



AQMeN (Applied Quantitative Methods Network)

Collaborative Small Grants Scheme

END OF AWARD REPORT

Title of project

A Scoping Study of Geographically Weighted Regression (GWR) Analysis of House Price Estimation: With Applications to Impacts of Crime, Ethnic/Religious Segregation and Landlord Portfolio Optimisation

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The project

Overview

The original aims of the project were to explore the potential benefits and applications of GWR.

(1) To scope-out whether Geographic Weighted Regression (GWR) house price models would offer improvements on existing house price estimation methods, particularly the Fik et al. (2003) Location Value Signature (LVS) approach and to scope potential use in a range of applications including:

- estimating house price impacts of crime in Glasgow
- ethnic/religious segregation in Belfast in collaboration with the Northern Ireland Housing Executive using the Cross Price Elasticities of Prices (CPEP—see Pryce 2013) approach.
- estimation of optimal landlord portfolios joint with Rettie and Co..
- alternatives to W matrix in spatial econometric estimation.

(2) To reflect on the broader potential application of the methods proposed, particularly to:

- Local Authority Housing Market Assessments
- Automatic Valuation and Council Tax Revaluation

(3) To develop training and knowledge exchange materials, and to run a training event on the use and applications of GWR.

Clearly, within the short project time period, our approach to aims (1) and (2) was not to produce a final set of models for each application (each of which would constitute a major project in its own right). Rather, the goal was to demonstrate “proof of concept” – that is, develop the research to the point of being able to confirm or contradict the potential usefulness of GWR in each applied area. The motivation for the project was that, by exploring the potential for a variety of new applications we would be able to lay the foundation for a potential research programme or series of specific projects.

Our goal was to explore these inter-disciplinary uses of GWR in criminology, sociology, housing economics and real estate finance, in collaboration with the Northern Ireland Housing Executive and Rettie and Co. Ltd. These collaborations would, we felt, help bring greater realism and richness to the scoping process, highlighting both potentialities and limitations of GWR. We have also tried to situate the GWR in existing academic literatures both to provide robust theoretical social science conceptual frameworks for our analysis and also to avoid duplication of existing work. For example, with respect to the use of GWR to estimate housing submarket boundaries, it is clear from recent work by Pryce (2013) that there are significant theoretical and statistical problems in the naive application of GWR. Nevertheless, we felt there was potentially considerable mileage in using GWR to estimate the first step in a new generation of housing market estimation methods based on house price dynamics rather than attribute coefficients.

In addition, we have successfully explored applications to social/religious segregation in Northern Ireland, to optimal landlord portfolio estimation and (unexpectedly) to the reform of Succession Law. These and other applications are discussed below under Beneficiaries and Collaboration.

Methodology – Analysis

This was a scoping project seeking to show proof of concept; at a minimum it sought to produce for a given city a table where for every dwelling in the dataset for a UK city, there was a value representing the difference in house prices for each quarter between two years, and to produce syntax that could then be applied to calculate this for subsequent year pairs. This was achieved for London for the years 2007 and 2008.

The project first linked together data from Nationwide on house prices, with data providing information on postcode locations from the Office for National Statistics Postcode Database. This provided an Ordnance Survey British National Grid reference (a six figure Easting and Northing) for each data observation in the Nationwide dataset as well as information on which of a number of different statistical and administrative geographies that each data observation fell within.

Geographic Weighted Regression was used to produce models which could predict house prices for 3 cities on a quarterly basis over a six year period using available data on an annual basis to predict the house value in a given year and quarter for dwellings for which there was data available on the house attributes but where the house value was not known.

A hedonic automatic valuation model was designed and run first as an Ordinary Least Square regression using the `lm` command in R, and then as a GWR regression using the `gwr.basic` and `gwr.predict` functions in the `GWmodel` package. Both exploratory and predictive models were produced.

Additional information on methodology is provided in the attached working paper.

