Assessing the Formula for Distributing NHS Revenues

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Introduction

Our aim in this report is to assess the methodology used in deriving formulae for the distribution of NHS revenues based on small area use of hospital beds. An influential series of research papers culminating in the report of Carr-Hill et al. (1994) (henceforth "the York study") has proposed the use of regression methods to separate the effects of supply and needs variables. The procedure consists of two stages. At the first stage a set of needs variables is chosen given certain supply factors. These supply factors are allowed to be simultaneously determined. At the second stage, the supply variables are excluded and a regression on the remaining needs variables alone is used to provide the resource allocation model. It is this final regression that is critical for the allocation of funds and it is the selection and interpretation of this equation that is the subject of this report.

In this analysis, which consists of two parts, we focus on the model for the standardised estimated cost measure of utilisation for acute specialties. In the first part we analyse the models, selection methods and estimation procedures used in the York study. In the second part of this report we extend the analysis and present results obtained by the multilevel modelling approach, which is used throughout the selection process.

In Part I, we begin our analysis by replicating the results of the York study. In this we have benefited from the close co-operation of the York researchers. Our assessment is then split into three areas. Firstly, we discuss the interpretation of the first stage regression equation that includes both supply and needs variables. Secondly, we consider the sensitivity of the final needs specification to the method used to exclude needs variables at the first stage. Finally, we consider the method used to select the final specification and present alternative specifications that are equally valid on statistical terms but which contain different needs variables.

In Part II, the multilevel modelling approach is analysed. The York study reaches the final model specification using the methods described in Part I, which amounts to standard regression methods. The estimates of the coefficients for the allocation formula, however, are obtained by the multilevel modelling estimation method. In this method, district effects, where districts are District Health Authorities

(DHA), are implicitly taken into account. We perform a similar analysis as in Part I, but based on the multilevel modelling approach from the outset. Also, *two* years of data on the cost measure of utilisation for acute care is used throughout, as this is used in the final allocation model in the York study. As we identify some different needs variables using the multilevel modelling approach, we investigate the impact of the different specifications on the allocation of NHS revenues to some specified areas. Finally, as the coefficients on the supply variables in the regressions do not indicate that demand is supply constrained we separate wards where demand is supply constrained from wards where this is not the case on the basis of data on average waiting times. A multilevel model is estimated for subsamples with low and with high waiting times.

Part I. Analysis of the York Study

1. The Model

The aim of the model is to relate standardised estimated costs to needs. In constructing the standardised cost measure the impact of local variation in the age and sex composition of the population is already largely accounted for in the standardisation procedure. Age and sex may also be regarded as needs variables, and so this procedure can be considered as a restriction on the way in which these needs variables enter the equation.

Variation in local utilisation rates are likely to depend on the local supply of health resources. To capture this, the York study included four supply factors relating to (i) the accessibility of NHS hospitals - ACCNHS, (ii) the accessibility of GPs - ACCGPS, (iii) (1-)the proportion of old people in nursing homes - HOMES* and (iv) the accessibility of private hospitals - ACCPRI. The detailed descriptive statistics for these variables are given in Appendix A. We denote these "supply" variables as S. Further, utilisation rates depend on a larger set of needs variables, including standardised illness measures, ethnic composition, degree of unemployment etc. These are also described in Appendix A. We denote these "needs" variables as N. The sample we use is the 1990/1991 survey and we have selected observations following the exact same procedure as in the York study.

The model used for selecting the set of needs variables to be used in the final resource allocation model may then be written

$$AC_i = S_i'\alpha + N_i'\beta + u_i \qquad i = 1, \ldots, N \tag{1}$$

where AC is the measure of utilisation for the acute specialties - NEWA91 in Appendix A. The parameters to be estimated are given by the vectors α and β. In estimating equation (1) the supply variables S are allowed to be simultaneously determined, that is they are allowed to be correlated with the unobservable effects u_i across the $i = 1, \ldots, N$ local wards. A set of variables Z is then chosen that includes N

plus a large number of other variables that influence the supply of resources. The model is then estimated by the Two Stage Least Squares procedure. The aim of this initial part of the regression analysis is to choose the vector of needs variables N among a large set of possible factors that represent variation in needs. A variety of selection criteria are used to choose the final specification and these are discussed below.

Once the needs variables N are chosen, the resource allocation rule is estimated through an ordinary least squares regression

$$AC_i = N_i'\gamma + \varepsilon_i. \tag{2}$$

The estimated parameters γ are then used as weights on the needs variables N to define the allocation rule.

Before considering alternative models and selection methods we present our estimates of equations (1) and (2) similar to the intermediate specification of the York study, Table 6.1. It is rather comforting that we were able to replicate the results of the York study closely. These results are not shown here. The results given in Tables 1(a) differ from the York study results for two reasons. Firstly, we use the household sickness rate HSIR074 instead of the more general SIR074, because HSIR074 is the variable used in the final allocation regression. Secondly, it appeared that the GP access variable was not transformed into the natural logarithm in the York study.

Table 1(a) presents the first stage of the approach described above, where, conditional on certain supply variables (ACCNHS through to ACCPRI), the needs variables (DENSITY through to SMR074) are chosen. This is used to choose the needs variables in the resource allocation rule although the rule itself is then estimated as a simple regression on the needs variables themselves as presented in Table 1(b)[3].

