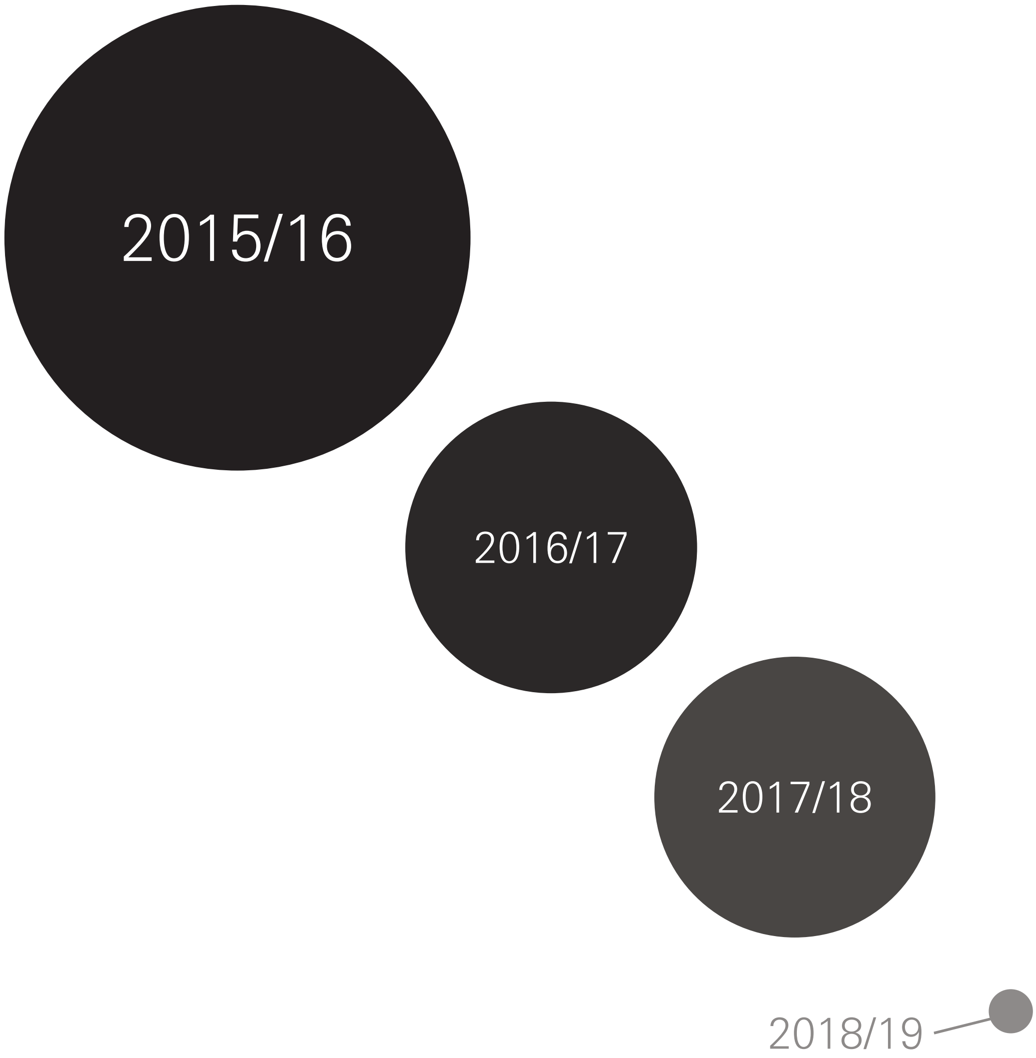
Research

March 2017

A year of plenty?

An analysis of NHS finances and consultant productivity

Technical appendix



Annual change in spending, %

The Health Foundation

Introduction

In March 2017, the Health Foundation published *A Year of plenty? An analysis of NHS finances and consultant productivity*.[1] In the report we modelled factors associated with consultant productivity in 150 acute and specialist hospitals in England between 2009/10 and 2015/16. We identified these factors using a multivariate regression model and data from providers' annual accounts and other publicly available sources.

