Technical note I: Comparing measures of hospital markets in England across market definitions, measures of concentration and products

1. Introduction

This document explores how a range of measures of the level of competition faced by NHS trusts varies across time for six sub groups of patients. Note that the analysis is at hospital trust level: for ease of presentation we refer to this as the hospital in the whole of this paper. Note also that we were not able to include the independent sector or ISTCs in the analysis as the relevant data were not available for these non-NHSD providers.

The patient sub-groups are defined by the product for which they are treated:

- All electives (all HRG v3.5 codes)
- Cataracts (HRG v3.5 codes: B13)
- Coronary artery bypass grafts (CABGs) (HRG v3.5 codes: E04)
- Hip replacements (HRG v3.5 codes: H80, H81)
- Emergency AMIs (HRG v3.5 codes: E11, E12)
- Maternities (Method of admission codes: 31 & 32)

We use data for four financial years:

- 2003/04
- 2004/05
- 2005/06
- 2006/07

We explore three methods of defining hospital markets:

- Fixed radius (FR) method
- Variable radius (VR) method
- Patient flow (PF) method

We consider two main measures of the level of competition within a hospital's market:

- The number of competitors (N)
- The Herfindahl-Hirschman Index (HHI)

The number of competitors within a hospital's market is simply a count of the number of hospitals geographically located within the market. The Herfindahl-Hirschman Index is defined as the sum of squared patient shares across all hospitals geographically located within the market. For a given hospital, its patient share is its share of the total number of patients that attended any hospital geographically located within the market. The equation for calculating the HHI of a market is given in Appendix A.

2. Methods of defining hospital markets

This section summarises the different methods of defining the market within which each hospital operates. The section summaries these methods in words; equations for calculating the N and HHI competition measures based on each method are given in Appendix A.

2.1 *Fixed radius (FR) method*

The fixed radius method defines markets as circular areas centred on hospitals' geographic locations. Thus, with this approach, there are as many markets as there are hospitals. The radius of each market is constrained to be equal to some arbitrary distance (in this document 20km). The greater the radius the more these markets will overlap. The level of competition in each market is measured by the number of hospitals located within the market or the HHI for hospitals within the market. These competition measures are sensitive to the chosen fixed radius.

2.2 *Variable Radius (VR) method*

Variable radius markets are defined in the same way as fixed radius markets except that the radius of each circular market is now set equal to the minimum distance required to capture a set percentage (in this document 75%) of the patients treated by the hospital at the centre of that market. As in the fixed radius markets, the level of competition in each market is measured by the number of hospitals located within the market or the HHI for hospitals within the market. These competition measures are sensitive to the chosen percentage for the variable radius.

2.3 *Patient flow (PF) method*

Measures of market competition based on patient flows have been implemented by Wong et al. (2005). A separate level of competition is calculated for each hospital. Thus, as with the fixed and variable radius markets, there are as many markets as there are hospitals. As above we can construct the number of competitors and the HHI measures of competition. Both measures are sensitive to the geographic scale of the neighbourhoods.

For both competition measures, the patient flow method has two steps. The first step measures the level of competition in each neighbourhood (in this document neighbourhoods are defined as MSOAs). The level of competition faced by each hospital is then calculated as a weighted average of the neighbourhoods it serves where the weights simply reflect the share of the hospital's patients that live in each neighbourhood.

For the N measure, the patient flow method first calculates the number of hospitals that each neighbourhood sends its patients to. The level of competition faced by the hospital is then the weighted average of this statistic across all neighbourhoods in the data.

For the HHI measure, the patient flow method first calculates the HHI for each neighbourhood in the data. This is the sum of squared shares of patients who attend each hospital. The level of competition faced by the hospital is then the average of these neighbourhood measures weighted by the share of the hospital's patients that live in each neighbourhood.

3. Correlations between competition measures

We first examine correlation coefficients between the different measures for the different methods and products. Comparing correlation coefficients for the different methods summarises the extent to which the different methods are measuring the same thing (Table 1). Comparing correlation coefficients for the different products summarises the extent to which the hospitals that are competitive for one product are also competitive for the other products (Table 2). Note in calculating these correlation coefficients we have pooled data from all four financial years. Some care should be also taken when interpreting the correlations related to the fixed and variable radius methods as these measures often have distributions whereby many hospitals are recorded as being perfect monopolies.

Table 1 shows that, for each product, the competition measures for the three methods are positively correlated and that the magnitude of these correlations are fairly large.

Table 1 - Correlation coefficients for the competition measures, reported separately for each product

	Fixed Radius (20km)	Variable Radius (75%)	Patient Flow (MSOA)
All Electives			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.5013	1	
Patient Flow (MSOA)	0.4452	0.3696	1
Hip Replacements			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.3997	1	
Patient Flow (MSOA)	0.4627	0.3134	1
Cataracts			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.4205	1	
Patient Flow (MSOA)	0.5577	0.2284	1
CABGs			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.7895	1	
Patient Flow (MSOA)	0.5258	0.4584	1
Emergency AMIs			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.3082	1	
Patient Flow (MSOA)	0.421	0.2119	1
Maternities			
Fixed Radius (20km)	1		
Variable Radius (75%)	0.4114	1	
Patient Flow (MSOA)	0.5892	0.4642	1

Table 2 shows that, for each method, the correlations between products are very strongly positive. Thus, hospitals that face high competition for one product face high competition for all products.

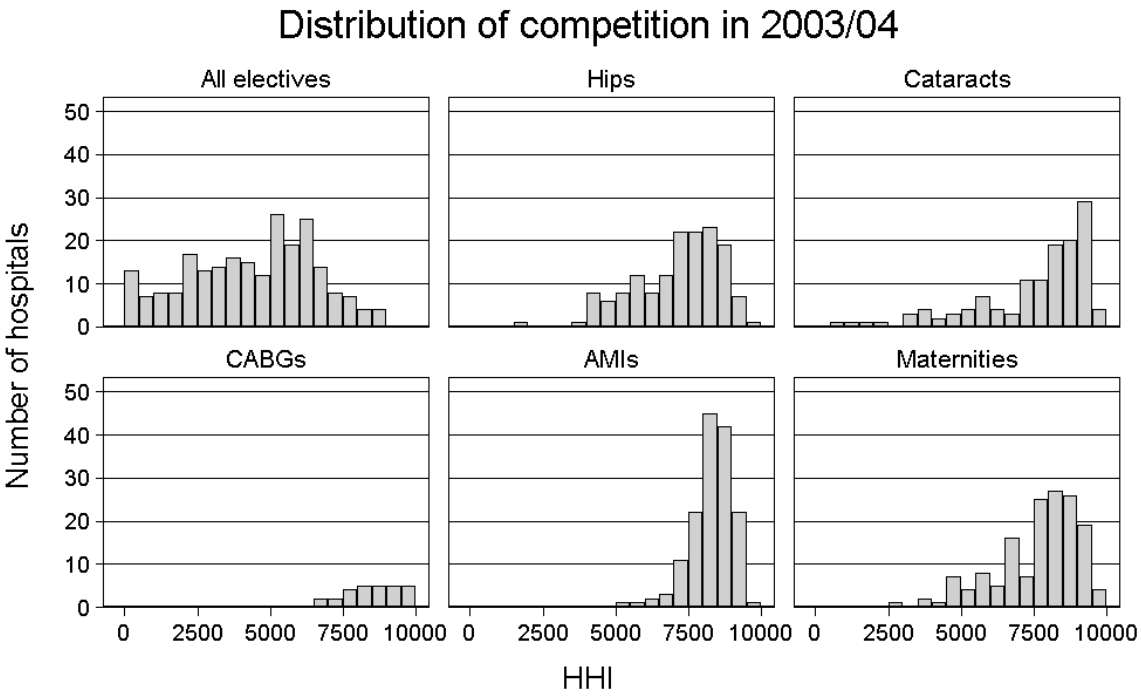
Table 2 - Correlation coefficients for the competition measures, reported separately for each method

	All Electives	Hip Replacements	Cataracts	CABGs	Emergency AMIs	Maternities
Fixed Radius (20km)						
All Electives	1					
Hip Replacements	0.9844	1				
Cataracts	0.9313	0.924	1			
CABGs	0.763	0.6979	0.7459	1		
Emergency AMIs	0.9829	0.9863	0.9358	0.699	1	
Maternities	0.985	0.9863	0.9416	0.7102	0.9987	1
Variable Radius (75%)						
All Electives	1					
Hip Replacements	0.821	1				
Cataracts	0.697	0.6261	1			
CABGs	0.5923	0.6301	0.5192	1		
Emergency AMIs	0.5203	0.7249	0.4575	0.4869	1	
Maternities	0.6982	0.7383	0.7389	0.5676	0.5658	1
Patient Flow (MSOA)						
All Electives	1					
Hip Replacements	0.8091	1				
Cataracts	0.6484	0.5383	1			
CABGs	0.2905	0.3332	0.3627	1		
Emergency AMIs	0.7706	0.7148	0.5903	0.4655	1	
Maternities	0.8093	0.7397	0.5927	0.4429	0.8145	1

4. Change in hospital competition over time

4.1 *Distribution of hospital competition in each year*

The graph below show the distribution of hospital competition in 2003/04 (the distributions in each of the next three years are highly similar). We use our preferred measure of competition, the HHI based on the patient flow method.



The distributions of the five specialised services lie to the right of that for the all electives distribution. This is expected since it is easier for a hospital to be a monopoly in a single service than for a basket of services. Out of the five specialised services, hip replacements appears the most competitive and AMIs the least competitive. Interestingly, the distribution of competition for cataracts had a very long left tail suggesting that, while the average hospital is fairly uncompetitive, there is a substantial minority of hospitals that are relatively more competitive. In contrast, the distribution of competition for AMIs is much narrower indicating that these hospitals are relatively similar in their levels of market power.

Table 3 presents the information in the above graphs in table format and extended to cover the years 2003/4 and 2006/7. Quantiles of the hospital level distribution of HHI scores are presented for each product market for 2003/04 and 2006/07.

Looking at the means of the HHI distributions, we see that CABGs are the most concentrated markets, then emergency AMIs, then Maternities, then Cataracts, then Hips and finally all electives. For CABG, less than 30 hospitals actually provide these services. Thus, why patients might want to choose, perhaps exercising choice is not feasible given the very long travelling distances involved. We expect hospitals to have high market power in terms of emergency AMIs since for these patients choice is not a possibility; patients go to their closest hospital out of medical necessity. Hip and Cataract are markets where we would expect more competition and they do indeed have lower mean HHIs than the other products.

Table 3 Hospital level descriptive statistics for the Herfindahl-Hirschman Index (HHI) calculated using the patient flow method, reported separately for each product.

