WP/17/36

IMF Working Paper

What has happened to Sub-Regional Public Sector Efficiency in England since the Crisis?

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INTERNATIONAL MONETARY FUND

 WP/17/36

IMF Working Paper

Institute for Capacity Development and Research Department

What has happened to Sub-Regional Public Sector Efficiency in England since the Crisis?

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February 2017

Abstract

This paper estimates public sector service efficiency in England at the sub-regional level, studying changes post crisis during the large fiscal consolidation effort. It finds that despite the overall spending cut (and some caveats owing to data availability), efficiency broadly improved across sectors, particularly in education. However, quality adjustments and other factors could have contributed (e.g., sector and technology-induced reforms). It also finds that sub-regions with the weakest initial levels of efficiency converged the most post crisis. These sub-regional changes in public sector efficiency are associated with changes in labor productivity. Finally, the paper finds that regional disparities in the productivity of public services have narrowed, especially in the education and health sectors, with education attainment, population density, private spending on high school education and class size being the most important factors explaining sub-regional variation since 2003.

JEL Classification Numbers: H40, H70

Keywords: public sector efficiency or productivity, sub-regional fiscal federalism

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[1] Without implication I thank Li Tang (for excellent stata support); Liz Baxter and Alimata Kini Kabore (for administrative assistance); Stephen Aldridge, Ray Brooks, Oya Celasun, David Coady, Trevor Fenton, Raffaela Giordano, Richard Hughes, Dora Iakova, Javier Kapsoli, Andy King, Zsóka Kóczán, Chris Morriss, Mico Mrkaic, David Phillips, Jonathan Portes, James Richardson, Baoping Shang, Petia Topalova, Yuan Xiao, and participants at the ICD seminar series (for their help and advice). Any errors or omissions are my own.

Contents

I. INTRODUCTION

"The thicket of complexity that exists between central and local [public sector] structures and diffusion of funding and advisory energies leads to unnecessary hurdles for those striving to translate ideas to job creating businesses."

Sir Witty, 2013

This paper seeks to address the following questions: (i) Has public sector efficiency or productivity at the sub-regional level improved or weakened in England during the fiscal consolidation of 2010–14? (ii) What has been the pattern across different sectors and sub-regions? (iii) Have sub-regions with lower initial levels of efficiency experienced stronger gains, implying some catch up in efficiency levels? (iv) Were deeper cuts in public spending associated with stronger efficiency gains? (v) Has there been any relationship between changes in public sector efficiency and labor productivity across sub-regions? (vi) What are the determinants of sub-regional variation in public sector service efficiency?

A. Motivation

Studying how efficiency changes during large fiscal consolidation episodes is relevant since efficiency gains—along with secular trends induced by sector-specific reforms and technological improvements, for example—can help limit the adverse impact of spending cuts on outcomes. Yet, there is little evidence on how large "exogenous" fiscal consolidation episodes affect sub-regional public sector efficiency (or productivity):[2] do they lead to unnecessary fat being trimmed or do existing institutional frameworks adjust to provide the same quality and quantity of services? In addition, little evidence is available documenting what happens to regional variation in the quantity or quality of public services. For example, would the less efficient sub-regions converge toward the others? Finally, the paper's questions are also relevant because public sector efficiency is considered to be an important ingredient of economic productivity and performance more broadly (Evans and Rauch, 1999; Afonso et al. 2003; Kibblewhite, 2011).

The United Kingdom (UK) provides a useful case study since a sizable fiscal consolidation to reduce the build-up of public debt in response to the global financial crisis (GFC) has been undertaken. Despite the fact that the UK is separated into 12 regions (Wales, Scotland and Northern Ireland and the nine NUTS1 statistical regions of England[3]), the majority of public

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[2] Efficiency and productivity are used interchangeably in this paper.