Activities

- Nationwide data sourced, collated, and analysed.
- Maps of coefficient variation produced for presentation to NIHE.
- Research visit to Belfast funded by NIHE – visit organised by Ellie Bates, involving also Gwilym Pryce and Jon Minton.
- 4th Dec 2013: Research workshop in collaboration with Dr Dot Reid in the Department of Urban Studies. Joint presentation by Ellie Bates, Dr Reid, Dr Jon Minton and Prof Pryce followed by brainstorm session to explore and plan the idea of applying our GWR model to Succession Law.
- 22nd Feb 2014: Training sessions for staff and postgraduate students – R a Gentle Introduction and Geographic Weighted Regression an Introduction
- 27th Feb 2014: GWR Knowledge Exchange Seminar

Findings

Our motivation for applying GWR was not that it could reveal directly where submarket boundaries lie, but that it could *potentially* offer a highly flexible way of estimating the first stage in a CPEP analysis which is essentially to provide a valuation model. In practice, this proved quite challenging and time consuming. The standard package developed by Fotheringham *et al.* to estimate did not provide the flexibility and advanced features needed to estimate the first stage of CPEP. As a result, we had to use the GWR package developed in R which none of the research team had any significant expertise in. So, one unanticipated benefit of the project has been to boost capacity in the knowledge of using R and this particular R package. A further complication was the fact that computing the predicted values from the GWR models proved more complex than anticipated (this is because each data point essentially has its own set of regression slopes). Also, the computing power and memory needed to run these routines on large datasets also proved problematic. Despite these challenges, we have nevertheless progressed with the research sufficient to demonstrate that GWR can indeed be used to develop a valuation model of the kind needed for the first stage of CPEP.

Our ability to estimate the value of individual dwellings using UK house price data also opens up the potential usefulness of this approach for a wide set of applications where automated property valuations are needed. For example, our model is developed to the point where it could in principle be used to assist with Council Tax revaluation. Though there is an important caveat here. It has become clear through the research that for GWR to work well, there needs to be a high spatial density of observations. In the context of house price data, this means that for a fully functioning AVM (automatic valuation model) to work well in a professional context, the user would need to have access to a large volume of house transactions relative to the total local housing stock. We used Nationwide data for our analysis on London, Glasgow and Belfast and this proved problematic for some areas as the Nationwide data only includes transactions based on Nationwide mortgage approvals. The Nationwide market share varies across the country and for Belfast we had relatively sparse observations. One very exciting outcome of our collaboration with Joe Frey (Director of Research, Northern Ireland Housing Executive) has been his help in exploring possible access to a

much more extensive dataset and a potentially fruitful collaboration with the University of Ulster. Discussions are at an early stage but the proposed collaboration could lead to a variety of new projects and applications. We have also confirmed the potential usefulness of our model for estimating the efficiency of landlord portfolios. More details on these below.

Outputs

- **The Working Paper** has taken longer to finalise due to some of the technical difficulties in implementing GWR to large house price datasets in a way that delivers the kind of outputs needed for CPEP. However, we now have an initial draft of a working paper which will be circulated via AQMEN and will highlight the value of using GWR compared to other techniques for modelling house prices. This paper will also form the basis of a submission to an academic journal.
- **Short research reports:** In practice this proved problematic due to the technical delays. However, we did deliver a Powerpoint presentation to the Northern Ireland Housing Executive on the potential usefulness on the application to the impacts of crime and religious/ethnic divisions and the application to landlord portfolios with non-technical summaries to be circulated among relevant stakeholders.
- **Sharing expertise** with AQMEN and Urban Studies research staff on how to develop and produce Geographic Weighted Regression models: we've done this via the planned workshops and events, plus collaborative projects emerging with Dr Allison Orr and Nigel Sprigings on optimal landlord portfolios, and with Dr Dot Reid on the reform of Succession Law.
- **A KE Seminar & two day Training event** advertised via Glasgow Social Statistics Group, ENHR, ERES and AQMeN. We also plan to run a training event later in the year in the Sheffield Methods Institute which will further help to disseminate these methods and findings.
- **Training materials** for use in UG and PG quantitative methods teaching to social scientists: an extensive set of slides have been developed which will be made available via AQMEN and also the www.gpryce.com website.