Because the test for heteroscedasticity is significant, the standard errors as reported in tables 1(a) and 1(b), and for all subsequent tables, are adjusted for the presence of heteroscedasticity, *i.e.* non-equal variances across the wards. Also, all the other tests presented - for simultaneity of the supply variables, misspecification, and

[3] This is the intermediate needs regression which is not presented in the York study.

Table 1(a). Results for the intermediate model

Weighted 2SLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4959
Variable	B	SE B	T
ACCNHS	0.0136	0.0542	0.2513
ACCGPS	0.0642	0.0630	1.0181
HOMES*	0.1450	0.0904	1.6036
ACCPRI	0.1629	0.0439	3.7135
DENSITY	-0.0247	0.0074	-3.3311
MANUAL	0.0813	0.0167	4.8578
OLDALONE	0.0791	0.0261	3.0357
S_CARER	0.0839	0.0216	3.8805
UNEMP	0.0523	0.0136	3.8409
PRIVRENT	0.0198	0.0060	3.2804
BLACK*	0.1748	0.0733	2.3850
HSIR074	0.1019	0.0307	3.3212
SMR074	0.1154	0.0242	4.7670
Test results	Distribution	Test	p-value
Simultaneity	Chi2[4]	14.64	0.0055
Misspecification	Chi2[31]	54.95	0.0051
Heteroscedasticity	Chi2[13]	92.80	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	1.636	0.4412

Table 1(b): The Needs Regression

Weighted OLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4842
Variable	B	SE B	T
DENSITY	0.0000	0.0022	0.0077
MANUAL	0.0339	0.0124	2.7266
OLDALONE	0.1387	0.0245	5.6666
S_CARER	0.0815	0.0196	4.1644
UNEMP	0.0642	0.0130	4.9455
PRIVRENT	0.0124	0.0040	3.0591
BLACK*	-0.2249	0.0692	-3.2497
HSIR074	0.1038	0.0289	3.5868
SMR074	0.1303	0.0225	5.7838
Test results	Distribution	Test	p-value
Misspecification	Chi2[35]	170.9	0.0000
RESET test	Chi2[2]	1.916	0.3836
Heteroscedasticity	Chi2[13]	108.3	0.0000

endogeneity of the mortality and sickness rates - are adjusted for heteroscedasticity. The notes in Appendix B provide more information on the regressions.

Due to the positive sign on the variable BLACK*, this variable was not considered a needs variable by the York researchers. It is interesting to note, however, that the coefficient of this variable *changes sign* in the needs regression in Table 1(b) and is significant.

2. Adjusting for Supply Variations

In this section we first raise the question as to the precise interpretation of the initial regression (1) which mixes both "supply" and "need" variables. Clearly, if all areas were subject to supply constraints then it is difficult to see how estimates based on actual costs could reliably identify differences in needs. For example, in an area where needs had risen due to increased overcrowding, if supply had not yet reacted to such an increase in needs, then a simple regression of costs on the needs variables would not pick up the variation in needs caused by overcrowding. In that case what would be needed is some measure of excess demand - for example, variation in the numbers on waiting lists. We explore information on waiting times in section 7.

Our interpretation of the regression used in the York study, that includes both supply and needs variables, is that of "slow" adjustment of supply to needs. That is that current usage to some extent reflects current changes in needs but also reflects historic supply differences which may, in turn, reflect historic needs. This may be especially the case for acute care where current usage is likely to reflect some part of current needs. The first stage equation therefore is a mixture of supply and needs effects. An alternative, but similar, interpretation is that the access variables reflect the "hassle" costs borne by the users.

Although it may be argued under either interpretation that supply variables such as ACCNHS could be removed when estimating the resource formula, should this be the case for variables such as ACCGPS? After all, the supply of resources to acute usage is unlikely to directly affect the supply of GPs. Table 2 presents the estimates of the resource allocation model, equivalent to those in Table 1(b) above, but in which ACCGPS is retained and it is interesting to note the large changes in some of the

"needs" coefficients. The PRIVRENT variable becomes small and insignificant, whereas the DENSITY variable now remains in the regression.

Table 2: Results conditional on ACCGPS

Weighted 2SLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4854
Variable	B	SE B	T
ACCGPS	0.1843	0.0580	3.1756
DENSITY	-0.0223	0.0074	-3.0202
MANUAL	0.0331	0.0125	2.6563
OLDALONE	0.1187	0.0257	4.6261
S_CARER	0.0571	0.0217	2.6355
UNEMP	0.0567	0.0134	4.2405
PRIVRENT	0.0017	0.0053	0.3222
BLACK*	-0.2079	0.0685	-3.0350
HSIR074	0.1199	0.0301	3.9827
SMR074	0.1335	0.0227	5.8746
Test results	Distribution	Test	p-value
Simultaneity	Chi2[1]	5.712	0.0169
Misspecification	Chi2[34]	153.6	0.0000
Heteroscedasticity	Chi2[13]	112.0	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	3.991	0.1359

What is important to note is the change in the size and significance of the resource allocation parameters. These are clearly very sensitive to the exclusion of the supply variables. It is also clear that ACCGPS is largely reflecting local population density. Indeed, this is a strong explanatory factor determining ACCGPS.