This technical appendix is provided for those with an interest in the technical aspects of health data and econometric modelling. It provides additional information on the methods used in the main report.[*]

Overview of methods

We examined factors associated with financial performance using a multivariate regression model. We constructed the model to identify the variables that are statistically significant determinants of consultant productivity. The model was run using the statistical software program SAS 7.1. We applied a stepwise function to exclude insignificant variables and subsequently arrive at the final model.

Model specification

$$Y = \propto + \sum ß_1 H + \sum ß_2 R + \sum ß_3 S$$

Where:

- Y: Log of cost-weighted activity per consultant
- H: Hospital characteristics
- R: Regional characteristics
- S: Staff characteristics

Data

Dependent variable

The dependent variable of this model is the cost-weighted activity per consultant, as a measure of consultant productivity. We estimated the labour productivity of consultants using an output–input ratio to assess the annual change in consultant productivity in the acute sector.

The input consists of the number of full time equivalent (FTE) staff for each hospital, adjusted to include agency staff. The number of FTE staff was adjusted for the use of agency and other non-permanent staff using trusts' financial annual accounts and creating a weight based on the proportion of total staff that were non-permanent staff.

[*] The full report is available to download from www.health.org.uk/publication/year-of-plenty

The output consists of hospital activity at provider level. The activity is case-mix adjusted and includes elective inpatient admissions, emergency inpatient admissions, A&E attendances (defined in the data as emergency medicine), day case admissions, consultant-led outpatient attendances, outpatient procedures and cancer multidisciplinary team meetings (CMTM). Building on the method used by Bojke et al (2015),[2] we adjusted for changes in case mix over time and between providers by weighting different types of activity at Health Resource Groups (HRG) level using the previous year's cost for each specific activity. First, the cost was adjusted for variation in price due to geographical location using the market force factor (MFF). This was calculated by multiplying the unit cost by the volume of activity. Then we adjusted for variations in case-mix activity. The method is described as a step-by-step below.

To calculate a provider's cost deflated by MFF

$C^{mff}_{ij} = TC_{ij} / MFF_j$

Weight the activity by cost

- Calculate the weight
  - w = national average cost for HRG_i / National average cost
- Apply weight to unadjusted activity
  - $CWA_j = \Sigma w_i A_{ij}$

Where:

- TC = Total cost
- w = weight
- A = unadjusted activity
- i = HRG_i
- j = Provider *j*
- C_{ij} = total cost incurred by provider *j* for HRG_i
- C^{mff} = total cost deflated by MFF

Independent variables

Staff characteristics

Skill mix is an important determinant of labour productivity.[3] Using data published by NHS Digital we calculated the percentage of nurses, administration and support staff employed within each trust (hospital) to examine which staff group was associated with consultant productivity. We also tested whether the use of temporary staff had an impact on consultant productivity. We used hospital financial accounts to obtain measures of the respective proportion of total nurses and support staff that were temporary. We used the proportion of temporary staff to adjust the number of FTE staff.

We tested whether the hospital staff turnover rate had an impact on consultant productivity. We wanted to test the hypothesis that higher turnover led to lower levels of productivity. To measure hospital turnover we calculated the number of consultants joining the hospital per leaver using NHS Digital data. We also tried using the leaving rate of consultants in our model, but we did not find a significant association between this variable and consultant productivity.

Hospital characteristics

To account for differences in **activity** we created an index of specialisation. Soederlund and Jacobs found that greater economies of specialisation is associated with greater efficiency.[4] To test this hypothesis we created an information theory index (ITI) for both inpatient and outpatient activity using the reference cost data. The index measures the level of dispersion of HRGs treated within hospitals. The lower the index, the least specialisation and the higher the index, the higher the level of specialisation (ie where more patients of the hospital fall in one HRG chapter). The index was calculated using the following formula:

$$ITI_h = \Sigma_i P_{ih} \log (P_{ih} \pi_i)$$

Where:

- ITI_h = case mix specialisation index for hospital *h*
- P_{ih} = proportion of activity in hospital *h* that fall into HRG *i*
- π_i = proportion of all hospitals' activity constituted by HRG *i*

We also included the number of delay transfers of care (DTOCs) in the hospitals as DTOCS can lead to cancelled operation and therefore greater inefficiency among surgeons. We used the number of DTOCs as of January published by NHS England.[5]

Teaching hospitals train residents, and because of this additional responsibility which is not captured in the activity measured, it could have an impact on the calculated level of productivity. Previous research found that teaching hospitals in US were less efficient due to time spend teaching residents and away from patient.[6] We included a dummy variable equal to 1 for teaching trusts to control for this effect.

