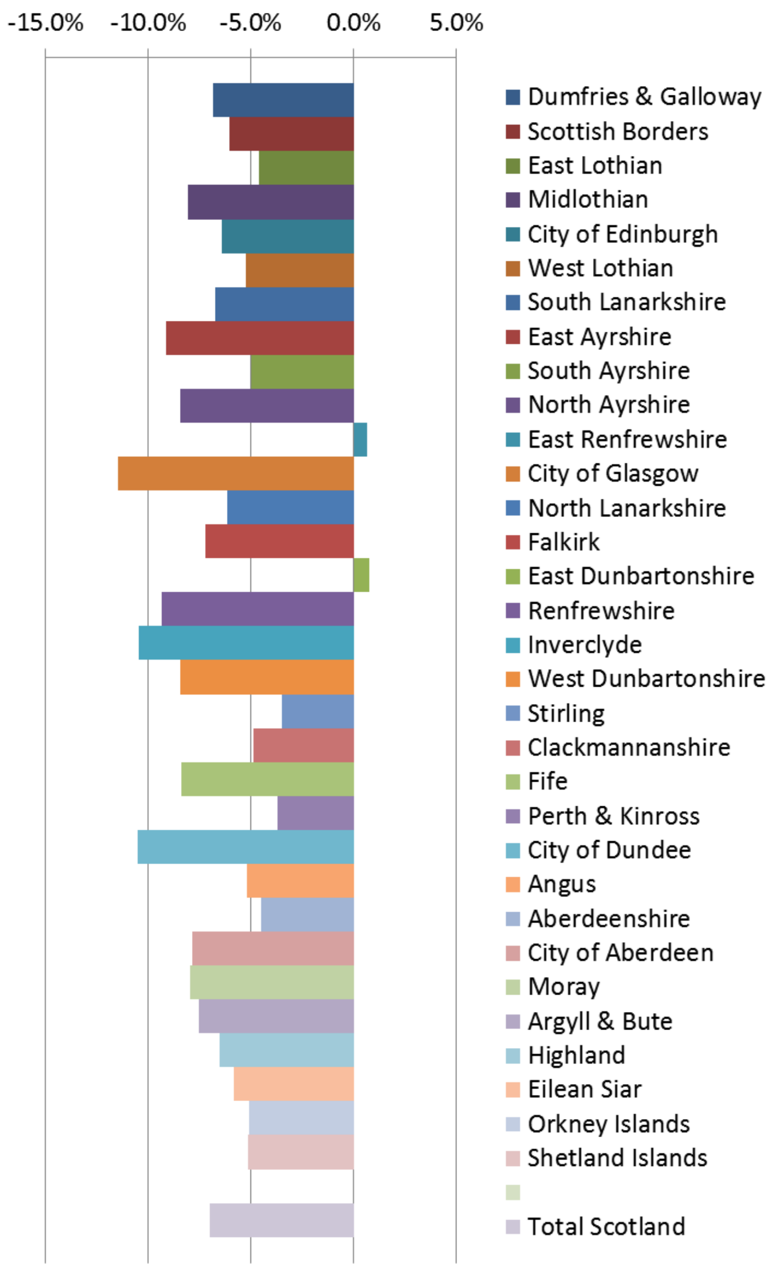


**Figure 43 Percentage difference in total trip productions by council area, 2037, Scenario ER minus reference case (BQ)**

[26] Source analysis in "cozn37er_INW.xlsm"

10.3.19 Figure 43 presents[27] the percentage change in zonal trip productions in 2037 for the scenario (ER) relative to the reference case (BQ) for each council area. The national overall reduction in trip productions by mechanised modes is -7%, with reductions greater than -10% occurring in the cities of Glasgow, Dundee and in Inverclyde. In contrast there was growth of around 0.5% in both East Renfrewshire and East Dunbartonshire, while remaining council areas declined by between -3.5% and -9.3%.

10.3.20 A comparison for the scenario ER of those council areas in Figure 43 that show the greatest and the least percentage declines in trip productions versus in Figure 42 those council areas presenting the greatest and least declines in the number of households with two or more cars, suggests that there is a reasonably close relationship between these two spatial patterns. This is as expected for the reasons above explaining the strong relationship within NTEM of high car ownership levels on high mechanised trip rates.

10.3.21 **This comparison suggests that the trip production mechanism works in practice in the form that is expected from the underlying methodology.**

10.3.22 **The comparison also highlights the crucial role that accurate car ownership forecasting should play in determining the future level of mechanised travel demand.**

## 10.4 Conversion of Transport Costs into Accessibility Information

10.4.1 Section 12 of the TELMoS12 MDR documents how the OD matrix of generalised costs that is output from the transport model is used to calculate origin and destination zonal accessibility measures for use in TELMoS.