[3] The nine NUTS1 regions of England are: North East, North West, Yorkshire and the Humber, East Midlands, West Midlands, East of England, Greater London, South East, and South West. For more details, see https://en.wikipedia.org/wiki/NUTS_statistical_regions_of_the_United_Kingdom.

spending is centrally financed,[4] unlike in many other countries where fiscal decentralization is more pronounced.[5] [6] This provides an "exogenous" shock which can be studied, since the extent of spending changes are not a function of levels or changes in spending efficiency in any one region or sub-region. Cognizant of the importance of public sector efficiency, a thorough review of government service productivity was initiated (Atkinson, 2005), with the Office of National Statistics (ONS) tasked with implementing the recommendations and providing estimates of multi-sector public sector productivity at the national level. The latest data indicate an improvement in overall public sector productivity post crisis (ONS, 2017).[7]

The novelty of this paper is a focus on sub-regional performance—relevant since discussions on fiscal decentralization (with the central authorities in London) are conducted at this level. Therefore, it combines official public spending data (at the English regional level[8]—i.e., the nine NUTS1 English regions barring Greater London, leaving eight regions[9]) and assembles sectoral output measures from various government departments (at the sub-regional level—i.e., 28 NUTS2 sub-regions or "counties"[10], with Greater London sub-regions excluded) to

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[4] Hence public expenditure is planned and controlled on a departmental basis within the *Comprehensive Spending Review* even for devolved funding for the Scottish Government, Welsh Assembly Government of Northern Ireland Assembly, or local government. Note that this paper does not present data nor study: (i) the efficiency of these devolved spending responsibilities (see https://www.gov.uk/guidance/devolution-of-powers-to-scotland-wales-and-northern-ireland for background); nor (ii) local level spending, which represents only a small fraction of total spending in England (Phillips, 2015).

[5] Many OECD countries have undertaken some form of fiscal decentralization, assigning more expenditure functions and revenue collection to local government in order to better account for regional preferences, increase the efficiency of public services, and enhance accountability (Oats 1972). In the process of doing so, these countries have monitored the efficiency (or productivity) of their public service delivery, assigning more spending powers to those decentralized areas that achieve larger efficiencies and thus more "value for money".

[6] Fiscal devolution plans were announced in late 2015 by the outgoing Chancellor Osborne, starting with the Greater Manchester Combined Authority—the so-called "City Deal", putting the devolution plan into practice. These plans largely focused on spending devolution—with some early discussion of partial devolution of business rates and council taxes (Chancellor's Budget Speech, November 2015). The incoming Prime Minister May stated the need for a fairer Britain in her October 2016 party conference speech, but concrete plans for fiscal devolution are yet to be announced.

[7] National-accounts' estimates of the government sector outputs and productivity are related to, but sufficiently different from, microeconomic measures of public sector performance targets, and thus cannot be used for the same purpose (Atkinson, 2005).

[8] Official spending data is only available at the regional NUTS1 level. Hence no variation within a region (i.e., across its sub-regions) is assumed. See Section II.A for more details.

[9] Greater London is excluded as is common practice in the literature given its outlier and global city status. Its inclusion broadly narrows variation across sub-regions vis-à-vis each other, but widens these vis-à-vis London, while the four observations of Greater London fall out of all regressions in this paper (due to an outlier test).

[10] County, Combined Authority, local and sub-region are used interchangeably. They refer to the NUTS2 classification shown in the Appendix. See https://en.wikipedia.org/wiki/NUTS_of_the_United_Kingdom.

estimate a sub-regional index of public efficiency. The approach used is related to Simar and Wilson (2007), Giordano and Tommasino (2013), and Giordano et al. (2015).