To conclude this section we briefly turn to the interpretation of the resource allocation regression itself. We will argue in the next section that it is not clear that the first stage equation is the best method of choosing the most appropriate variables for this regression and we have just seen the sensitivity of the coefficients to the omission of the supply factors. It is clearly not a "reduced form" in the sense that it does not include all the exogenous variables that explain the supply factors in the first stage regression. But is it a "needs" relationship? To instrument the supply variables in the first stage regression there must be exogenous variables other than the current needs

variables that affect supply, otherwise the model is not identified. However, these variables will typically be correlated with genuine needs variables. Therefore once the supply factors are excluded the second stage regression will pick up needs effects *plus* any correlation with the exogenous variables that determine supply.

3. The Selection of Needs Variables

In this section we consider whether the model selection approach that uses the first stage regression to choose the needs variables is the most appropriate for choosing the resource allocation regression. To do this we highlight the role of two variables - CROWDED and NONWHITE - across the two stages. In the first stage, reported in Table 3(a), CROWDED and NONWHITE are insignificant and would be dropped. The NONWHITE variable even has the "wrong" sign - as was the case for

Table 3(a): Including NONWHITE and CROWDED

Weighted 2SLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4956
Variable	B	SE B	T
ACCNHS	0.0500	0.0546	0.9157
ACCGPS	0.0880	0.0697	1.2618
HOMES*	0.1267	0.0894	1.4173
ACCPRI	0.1137	0.0429	2.6502
DENSITY	-0.0262	0.0080	-3.2654
MANUAL	0.0740	0.0173	4.2877
OLDALONE	0.0907	0.0261	3.4747
S_CARER	0.0744	0.0228	3.2701
UNEMP	0.0435	0.0143	3.0462
PRIVRENT	0.0152	0.0058	2.6120
NONWHITE	-0.0040	0.0046	-0.8794
CROWDED	0.0137	0.0090	1.5283
HSIR074	0.0892	0.0310	2.8794
SMR074	0.1139	0.0241	4.7342
Test results	Distribution	Test	p-value
Simultaneity	Chi2[4]	6.909	0.1408
Misspecification	Chi2[30]	60.97	0.0007
Heteroscedasticity	Chi2[13]	92.55	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	3.064	0.2161

Table 3(b): CROWDED and NONWHITE in the Needs Regression

Weighted OLS regression	N = 4940		R2 = 0.4882
Dep. Var. NEWA91			
Variable	B	SE B	T
DENSITY	-0.0057	0.0026	-2.2244
MANUAL	0.0262	0.0132	1.9872
OLDALONE	0.1390	0.0241	5.7702
S_CARER	0.1091	0.0190	5.7422
UNEMP	0.0344	0.0139	2.4838
PRIVRENT	0.0061	0.0041	1.5031
NONWHITE	0.0144	0.0035	4.0900
CROWDED	0.0231	0.0085	2.7018
HSIR074	0.0990	0.0295	3.3536
SMR074	0.1182	0.0225	5.2505
Test results	Distribution	Test	p-value
Misspecification	Chi2[34]	136.1	0.0000
RESET	Chi2[2]	2.950	0.2288
Heteroscedasticity	Chi2[13]	105.1	0.0000

BLACK* in Table 1(a) above. However, once the supply variables are omitted these variables become highly significant and the sign of NONWHITE changes, as reported in Table 3(b). There appears no statistical reason why these variables should not have been retained.

4. Choosing Between Models

In this section we allow a wider choice of needs variables by using the original 30 needs variables selected in the York study, and choose a specification which on standard criteria is as equally valid as the one chosen in the York study.

Firstly, Tables 4(a) and 4(b) reproduce the preferred parsimonious specification of the York study. In Table 4(c) the access to GP variable is retained for comparison with Table 1(c) above. Tables 5(a) and 5(b) produce the alternative model.

The parsimonious model:

The results of the first stage regression, Table 4(a), are very close to those in the York study, Table 6.3. The DENSITY variable, which is highly significant in the

first stage regression, but is insignificant in the second stage needs regression, together with the MANUAL variable are removed from the model for the final allocation regression. In the York study this final needs regression is based on two years of observations on the utilisation rates, 1990/91 and 1991/92. This procedure of combining the two years of information on the utilisation rate has quite a large impact on the coefficient of the illness rate, HSIR074, which is 0.1013 in the needs regression, Table 4(b), 0.1227 in the needs regression excluding DENSITY and MANUAL, and finally equal to 0.2023 in the York study, Table 6.4. This occurs due to the fact that the current illness rate (1990/91) is an important factor in explaining the future utilisation rate (1991/92), with a coefficient of 0.2848 and a t-statistic of 11.79 in the OLS regression.[4] In the final regression, the York study uses as the utilisation measure the average of the two years, which results in approximately the average of the two coefficients.