10.4.2 The output files produced by TMfS are documented in TELMoS12 PN17:

> "4.02 The data transferred is used in the land use model's calculation of accessibility. It includes a set of 18 files (in each transport model year) that provide information on inter- and intra-zonal generalised costs for:
>
> (a) four transport modes (car, public transport, light goods vehicle and other goods vehicle);
>
> (b) three time periods (AM peak, inter-peak and PM peak); and
>
> (c) for passenger travel only, in-work and not in work travel.
>
> 4.03 There is one 'total' value for generalised cost for each combination of mode, time period and work status. There is no disaggregation into money, time or other components."

[27] Source analysis in "tmfs37_AER_INW.xlsm"

10.4.3 These generalised costs of travel (measured in units of time - minutes[28]) by zone pair are used to create seven zonal accessibility measures, segmented into five passenger trip purposes (1 - Commuting SEL 1, 2 - Commuting SEL 2, 3 - Employers business, 4 – Shopping, 7 - Education), as well as purpose 5 – light goods and 6 - other goods vehicles. Separate files are produced for origin and for destination zones and sets of files are generated individually for the TELMoS runs for each of the five intervening years through until the year of the next run of the transport model.

10.4.4 The accessibilities related to passenger travel are calculated using weighted logsum averages of the generalised costs for the three passenger modes (car public, transport and walking). There is no modelling of walking within TMfS, so walking (generalised cost (i.e. time) in TELMoS is based on distances produced by TMfS12, converted using an average walking speed of 6 km per hour. Where the time taken to walk is greater than 20 minutes then the calculation of time is doubled (for the time in excess of 20 minutes).

10.4.5 The accessibility measures are distinguished between those with 0, 1 or 2 + cars in their household, which implies that an implicit mode and destination choice model, segmented by household car-ownership type and by trip purpose, is used in effect within TELMoS to create these logsum zonal accessibility values. This approach suggests that consistent choice hierarchies and parameter values should be expected to be applied within the analogous choice stages common to TELMoS and TMfS.

10.4.6 However, our review of the documentation indicates that there are a number of important differences between the TMfS[29] and TELMoS[30] models in the form in which the generalised cost of travel by mode between zone pairs enters into their respective choice procedures:

a) TMfS uses the weighted sum of the cost plus the log of cost, whereas TELMoS includes just the cost term;
b) TMfS uses choice coefficients that have values common to all zone pairs, whereas in TELMoS the value of the mode choice coefficient can vary with the distance from zone i to j;
c) TMfS uses a choice hierarchy of mode above destination, whereas TELMoS uses the reverse with destination above mode;
d) TMfS uses only car and public transport within its passenger mode choice options, while TELMoS includes both these mode but also walk.[31]

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[28] See Section 2.4 of TMfS Demand Model Development Report (2015)
[29] Based on documentation in TMfS 12 DMD Section 4.4.
[30] Based on documentation in TELMoS12 MDR Chapter 12 and Appendices A1 to A4.
[31] Response from DSC: *PN75 was written in response to similar issues being raised for TELMoS07 and TMfS07. We believe the conclusion was that no change in the modelling approach was justified (at that time). We are not aware of any new research and/or analysis that would justify a different conclusion being reached now.*
**Auditor response**: See discussion below in footnote to para. 10.4.8.

10.4.7 In the calibration of the choice parameters in TMfS it was found that the destination choice was more sensitive than the mode choice, due to the scaling factor for destination choice being the larger. In TELMoS there is no corresponding calibration of these parameter values, nor are they carried across from TMfS. Instead the MDR states:

> "12.3.4 The accessibility calculations themselves are shown in the Appendix A.2, which explains the different hierarchy calculations. The destination and mode parameters used are shown in and are input in blocks ACIN01 and ACIN02 respectively. The coefficients used in the accessibility calculations are values for mode and destination choice which DSC (and others) have used in a range of studies dating back to the 1990 Edinburgh JATES study."