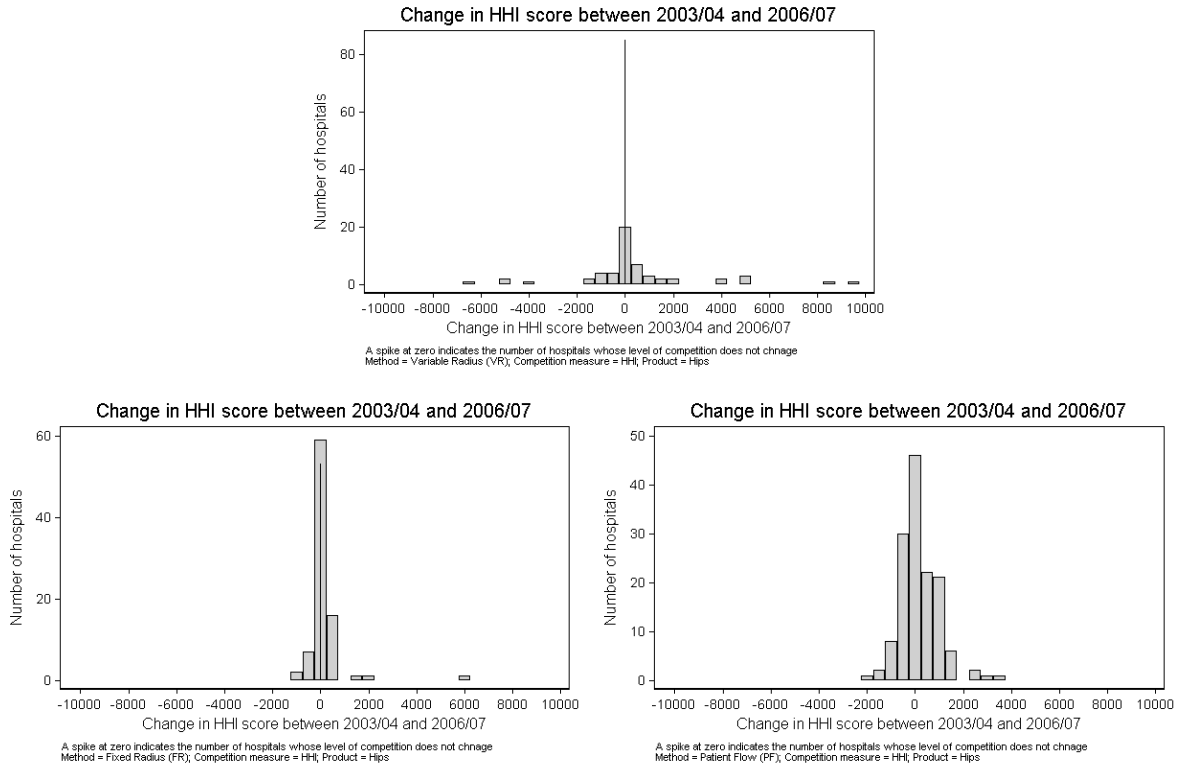
Product	Year	No.	Mean	Min.	10th	25th	50th	75th	90th	Max.
All electives	2003/04	230	4401	3	1326	2862	4700	6105	6965	8928
	2004/05	233	4370	2	1079	2690	4572	6245	6967	8881
	2005/06	231	4327	2	1175	2624	4512	6174	7085	8845
	2006/07	222	4341	54	1191	2747	4394	6168	7030	8817
Hips	2003/04	150	7128	1968	4957	6051	7419	8226	8726	9706
	2004/05	145	7255	1836	5281	6254	7608	8314	8816	9674
	2005/06	145	7471	2251	5893	6839	7676	8380	8941	9505
	2006/07	143	7362	1989	5630	6552	7666	8375	8718	9435
Cataracts	2003/04	128	7533	675	4316	6781	8200	9031	9341	9666
	2004/05	127	7793	1563	5018	7107	8496	9019	9476	9727
	2005/06	127	7805	1432	5245	7126	8415	9013	9378	9772
	2006/07	125	7692	2029	5070	7095	8255	8886	9333	9701
CABGs	2003/04	28	8493	6678	7096	7944	8554	9216	9656	9781
	2004/05	29	8487	5944	6235	7866	8809	9529	9656	9745
	2005/06	29	8754	7329	7596	8245	8940	9373	9606	9716
	2006/07	29	8584	6326	7470	8128	8699	9103	9614	9676
AMIs	2003/04	150	8323	5494	7372	7968	8439	8866	9107	9546
	2004/05	151	8257	5477	7258	7861	8393	8835	9091	9437
	2005/06	151	8226	4244	7121	7883	8414	8855	9055	9481
	2006/07	147	8201	3716	7205	7819	8342	8786	9069	9374
Maternities	2003/04	152	7664	2784	5505	6809	8013	8744	9142	9650
	2004/05	152	7667	2948	5483	7001	8006	8710	9147	9635
	2005/06	151	7680	2504	5423	7075	8019	8798	9162	9594
	2006/07	148	7636	2089	5376	7010	7976	8607	9070	9580

4.2 *Change in hospitals' competition (based on each method) for hip replacements*

In this section we look at the change in competition between 2003/04 and 2006/07.

The first thing we want to illustrate is why our preferred method is the patient flow approach and not the fixed or variable radius approaches. To illustrate the differences between methods, we focus on hospital competition for hip replacements. The first graph below is for the fixed radius method, the second graph for the variable radius method and the third for the patient flow method. Under the fixed and variable radius methods the levels of competition experienced by over 50 hospitals' is unchanged over the four year period. These hospitals are all measured as being perfect monopolies (HHI = 10000) at both the start and end of the four year period. This is important as it means that using the fixed or variable radius methods leads us to conclude there is no within hospital variation in the level of competition experienced by hospitals for approximately one third of the hospitals that provide hip replacements. This high proportion reflects the way in which these two methods define hospital markets.

In contrast, the patient flow method shows the level of competition faced by all hospitals changes over the four year period. Of course, hospitals that show no change in the level of competition they face when using the fixed and variable radius methods only show very small changes under the patient flow approach.

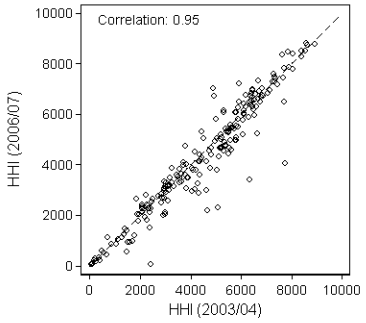


4.3 *Change in hospitals' HHIs (based on the patient flow method) for each product*

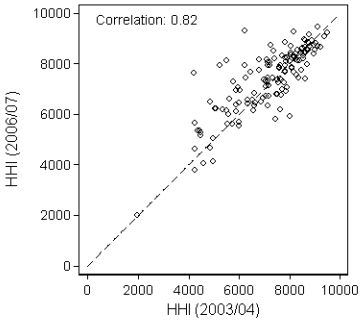
In this Section we produce scatter plots of hospitals' HHIs, based only on the patient flow method, for each product in turn. On the y-axis we plot hospitals' HHIs in 2006/07, on the x-axis we plot hospitals HHIs in 2003/04.

The graphs again show that the level of competition faced by hospitals is fairly stable over the four years; few scatter points lie far away from the 45 degree line. The correlations between the HHIs for the two years range from 0.75 to 0.97 for the six products. The markets for hips and cataracts (products where we expect pro competition reforms to have the biggest impact) appear slightly more noisy than the other markets.

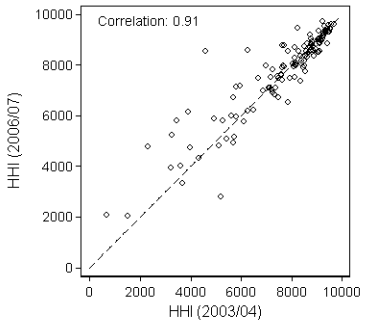
Hospitals' HHI scores in 2003/04 and 2006/07
All electives



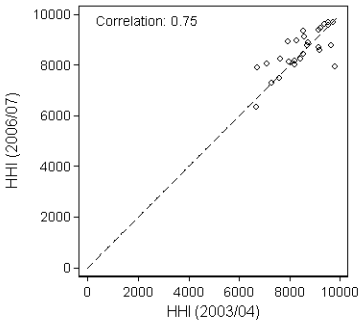
Hospitals' HHI scores in 2003/04 and 2006/07
Hips



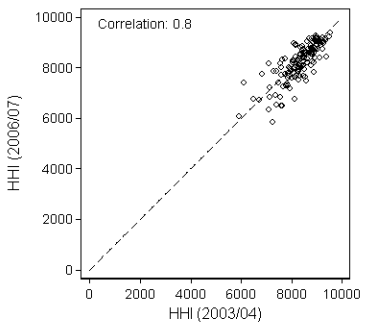
Hospitals' HHI scores in 2003/04 and 2006/07
Cataracts



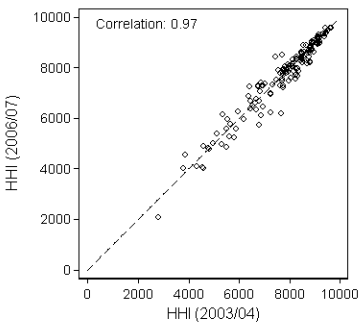
Hospitals' HHI scores in 2003/04 and 2006/07
CABGs



Hospitals' HHI scores in 2003/04 and 2006/07
AMIs



Hospitals' HHI scores in 2003/04 and 2006/07
Maternities



5. Variance partition coefficients (VPC)

For each competition measure-method-product combination, we decompose the total variation in the competition measure into the part that lies between hospitals and the part that lies within hospitals, across financial years. We use data from all four financial years.

Table 4 Table of between and within standard deviation for the Herfindahl-Hirschman Index (HHI) calculated using the patient flow method, reported separately for each product.

Variable		Mean	Std. Dev.	Min	Max	Observations
All electives	Overall	4359.578	2200	2	8928	N = 916
	Between		2193	2	8852	n = 241
	Within		290	1614	6348	T-bar = 3.8
Hip replacements	Overall	7302.19	1362	1836	9706	N = 583
	Between		1341	2011	9628	n = 153
	Within		438	5132	9161	T-bar = 3.8
Cataracts	Overall	7705.729	1808	675	9772	N = 507
	Between		1848	1507	9636	n = 130
	Within		372	4706	9071	T-bar = 3.9
CABGs	Overall	8580.357	896	5944	9781	N = 115
	Between		781	6869	9711	n = 30
	Within		434	6614	9668	T-bar = 3.8
AMIs	Overall	8252.179	790	3716	9546	N = 599
	Between		772	4652	9393	n = 152
	Within		263	7168	9290	T-bar = 3.9
Maternities	Overall	7661.858	1415	2089	9650	N = 603
	Between		1430	2581	9615	n = 154
	Within		176	6583	8254	T-bar = 3.9

The table shows that for each product, the vast majority of variation lies between hospitals; hospitals' levels of competition are very stable over time.

An alternative way of summarising the extent to which variation in hospital competition lies between hospitals rather than within hospitals between years is to calculate variance partition coefficients (VPC). The VPC is calculated as the proportion total variation in the competition measure that lies between hospitals and its value can range between zero and one. VPCs close to one would suggest that there are relatively large differences between hospitals but relatively small differences within hospitals over time. In other words hospitals are heterogeneous and the differences between hospitals remain roughly stable over time. On the other hand, VPCs close to zero would suggest that any long run differences between hospitals' levels of competition are relatively small compared to the year-to-year variation that they tend to experience.