We also wanted to test whether hospital capacity in terms of beds has an impact on productivity. We measured hospital **size** by including the average number of beds available in the hospital. We used data published by NHS England on average number of beds available by hospital from January to March – the last quarter of the financial year.[7]

We also examined the **cost profile** of the hospital. As an indicator of capital investment we included private financial initiative (PFI) as a proportion of total cost. We wanted to test whether the financial performance of the trust was associated with labour productivity, and whether trusts with a PFI cost have higher labour productivity assuming it has better infrastructure resulting from capital investment. We used data from the hospital financial accounts to calculate the cost of PFI as a proportion of total operating cost. We also wanted to see if financial performance of the hospital had an impact on labour productivity. We used hospital financial accounts to calculate the proportion of net deficit to the total cost.

We also accounted for regional variations, as Bojke et al (2013)[8] found that productivity in the NHS varies by region from 5% above the national average to 6% below. We used a dummy variable to identify the hospital's area team. We also tested whether the rurality was a factor associated with labour productivity. We used ONS data on rural and urban area classifications and matched the data to hospitals based on the Lower Layer Super Output Area (LSOA). This data include six categories:

- Urban with major conurbation.
- Predominantly urban.
- Urban with city and town.
- Urban with significant rural.
- Largely rural.
- Mainly rural.[9]

We used a categorical variable from 1 to 6 to identify the hospital rural–urban category based on the hospital postcode. None of the hospitals in our sample fell into the largely or mainly rural categories.

To account for regional variation we also tried to include the area team of the hospital. However, we were concerned that including a regional variable might mask regional differences that can be improved through policy intervention. We were encouraged that our model without the area team performed better against the Akaike information criterion (AIC) value, which was lower in our model without area team variables. This allowed us to reveal more variables that were associated with consultant productivity otherwise masked by these variables. Variables on number of DTOCs and NHS wage compared to average regional wage became significant in our model. The AIC without the area team values was 13539.89 and with the area team values it was 14170.46. We therefore decided to define the model without the area team variables from the model.

Previous research found that large pay gaps between government regulated wage, such as in the NHS, and outside (unregulated) wage results in lower level of productivity in English hospitals.[10] Using the *Average annual survey of hours and earnings*, published by the ONS,[11] and cost of salary and wage from hospital financial accounts, we calculated the ratio of the trust salary and wage cost per full time equivalent (FTE) to the average earning by FTE in its local authority to compare the NHS wage to the average rage of the region.

Staff **motivation** is thought to be a determinant of labour productivity.[3] We used the summary score on staff motivation at work from the NHS staff survey[12] to measure the hospital employees' motivation.

We also tested to see if **deprivation** has an impact on labour productivity, as the level of deprivation may have an impact on the complexity of the hospital's activity. We used the index of multiple deprivation (IMD) rank as a measure of deprivation. We used data from the Department for Communities and Local Government, based on the hospital postcode.[13]

Multicollinearity diagnostic test

A common problem in the use of a multivariate regression model is the presence of collinearity* between variables. Including many variables that are highly correlated can have adverse effect on the regression coefficient in the model. To mitigate this issue, we first identified pairwise correlations between variables and then ran a regression model using all predictors of consultant's input/output ratio, requesting a collinearity diagnostics in SAS. The results of the collinearity diagnostics are summarised in Table A. We examined the eigenvalue of each variable, as elevated values may indicate high level of numerical error and the variance inflation factors which measures variance due to collinearities.[14]