Table 4(a): Results for parsimonious model

Weighted 2SLS regression	N = 4940		R2 = 0.4944
Dep. Var. NEWA91			
Variable	B	SE B	T
ACCNHS	-0.0056	0.0522	-0.1067
ACCGPS	0.1760	0.0474	3.7130
HOMES*	0.0878	0.0883	0.9947
ACCPRI	0.1483	0.0407	3.6467
DENSITY	-0.0363	0.0060	-6.0518
MANUAL	0.0699	0.0165	4.2361
OLDALONE	0.0987	0.0259	3.8063
S_CARER	0.0599	0.0203	2.9428
UNEMP	0.0529	0.0136	3.8917
HSIR074	0.1093	0.0304	3.5960
SMR074	0.1179	0.0243	4.8532
Test results	Distribution	Test	p-value
Simultaneity	Chi2[4]	22.85	0.0001
Misspecification	Chi2[33]	68.18	0.0003
Heteroscedasticity	Chi2[13]	92.97	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	4.640	0.0983
Restrictions BLACK* and PRIVRENT	Chi2[2]	13.74	0.0010

[4] The coefficient of S_CARER is insignificant in this regression.

Table 4(b): The Needs Regression from the Parsimonious Specification

Weighted OLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4814
Variable	B	SE B	T
DENSITY	-0.0013	0.0021	-0.5940
MANUAL	0.0167	0.0116	1.4375
OLDALONE	0.1624	0.0230	7.0637
S_CARER	0.0859	0.0191	4.5063
UNEMP	0.0786	0.0126	6.2227
HSIR074	0.1013	0.0292	3.4760
SMR074	0.1365	0.0225	6.0730
Test results	Distribution	Test	p-value
Misspecification	Chi2[37]	192.3	0.0000
RESET test	Chi2[2]	3.544	0.1700
Heteroscedasticity	Chi2[13]	107.1	0.0000

The results conditional on the GP access variable, Table 4(c), again indicate the sensitivity of the size and significance of the resource allocation parameters to the removal of the supply variables from the model.

Table 4(c): Results conditional on ACCGPS

Weighted 2SLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4842
Variable	B	SE B	T
ACCGPS	0.2201	0.0437	5.0334
DENSITY	-0.0263	0.0055	-4.7914
MANUAL	0.0257	0.0118	2.1787
OLDALONE	0.1118	0.0257	4.3568
S_CARER	0.0600	0.0201	2.9849
UNEMP	0.0607	0.0134	4.5202
HSIR074	0.1263	0.0302	4.1833
SMR074	0.1376	0.0227	6.0729
Test results	Distribution	Test	p-value
Simultaneity	Chi2[1]	14.78	0.0001
Misspecification	Chi2[36]	156.8	0.0000
Heteroscedasticity	Chi2[13]	111.8	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	3.390	0.1836

An alternative model:

Results for an alternative model specification are given in Table 5(a). In comparison to the intermediate specification of the York study (see Table 1(a)) the variables UNEMP, OLDALONE and S_CARER are removed from the model, whereas the variables NOCAR and INACLPAR* are added to the specification. According to the misspecification test this specification cannot be rejected (p-value = 0.0026 > 0.001, Table 5(a)), and is in between the intermediate specification (p-value 0.0051, Table 1(a)) and the parsimonious specification (p-value 0.0003, Table 4(a)). Also, this alternative model has one "needs" variable less than the intermediate model, and one more than the parsimonious model. The NOCAR variable may not be considered a "needs" variable by itself in the sense of directly impacting on health status. However, it seems a good proxy variable of underlying circumstances determining the need for health care.

Table 5(a): Results for an Alternative Model Specification

Weighted 2SLS regression Dep. Var. NEWA91	N = 4940		R2 = 0.4945
Variable	B	SE B	T
ACCNHS	-0.0390	0.0555	-0.7036
ACCGPS	0.0524	0.0806	0.6508
HOMES*	0.0682	0.0938	0.7272
ACCPRI	0.2049	0.0448	4.5757
DENSITY	-0.0222	0.0086	-2.5907
MANUAL	0.0744	0.0173	4.3044
INACLPAR*	-0.4415	0.0999	-4.4185
NOCAR	0.0587	0.0191	3.0689
BLACK*	0.1975	0.0733	2.6955
PRIVRENT	0.0213	0.0061	3.4937
HSIR074	0.1479	0.0299	4.9414
SMR074	0.1100	0.0246	4.4665
Test results	Distribution	Test	p-value
Simultaneity	Chi2[4]	22.14	0.0002
Misspecification	Chi2[32]	68.94	0.0026
Heteroscedasticity	Chi2[13]	95.29	0.0000
Endogeneity of HSIR074 and SMR074	Chi2[2]	1.513	0.4694

Table 5(b): The Alternative Needs Regression

Weighted OLS regression	N = 4940		R2 = 0.4834
Dep. Var. NEWA91			
Variable	B	SE B	T
DENSITY	-0.0022	0.0024	-0.9370
MANUAL	0.0182	0.0127	1.4334
INACLPAR*	-0.4026	0.0956	-4.2107
NOCAR	0.0894	0.0124	7.1914
BLACK*	-0.1986	0.0686	-2.8930
PRIVRENT	0.0156	0.0040	3.9021
HSIR074	0.1268	0.0249	5.0985
SMR074	0.1368	0.0218	6.2805
Test results	Distribution	Test	p-value
Misspecification	Chi2[36]	172.8	0.0000
RESET test	Chi2[2]	1.655	0.4371
Heteroscedasticity	Chi2[13]	107.5	0.0000

Part II. Multilevel Modelling

5. The Multilevel Modelling Procedure

The parsimonious model was estimated in the York study by the multilevel model estimation technique, utilising the two years on the cost utilisation measure. The estimated coefficients of this specification are the final results used in the allocation formula. As the MANUAL variable was found to be insignificant in the OLS regression, this variable was not considered in the final multilevel model specification.