It helps when interpreting the magnitude of the following VPCs to consider the values of VPCs typically found in other types of data. For example, in panel data studies, that follow

individuals over time, outcome variables such as wages typically have VPCs around 0.8. Thus, most of the variation in wages lies between individuals and each individual's wage rate is fairly stable over time. However, in grouped data, for example, pupils within schools, VPCs can be much lower. For pupils within schools, the VPC for pupils' achievements is typically between 0.1 and 0.2. Thus, here, the average differences in achievement between schools are relatively small compared to the variation in pupils' achievement found within schools.

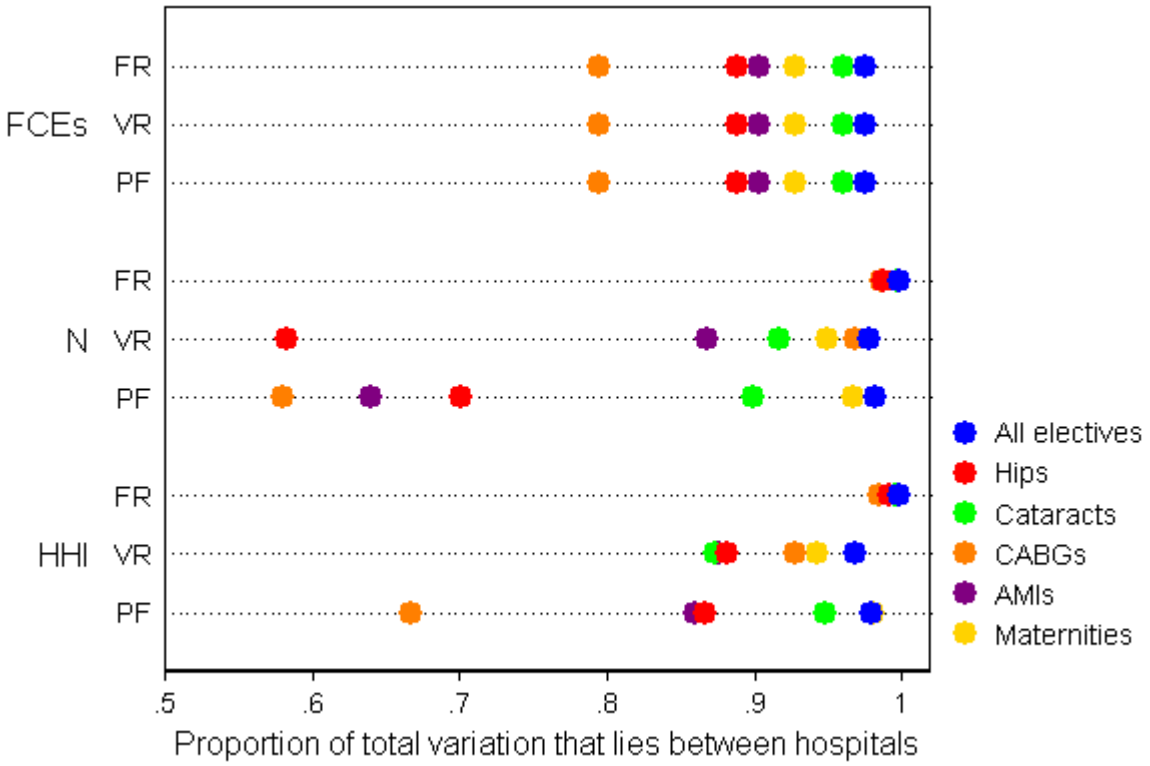
The VPC can also be interpreted as the intra-hospital correlation coefficient (ICC). This is the correlation between the levels of competition for two randomly chosen years for the same hospital. Thus a VPC/ICC close to one suggests that the levels of competition faced by hospitals are highly correlated from one year to the next.

Table 5 reports the VPCs for all possible combinations of the FCE, N and HHI competition measures, for the three different methods of defining hospital markets and for the six different products that we consider. This gives in total 54 VPCs. The final row of the table presents the VPCs for the HHI measure calculated using the patient flow method. This row corresponds to the information presented in Table 4.

Table 5 Variance partition coefficients for all three competition measures calculated using each competition method, reported separately for each product.

Competition measure	Competition method	All	Hips	Cataracts	CABGs	AMIs	Maternities
FCE	Fixed radius	0.98	0.89	0.96	0.81	0.90	0.93
	Variable radius	0.98	0.89	0.96	0.81	0.90	0.93
	Patient flow	0.98	0.89	0.96	0.81	0.90	0.93
N	Fixed radius	1.00	0.99	1.00	0.99	1.00	1.00
	Variable radius	0.98	0.58	0.92	0.97	0.87	0.95
	Patient flow	0.98	0.70	0.90	0.60	0.64	0.97
HHI	Fixed radius	1.00	0.99	1.00	0.98	1.00	1.00
	Variable radius	0.97	0.88	0.87	0.93	0.88	0.94
	Patient flow	0.98	0.87	0.95	0.68	0.86	0.98

To ease the comparison of these VPCs across measures methods and products, we plot them as a figure:



The vast majority of VPCs lie between 0.85 and 1.0 suggesting that most of the variation in the data lies between hospitals rather than within. The high VPCs inform us that, hospitals face different levels of competition but these levels remain fairly stable over time. Looking across all the VPCs we see that the highest VPCs are for all electives (by far the highest volume product). The lowest VPCs tend to be for the lower volume products such as CABGs, hip replacements and AMIs.

5.1 *Finished consultant episodes (FCEs)*

The number of FCEs per hospital year does not depend on the choice of method (FR, VR and PF). However, there are differences in the VPCs between products, but as described above, this may in part reflect differences in the numbers of patients treated for each product.

5.2 *Number of competitors (N)*

Using the fixed radius method, there is very little variation across products in the VPCs for the number of competitors. All the VPCs are very close to one indicating that the number of competitors that hospitals face is very stable over time. This is expected as few hospitals will open or close over such a short period.

There are larger differences in the VPCs between products when we use the variable radius method. This is because the size of the geographical markets under the variable radius method can vary from year to year which is not the case with the FR market which is always 20km. Thus hospitals just inside the boundary of a variable radius market in one year might be just outside in a subsequent year. This either 100% in or either 100% out feature of variable (and fixed) markets is clearly a limitation of these methods. The market for hips seems different from the other products. There is notable year-to-year variation in the number of competitors that hospitals face for this product. Note this is not due to the introduction of ISTCs (many of which provide orthopaedics) since ISTCs are not included in the sample.

5.3 *Herfindahl-Hirschman Indices (HHI)*

For HHIs, the fixed radius method again shows hospitals to be very stable in terms of the levels of competition they face. The variable radius method shows slightly higher proportions of within hospital year-to-year variation while the patient flow method shows slightly more again.

6. Summary

- The fixed and variable radius methods are very limited as they describe substantial proportions of hospitals as perfect monopolies
- The definition of market concentration within method is similar across products, showing that it may not matter too much which products are selected to measure concentration at a trust level.
- Even with the patient flow method, variance partition coefficients indicate that the level of competition faced by hospitals is very stable over time

References

Wong, H. S., Zhan, C. L. & Mutter, R. (2005) Do different measures of hospital competition matter in empirical investigations of hospital behavior. *Review of Industrial Organization,* 26**,**61-87

Appendix A

This appendix gives the formulas used to calculate the different competition measures.

A.1 *Fixed and variable radius markets*

The number of competitors in a hospital's market m is simply the number of hospitals located within the market J_m excluding the hospital under consideration.

$$N_m = J_m - 1$$

The HHI for hospital market m can be written as:

$$HHI_m = \sum_{j=1}^{J_m} \left(\frac{n_j}{n_1 + n_2 + \cdots + n_{J_m}} \right)^2$$

where j indexes hospitals geographically located within the market and n_j denotes the number of patients who attend hospital j.

A.2 *Patient flow markets*

The number of competitors for hospital j can be written as:

$$N_j = \sum_{k=1}^{K} \left(\frac{n_{kj}}{n_j} \right) J_k$$

where k indexes neighbourhoods, n_j denotes the number of patients who attend hospital j, n_{jk} denotes the number of patients who live in neighbourhood k that attend hospital j and J_k is a count of the number of hospitals attended by patients from neighbourhood k. Wong et al. (2005) suggest only counting the number of hospitals attended amongst the 75 percent subset of patients who attend the most popular hospitals. However, we have not implemented this in this document.

The HHI for hospital j can be written as:

$$HHI_j = \sum_{k=1}^{K} \left(\frac{n_{kj}}{n_j} \right) HHI_k, \qquad HHI_k = \sum_{j=1}^{J} \left(\frac{n_{jk}}{n_k} \right)^2$$

$$n_{kj} = n_{jk}$$

where n_k and n_{jk} are defined as before.

Technical Note II: Hospital competition measures – In depth comparison for 2003/04 only

1. Introduction

This document compares a range of hospital level competition measures across different definitions of hospital markets and across four sub group of patients. These sub groups are defined by the product for which they are treated:

- Cataracts (HRG v3.5 codes: B13)
- Coronary artery bypass grafts (CABGs) (HRG v3.5 codes: E04)
- Hip replacements (HRG v3.5 codes: H80, H81)
- Emergency AMIs (HRG v3.5 codes: E11, E12)

We explore a range of approaches to measuring market competition:

1. Geopolitical boundaries
2. Fixed radius
3. Variable radius
4. Elzinga-Hogarty approach based on actual or predicted patient flows
5. Department of Health market power index
6. Kessler-McClellan approach based on actual or predicted patient flows

Each of these approaches summarise hospital market competition by either a count of the number of competitors within the market or by calculating Herfindahl-Hirschman Indices (HHI). The HHI is defined as the sum of squared patient shares across all hospitals geographically located within the market where, for a given hospital, the patient share is the hospital's share of the total number of patients that attended hospitals within the market. The equation for calculating the HHI of a market is given in Appendix A.

2. Approaches to measuring hospital market competition

This section summarises the different approaches to measuring hospital market competition in words. Equations for competition measures based on each method are given in Appendix A.

2.1. *Geopolitical boundaries*

Geopolitical markets are defined as administrative areas (e.g. regions). Markets do not overlap. The level of competition in each market is measured by the number of hospitals or the HHI for hospitals within the market. The competition measures are sensitive to the chosen scale of geography. The level of competition faced by a specific hospital is simply the level of competition in the market within which they are geographically located.

2.2 *Fixed radius*

Fixed radius markets are circular markets centred on hospitals locations. Thus, with this approach, there are as many markets as there are hospitals. The radius of each market is constrained to be equal to some arbitrary distance (e.g. 15 miles). The higher the radius the more markets will overlap. The level of competition in each market is measured by the number of hospitals or the HHI for hospitals within the market. The competition measures are sensitive to the chosen fixed radius.