Table A: Results of multicollinearity test

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Intercept	1	59.69462	12.944	4.61	<.0001	.	0
Year	1	-0.02565	0.0064	-3.98	<.0001	75%	1.32691
Log of deficit as a percentage of total cost	1	-0.0131	0.0063	-2.1	0.0364	88%	1.13774
Log of percentage of temporary staff, %, (log)	1	0.00731	0.011	0.67	0.5052	75%	1.32649
Log of percentage of nurses	1	0.39855	0.0804	4.96	<.0001	80%	1.24387
Teaching	1	-0.3084	0.0263	-11.72	<.0001	65%	1.5322
Specialisation (information theory index)	1	-0.36499	0.019	-19.22	<.0001	68%	1.47359
Log of percentage of support staff	1	0.05117	0.0195	2.62	0.009	92%	1.08346
Deprivation, IMD score	1	0.0007426	0.0007	1.08	0.2819	88%	1.14092
Combined Code	1	0.02494	0.0197	1.27	0.2062	85%	1.17438
Number of beds	1	-0.00000769	2E-05	-0.42	0.6776	44%	2.28338
Log of percentage of PFI cost	1	0.00455	0.0035	1.29	0.1976	90%	1.10628
NHS wage/ regional wage	1	0.09936	0.0359	2.77	0.0058	82%	1.22506
Log of consultant leaving rate	1	-0.0441	0.0228	-1.93	0.054	95%	1.05413
DTOCs	1	-0.00001257	2E-05	-0.67	0.5004	70%	1.42405

* In statistics collinearity exist when two or more variables in a model can be linearly predicted from the other with substantial degree of accuracy

We found correlation between the proportion of net deficit to total cost and the percentage of temporary staff and the index of specialisation due to elevated eigenvalue and high variance of inflation. This supports previous research that found a significant association between deficit and use of temporary staff and specialist hospitals.[15] We therefore excluded this variable on financial performance from the model. Following the removal of this variable the tolerance value of the variable specialisation of inpatient activity increased to 72%. This means that less variation in these variables is explained by other variables in the model.

Table B provides the summary statistics of the variables included in the model.

Table B: Summary statistics of variables in the model

Variable	Mean	Standard Deviation	Sum	Minimum	Maximum
Consultant productivity (y)	2601	773.2292	2437533	494.93474	6433
Year	2011	1.714	1884759	2009	2014
Percentage of nurses	0.31525	0.03664	295.38465	0.10181	0.50334
Teaching	0.195	0.397	183	0	1
ITI_IP	0.220	0.556	206.258	0.002	2.514
Percentage of Support staff	0.2742	0.08706	256.92801	0	1.68935
IMD	21.34923	13.536	20004	1.871	77.391
Combined Code	4.10672	0.435	3848	4	6
Number of beds	1336	695.507	1251558	95.344	3648
Percentage of PFI	0.00841	0.01585	7.85981	-0.00132	0.12162
NHS wage/ regional wage	1.191	0.275	1091	0	2.12437
Consultant leaving rate	0.05755	0.024	53.9241	0.0106	0.2792
DTOCs	526.687	555.220	476652	0	5286

Results

After carefully selecting which variables to include in the model, we ran a multivariate regression in SAS using the stepwise option to identify the variables that are statistically significant at a significance level of 0.05. In the final model, the included independent variables explained approximately 52% of the variation in consultant productivity (R squared =0.52). Table C summarises the results of our model.

Table C: Results from the multivariate regression model of variable that were statically significant at a 95% confidence level

Variable	Parameter estimate	Standard error	Type II SS	F Value	Pr > F
Intercept	40.09609	8.56722	0.92408	21.9	<.0001
Year	-0.01598	0.00426	0.59285	14.05	0.0002
Log of nurses, %	0.24573	0.06699	0.56759	13.45	0.0003
Teaching	-0.29498	0.0185	10.72071	254.12	<.0001
ITI	-0.34676	0.01404	25.74132	610.16	<.0001
Log of support staff, %	0.06653	0.01754	0.60664	14.38	0.0002
Combined code	0.07255	0.01701	0.7674	18.19	<.0001
Log of PFI, %	0.00683	0.00278	0.25429	6.03	0.0143
NHS wage/ regional wage	0.10746	0.02679	0.67898	16.09	<.0001
DTOCs	-2.8E-05	1.4E-05	0.16721	3.96	0.0468