The multilevel model specification takes account of district effects, the districts being the 186 District Health Authorities (DHA). The multilevel needs regression is specified as

$$AC_{ij} = N_{ij}'\gamma + \nu_j + \varepsilon_{ij}. \tag{3}$$

where the index ij denotes the ith ward in district j, and where ν_j is the district effect. The standard approach in multilevel modelling is to specify ν_j as a random variable with mean zero, and to estimate the model by the method of (iterative) generalised least squares (GLS). This improves the efficiency of the estimator as compared to OLS, but OLS itself is unbiased and consistent.

However, when the district effects ν_j are correlated with the needs variables, the OLS and multilevel random effects estimator are inconsistent. A consistent estimator for γ in this case is to estimate the model by OLS with separate dummy variables for each district included. This estimator for γ is the same as the OLS estimator in the model where the needs and utilisation variables are taken in deviation from the district mean.

When group sizes are large, i.e. when the districts contain many wards, the multilevel random effects estimator and the dummy variable estimator are equivalent (see Blundell and Windmeijer (1995)). The average number of wards in the 186 districts is equal to 26.64, which does turn out to be sufficiently large. The results of the random effects estimator, of the York study, the dummy variable estimator are presented in Table 6 for the final specification of the York study. The dependent

variable in this case is the average of two years (91/92) of utilisation costs of acute care. The needs variables, however, are measured in one year (91) only. It is clear that the two estimators give virtually identical results.

Table 6: Multilevel Modelling results

Weighted regression Dep. Var. NEWA9192	Multilevel GLS N = 4953			Dummy variable OLS N = 4955 R2 = 0.4569		
Variable	B	SE B	T	B	SE B	T
OLDALONE	0.0765	0.0130	5.8846	0.0725	0.0130	5.5795
S_CARER	0.0436	0.0121	3.6033	0.0425	0.0122	3.4763
UNEMP	0.0287	0.0092	3.1196	0.0283	0.0093	3.0520
HSIR074	0.2528	0.0183	13.8142	0.2572	0.0184	13.9525
SMR074	0.1619	0.0131	12.3588	0.1622	0.0131	12.3489
Test results				DoF	Test	p-value
Misspecification				39	229.08	0.0000
RESET test				2	1.3744	0.5030
Heteroscedasticity				5	43.086	0.0000

Notes: The standard errors are not corrected for heteroscedasticity. The test for misspecification is based on the results for N = 4940.

As mentioned before, the MANUAL variable was dropped from the original model because it was not significant in the needs regression estimated by OLS. As the results of Table 7 show, however, this variable is significant in the multilevel model specification. A large change is in the value of the coefficient of HSIR074, which drops from 0.2528 to 0.1422.

Table 7: Results final model with MANUAL

Weighted regression Dep. Var. NEWA9192	Dummy variable OLS N = 4955 R2 = 0.4695		
Variable	B	SE B	T
MANUAL	0.0849	0.0097	8.7799
OLDALONE	0.1086	0.0139	7.8138
S_CARER	0.0328	0.0147	2.2256
UNEMP	0.0443	0.0102	4.3575
HSIR074	0.1422	0.0269	5.2799
SMR074	0.1491	0.0168	8.9018
Test results	DoF	Test	p-value
Misspecification	38	168.19	0.0000
RESET test	2	2.7870	0.2482
Heteroscedasticity	6	50.185	0.0000

The differences between the OLS and the multilevel modelling results suggest that a model search that takes account of the district effects from the outset may lead to the identification of different needs variables. We therefore repeat the search, estimating the equations by dummy variable ordinary least squares and two-stage least squares. The latter is equivalent to regular two-stage least squares in a model where all variables, including the instruments, are transformed in deviations from the district means. Again, for large group sizes, the dummy variable two-stage least squares estimator is equivalent to the random effects generalised two-stage least squares estimator.