2.3 *Variable Radius*

Variable radius markets are defined in the same way as fixed radius markets except that the radius of each circular market is now set to equal the minimum distance required to capture a set percentage (e.g. 75% or 90%) of the patients treated by the hospital at the centre of that market. The level of competition in each market is measured by the number of hospitals or the HHI for hospitals within the market. The competition measures are sensitive to the chosen percentage for the variable radius.

2.4 *Elzinga-Hogarty based on actual/predicted patient flows*

Elzinga-Hogarty markets are groupings of geographic areas (e.g. PCTs) which satisfy two conditions:

- At least 75% of the patients who live in the market are treated in the market
- At least 75% of the patients treated in the market live in the market

Typically a third requirement is that the markets are defined as groupings of *contiguous* geographical areas. Elzinga-Hogarty markets do not overlap. The level of competition in each market is measured by the number of hospitals or the HHI for hospitals within the market. The competition measures are sensitive to the chosen percentage, here 75%, used in the definition of the markets. They are also sensitive to the chosen scale of geography used for the areas which form the building blocks of the market. The level of competition faced by a specific hospital is simply the level of competition in the market within which they are geographically located.

2.5 *Department of Health market power index (MPI)*

The Department of Health define an index of market competition which they refer to as the market power index (MPI). The MPI for each hospital is the sum of shares of patients from each PCT who attend that hospital. Note, unlike the HHI index, this index is not constrained to lie between zero and one. This competition measure is sensitive to the chosen scale of geography (here PCT).

2.6 *Kessler-McClellan approach based on predicted patient flows*

Measures of market competition based on *predicted* patient flows have been implemented by Gowrisankaran and Town (2003) and Kessler-McClellan (2000). The Kessler-McClellan (2000) approach estimates patient level hospital choice models. The predicted probabilities from these models are used to derive measures of competition that are based on *predicted* flows of patients from neighbourhoods to hospitals rather than on *actual* flows. Thus, the *predicted* HHI for each hospital is the weighted average of *predicted* neighbourhood level HHIs where the weights are the *predicted* share of the hospital's patients who come from that neighbourhood. The *predicted* HHI for each neighbourhood is the sum of squared *predicted* shares of patients from that neighbourhood who attend each hospital. This competition measure is sensitive to the geographic scale of the neighbourhoods.

The Kessler-McClellan approach described here is based on predicted patient flows. However, it can equally be based on actual patient flows (see, for example, Wong et al., 2005). Similarly, each of the earlier approaches are based on actual patient flows but could equally be calculated using predicted patient flows from, for example, patient level hospital choice models. In this document we shall present results for the Kessler-McClellan approach based on actual patient flows and the Elzinga-Hogarty approach where we define the markets using predicted patient flows, but the HHI measures are still calculated using actual patient flows.

3. Descriptive statistics based on HES data

3.1 *What we have explored*

Table 1 summarises the different hospital competition measures and approaches that we have considered. We have considered a number of different specifications for each approach. For example, for the fixed radius approach we consider setting the radius to distances in 5km jumps between 10km and 30km. The table denotes with an asterisk the preferred specification for each approach. The rest of the document focuses on these preferred specifications.

Table 1 Summary table of the different hospital competition measures and the different hospital market definitions that we consider.

Hospital market definitions	Alternative specifications considered	Actual number of competitors within the market (N)	Predicted number of competitors within the market (N)	Actual HHI within the market (HHI)	Predicted HHI within the market ($\hat{HHI}$)
1. Geopolitical boundaries	(1) GOR*, (2) SHA, (3) PCT	X		X	
2. Fixed radius	(1) 10km, (2) 15km, (3) 20km*, (4) 25km, (5) 30km	X		X	
3. Variable radius	(1) 60%, (2) 75%*, (3)90%	X		X	
4. Elzinga-Hogarty	(1) Contiguous PCTs*, (2) Contiguous MSOAs, (3) Non-contiguous PCTs*, (4) Non-contiguous MSOAs	X	X	X	X
5. Department of Health market power index (MPI)	(1) GOR, (2) SHA, (3) PCTs*, (4) Postcode districts, (5) MSOAs			X	
6. Kessler-McClellan	For the hospital choice models used to compute predicted probability that each patient goes to each hospital, we experiment with the following: Single overall sample vs. Regional samples* 0km, 100km*, 250km, Linear distance vs. Non-linear distance* Neighbourhoods: GOR, SHA, PCTs, Postcode districts, MSOAs*, Patients	X		X	X

Note: * denotes preferred version of the hospital level market definition.

3.2 *Descriptive statistics of competition measure*

Table 2 gives descriptive statistics summarising the different approaches to measuring competition. We first discuss each method in turn:

- Defining hospital markets as GORs leads to nine very large markets where each market is characterised by having a high number of competitors and a low HHI relative to the competition measures calculated using the other approaches. All hospitals within the same market are treated as experiencing the same level of competition. Thus, an undesirable result of this method is that we can only separate hospitals, in terms of the level of competition they face, into nine distinct groups. The level of competition faced by hospitals within regions will clearly vary, if only by a small amount. Ideally, we therefore want a competition measure which reflects this by awarding each hospital a unique level of competition.

- Defining hospital markets as the fixed or variable radius circular areas about hospital locations leads to as many markets as there are hospitals. This initially seems attractive as it could allow every hospital to face a unique level of competition. However, many of the hospital markets defined by the fixed and particularly by the variable radius approaches do not overlap and so the hospitals at the centre of these markets are monopolies. For example, using the variable radius approach, 88 out of 128 hospitals that provide cataracts are described as monopolies. While all of these hospitals may have a high degree of market power, we also expect them all to face, at least some, competition and this is not reflected by these fixed and variable radius methods. Thus, despite creating as many markets as there are hospitals, these methods still do not allow us to separate many hospitals from one another in terms of the level of competition they face.

- The Elzinga-Hogarty approach tends to lead to a relatively small number of non-overlapping markets. Thus, this approach suffers from the same problem as that found with the geopolitical boundaries approach: we can only separate hospitals, in terms of the level of competition they face, into as many groups as there are markets. The Elzinga-Hogarty approach based on predicted patient flows tends to lead to fewer markets (and therefore markets of a larger geographical size) than the Elzinga-Hogarty approach based on actual patient flows. For example, using actual patient flows, the Elzinga-Hogarty approach finds 62 markets for cataracts, while using predicted patient flows, the Elzinga-Hogarty approach finds only 33markets.

- Unlike the other approaches, the Kessler-McClellan approach, whether using actual or predicted patient flows, describes no hospitals as perfect monopolies. Further more, each hospital is awarded a unique level of competition. Thus, this approach allows us to separate all hospitals from one another in terms of the level of competition they face. There are some interesting differences between the hospital level HHIs based on actual patient flows and those based on predicted patient flows. The distribution of hospital level HHIs based on predicted patient flow data tends to be narrower and to the left of that based on actual patient flows. Thus, relative to the actual flow data, the predicted flow

data leads us to conclude that hospitals are relatively more competitive and also relatively less variable in terms of their levels of competition. The predicted flows are based on patient level hospital choice models that are based principally on the distances between patients and hospitals. This suggests that if patients choose hospitals simply on distance, hospitals would be more competitive than they actually are. This in turn suggests that the patient level hospital choice models omit important determinants of hospital choice, for example hospital quality, which might lead some hospitals to have more market power than they would do if patients simply choose on distance.

- The DoH MPI is hard to interpret. It is increasing in market power. However, unlike HHI it is not bounded between 0 and 10000 and unlike the count of the number of competitors in the market, it does not have a simple intuitive meaning. This approach also does not do a very good job of separating hospitals from one another in terms of the level of competition they face.

Next we compare the competition methods for specific products:

- Comparing within products, across methods, we see that the different methods suggest very different levels of competition. Consider the distribution of hospital level HHIs for cataracts. At the median the calculated HHIs from the seven different methods listed in the table take the values 878, 5620, 10000, 4143, 1399, 8520 and 6519. Thus some methods suggest that the median hospital has very little market power while other methods suggest that the median hospital has considerable market power or is even a monopoly. In Ssection 3.2 we shall compare the extent to which the distributions of HHIs computed using the different methods are correlated.

Table 2 Hospital level descriptive statistics for the competition measures, reported separately for each product. In the table: N = number of competitors, HHI = Herfindahl-Hirschman Index and MPI = Market Power Index

	Approach	No. of markets	No. of hospitals	No. of monop-olies	Mean	Min.	5th	10th	25th	50th	75th	90th	95th	Max.
	Cataracts													
N	Geopolitical boundary (GOR)	9	128	0	15	3	7	12	13	15	18	19	19	19
N	Fixed radius (20km)	128	128	57	3	0	0	0	0	1	3	13	16	18
N	Variable radius (75%)	128	128	88	1	0	0	0	0	0	1	2	2	15
N	Actual Elzinga-Hogarty (PCT)	62	127	36	4	0	0	0	0	2	4	16	16	16
N	Predicted Elzinga-Hogarty (PCT)	33	127	20	18	0	0	0	3	9	42	42	42	42
N	Actual Kessler-McClellan (MSOA)	N/A	128	0	2	1	1	2	2	2	3	4	4	5
HHI	Geopolitical boundary (GOR)	9	128	0	992	623	623	623	674	878	1132	1338	1499	3196
HHI	Fixed radius (20km)	128	128	57	6445	1385	1728	1856	2906	5620	10000	10000	10000	10000
HHI	Variable radius (75%)	128	128	88	8401	1826	3877	5000	5689	10000	10000	10000	10000	10000
HHI	Actual Elzinga-Hogarty (PCT)	62	127	36	5308	1872	1872	1872	2607	4143	10000	10000	10000	10000
HHI	Predicted Elzinga-Hogarty (PCT)	33	127	20	2826	453	453	453	453	1372	3156	10000	10000	10000
HHI	Actual Kessler-McClellan (MSOA)	N/A	128	0	8051	3742	5222	5815	7416	8520	9188	9432	9548	9702
HHI	Predicted Kessler-McClellan (MSOA)	N/A	128	0	6141	2234	2548	2857	4670	6519	7800	8511	8740	9751
MPI	Department of Health (PCT)	N/A	128	0	2	0	0	1	1	2	3	4	5	11
	CABGs													
N	Geopolitical boundary (GOR)	9	28	0	3	0	1	1	2	2	7	7	7	7
N	Fixed radius (20km)	28	28	18	2	0	0	0	0	0	7	7	7	7
N	Variable radius (75%)	28	28	14	3	0	0	0	0	1	7	7	11	13
N	Actual Elzinga-Hogarty (PCT)	4	28	1	10	0	1	1	11	11	12	12	12	12
N	Predicted Elzinga-Hogarty (PCT)	2	28	1	25	0	26	26	26	26	26	26	26	26
N	Actual Kessler-McClellan (MSOA)	N/A	28	0	1	1	1	1	1	1	1	2	2	2
HHI	Geopolitical boundary (GOR)	9	28	0	3409	1527	1527	1527	1527	3442	4251	5341	5341	10000
HHI	Fixed radius (20km)	28	28	18	7245	1527	1527	1527	1527	10000	10000	10000	10000	10000
HHI	Variable radius (75%)	28	28	14	6200	858	976	1527	1527	7658	10000	10000	10000	10000
HHI	Actual Elzinga-Hogarty (PCT)	4	28	1	1549	848	848	848	848	1016	1016	5078	5078	10000
HHI	Predicted Elzinga-Hogarty (PCT)	2	28	1	767	426	426	426	426	426	426	426	426	10000
HHI	Actual Kessler-McClellan (MSOA)	N/A	28	0	8801	7213	7761	7797	8363	8842	9329	9723	9781	9848
HHI	Predicted Kessler-McClellan (MSOA)	N/A	28	0	5859	2808	2811	3089	4051	6217	7726	8690	8876	9238
MPI	Department of Health (PCT)	N/A	28	0	11	4	4	6	8	11	13	16	18	20