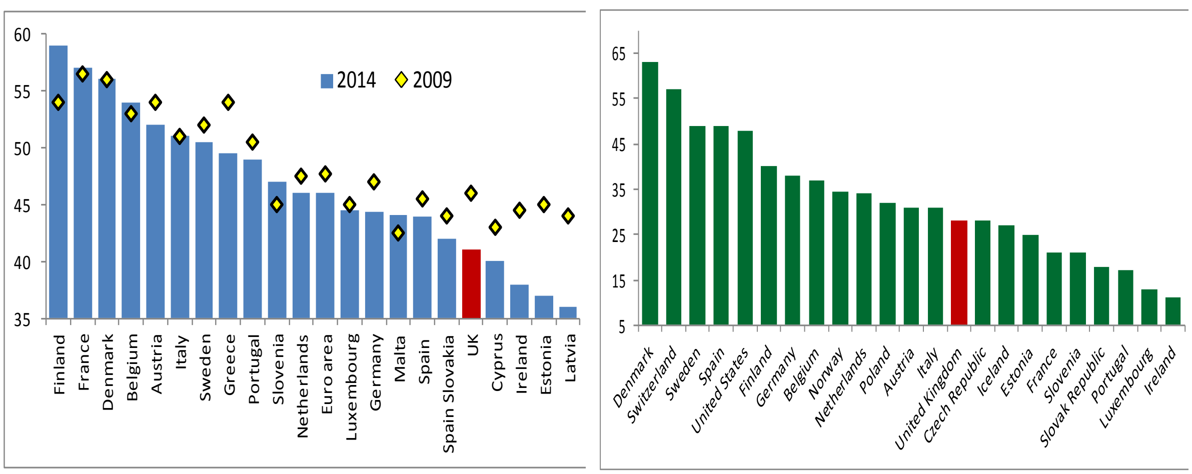
B. Stylized facts

Before estimating sub-regional public sector efficiency and addressing the main questions this paper seeks to answer, a few relevant stylized facts on public sector spending, three key sectoral outputs (education, health and economic services), and productivity for the UK and its English regions are shown next to set the stage for the empirical section.

Public and sub-regional spending in the UK are well below those of large EU and OECD economies (Figure 1). Government expenditure in the UK is below the European average and significantly below most comparator economies (Figure 1, left panel). This trend has become more pronounced and could continue in the future given the need for medium-term fiscal consolidation and the large current account deficit.[11] The size of spending at the sub-regional level is also well below comparator economies (Figure 1, right panel).

Figure 1. Cross-country Developments in Public Spending

General public spending (share of GDP) *Sub-regional spending (share of total, 2010)*



Sources: World Economic Outlook and Heseltine (2012)

Recent developments in sectoral public spending, achievement, and efficiency[12] in England appear to be correlated (Figure 2). Given the large spending-led fiscal consolidation effort, it would be interesting to see how real education public spending per pupil, health and

[11] The UK's fiscal deficit remains relatively high by international standards as to a lesser degree does the debt ratio. Moreover, consolidation has been mostly expenditure-based. For more details on past fiscal impulse, consolidation since the crisis, and future fiscal direction and policies, see the IMF's Article IV Consultation reports, via: https://www.imf.org/external/country/GBR/index.htm

[12] See Section II and III for the estimation of efficiency.

economic service expenditure per head (inputs) changed between the pre- and post-crisis periods, 2003–07 and 2010–14, respectively. It is also useful to see if there were any changes in achievement (outputs) associated with these spending changes, for example here in this paper, in high school education attainment of GCSE scores, life expectancy at the age of 65 years, and the number of private enterprises created themselves.[13] These "inputs" and "outputs" have been widely used in the literature (e.g., Boyle, 2011; Giordano and Tommasino, 2013; reports of the UK's National Audit Office), and Section IV.B examines a few alternative outputs.[14] [15] Caveats in the choice of these outputs should be noted. First, cuts in primary education spending post-crisis would take some years to influence GCSE scores and more intermediate results (such as Key Stage 2 scores) are not examined due to data constraints at the sub-regional level. In addition, no distinction between private and state schools or pupils has been made given data constraints. Having said that, data from the Department of Education points to gradual improvement in national Key Stage 2 scores and regional pupil-to-teacher ratios in both primary and secondary education. Second, health spending not only aims to prolong life at birth or old age, but also to improve the quality of life—for example, by relieving chronic pain or addressing problems with mobility. Moreover, faster moving health outputs (e.g., hospital waiting lists, numbers of surgeries or hospital and clinic visits) would be preferable—but data limitations at the sub-regional level prevent such a choice. Also since life expectancy is a slow moving variable, studying changes over an even longer time horizon may be warranted—a task left for future research. Third, these and other quality adjustments, while important, are not studied at the sub-regional level, and thus are left for future research.[16]