A parsimonious model specification, where no single needs variable can be added to the equation with the supply variables included, which has a t-value larger than 1.95, is presented in Table 8a and 8b. The identified needs variables which are the same as in the York specification are SMR074, HSIR074, MANUAL and OLDALONE. Different variables are NOCAR and RNEWCOMM, which come in the

Table 8(a): Results for the Multilevel Parsimonious Model

Weighted regression	Dummy variable 2SLS		
Dep. Var. NEWA9192	N = 4940	R2 = 0.4776	
Variable	B	SE B	T
ACCNHS	-0.0556	0.0954	-0.5825
ACCGPS	-0.1398	0.0355	-3.9380
HOMES*	0.0058	0.0539	0.1082
ACCPRI	0.2173	0.0960	2.2640
NOCAR	0.0807	0.0122	6.6075
RNEWCOMM	0.0154	0.0026	5.8808
MANUAL	0.0946	0.0128	7.3834
OLDALONE	0.0585	0.0166	3.5233
HSIR074	0.1309	0.0230	5.6977
SMR074	0.1366	0.0172	7.9525
Test results	DoF	Test	p-value
Simultaneity	4	46.846	0.0000
Misspecification	34	97.549	0.0000
Heteroscedasticity	6	35.590	0.0000
Endogeneity of HSIR074 and SMR074	2	1.6080	0.4475

Table 8(b): The Multilevel Parsimonious Needs Regression

Weighted regression	Dummy variable OLS		
Dep. Var. NEWA9192	N = 4955	R2 = 0.4720	
Variable	B	SE B	T
NOCAR	0.0487	0.0093	5.2419
RNEWCOMM	0.0106	0.0022	4.7134
MANUAL	0.0828	0.0099	8.3547
OLDALONE	0.0607	0.0161	3.7657
HSIR074	0.1557	0.0208	7.4960
SMR074	0.1530	0.0150	10.1769
Test results	DoF	Test	p-value
Misspecification	38	140.82	0.0000
RESET test	2	6.0321	0.0490
Heteroscedasticity	6	37.195	0.0000

place of S_CARER and UNEMP. The access to GP's variable now has a negative impact. The sign of the coefficient for ACCNHS is negative, which is implausible, but insignificant. Again, the access to private hospitals has a large positive coefficient. The test for misspecification is equal to 97.55 and indicates some misspecification in terms of omitted variables, but this value is much lower than the multilevel equivalent of the parsimonious model in the York study (the standard regression results of this model were presented in Table 4(a)). The test statistic for this model, which has 37 degrees of freedom, is equal to 163.74.

As mentioned before, the NOCAR variable may not seem a proper "needs" variable. When this variable is excluded from the specification search, the model as presented in Table 9 is preferred. The variables N_CARER, CROWDED and INACLPAR* now enter the specification. In the model with the supply variables no single needs variable can be added that has a t-value larger than 2.15. The sign of the coefficients on the supply variables are the same as before, but are insignificant, and therefore the coefficients on the needs variables do not change much when the supply variables are removed.

Table 9(a): Results for the Multilevel Alternative Model

Weighted regression Dep. Var. NEWA9192	Dummy variable 2SLS N = 4940	R2 = 0.4760	
Variable	B	SE B	T
ACCNHS	-0.0266	0.0873	-0.3040
ACCGPS	-0.0514	0.0298	-1.7277
HOMES*	0.0373	0.0539	0.6926
ACCPRI	0.1106	0.0903	1.2248
N_CARER	0.0457	0.0104	4.3931
CROWDED	0.0266	0.0063	4.2041
INACLPAR*	-0.2672	0.0754	-3.5420
RNEWCOMM	0.0114	0.0032	3.6138
MANUAL	0.0896	0.0133	6.7421
OLDALONE	0.0716	0.0177	4.0487
HSIR074	0.1351	0.0235	5.7537
SMR074	0.1491	0.0170	8.7888
Test results	DoF	Test	p-value
Simultaneity	4	13.107	0.0108
Misspecification	32	116.92	0.0000
Heteroscedasticity	8	82.155	0.0000
Endogeneity of HSIR074 and SMR074	2	6.8264	0.0329

Table 9(b): The Multilevel Alternative Needs Regression

Weighted OLS regression Dep. Var. NEWA9192	Dummy variable OLS N = 4955	R2 = 0.4749	
Variable	B	SE B	T
N_CARER	0.0439	0.0106	4.1506
CROWDED	0.0285	0.0058	4.9245
INACLPAR*	-0.2921	0.0720	-4.0561
RNEWCOMM	0.0095	0.0028	3.3972
MANUAL	0.0834	0.0102	8.1722
OLDALONE	0.0634	0.0167	3.7994
HSIR074	0.1274	0.0235	5.4209
SMR074	0.1502	0.0154	9.7764
Test results	DoF	Test	p-value
Misspecification	36	123.60	0.0000
RESET test	2	2.5542	0.2789
Heteroscedasticity	8	86.316	0.0000

Results conditional on GP access

Table 10 presents results for the parsimonious model needs regression with ACCGPS being retained in the model. (The results for the alternative model with ACCGPS are not presented as the coefficient on ACCGPS is not significant and results do not change).

The effect of better access to GP's is negative on the acute care utilisation, indicating that GP's offer services which are substitutes to the hospital care provision. In comparison to the needs regression, the coefficient on NOCAR changes most, from 0.0487 to 0.0764.