	Hip replacements													
N	Geopolitical boundary (GOR)	9	150	0	18	7	7	8	14	16	22	23	23	23
N	Fixed radius (20km)	150	150	55	4	0	0	0	0	1	5	16	19	21
N	Variable radius (75%)	150	150	91	2	0	0	0	0	0	1	3	10	56
N	Actual Elzinga-Hogarty (PCT)	54	149	34	13	0	0	0	1	4	38	38	38	38
N	Predicted Elzinga-Hogarty (PCT)	17	149	5	30	0	1	2	25	42	44	44	44	44
N	Actual Kessler-McClellan (MSOA)	N/A	150	0	2	1	1	1	2	2	2	2	3	3
HHI	Geopolitical boundary (GOR)	9	150	0	734	541	541	541	563	655	791	1344	1512	1512
HHI	Fixed radius (20km)	150	150	55	5527	672	766	901	1872	5002	10000	10000	10000	10000
HHI	Variable radius (75%)	150	150	91	7723	240	1090	3114	5138	10000	10000	10000	10000	10000
HHI	Actual Elzinga-Hogarty (PCT)	54	149	34	3874	380	380	380	380	2384	6339	10000	10000	10000
HHI	Predicted Elzinga-Hogarty (PCT)	17	149	5	1257	292	292	292	292	292	489	4028	5137	10000
HHI	Actual Kessler-McClellan (MSOA)	N/A	150	0	7676	5140	5882	6092	6817	7879	8480	8903	9108	9704
HHI	Predicted Kessler-McClellan (MSOA)	N/A	150	0	5043	1937	2243	2681	3254	4941	6805	7642	7995	9549
MPI	Department of Health (PCT)	N/A	150	0	2	1	1	1	1	2	3	3	4	5
	Emergency AMIs													
N	Geopolitical boundary (GOR)	9	150	0	17	7	7	8	15	16	22	23	23	23
N	Fixed radius (20km)	150	150	54	4	0	0	0	0	1	5	15	18	21
N	Variable radius (75%)	150	150	111	0	0	0	0	0	0	1	1	2	4
N	Actual Elzinga-Hogarty (PCT)	92	148	68	2	0	0	0	0	1	3	6	7	7
N	Predicted Elzinga-Hogarty (PCT)	27	148	15	17	0	0	0	7	15	23	34	34	34
N	Actual Kessler McClellan (MSOA)	N/A	150	0	2	1	1	1	1	2	2	2	2	2
HHI	Geopolitical boundary (GOR)	9	150	0	727	498	498	498	578	670	754	1356	1412	1412
HHI	Fixed radius (20km)	150	150	54	5414	629	748	922	1746	5001	10000	10000	10000	10000
HHI	Variable radius (75%)	150	150	111	8696	2301	3738	5051	6658	10000	10000	10000	10000	10000
HHI	Actual Elzinga-Hogarty (PCT)	92	148	68	6488	1769	1786	1786	2905	5684	10000	10000	10000	10000
HHI	Predicted Elzinga-Hogarty (PCT)	27	148	15	1988	405	405	405	489	786	1493	10000	10000	10000
HHI	Actual Kessler-McClellan (MSOA)	N/A	150	0	8745	6710	7833	8045	8473	8830	9094	9297	9410	9669
HHI	Predicted Kessler-McClellan (MSOA)	N/A	150	0	5645	1814	2684	3000	3979	5685	7313	8248	8967	9886
MPI	Department of Health (PCT)	N/A	150	0	2	1	1	1	1	2	3	3	4	5

Note, the number of hospitals for the Elzinga-Hogarty method are lower than the other methods as these are based on an older version of the data.

3.3 *Correlations between competition measures, reported separately by product*

This section gives correlation coefficients which summarise the extent to which the different approaches are measuring the same thing. Some care should be taken when interpreting many of these correlations as the measures which are being correlated often have strange distributions. This is because many of the approaches do a poor job of separating hospitals from one another in terms of the level of competition they face and often record many hospitals as being perfect monopolies:

- All the N measures – which give the number of competitors for each hospital - tend to be positively correlated with one another

- All the HHI measures tend to be positively correlated with each other, often with correlations in excess of 0.5. Notable exceptions are for the cataract correlations between the HHIs measured by the geopolitical boundary approach and all other HHI measures. These correlations are often negative. However, with only nine regions, hospitals fall into only nine distinct levels of market competition and so not too much should be read into these "incorrectly" signed correlations.

- The number of competitors measures are strongly negatively correlated with the HHI measures since the more competitors in the market the more competitive the market tends to be.

- Like the HHI statistic, the MPI statistic attempts to measure the market power of each hospital. Thus the MPI and HHI statistics tend to be positively correlated while the MPI and N statistics tend to be negatively correlated.

Figure 1 and 2 show scatter plots that correspond to the correlations reported in Table 3. We only report the scatter plots for the HHI measures. The graphs clearly show many of the features of the indices discussed so far. For example, the large number of points stacked up at 10000 on many of the graphs show how many of the approaches describe high numbers of hospitals as monopolies who face no competition from other hospitals at all. The graphs for the geopolitical boundaries and the Elzinga Hogarty method sometimes show the scatter points to be positioned in short straight lines. This occurs where markets are large and so all hospitals within the market are described as facing the same level of competition.

Table 3 Correlation coefficients for the competition measures, reported separately for each product. In the table: N = number of competitors, HHI = Herfindahl-Hirschman Index and MPI = Market Power Index

		Geopolitical boundary (GOR)	Fixed radius (20km)	Variable radius (75%)	Actual Elzinga-Hogarty (PCT)	Predicted Elzinga-Hogarty (PCT)	Actual Kessler-McClellan (MSOA)	Geopolitical boundary (GOR)	Fixed radius (20km)	Variable radius (75%)	Actual Elzinga-Hogarty (PCT)	Predicted Elzinga-Hogarty (PCT)	Actual Kessler-McClellan (MSOA)	Predicted Kessler McClellan (MSOA)	Department of Health (PCT)
	Cataracts														
N	Geopolitical boundary (GOR)	1.00													
N	Fixed radius (20km)	0.46	1.00												
N	Variable radius (75%)	0.20	0.53	1.00											
N	Actual Elzinga-Hogarty (PCT)	0.39	0.84	0.48	1.00										
N	Predicted Elzinga-Hogarty (PCT)	0.39	0.54	0.26	0.54	1.00									
N	Actual Kessler-McClellan (MSOA)	0.45	0.64	0.28	0.66	0.46	1.00								
HHI	Geopolitical boundary (GOR)	-0.60	0.25	0.15	0.24	0.05	0.06	1.00							
HHI	Fixed radius (20km)	-0.38	-0.72	-0.34	-0.57	-0.35	-0.52	-0.10	1.00						
HHI	Variable radius (75%)	-0.09	-0.38	-0.66	-0.35	-0.17	-0.21	-0.19	0.43	1.00					
HHI	Actual Elzinga-Hogarty (PCT)	-0.14	-0.43	-0.28	-0.66	-0.39	-0.44	-0.15	0.43	0.35	1.00				
HHI	Predicted Elzinga-Hogarty (PCT)	-0.20	-0.37	-0.19	-0.39	-0.67	-0.40	-0.01	0.51	0.26	0.53	1.00			
HHI	Actual Kessler-McClellan (MSOA)	-0.37	-0.65	-0.30	-0.72	-0.40	-0.91	-0.10	0.55	0.22	0.53	0.41	1.00		
HHI	Predicted Kessler McClellan (MSOA)	-0.43	-0.80	-0.38	-0.73	-0.57	-0.74	-0.10	0.83	0.39	0.52	0.60	0.77	1.00	
MPI	Department of Health (PCT)	-0.24	-0.14	0.30	-0.14	-0.13	-0.41	0.16	0.08	-0.23	-0.01	0.06	0.38	0.23	1.00
	CABGs														
N	Geopolitical boundary (GOR)	1.00													
N	Fixed radius (20km)	0.97	1.00												
N	Variable radius (75%)	0.70	0.80	1.00											
N	Actual Elzinga-Hogarty (PCT)	0.24	0.13	0.16	1.00										
N	Predicted Elzinga-Hogarty (PCT)	0.18	0.13	0.15	0.59	1.00									
N	Actual Kessler-McClellan (MSOA)	0.44	0.39	0.32	0.15	0.30	1.00								
HHI	Geopolitical boundary (GOR)	-0.82	-0.67	-0.21	-0.28	-0.17	-0.47	1.00							
HHI	Fixed radius (20km)	-0.96	-0.97	-0.76	-0.16	-0.14	-0.47	0.69	1.00						
HHI	Variable radius (75%)	-0.70	-0.78	-0.88	-0.26	-0.19	-0.42	0.31	0.79	1.00					
HHI	Actual Elzinga-Hogarty (PCT)	-0.27	-0.18	-0.21	-0.93	-0.84	-0.24	0.28	0.21	0.29	1.00				
HHI	Predicted Elzinga-Hogarty (PCT)	-0.18	-0.13	-0.15	-0.59	-1.00	-0.30	0.17	0.14	0.19	0.84	1.00			
HHI	Actual Kessler-McClellan (MSOA)	-0.47	-0.43	-0.37	-0.15	-0.29	-0.99	0.49	0.52	0.46	0.24	0.29	1.00		
HHI	Predicted Kessler McClellan (MSOA)	-0.82	-0.80	-0.60	-0.29	-0.32	-0.72	0.68	0.83	0.70	0.37	0.32	0.75	1.00	
MPI	Department of Health (PCT)	-0.11	-0.04	0.17	0.08	0.12	-0.47	0.34	0.07	-0.11	-0.11	-0.12	0.46	0.19	1.00