10.4.8 Given the incremental manner in which both TMfS and TELMoS have been first developed and then enhanced over the years, it is perhaps understandable that some differences exist between them. However, the use of conflicting choice hierarchies between them is particularly unhelpful as it may imply conflicting rates of responses to mode or destination zone specific policy measures. **There is now a strong case for removing unnecessary differences between their choice models in the next round of updates and enhancements to TMfS and TELMoS.** This would then ensure that the scale of their responses to policy and investment measures would be consistent across them.[32]

[32] Response from DSC: T*his was considered in the Audit during the last commission and the conclusion was that there was no case for the same choice hierarchy as the choice is different.*
**Auditor response**: This is perhaps the only topic on which a significant difference of opinion exists between the auditor and the model developer. My primary reservation relates to the locational relationship between resident labour and employment and to uncertainty regarding its sensitivity to transport cost changes.
Accordingly, it would be informative at some future date to examine two sensitivity tests, each based on a common set of significant local modal transport improvements. In one test, only the TMfS changes in modal trip patterns by trip purpose would be examined, but without any relocation of activity over time. The other test would include such relocation effects. The interest is to compare the gross and the net travel responses to ensure that both appear to be plausible and that the resulting elasticities are those expected. The local changes in population and employment patterns and in commuting patterns should also be examined.
To obtain maximum information from this test it would be preferable to examine a set of different transport generalised cost/time changes in separate distant parts of the country. The aim is to have a cross-section of examples within the test, each just one cost change in one corridor within a specific TTWA, some on road and some on rail, with perhaps some as improvements and others as disimprovements. Each cost change should be large enough to lead to a significant travel change within its corridor but not large enough to impact further afield. In this way the pair of runs would enable a cross-section of example responses to be reviewed cost-effectively for different types of modes and of settlements.
Provided that the resulting travel responses and elasticities appear to be reasonable, across modes and trip purposes, then there would be solid support for the current differentiated procedures between TELMoS and TMfS.
It would be helpful also to explore, whether the large difference in employment change and resident labour change in Clackmannanshire discussed in TN002 is at all related to the above issues.

10.4.9 The zone pair travel impedance is currently measured in units of minutes per trip, rather than of disutility, so that these units of measurement are invariant across all travel segments and across both models thus simplifying the introduction of parameter values that are consistent across the models.

**10.4.10 Because the choice hierarchy and its parameter values have already been calibrated within TMfS based on observed behaviour, it seems appropriate that these should be ported across for direct use within TELMoS, thus adopting the TMfS approach for the differences a) to c) above.**

10.4.11 **The only exception relates to the difference d) above, where instead the inclusion of the walk mode within TELMoS should be replicated within TMfS.** This is because of the continuing importance of both the walk and cycle modes within the denser urban areas, particularly in and around Edinburgh (Cycling Scotland, 2015), where observed growth in car ownership rates has been low or negative and where alternatives to car have increased their competitiveness.

10.4.12 This is likely to also imply that some adjustments to the segmentation of household / traveller types and of trip purposes may need to be made so as to avoid *unnecessary* differences between models. This does not imply that the level of segmentation detail must be identical across models but rather that the classes adopted in one model should be simple aggregates of those used in the other, unless there are strong reasons otherwise.

10.4.13 The recommendation above for increased consistency between TMfS and TELMoS should not in itself imply a reduction in consistency between TELMoS and any other models such as CSTM to which it is interfaced. On the contrary, the switch to use in TELMoS the calibrated parameters and choice hierarchies from TMfS appears likely to make TELMoS more similar also to the policy responsiveness of these other models.

## 10.5 EXAMINATION OF ACCESSIBILITY IMPACTS

10.5.1 In their Note TN002, the auditors requested

"that DSC and SIAS should provide outputs from TMfS and TELMoS which demonstrate:

- How TELMoS accessibility scores for urban and rural zones vary, linked to variations in TMfS transport costs (both PT and car), and proximity of relevant trip attractions.
- How the accessibility scores for given zones alter due to changes in TMfS costs (both PT and car)."

10.5.2 The test runs PQ/PR (do-minimum) and PS/PU (A9 Perth–Inverness scheme)[33] are analysed here to demonstrate the impact of TMfS cost changes resulting from the A9 scheme on the TELMoS forecasts of household and employment location patterns from 2027 onwards. The planning data file TAV_<><>.CSV that is output by TELMoS and then *input* to the trip end model for the year 2032, has been examined to understand the chain of accessibility impacts of TMfS transport supply changes on the resulting TELMoS land use changes and then through to the associated trip end estimates for future years.

10.5.3 The clearest way to illustrate the scale and spatial pattern of the changes in location patterns that have resulted from the investment in the A9 scheme is to graph the percentage difference in total households and employee numbers by council area. These are illustrated in Figure 44 and Figure 45 respectively graphing the A9 scheme policy run PU, less the do-minimum run PR, annually from the entry of the scheme into TMfS in 2027, through to 2037. The A9 scheme would primarily improve the accessibility of the Highlands and Moray northern council areas to Perth and southwards to the Central Belt.