A. Project beneficiaries

1. **Reform of Succession Law:** An unanticipated potential beneficiary of our GWR project are family members currently disinherited through Succession Law. Reform of Succession Law has recently been examined as part of the Scottish Law Commission's (SLC) 7th Programme of Law Reform. This produced a Draft Bill and the subject is likely to come before the Parliament in the next session. Application of our GWR model could have a very powerful role to play in providing the evidence base on house price change needed to inform the reform process. More details on this are given below under *Collaborations: Dr Dot Reid and Succession Law*.
2. **Researchers** with an interest in developing better models of housing market segmentation, automatic valuation methods, spatial statistics and/or portfolio optimisation; and researchers interested in using GWR and linking it with other methods and applications: even though there is a package already developed in R, and although we have demonstrated that GWR can indeed be applied to all these topics, our experience is that using the R toolkit for this type of work is not a trivial task. So, while we do believe that researchers in these various fields could potentially benefit from these methods, we feel that there is considerable merit in providing ways to simplify and clarify the use of the R package for this type of application. This will be a goal of our proposed future work on the model.
3. **Practitioners** in local authorities seeking to improve local Housing Market Assessments or find robust ways to improve and update Council Tax valuations: again, we feel we have demonstrated "proof of concept" but there are issues of data and also the technical complexities of using R to run the model. There is therefore a real need/opportunity to develop a more user friendly toolkit that local authorities could use for this kind of work and we plan to propose this in our plans to bid for further funds. As part of the current project we did explore different potential platforms for this including R Panel and R Shiny and it seems likely that the latter would be the best computing framework to develop a more accessible interface.
4. **Develop understanding of advanced quantitative methods** amongst social science researchers: the resources and training planned and provided will, we believe, advance the knowledge base of advanced quantitative techniques. It will enable someone trained through previous AQMeN training courses (including on GWR) to further develop these skills and share them in others.
5. **Actively sharing developments** in quantitative research techniques with other researchers: in addition to the immediate KE and training events and resources, we are exploring longer term plans to disseminate the methods developed in our project through the AQMeN USIRP project, future research bids (which will include training courses as proposed outputs) and through the Sheffield Methods Institute.

B. Project impact

The project's findings confirm the potential usefulness of GWR in CPEP. As a result, we seek to apply the approach in related projects (particularly the AQMEN URSIP project) and also explore the potential for further funding applications and collaboration with stakeholders, particularly with respect to the use of the method to improve Local Authority Housing Market Assessments.

Housing Market Assessment analysis which are a statutory requirement for local authorities. This typically entails understanding the structure of housing submarkets within local authorities and the pattern of house price dynamics at small area level. This research will potentially open up new ways to understand housing submarkets and offer an unprecedented level of detail on patterns of house price dynamics at the local level.

Perhaps most importantly, this detail could also lay the foundation for council tax revaluation which is decades overdue partly as a result of the cost of updating estimates on property values. Our proposed methodology could offer new levels of precision in developing Automatic Valuation Models for local authorities, and lead to greater fairness and consistency in council tax banding.

C. Collaborative components

1. **Northern Ireland Housing Executive (Joe Frey):** A very fruitful aspect of our collaboration with Joe Frey was the help he and his colleagues were able to provide in helping us map out a set of research questions that could be explored using the GWR CPEP approach. This has confirmed and hugely enriched our understanding of the potential applications of the GWR CPEP model to issues of genuine and practical interest to policy makers in a particular urban context. For example, by combining the CPEP research with qualitative knowledge of segregation in Belfast and with Census data on religious mix, we could compare and contrast perceptions of integration (based on social network analysis of CPEP as a measure of dwelling substitutability) with actual patterns of mix. The potential usefulness of GWR CPEP to distinguish between social mix and social integration in the context of the religious divides in Northern Ireland has initiated a conversation with policy makers in the NIHE which we hope to continue in the longer term through the AQMEN Urban Segregation and Inequality Research Project.
2. **Rettie & Co.:** Collaboration with Rettie & Co. and with colleagues in Urban Studies (Nigel Sprigings and Allison Orr) also allowed us to explore the application of the GWR model to landlord property portfolios. Rettie very generously provided us with landlord data to allow us to explore whether, in principle, the GWR model could be used to estimate optimal landlord portfolios. In addition we have been working with two academics from the Department of Urban Studies at the University of Glasgow: Dr Allison Orr (an expert in commercial real estate and portfolio theory) and Nigel Sprigings (an expert the private rented sector and landlord behaviour). This has led to development of a proposed programme of work for which we hope to seek Research Council funding.
3. **Dr Dot Reid and Succession Law:** An exciting unanticipated outcome of the research was the collaboration with Dr Reid from the School of Law at the University of Glasgow which highlighted the potential to use our GWR framework to provide the evidence base needed for efficient reform of Scottish Succession Law. The following summary is taken from Dr Reid's description of how we could potentially have an important contribution. In order to explain why the proposed research is important, it is necessary to explain a little about inheritance law. Traditionally (for centuries) children and spouses have had automatic inheritance claims (Legal Rights, which is a term of art in succession law), each being entitled to one third of the moveable estate of the deceased (i.e. the children as a group are entitled to one third, the spouse one third). In effect, even if the deceased has made a will, you cannot disinherit either a spouse or children if you leave behind any moveable property, including cash, shares, bank accounts etc. If the deceased died intestate (or even partially intestate) another set of rights kick in which take priority over Legal Rights. These are the Prior Rights of the spouse or civil partner, which were introduced in the Succession (Scotland) Act 1964 in order to give more protection to a surviving spouse. The policy aim was to enable the surviving spouse to remain in the family home, with a roof over her head, furniture in the home, plus a cash sum. It should be noted that Prior Rights can only be claimed on an intestate estate and although around 2/3 of the Scottish population have not made a will, those most likely to have done so are those who have high value estates to leave behind. The majority of intestate estates are, therefore, relatively low in value (it is