	Hip replacements														
N	Geopolitical boundary (GOR)	1.00													
N	Fixed radius (20km)	0.48	1.00												
N	Variable radius (75%)	0.23	0.42	1.00											
N	Actual Elzinga-Hogarty (PCT)	0.54	0.64	0.33	1.00										
N	Predicted Elzinga-Hogarty (PCT)	0.41	0.41	0.18	0.29	1.00									
N	Actual Kessler-McClellan (MSOA)	0.38	0.50	0.29	0.33	0.29	1.00								
HHI	Geopolitical boundary (GOR)	-0.87	-0.21	-0.09	-0.32	-0.33	-0.27	1.00							
HHI	Fixed radius (20km)	-0.35	-0.74	-0.29	-0.45	-0.45	-0.39	0.11	1.00						
HHI	Variable radius (75%)	-0.17	-0.43	-0.58	-0.28	-0.22	-0.28	0.00	0.43	1.00					
HHI	Actual Elzinga-Hogarty (PCT)	-0.28	-0.38	-0.21	-0.70	-0.20	-0.36	0.17	0.28	0.24	1.00				
HHI	Predicted Elzinga-Hogarty (PCT)	-0.22	-0.27	-0.12	-0.13	-0.76	-0.19	0.18	0.38	0.23	0.11	1.00			
HHI	Actual Kessler-McClellan (MSOA)	-0.42	-0.60	-0.34	-0.40	-0.35	-0.96	0.26	0.48	0.33	0.43	0.25	1.00		
HHI	Predicted Kessler McClellan (MSOA)	-0.31	-0.72	-0.28	-0.37	-0.48	-0.51	0.14	0.85	0.42	0.28	0.47	0.60	1.00	
MPI	Department of Health (PCT)	-0.23	-0.24	0.17	-0.16	-0.03	-0.37	0.18	0.19	-0.13	0.11	0.07	0.36	0.28	1.00
	Emergecny AMIs														
N	Geopolitical boundary (GOR)	1.00													
N	Fixed radius (20km)	0.49	1.00												
N	Variable radius (75%)	-0.10	0.11	1.00											
N	Actual Elzinga-Hogarty (PCT)	0.26	0.37	0.07	1.00										
N	Predicted Elzinga-Hogarty (PCT)	0.06	0.25	0.12	0.17	1.00									
N	Actual Kessler-McClellan (MSOA)	-0.01	0.12	0.12	0.20	0.19	1.00								
HHI	Geopolitical boundary (GOR)	-0.91	-0.24	0.19	-0.20	-0.02	0.02	1.00							
HHI	Fixed radius (20km)	-0.31	-0.74	-0.21	-0.27	-0.30	-0.28	0.11	1.00						
HHI	Variable radius (75%)	0.05	-0.15	-0.92	-0.14	-0.12	-0.18	-0.15	0.27	1.00					
HHI	Actual Elzinga-Hogarty (PCT)	-0.24	-0.31	-0.10	-0.89	-0.15	-0.31	0.19	0.25	0.16	1.00				
HHI	Predicted Elzinga-Hogarty (PCT)	-0.07	-0.30	-0.19	-0.19	-0.66	-0.27	0.01	0.47	0.22	0.19	1.00			
HHI	Actual Kessler-McClellan (MSOA)	-0.20	-0.39	-0.12	-0.41	-0.30	-0.87	0.13	0.44	0.23	0.46	0.34	1.00		
HHI	Predicted Kessler McClellan (MSOA)	-0.17	-0.69	-0.24	-0.34	-0.38	-0.36	-0.02	0.87	0.29	0.31	0.57	0.53	1.00	
MPI	Department of Health (PCT)	-0.26	-0.35	0.16	-0.18	-0.07	-0.24	0.19	0.31	-0.11	0.15	0.21	0.37	0.33	1.00

Figure 1 Scatter plot matrices for HHI measures for: cataracts (top) and CABGs (bottom)

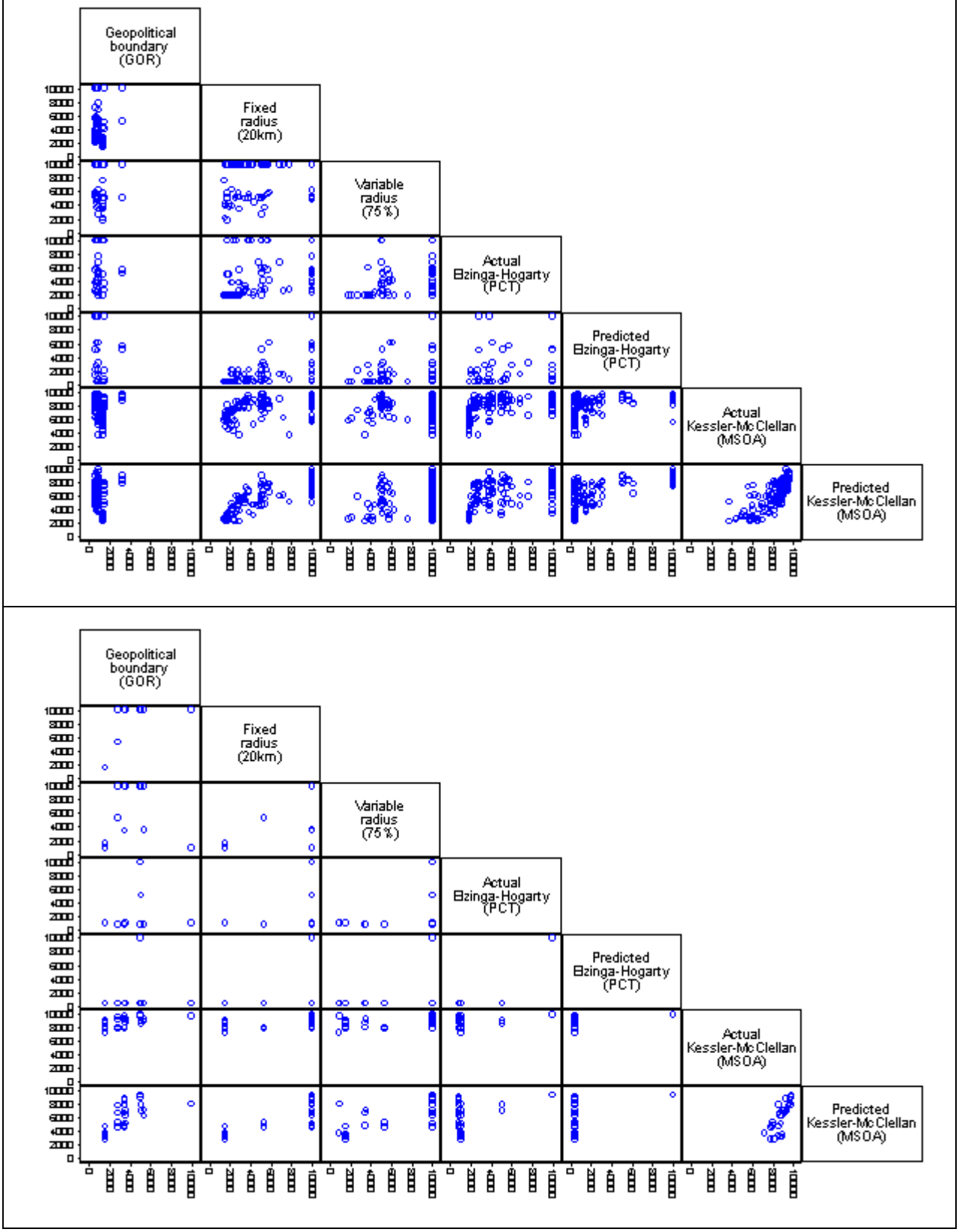
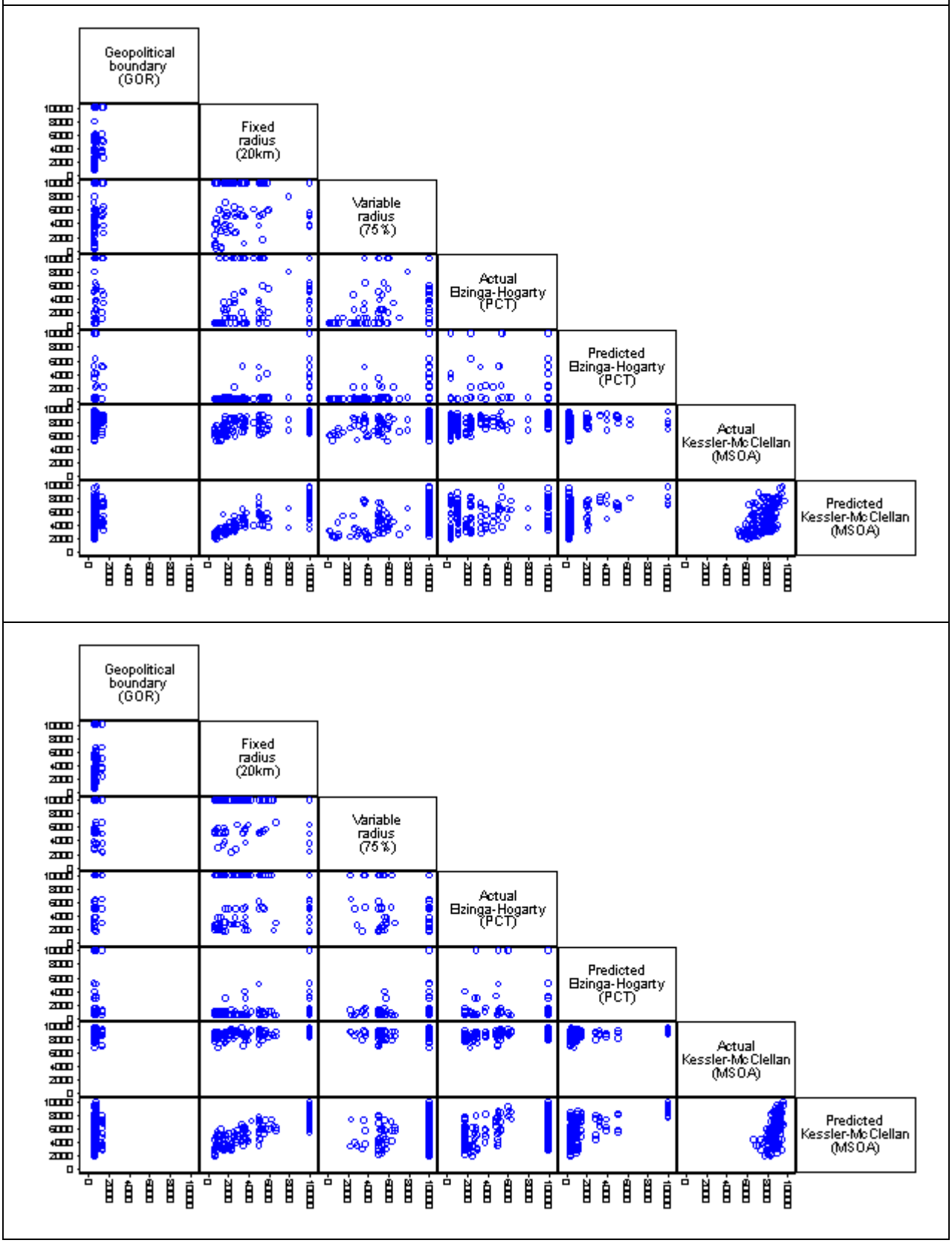


Figure 2 Scatter plot matrices for HHI measures for: hip replacements (top) and Emergency AMIs (bottom)



3.3 *Correlations between products, reported separately by competition measure*

In section 3.2 we examined the association between different competition methods for each product in turn. We used correlation coefficients and scatter plot matrices to summarise those associations. In this section we examine the association between the different products for each competition measure in turn. In doing this, we seek to show the extent to which hospitals which face competitive markets for one product tend to face competitive markets for the other product.