10.5.4 The percentage change impact for households that is forecast from the scheme is tiny at the council area level, with growth increases by 2037 of around 0.07% for Highlands, Moray and Perth[34]. It can be seen from Figure 44 that their systematic growth trends are only marginally greater in magnitude than the random noise variations in household numbers in other council areas that have arisen from these model runs.

[33] These test runs PQ and PS refer to the TELMoS runs to 2032, whereas the corresponding PR and PU runs take the outputs from the TMfS run of 2032 as the basis to then run TELMoS through to 2037.

[34] These three council areas are illustrated by dashed lines

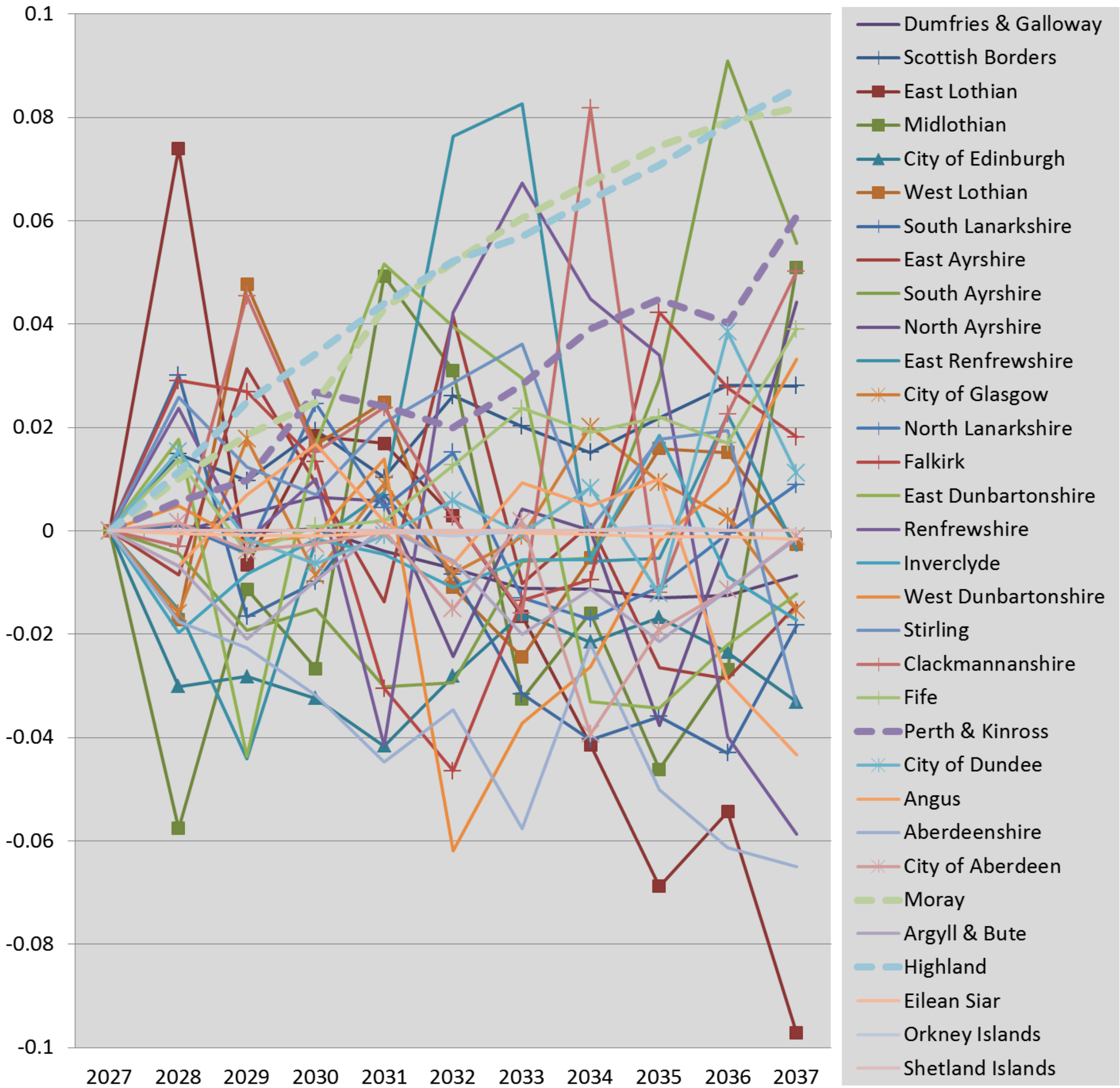


**Figure 44 Percentage difference in total households by council area to 2037 for A9 Scheme (PS/PU) minus do-minimum case (PQ/PR)**

10.5.5 The percentage impact on employment from the A9 scheme that is forecast in Figure 45 at the council area level by 2037 is considerably greater than that for households, though it is still small. There are small employment gains in Highlands (0.7%) and in Perth (0.4%) and no change in Moray, a magnitude and pattern that is plausible.