Still it could be argued that for private sector productivity, for example, what matters in the end is the not the efficiency of public spending per se, but the actual quantity and quality of public services that is being provided (even if there is some waste). For example, if the decline in public spending on education was associated with a proportional decline in high school achievement, that may be damaging to the UK's productivity regardless of what happened to public sector efficiency.

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[13] The number of active enterprises is considered to be a good proxy for the effectiveness of public spending on economic affairs since enterprises take root and succeed in regions or sub-regions with adequate housing, transport connectivity, job centres, and the like. And these enterprises in turn contribute to employment, economic growth and productivity more broadly. Moreover, it should be noted that the structure of the English economy has not altered dramatically since 2003 outside of Greater London. See Section IV.B for robustness checks and alternative achievement (i.e. output) metrics.

[14] HM Treasury's "Public Expenditure by Country, Region and Function" Chapter 9, Table 9.15, which is the source of the spending data in this paper (see data appendix), shows comparable spending data per head and other summary statistics.

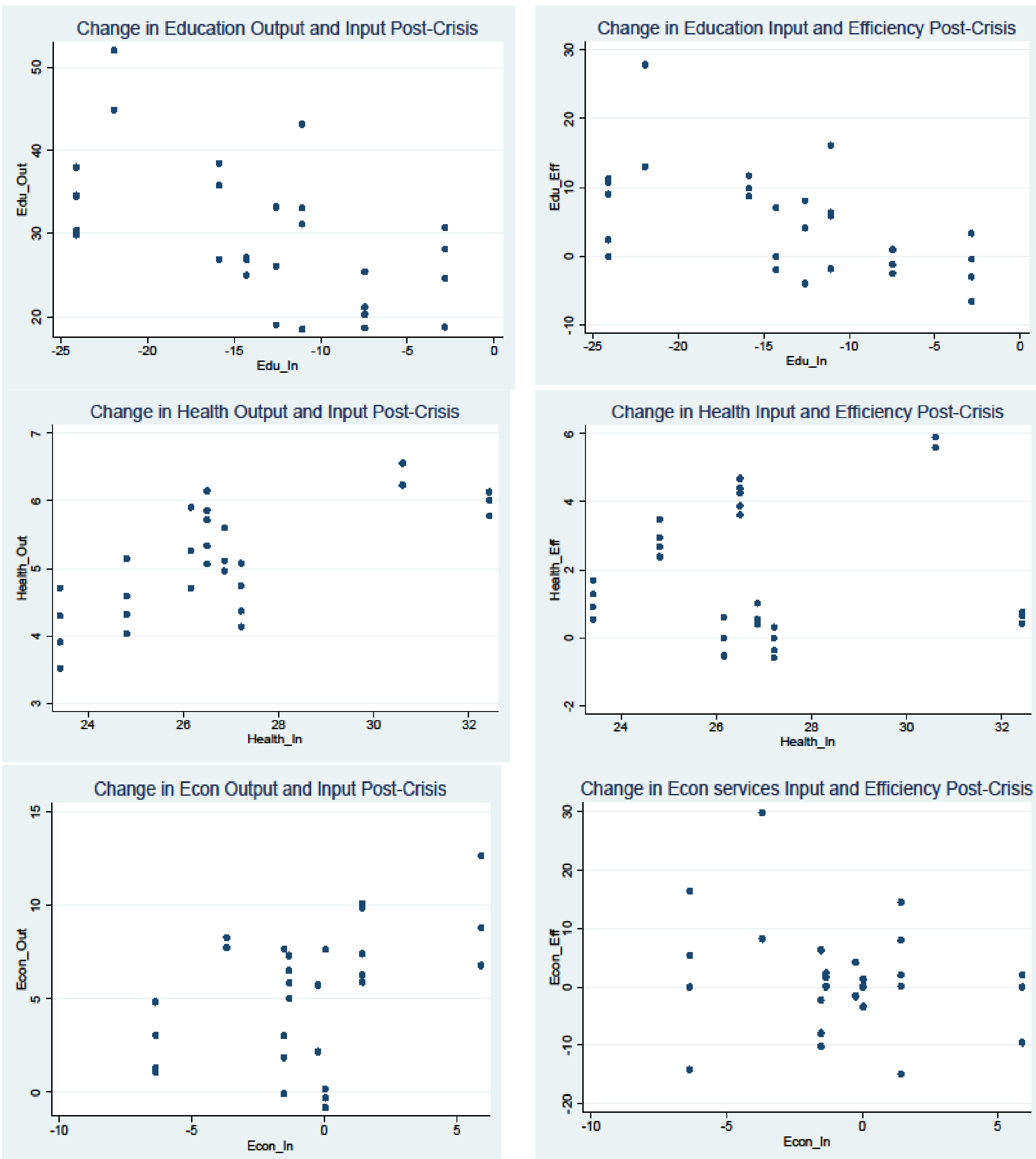
[15] Recent National Audit Office and Department for Business Innovation and Skills reports show comparable spending data and attainment proxies for health and education and other relevant summary statistics. In terms of the choice of proxies of attainment, other studies have also used higher education or cross-country OECD PISA scores for education (available at the national level) and life expectancy at birth or mortality rates for health. Some alternatives are explored in Section IV.B of the paper, subject to data availability at the NUTS2 level.