Table 4 reports the correlation for each pairwise comparison of products for each method of producing the HHI competition measure.

Table 4 Correlation coefficients for the four products, reported separately for each HHI competition measures.

	Cataracts	CABGs	Hip replacements	Emergency AMIs
Geopolitical boundary (GOR)				
Cataracts	1.00			
CABGs	0.40	1.00		
Hip replacements	0.87	0.73	1.00	
Emergency AMIs	0.83	0.74	0.99	1.00
Fixed radius (20km)				
Cataracts	1.00			
CABGs	0.71	1.00		
Hip replacements	0.93	0.68	1.00	
Emergency AMIs	0.94	0.67	0.99	1.00
Variable radius (75%)				
Cataracts	1.00			
CABGs	0.39	1.00		
Hip replacements	0.54	0.54	1.00	
Emergency AMIs	0.09	-0.12	0.45	1.00
Actual Elzinga-Hogarty (PCT)				
Cataracts	1.00			
CABGs	0.13	1.00		
Hip replacements	0.42	0.07	1.00	
Emergency AMIs	0.64	0.25	0.31	1.00
Predicted Elzinga-Hogarty (PCT)				
Cataracts	1.00			
CABGs	0.14	1.00		
Hip replacements	0.76	0.02	1.00	
Emergency AMIs	0.27	-0.13	-0.09	1.00
Actual Kessler-McClellan (MSOA)				
Cataracts	1.00			
CABGs	0.40	1.00		
Hip replacements	0.41	0.32	1.00	
Emergency AMIs	0.37	0.50	0.52	1.00
Predicted Kessler McClellan (MSOA)				
Cataracts	1.00			
CABGs	0.88	1.00		
Hip replacements	0.69	0.66	1.00	
Emergency AMIs	0.73	0.55	0.85	1.00

Figures 3, 4, 5 and 6 present the same information as that contained in Table 3; the scatter plots are for each pairwise comparison of products for each method of producing the HHI competition measure.

The plots show that some methods lead to stronger associations between products that others. For example, the fixed radius and the Kessler and McClellan approach based on both actual and predicted flows all lead to strong associations while weaker ones appear when we use the other methods.

Figure 3 Scatter plot matrices for HHI measures based on geopolitical boundaries (GOR)

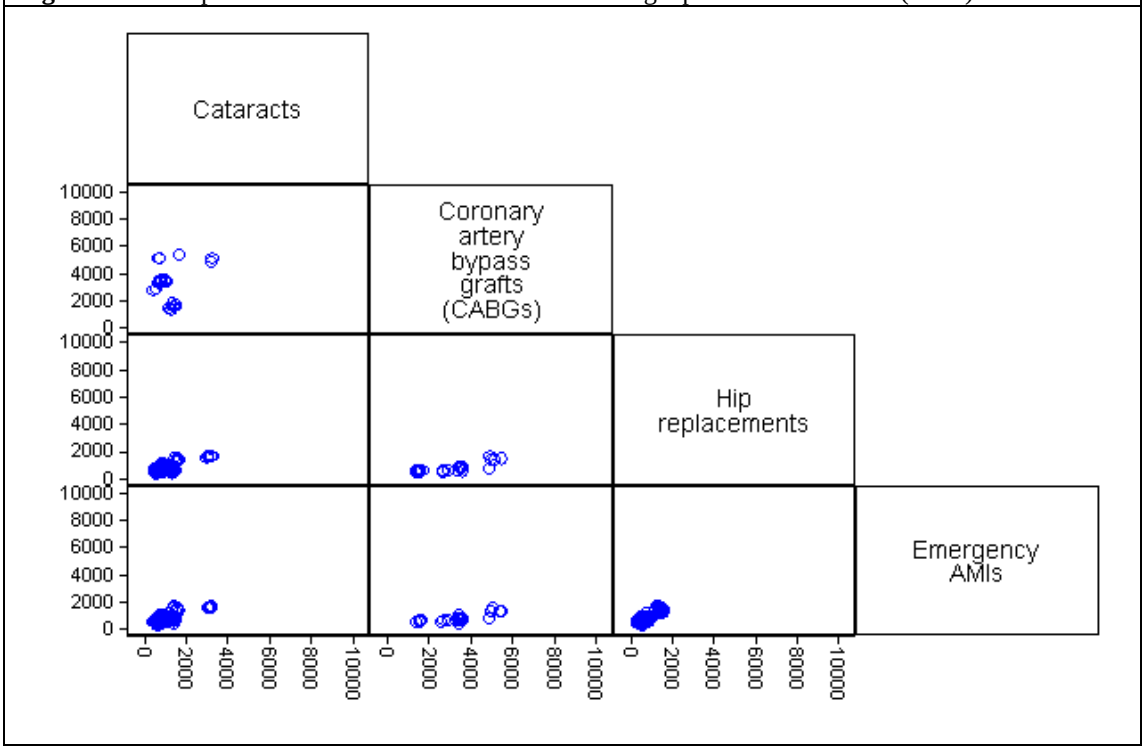


Figure 4 Scatter plot matrices for HHI measures based on fixed radius (20km) (top) and variable radius (75%) (bottom)approaches

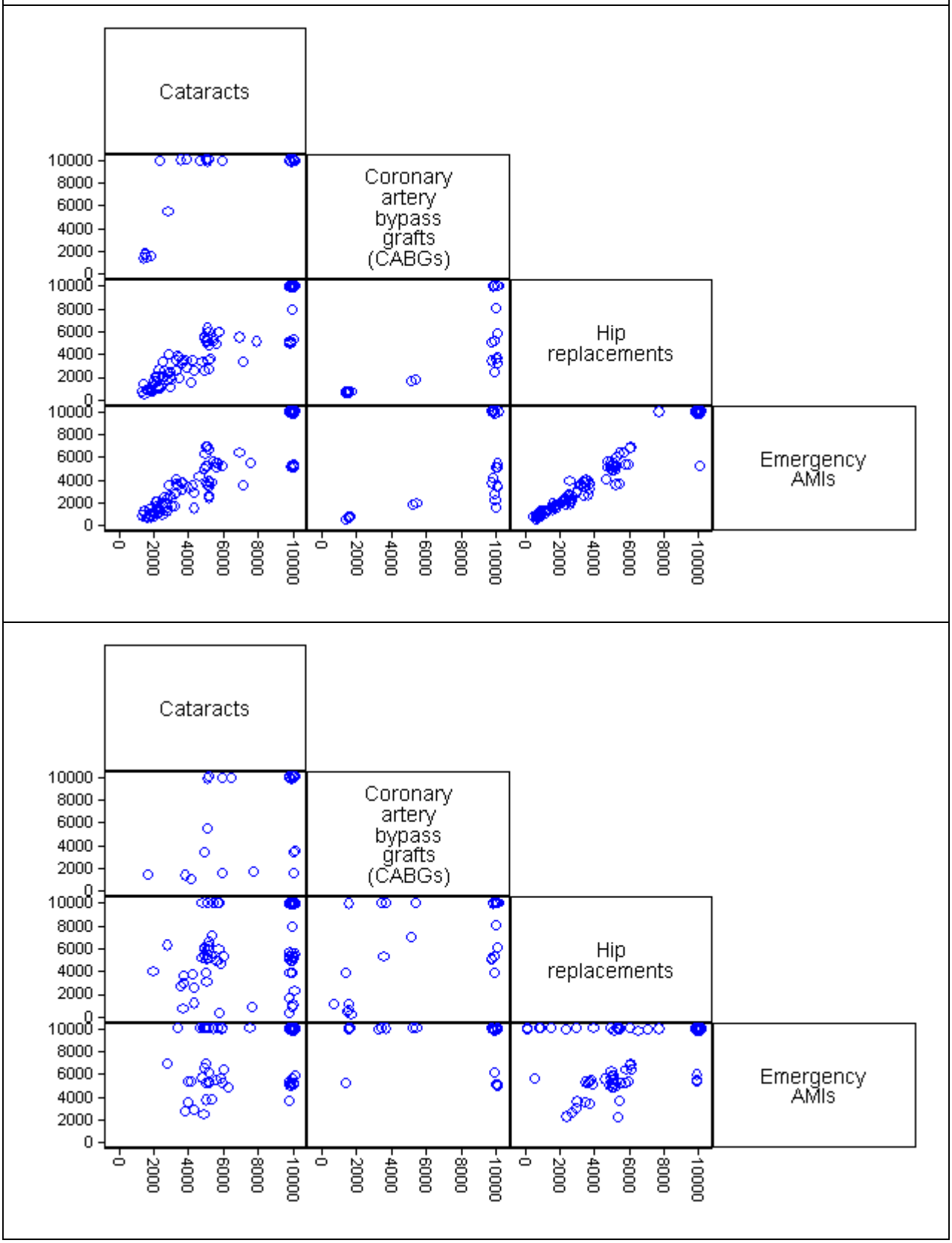


Figure 5 Scatter plot matrices for HHI measures based on Elzinga Hogarty based on actual patient flows (top) and on Elzinga Hogarty based on predicted patient flows (bottom)