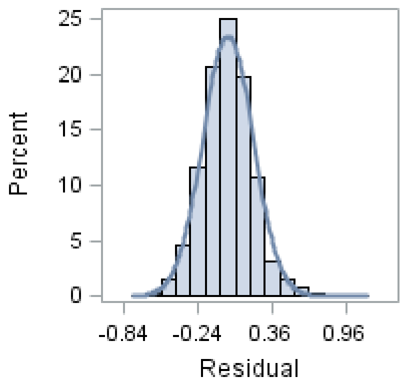
Table D summarises the results of the stepwise selection process, showing the variables included in the final model sorted from most to least significant.

Table D: Summary of stepwise selection process

Step	Variable Entered	Variable Removed	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	ITI		1	0.2783	0.2783	436.223	334.71	<.0001
2	Teaching		2	0.2019	0.4802	73.8728	336.82	<.0001
3	year		3	0.0098	0.4901	58.1093	16.72	<.0001
4	Log of support staff, %		4	0.0093	0.4994	43.3558	16.04	<.0001
5	Combined code		5	0.0061	0.5054	34.3576	10.65	0.0011
6	NHS wage/ regional wage		6	0.0056	0.511	26.2604	9.88	0.0017
7	Log of nurses, %		7	0.0067	0.5178	16.1027	12.04	0.0005
8	Log of PFI, %		8	0.0039	0.5217	11.1203	6.97	0.0085
9	DTOCs		9	0.0022	0.5238	9.1608	3.96	0.0468

Figures A and B shows that residual for the model are normally distributed. Figure C shows the residual plots of the significant variables versus the predicted value (consultant's activity/FTE). It shows the distribution of the dependent variables and its relationship with the independent variable (consultant's activity/FTE). Overfitting can occur, especially in a small sample size. However, Figures A and C (overleaf) show that the data seem randomly dispersed around the horizontal axis.