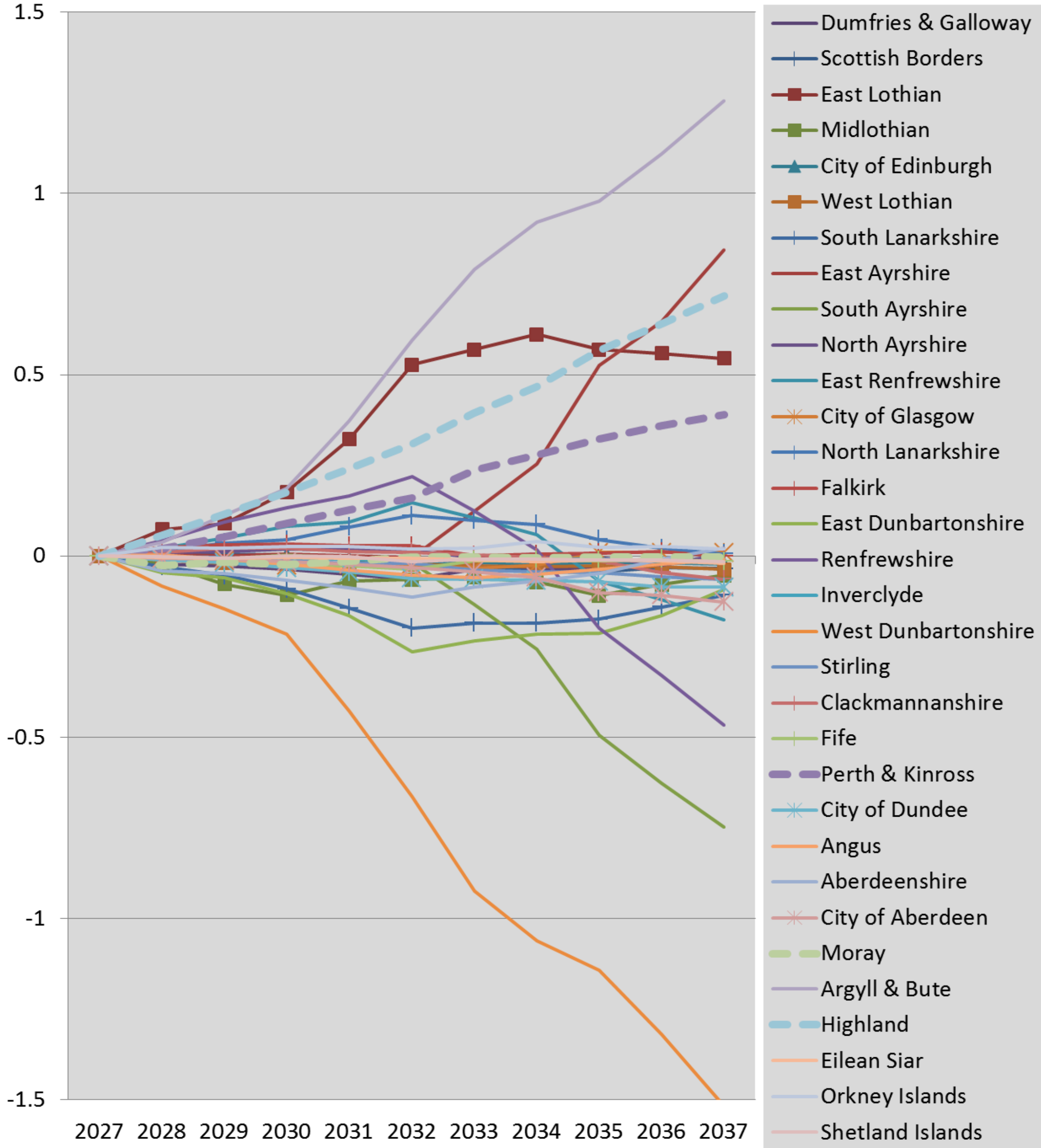


**Figure 45 Percentage difference in total employment by council area to 2037 for A9 Scheme (PS/PU) minus do-minimum case (PQ/PR)**