[16] The "quality" of these public services does vary at least at the level of NUTS1 region (see the Cavendish Review (2013), the National Audit Office (2012) report, and various King's Fund research papers and reports).

Scatter plots provide an intuitive first cut of the data at the 28 sub-regional and 8 regional levels between 2003 to 2014. The plots suggest that the post-crisis changes in spending per pupil and high school education attainment (proxied by the change in GSCE scores) are strongly and *negatively* correlated (Figure 2, first left panel), as are the changes in spending

Figure 2. Sectoral Inputs and Outputs and Efficiency

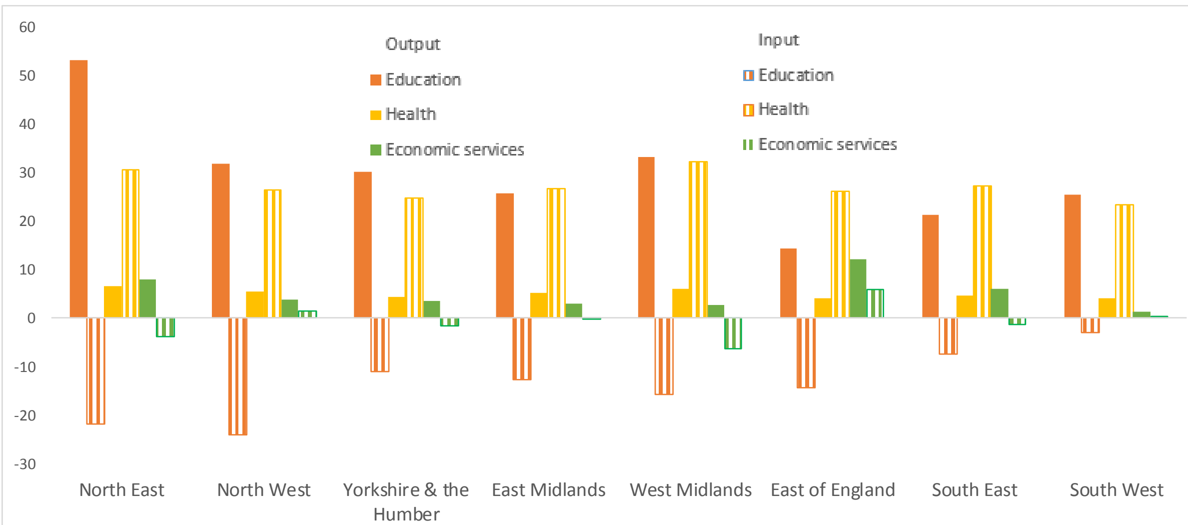
(Real £s per head or pupil, in percent)