Table 10: Results for the Multilevel Parsimonious Needs regression, conditional on ACCGPS

Weighted regression	Dummy variable 2SLS		
Dep. Var. NEWA9192	N = 4940	R2 = 0.4755	
Variable	B	SE B	T
ACCGPS	-0.0863	0.0159	-5.4279
NOCAR	0.0764	0.0114	6.6916
RNEWCOMM	0.0169	0.0025	6.9092
MANUAL	0.0797	0.0101	7.9022
OLDALONE	0.0647	0.0162	4.0025
HSIR074	0.1394	0.0215	6.4862
SMR074	0.1463	0.0151	9.6794
Test results	DoF	Test	p-value
Simultaneity	1	27.589	0.0000
Misspecification	37	110.65	0.0000
Heteroscedasticity	6	37.108	0.0000
Endogeneity of HSIR074 and SMR074	2	2.1954	0.3336

6. Impact on Revenue Allocations

The models we have found by using the two years of data on the dependent variable and the multilevel modelling approach throughout the analysis are quite similar to the model adopted by the York study, but differ in certain needs variables. The important question then is whether these different specifications give rise to different

resource allocations. In Table 11, the allocation results are given for four different model specifications, viz. the York model, the York model plus MANUAL, the parsimonious model and the alternative model, using the estimation results as presented in Tables 6 (dummy variable OLS results), 7, 8(b) and 9(b). The allocation effects are given for areas that are clustered on the basis of certain characteristics. The effect of adding MANUAL to the York specification is that it removes resources from the Inner London and Inner City Deprived areas. The same effect occurs for the parsimonious specification, whereas the alternative specification allocates more resources to the Inner London area than the York specification.

Table 11: Different Model Specifications and Resource Allocations

Cluster summaries	York	York + MAN	Pars	Altern
Inner London	112.9	110.2	111.2	117.7
Mixed Status London	100.4	99.3	100.9	104.4
Outer London	94.1	93.9	94.7	95.9
Inner City Deprived	113.6	111.7	111.8	111.7
Urban Areas	108.0	107.3	107.4	106.0
Resort and Retirement Areas	96.2	96.8	96.0	96.4
High-Status Suburban	93.4	94.3	94.0	93.7
High-Status Rural	87.8	89.3	89.7	90.4
High-Status Urban	97.9	98.3	98.1	97.1
Rural Areas	95.9	97.0	96.4	95.3
Dormitory Towns	106.7	103.4	105.0	109.2

7. Waiting Times

It is likely that the hospital care market is supply constrained. However the estimated coefficients on the supply variables in the models do not indicate that this is the case, with for example the access to NHS hospitals having a negative effect, and a positive effects of access to private hospitals. Using waiting time data, we can split the sample into wards with a low average waiting time, and which are therefore not supply constrained, and into wards with a high average waiting time, which are supply constrained. Although the precise data on waiting times may suffer from measurement problems, this rough split into 'high' and 'low' levels should provide an indication of

supply constraints. Results for the parsimonious model are presented in Table 12 for subsamples of wards with average waiting times less than 100 days, or more than 140 days. It is clear that for wards with long waiting times, the supply variables become effective, with a positive effect of the access to NHS hospital beds variable and a negative effect of access to private hospitals.

Table 12: Multilevel Modelling Results conditional on Waiting Times

Weighted regression Dep. Var. NEWA9192	Dummy variable OLS WT < 100 N = 1362	 R2 = 0.4707		Dummy variable 2SLS WT > 140 N = 1081	 R2 = 0.4809	
Variable	B	SE B	T	B	SE B	T
ACCNHS				0.1545	0.0770	2.0059
ACCGPS				-0.1250	0.0470	-2.6612
HOMES*				-0.1222	0.1025	-1.1922
ACCPRI				-0.0843	0.0709	-1.1894
NOCAR	0.0734	0.0190	3.8674	0.0666	0.0204	3.2715
RNEWCOMM	0.0077	0.0040	1.9313	0.0198	0.0048	4.1054
MANUAL	0.0589	0.0160	3.6828	0.0976	0.0239	4.0880
OLDALONE	0.0608	0.0302	2.0140	0.0611	0.0325	1.8835
HSIR074	0.1033	0.0445	2.3191	0.1423	0.0432	3.2937
SMR074	0.1848	0.0279	6.6200	0.1712	0.0394	4.3409

Conclusion

Our aim in this preliminary report has been to assess the methodology used in deriving formula for the distribution of NHS revenues based on small area use of hospital beds. The methodology we are examining is one that uses cross-section regression methods to derive a relationship between a measure of utilisation rates for particular specialties and indicators of needs. In this analysis we focus on the standardised estimated cost measure of utilisation for acute specialities. Since measured utilisation is likely to be determined in part by short-run supply constraints as well as needs, the method developed in the York study controls for supply factors when choosing which needs variables are to be included. The supply variables are eventually excluded and a regression on the chosen needs variables alone is then used to provide the resource allocation model. It is this final regression that is critical for the allocation of funds and it is the selection and the interpretation of this equation that has been the subject of this report, which consists of two parts. In Part I, the methodology and estimation results of the York study are examined. In Part II, we extend the analysis to a model search on the basis of multilevel modelling,

In Part I, we began our analysis by considering the precise specification chosen by the York study. We found that we could broadly replicate their results although we have found that the inclusion of a second year of data on the utilisation rate has a large effect on the conclusions. Our assessment has been split into three areas. Firstly, we considered the interpretation of the model that includes both supply and needs variables. We argued that it may not be sensible to exclude all supply variables when considering a specific resource allocation rule. For example, in assessing resources allocated to acute hospital specialities is it sensible to condition on GP access or not? The resulting allocation rule is found to be quite sensitive to this issue.