10.5.6 Surprisingly, there are larger forecast percentage gains in employment in East Lothian (0.9%) and Argyll & Bute (1.3%), while the largest percentage reductions in employment arise in Renfrewshire (-0.5%), South Ayrshire (-0.7%) and West Dunbartonshire (-1.5%). These all are areas that are distant from the A9 scheme so that the underlying reason for these scheme-induced employment changes is not clear. The growth and decline trends in these distant areas are too large and too consistent through time to be likely to be just a result of minor random model noise. **Accordingly, the operation of the underlying**

**accessibility mechanism in influencing the location of individual employment sectors requires further investigation.**[35]

10.5.7 These unexpected employment impacts in areas remote from the scheme may simply be a manifestation of the inconsistencies in land use responses that could be generated due to the lack of consistency in the choice hierarchy and parameters between TELMoS and TMfS that has been discussed at the end of Section 10.4 above, so that removing these inconsistencies may be a good starting point for investigation.

# 11 SUMMARY OF FINDINGS AND RECOMMENDATIONS

11.1.1 The main recommendations for future actions and enhancements to TELMoS are now summarised based on the findings of the model audit analyses that have been documented above.

11.1.2 A wide variety of distinct source documents have needed to be utilised in Section 10 above to develop a clear picture of the operation of the data processing and data flows relating to the interface between TELMoS12 and TMfS12. This proliferation of documentation sources makes it difficult to grasp the exact functioning of the interface and it increases the chances of misinterpretation of its operation.

> **BR1:** Reorganise and unify the documentation of the interface into a single, updated and complete description.[36]

11.1.3 This may be best allocated to a standalone interface document that can then be referenced directly without duplication from each of the TELMoS and the TMfS model description documents. An analogous document could also be produced to document the interface used between TELMoS and CSTM.[37]

11.1.4 The car ownership patterns produced by TELMoS are a very important input to the forecasts in TMfS since they are a major determinant of the spatial pattern of car demand, as well as of the overall level of demand for travel, by virtue of the use in TMfS of overall trip rates for mechanised modes, which differ between car ownership categories.

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[35] Response from DSC: *In the work for the A9 Business Case we did discuss raise concerns about 'noise' in the generalised cost data that was received from the transport modellers. This manifested itself in the calculations of accessibility made within TELMoS that are then used within the modelling of location choices.*
*Some of the changes (ie along the A82) would 'defended' by the transport modellers as being a reduction in congestion along that route as some trips between Glasgow and Highland were re-assigned to the A9.*
[36] Response from DSC: *Noted. We would suggest that the Lot 1 and Lot 3 consultants appointed to the new commission jointly scope some such documentation.*
[37] Response from DSC: *The TELMoS14 model development report includes an enhancement for the development of interface mechanism to one or more regional models. Standard documentation of the approach to interface should be prepared – with variant approaches identified and documented as an appendix.*

11.1.5 Although there is a very close match in TELMoS to the observed household numbers in total for 2011, there are consistent and significant differences from the observed values in the car ownership composition of these households in 2011 both at the council area level and at the overall national level for Scotland.

> **BR2:** The methodology that was adopted to create the COZN file for 2011 should be revisited to ensure that an improved match to the observed 2011 household car ownership shares is achieved across all zones.[38]

11.1.6 The realism of the forecasts that are made of the car ownership categorisation of households was checked using three complementary approaches:

- A broad comparison of the forecasts from 2007 to 2031 against the outturn Census trends from 2001 to 2011 but using the earlier TELMoS07 model runs rather than the current TELMoS12 model runs;
- A comparison of the short term forecasts from 2011 to 2021 from the TELMoS12 reference case run BQ, again against the outturn Census trends from 2001 to 2011;
- A long term review of the TELMoS12 forecast trends through to 2037.

11.1.7 This review of the forecast household car ownership trends has identified a very wide range of trajectories both over time and between council areas. These trajectories rarely match observed previous trends in their particular area and in some cases they appear to reverse them. There may be behavioural evidence that can be assembled that justifies both the specific major deviations from the average trajectories and the reversals of the previous trends presented for particular areas.

> **BR3:** However, if such evidence is not forthcoming it would be wise to reorganise the forecasting model:
>
> - to match the observed base year spatial pattern of household car ownership rates;
> - to then forecast a zonal pattern of change in these household car ownership rates that is less extreme in its differentiation between areas and that does not present radical reversals from past local trends except where there is evidence to support them.
>
> To achieve such improvements to forecasting performance it is likely that significant changes will need to be made to the current household car ownership model structure and/or parameters and suggestions based on the forthcoming new version of DfT's NATCOP model have been provided on how this might be achieved.