Sources and notes: Author's estimates based on official UK data at the NUTS1 level for inputs/spending and NUTS2 aggregated up to NUTS1 for outputs/achievement. Change refers to that between the average of the pre-crisis (2003-07) and the post-crisis (2010-14), in percent. Spending is in real £s per head or pupil.

per pupil and estimated efficiency[17] (Figure 2, first right panel), while the changes in health spending per head and health output (proxied by the change in life expectancy at 65 years of age) are *positively* correlated (Figure 2, second left panel), as are the changes in health spending per head and estimated efficiency (Figure 2, second right panel). The picture is less definitive for the changes in economic services (as proxied by the change in the number of private enterprises), although some positive correlation is apparent between inputs and outputs (Figure 2, third left panel) and negative between efficiency and inputs. Underestimated regional transportation spending may be behind these results (see annex).

Figure 3. Post Crisis Change in Regional Public Spending vs. Achievements
(in percent)



Sources and notes: Author's estimates based on official UK data at the NUTS1 level for inputs/real spending and NUTS2 aggregated up to NUTS1 for outputs/achievement. Change between average pre (2003-07) and post (2010-14) crisis, in percent. Spending is in real £s per head or pupil.

Another first cut at the data suggests that while the large spending-led consolidation meant cuts across most spending categories in England, it was education spending per pupil that fell most dramatically, but achievement (at least in terms of the outputs used in this paper) was not adversely affected, rising instead across all sectors, including education (Figure 3 and annex Tables A.1 and A.2). The following findings, aggregated to the regional NUTS1 level, emerge:

- Public health inputs or spending per head actually increased sharply across all English regions without exception post-crisis despite the large fiscal consolidation (Figure 3, yellow striped-bars),[20] unlike that of education spending per pupil which declined sharply

[17] See Section II and III for the estimation of efficiency.

[20] The increases in real health spending could be overestimated if health sector deflators have not been adjusted concomitantly with rising health care costs.

(Figure 3, orange striped-bars), particularly in the North. These spending cuts in education (which more than offset the health spending increases), were large with considerable variation across regions. Changes in public spending on economic services exhibit more sub-regional variation, with small cuts in some regions and small increases in others (Figure 3, green striped-bars).

- There was no proportional decline in outputs commensurate with the proportional decline in spending, rather all outputs improved post crisis. In particular, life expectancy increased marginally (health output);[21] GCSE achievement improved sharply[22] (education output) most notably in the North and Midlands, and the number of enterprises expanded a little (economic services output) across regions, most notably in the East of England (Figure 3, yellow, orange and green solid-bars, respectively).[23]

These initial results suggest that despite large spending cuts, actual output (at least in terms of "quantities" measured here) has not suffered—rather it seems that excess fat in public spending has been trimmed.[24] As mentioned, in the education sector in particular, Key Stage 2 results (tested at the end of primary school for pupils typically aged 11 years old) are unavailable at the sub-regional level but data on teacher-to-pupil ratios and class size (whether primary or high school) suggest gradual improvement post crisis.[25] Clearly, factors other than changes in public spending could be driving these improvements—for example, technological improvements from computing, specific education and health sector reforms,[26] and possibly incentives of sub-regional authorities to achieve greater "value for money" in

[21] While this small improvement is an important achievement given that life expectancy is a slow moving variable, the trend has been slowly upward in most OECD economies, including the UK.