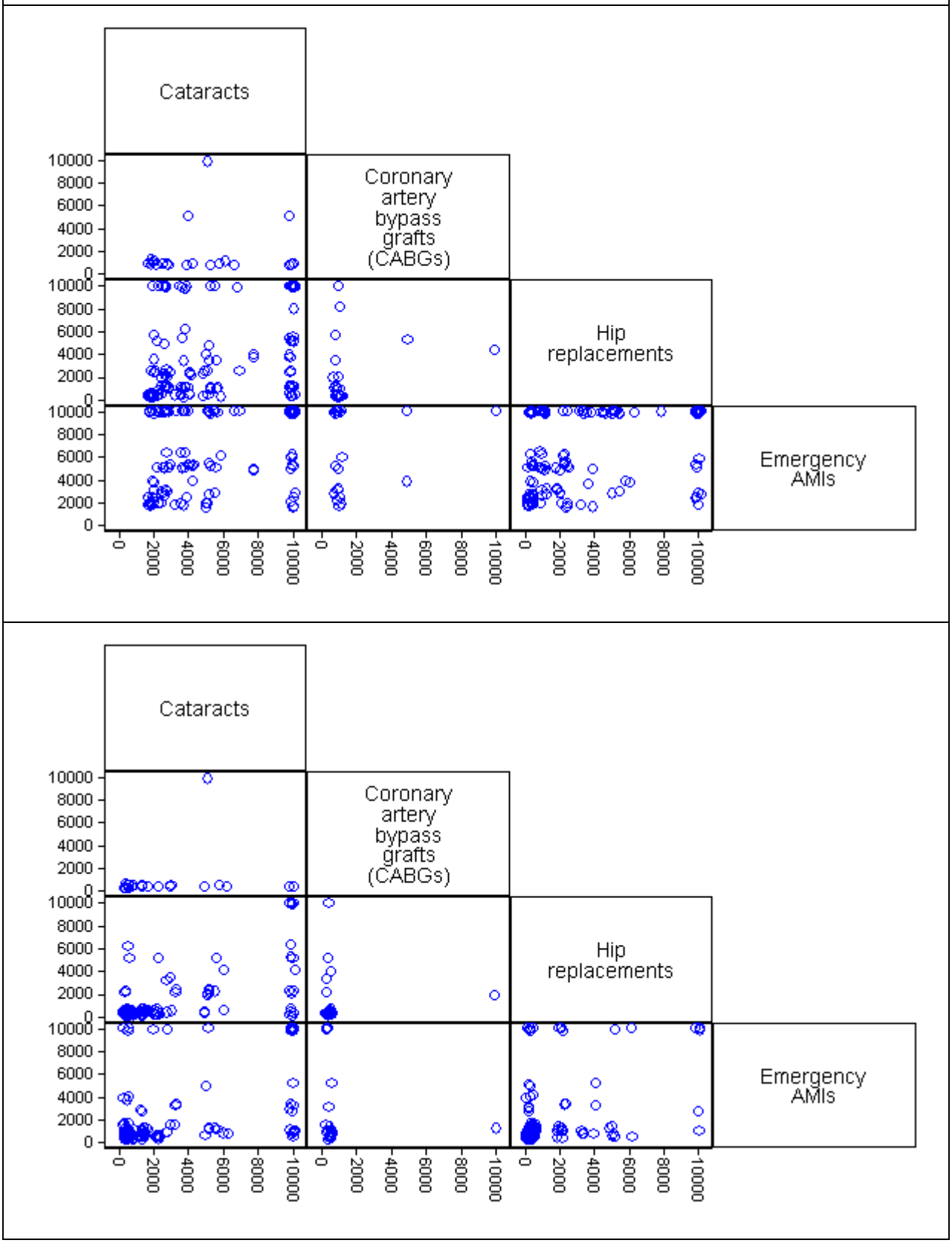
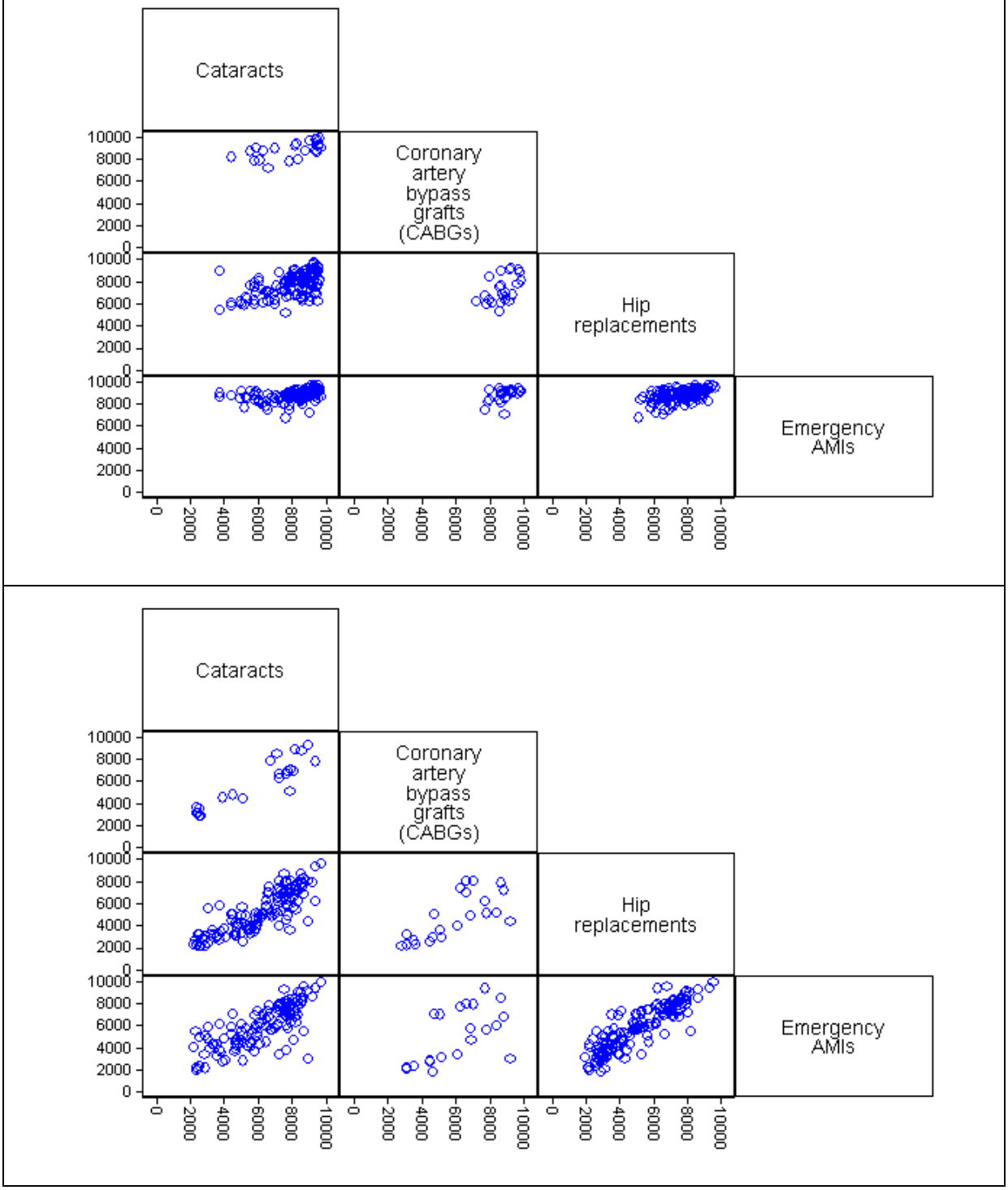


Figure 6 Scatter plot matrices for HHI measures based on: actual Kessler-McClellan hip replacements (top) and predicted Kessler-McClellan (bottom)



4. Summary

- For each product, the competition measures are positively and moderately correlated between methods

- For each method, the competition measures are positively and fairly strongly correlated between products

- HHI competition measures based on fixed and variable radius and the actual and predicted Elizinga Hogarty methods all describe a substantial minority of hospitals as being perfect monopolies (i.e. HHI = 10000).

- The Elzingha Hogarty (E-H) in general defines markets as covering a large geographical area. Thus for a given location of hospitals across geographical space, this definition produces markets which are characterised as being relatively competitive. Further, the apparent level of competitiveness using this measure is considerably greater than when using any other definition of a hospital market. This is similar to international evidence for health care markets using the E-H measure and fits with the criticism in the international literature that argues that the E-H measure leads to markets being erroneously defined as competitive.

- HHI competition measures based on actual and predicted patient flow methods give very similar results

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Appendix A

This appendix gives the formulas used to calculate the different competition measures.

A.1 *Geopolitical boundaries, fixed radius, variable radius and Elzinga-Hogarty markets*
The number of competitors in market m is simply the number of hospitals located within the market J_m excluding the hospital under consideration.

$$N_m = J_m - 1$$

The HHI for market m can be written as:

$$HHI_m = \sum_{j=1}^{J_m} \left(\frac{n_j}{n_1 + n_2 + \cdots + n_{J_m}} \right)^2$$

where j indexes hospitals geographically located within the market and n_j denotes the number of patients who attend hospital j. The level of competition faced by a specific hospital is simply the level of competition in the market within which they are geographically located.

A.2 *Department of Health market power index (MPI)*
The MPI for hospital j can be written as:

$$MPI_j = \sum_{k=1}^{K} \left(\frac{n_{jk}}{n_k} \right)$$

where k indexes PCTs, n_k denotes the number of patients from PCT k and n_{jk} denotes the number of patients from PCT k that attend hospital j. The geographical units need not be PCTs, they could equally be MSOAs or any other set of geographical units.

A.3 *Kessler-McClellan approach based on actual patient flows*
The number of competitors for hospital j can be written as:

$$N_j = \sum_{k=1}^{K} \left(\frac{n_{kj}}{n_j} \right) J_k$$

where k indexes neighbourhoods, n_j denotes the number of patients from hospital j, n_{jk} denotes the number of patients from neighbourhood k that attend hospital j and J_k is a count of the number of hospitals attended by patients from neighbourhood k. Wong et al. (2005) suggest only counting the number of hospitals attended amongst the 75 percent subset of patients who attend the most popular hospitals.

The HHI for hospital j can be written as:

$$HHI_j = \sum_{k=1}^{K} \left(\frac{n_{kj}}{n_j} \right) HHI_k, \qquad HHI_k = \sum_{j=1}^{J} \left(\frac{n_{jk}}{n_k} \right)^2$$

$$n_{kj} = n_{jk}$$

where n_k and n_{jk} are defined as before.

A.4 *Kessler-McClellan approach based on predicted patient flows*

The predicted number of competitors for hospital j can be written as:

$$\hat{HHI}_j = \sum_{k=1}^{K} \left(\frac{\hat{n}_{kj}}{\hat{n}_j} \right) \hat{J}_k,$$

$$\hat{n}_j = \sum_{i=1}^{n} \hat{\pi}_{ij}, \qquad \hat{n}_{kj} = \hat{n}_{jk} = \sum_{i=1}^{n_k} \hat{\pi}_{ij}$$

where k indexes neighbourhoods and i indexes patients. The term $\hat{n}_j$ denotes the predicted number of patients who attend hospital j and $\hat{n}_{jk}$ denotes the predicted number of patients from neighbourhood k that attend hospital j. The term $\hat{\pi}_{ij}$ denotes the predicted probability that patient i attends hospital j while $\hat{J}_k$ is a count of the number of hospitals that patients from neighbourhood k are predicted to attend (note, we ignore hospitals where less than 1 patient are predicted to flow).

The predicted HHI for hospital j can be written as:

$$\hat{HHI}_j = \sum_{k=1}^{K} \left(\frac{\hat{n}_{kj}}{\hat{n}_j} \right) \hat{HHI}_k, \qquad \hat{HHI}_k = \sum_{j=1}^{J} \left(\frac{\hat{n}_{jk}}{\hat{n}_k} \right)^2$$

$$\hat{n}_j = \sum_{i=1}^{n} \hat{\pi}_{ij}, \qquad \hat{n}_k = \sum_{i=1}^{n_k} \sum_{j=1}^{J_i} \hat{\pi}_{ij}, \qquad \hat{n}_{kj} = \hat{n}_{jk} = \sum_{i=1}^{n_k} \hat{\pi}_{ij}$$

where k indexes neighbourhoods and i indexes patients. The terms $\hat{n}_j$, $\hat{n}_{jk}$ and $\hat{\pi}_{ij}$ are defined as before. The term $\hat{n}_k$ denotes the predicted number of patients from neighbourhood k.