11.1.8 The manner in which the results output from TELMoS are used to generate the trip ends within TMfS was examined. The provision of the planning data from TELMoS for use in the trip end estimation and car ownership segmentation within TMfS is carried out in an effective fashion throughout; it maintains a suitably high degree of segmentation in a consistent manner. This data is then used in tandem

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[38] Response from DSC: *The comments above explain the difference in the base year (2012 – not 2011) and the 2011 Census. When preparing TELMoS12 there was no 2011 Census material available. SHS data was used. TELMoS14 has had wider access to Census material. The audit of that model should find consistency between the 2011 Census and the TELMoS14 calculations of car ownership in 2011 that were used to calculate the 2014 base.*

with the trip rates input from NTEM in a suitable fashion to generate the required zonal trip productions, segmented by trip purpose and car ownership category. A few suggestions have been provided for minor enhancements to the procedures in order to further improve its overall performance. The documentation of this procedure should be improved as part of recommendation 1 above, so as to clarify that the assumptions that we made above to in-fill gaps in the existing documentation are soundly based.

11.1.9 DSC has provided the auditor with the relevant input and output files for the trip end model for the final year 2037 for the reference case run BQ and alternative scenario ER (Low population, Low economic growth). These files, together with the standard yearly zonal activity output files from TELMoS have been examined to understand the impact of TELMoS land use changes on TMfS trip generation patterns.

11.1.10 A comparison for the scenario ER of those council areas that show the greatest and the least percentage declines in trip productions versus those council areas presenting the greatest and least declines in the number of households with two or more cars, suggests that there is a reasonably close relationship between these two spatial patterns. This is as expected due to the strong relationship within the parameters governing trip rates in NTEM between high car ownership levels and high mechanised trip rates. In general the comparisons suggest that the trip production mechanism works in practice in the form that is expected from the underlying methodology. The comparison also highlights the crucial role that accurate car ownership forecasting should play in determining the future level of mechanised travel demand.

11.1.11 The next step in the audit examined the reverse direction of the interface, in which the transport costs and characteristics output from TMfS are used to influence the forecast location pattern of floorspace, households and employment within TELMoS. The zone to zone transport supply characteristics that are output from TMfS are segmented by mode and time period and are then transformed into zonal accessibility measures segmented by trip purpose for origins and destinations for use within TELMoS. This transformation mirrors the analogous transport model stages of mode and destination choice carried out in TMfS. On theoretical grounds it would be expected that consistent choice hierarchies and parameter values should be applied within the analogous choice stages common to TELMoS and TMfS but this consistency is not present, presumably due to historic differences in their model development trajectories. The use of conflicting choice hierarchies between them is particularly unhelpful as it may imply conflicting rates of responses to mode or destination zone specific policy measures.

> **BR4:** There is now a strong case for removing unnecessary differences between their choice hierarchies and parameter values in the next round of updates and enhancements to TMfS and TELMoS.

**11.1.12** This should then ensure that the scale of their responses to policy and investment measures would be consistent across them.[39] Because the choice hierarchy and its parameter values have already been directly calibrated within TMfS using procedures that are based on observed behaviour,

> **BR5:** It seems appropriate that the choice hierarchy and its parameter values should be ported across from TMfS for direct use within TELMoS, thus adopting the TMfS approach when resolving any differences. The only exception is that the inclusion of the walk mode within TELMoS should be replicated within TMfS.

11.1.13 This proposal for the inclusion of car and cycle in TMfS is because of the continuing importance of both the walk and cycle modes within the denser urban areas, particularly in and around Edinburgh (Cycling Scotland, 2015), where observed growth in car ownership rates has been low or negative and where alternatives to car have increased their competitiveness.

11.1.14 This recommendation above for increased consistency between TMfS and TELMoS should not in itself imply a reduction in consistency between TELMoS and any other models such as CSTM to which it is interfaced. On the contrary, the switch to use in TELMoS the calibrated parameters and choice hierarchies from TMfS appears likely to make TELMoS more similar also to the policy responsiveness of these other models.