very difficult to quantify the value with any accuracy because of the lack of data from the Scottish Court Service). If the deceased died intestate, therefore, Prior Rights take priority, followed by Legal Rights. Any increase in the value of Prior Rights will, therefore, impact most on the children of the deceased. Prior Rights have 3 components: (a) a claim on the deceased's heritable property. This is a fixed sum, which is increased by statutory instrument. The claim is on the property of the deceased so if the property is jointly owned by both spouses, the claim will be on one half of the net value. (b) a claim on the deceased's moveable property (physical property, intended to be the furnishings in the home), again a fixed sum. (c) a cash sum which can be claimed against the rest of the estate after rights (a) and (b) have been satisfied. The cash sum is reduced if the deceased had children. It is claim (a) above which is the subject of the potential collaboration between Dot Reid and the GWR project. The deceased's heritable property, assuming the deceased is a home owner, is likely to be the most valuable element in the estate. The amount claimable has increased very significantly, particularly since 2001. Dr Reid has argued that it is overly generous to the spouse, with the result that in most intestate estates the children of the deceased will be disinherited. This is particularly problematic for reconstituted families. Crucially, there is a serious problem that the raising of the value of the housing claim is not based on hard evidence. The collaboration with Dr Reid has highlighted how our GWR model could provide a much more robust evidence base for Succession Law, the outcome of which is that we plan to work with the Scottish Law Commission to develop a Research Council bid to focused on informing the reform of Succession Law in Scotland and potentially also equivalent reform in England and Wales.

D. Innovative use of advanced quantitative methods

The project used Geographic Weighted Regression to both explore and predict house price data. Whilst the use of GWR for exploring data is common, use for prediction is less common and a growing area of research. This project in particular has examined the impact of ample size of GWR and raises potential interesting future areas of research relating to produce GWR estimates for larger datasets.

This project in addition innovatively linked together an SQL Server Express database and the statistical platform R, enabling data from a range of locations across the UK to be quickly analysed using the same models and variables. Now that linked databases of Nationwide house price data and ONS postcode information have been produced, these can potentially be used for analysis for other cities, in addition to Glasgow, Belfast and London.

In addition since all parts of the project analysis have been coded in R script or SQL, the analysis can be replicated by other researchers interested in similar research methods. The working paper makes available example R and SQL code used in the project so that these can be utilised by other researchers interested in producing similar models.

E. Knowledge exchange value of the project

In addition to the KE workshop on 27th Feb 2014, we have a further workshop planned for 17th March 2014. Perhaps most importantly, our visit to Belfast in early February to meet with the NIHE Research Director proved to be a very valuable opportunity to exchange knowledge and the NIHE have expressed considerable enthusiasm for seeing our work continue in collaboration with them. We feel there is a very real prospect then of a long-term partnership emerging with this policy maker which could be an outstanding example of genuine knowledge exchange.

F. Attached documents and resources

Draft Working Paper summarising methods and results

GWRWorkingPaper_Draft28Feb2014_eb_gp_3c.pdf

Power point slides for Training and Knowledge exchange events

RintroFeb2013v2a.pdf

GWRanIntroductionTrainingNotes.pdf

GWRKESeminar.pdf

The training materials can also be downloaded from the following Dropbox link (as at 03 March 2014)

<https://www.dropbox.com/sh/f8zoel9ftkz2h37/DjlrMowwZ5>

Links to Eventbrite promotions of Training and Knowledge exchange events

R a gentle introduction

<http://www.eventbrite.co.uk/e/r-a-gentle-introduction-tickets-10627004657>

GWR an Introduction Course

<http://www.eventbrite.co.uk/e/gwr-knowledge-exchange-seminar-tickets-10733362777>

GWR Knowledge Exchange Seminar

<http://www.eventbrite.co.uk/e/gwr-knowledge-exchange-seminar-tickets-10733362777>

(To follow – Financial report)