Figures A and B: Residual plots of the dependent variables



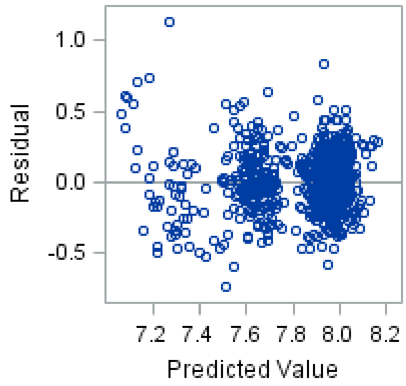
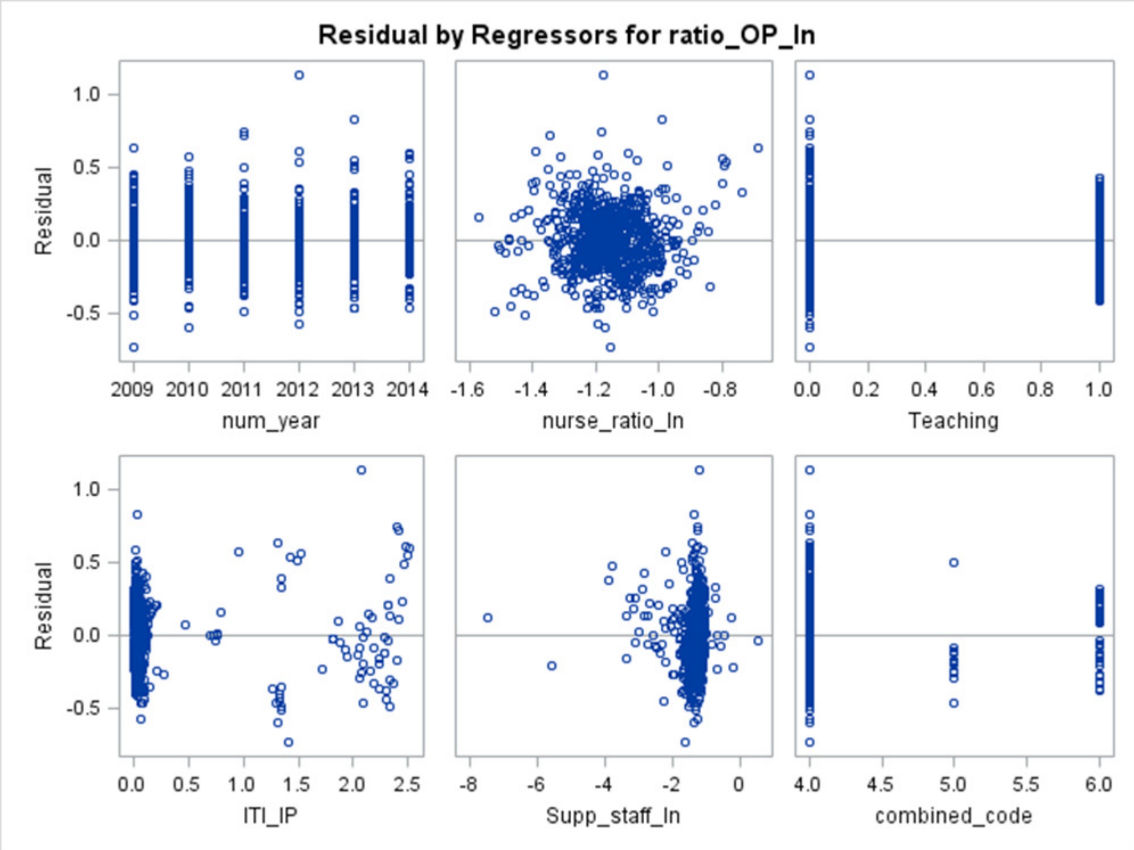
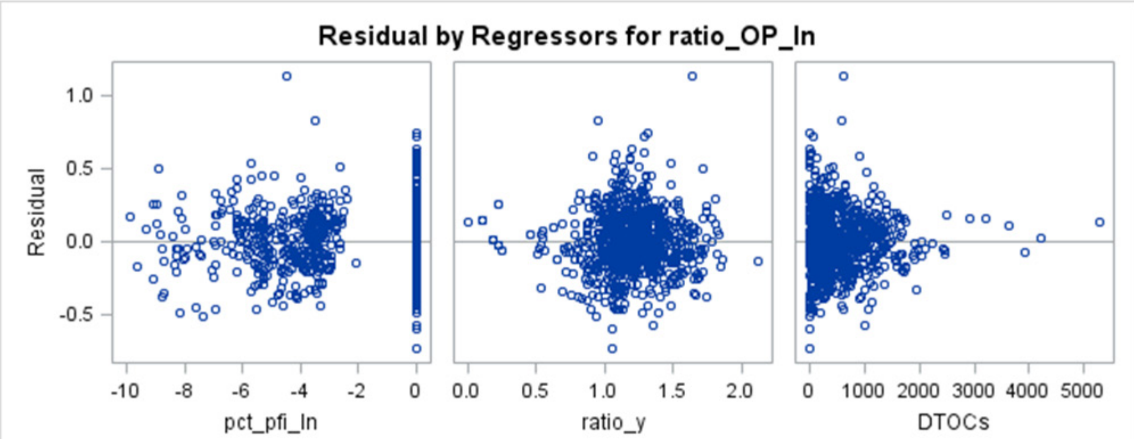


Figure C: Residuals plots of significant variable





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The Health Foundation is an independent charity committed to bringing about better health and health care for people in the UK.

Our aim is a healthier population, supported by high quality health care that can be equitably accessed. We learn what works to make people's lives healthier and improve the health care system. From giving grants to those working at the front line to carrying out research and policy analysis, we shine a light on how to make successful change happen.

We make links between the knowledge we gain from working with those delivering health and health care and our research and analysis. Our aspiration is to create a virtuous circle, using what we know works on the ground to inform effective policymaking and vice versa.

We believe good health and health care are key to a flourishing society. Through sharing what we learn, collaborating with others and building people's skills and knowledge, we aim to make a difference and contribute to a healthier population.

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