11.1.15 The test runs PQ/PR (do-minimum) and PS/PU (A9 Perth–Inverness scheme) were analysed to demonstrate the impact of TMfS cost changes resulting from the A9 scheme on the TELMoS forecasts of household and employment location patterns and then through to the associated trip end estimates from 2027 onwards. The percentage change impact for households that is forecast from the scheme is tiny at the council area level, with growth increases by 2037 of around 0.07% for Highlands, Moray and Perth. Their systematic growth trends are only marginally greater in magnitude than the random noise variations in household numbers in other council areas that have arisen from these model runs. Although this elasticity of household response appears low, there is a shortage of unequivocal authoritative research evidence on the magnitude and direction of such responses. Accordingly, it may be safer to be under-responsive rather than over-responsive in this relationship.

11.1.16 The percentage impact on employment from the A9 scheme that is forecast by 2037 is considerably greater than that for households, though it is still small. There are small employment gains in Highlands (0.7%) and in Perth (0.4%) and no change in Moray, a magnitude and pattern that is plausible. Surprisingly, there are rather larger forecast percentage gains and losses in employment in areas that are distant from the A9 scheme so that the underlying reason for these latter scheme-induced employment changes is not clear. The growth and decline trends in

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[39] Response from DSC: *See comments above – the approach adopted in TELMoS12 is the same as that applied in TELMoS07. At that time it was concluded that there was not a strong case for changing choice hierarchies etc. We don't believe that a new case has been made.*
**Auditor response:** See alternative viewpoint presented in the footnote above to para. 10.4.8.

these distant areas are too large and too consistent through time to be likely to be just a result of minor random model noise.

> **BR6:** Accordingly, the operation of the underlying accessibility mechanism in influencing the location of individual employment sectors requires further investigation.[40]

11.1.17 These unexpected employment impacts in areas remote from the scheme may simply be a manifestation of the inconsistencies in land use responses that could be generated due to the lack of consistency in the choice hierarchy and parameters between TELMoS and TMfS, as raised in recommendation 4 above, so that removing these inconsistencies may be a good starting point for investigation.[41]

11.1.18 This opportunity to examine and audit the functioning of the interface from TELMoS to TMfS and its reverse has proved to be informative. It has demonstrated the critical importance to both models of having an accurate and reliable car-ownership forecasting mechanism and has highlighted an urgent need for improvement in this mechanism. For many of the interchanges of data between models, the current procedures appear to be working well. However, some of the employment location responses to transport supply changes seemed implausible and this highlights the need for consistency between the models in choice model representation, whenever there is duplication in functionality between the models.

> **BR7:** In future audits, the analysis of the effectiveness of the operation of the interfaces between the individual models should be allocated to one of the auditors of the individual models. This would ensure that important aspects within the modelling system as a whole do not get left aside without proper scrutiny.

# 12 References

Cycling Scotland (2015) Annual Cycling Monitoring Report: 2015. http://www.cyclingscotland.org/policy/monitoring

LeVine, S & P Jones (2012) On the Move: Making sense of car and train travel trends in Britain. Report for the RAC Foundation.

ME&P (2000) Land-Use Indicators and Trip End Models: Final Report. For HETA Division of the Department of the Environment, Transport and the Regions. http://webarchive.nationalarchives.gov.uk/20110202223628/http://www.dft.gov.uk/pgr/economics/ntm/

[40] Response from DSC: *Noted. See comments earlier (footnote to para. 10.5.6) regarding concern with noise in TMfS.*

[41] Response from DSC: *It is not clear why the differences in choice hierarchy between TELMoS and TMfS would give rise to inconsistent responses within one model. Also not clear what would constitute an inconsistency rather than just a difference between the transport and land use impacts.*
**Auditor response:** See alternative viewpoint presented in the footnote above to para. 10.4.8.

# 13 Minor Queries

13.1.1 Why in the TMFS file are zone 67 and the final four zones 709 to 712, each populated throughout with values of “1”, rather than with meaningful values?[42]

13.1.2 Why in the TAV file are the zones 67, 143, 170, 173, 427, 429, 439, 450 and the final four zones 709 to 712 populated in the final column HS with values close to 1, rather than values with magnitudes of 100 – 200,000 typical of the other zones? Is it simply that these zones have no school places in them?[43]

[42] Response from DSC: Zone 67 and zones 709-12 do not contain any resident households. Within the TMfS<><>.csv files they are shown as having zero persons in each category.
**Auditor response:** See tmfs37_AER and tmfs37_ABQ.
[43] Response from DSC: *To what file does this query relate. In TELMoS’ TAV<><>.csv the final column is column I. Column H contains details of employment associated with education. If there is no education land use within a zone then there will be no education-related employment. The figures in column H of DSC’s TAV file have values ranging from 0 to 5,700.*
**Auditor response:** This refers to column 4 of files tav_37_AER and tav_37_ABQ.