Secondly, we analysed the sensitivity of the final needs specification to the method used to exclude needs variables at the first stage. It is not clear that eliminating needs variables at the first stage was an appropriate selection approach. We found that if variables that had been excluded at the first stage due to lack of significance are retained in the second stage regression, their sign and significance can change quite dramatically. As an example, we retained the NONWHITE and CROWDED variables in the first stage although their t-values are both less than two and NONWHITE has a

perverse negative sign. However, in the final stage needs regression they both now have the "correct" sign and their t-values exceed 2.5.

Finally, we considered the overall method used to select the final specification and present alternative specifications that contain a different subset of needs variables but which can be considered as "equally valid" on statistical terms.

In Part II we presented results of a specification search, based on similar arguments as the York study, but using multilevel modelling from the outset. The resulting models are similar to the York specification, but differ in certain needs variables. The impact of the different specifications on the allocation of resources has been analysed for certain areas with similar characteristics. Further, information on average waiting times has been used to split the sample in a part which is likely to be supply constrained (high waiting times), and a part which is likely to be not supply constrained (low waiting times).

Appendix A

Table A1: Descriptive statistics

Variables used in the regression					
Variable	Description	Mean	Std. Dev.	Min	Max
NEWA91	standardised estimated costs 1990-91 acute	93.9272	23.0603	21.3269	269.2445
NEWA9192	" " (1990-91 + 1991-92) /2	97.2742	21.1863	24.9498	262.2849
ACCNHS	NHS hospital accessibility	2.3448	0.7516	0.5718	4.7522
ACCGPS	GP accessibility	0.5283	0.1271	0.1620	0.9608
HOMES*	1-proportion of 75+ in nursing and residential homes	0.9436	0.0640	0.5895	1.0000
ACCPRI	private hospital accessibility	0.1736	0.1280	0.0154	2.0717
SMR074	standardised mortality ratio - ages 0-74	99.4780	23.1552	19.9311	235.1680
HSIR074	standardised illness ratio - ages 0-74, for residents in households only	99.0107	30.5855	40.3261	252.5906
DENSITY	population density	25.9558	27.8047	0.0725	273.9676
MANUAL	proportion of persons with head in manual class	0.4623	0.1459	0.0585	0.8387
OLDALONE	proportion of those of pensionable age living alone	0.3328	0.0578	0.1524	0.6424
S_CARER	proportion of dependants in single carer households	0.1945	0.0592	0.0488	0.4684
N_CARER	proportion of dependants in no carer households	0.1475	0.0517	0.0168	0.4381
INACLPAR*	1-proportion of families economically inactive lone parent	0.9581	0.0367	0.7015	1.0000
BLACK*	1-proportion of residents in black ethnic groups	0.9822	0.0429	0.5343	1.0000
NONWHITE	proportion of residents in non-white ethnic groups	0.0573	0.1040	0.0002	0.9021
CROWDED	proportion household residents in crowded accommodation	0.0445	0.0402	0.0012	0.5700
UNEMP	proportion of the economically active that is unemployed	0.0919	0.0530	0.0238	0.4411
NOCAR	proportion of residents in households with no car	0.2366	0.1424	0.0206	0.8195
RNEWCOMM	proportion of residents born in the New Commonwealth	0.0327	0.0535	0.0006	0.5040
PRIVRENT	proportion of residents in privately rented accom.	0.0602	0.0524	0.0022	0.4889
TPOP	ward population ($\times 10^3$)	9.6479	3.6111	4.0930	33.0730
WT	Waiting Time (in days)	120.8459	37.9921	19.857	572.4927
#wards per district		26.6398	12.2043	6.0000	95.0000

Note: In the regressions, natural logarithms are taken of all variables

Appendix B: Notes to the regressions

- All models in Part I are estimated including 14 regional dummies
- Standard errors are heteroscedasticity adjusted
- The test for heteroscedasticity in Part I is a test for equal variances in the 14 regions
- The regressions are weighted by weights $w_j = N * \frac{TPOP_j}{\sum_{i=1}^{N} TPOP_i}$.
- The instruments used in the 2SLS regressions are SMR074-PRIVRENT (see Table A.1) plus the regional dummies (in Part I), plus A11, A21, A23, A51, A53, A55, A61, A72, A73, A75, A76, A771, A78, A81IN, A82, A91, A92, A101, A102, LILLH, HSIR75, SMR75, A131, A141, A143, A144, A145, A151, PBIR, PURB (see Data Manual (1994) for descriptions).
- The test procedures presented in the 2SLS tables in Part I are similar to the ones used in Carr-Hill *et al.* (1994) and are all well described in Godfrey (1988, Ch.5). The difference is that the tests are adjusted for heteroscedasticity. The four tests have null hypotheses of no simultaneity of the supply factors, no misspecification, no heteroscedasticity and no endogeneity of HSIR074 and SMR074, respectively. For example, if the test for misspecification is significant, indicated by a small p-value (<0.001), then the null of correct specification is rejected. The misspecification test in the OLS tables is a test for omitted variables (of the instrument set). The RESET test in the OLS tables is a test for functional form.

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