[22] The Department of Education points to GCSE score inflation, in part attributed to measurement issues rather than a change in education output.

[23] Despite these improvements, employers complain about skill deficiencies among the young and those with relatively low education attainment. In addition, there is a high proportion of negative growth firms and room to improve leadership and managerial capabilities (Heseltine 2012).

[24] Afonso et al. (2007) estimated a measure of public sector of efficiency and showed that output efficiency ranked 16th out of 23 OECD economies, suggestive of some waste in public expenditure.

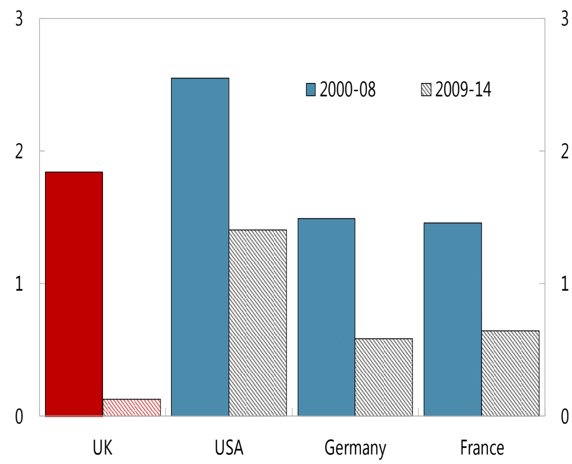
[25] It is difficult to include Key Stage 2 examination results not least because standards have been revised, becoming more challenging. Nevertheless, the Department of Education reports improvements at this Stage (in reading, writing and maths). Also since the early 2000s the number of pupils per qualified teacher has fallen.

[26] Sector-specific reforms that could have contributed to the post-crisis increase in outputs are as follows. For education, while reforms from the Thatcher to Blair governments (which aimed for greater diversity, flexibility and choice, backed by school autonomy and central government accountability) produced better examination results, they also resulted in greater variation (i.e., polarization of performance between the best and worst schools) (Whitty 2000 and 2014). For health, private spending and productivity in the sector have fallen recently (Lloyd 2015), possibly contributing to lower quality outputs despite a broad and complex set of reforms since 1997—and yet many challenges remain (Boyle 2011).

the wake of fiscal decentralization, among others. And as mentioned, the "quality" of these outputs has not been measured and may not have a clear sectoral variation. Moreover, the long-term impact of the spending cuts may not be felt for years to come. Finally, it should be noted that during the GFC employment (in education and health specifically and in the overall economy more broadly) did not decline as sharply as in other OECD economies affected by the GFC, with the national unemployment rate in the UK remaining well below many of these economies. Hence, the cuts in spending do not appear to have affected at least the "quantity" of teachers, despite their real wages seeing modest declines.[27] This along with lower pupil-to-teacher ratios (in primary and secondary) may well have contributed to some of the improved outputs, along with the incentives induced from sharp cuts in spending per pupil in the education sector, for example.

Figure 4. Cross-country Productivity

(average annual percent growth in output per hour)



Sources: Haver Analytics and IMF staff calculations.

After 2008, overall economic output productivity growth in the UK declined much more than other advanced economies (Figure 4). Economic output productivity has been shown to be associated with public sector productivity or efficiency—also a proxy for the quality of governance (Giordano et al., 2015). Hence raising public sector productivity or efficiency might help boost overall productivity in the UK, which has seen the average annual growth of output per worker drop from almost 2 percent during 2000-08 to nearly zero during 2009-

[27] Machin (2015) shows real wages to have declined nationally between 0.5 to 2.2 per annum between 2008-14 (explanations include a decoupling of wages and productivity growth; the decline of union membership and thus collective wage bargaining; slack in labor market; among others). The Independent Newspaper reported (on 10 January 2016) nominal teachers' pay rises having been limited to around one percent for the past five years, with schools finding it increasingly difficult to recruit qualified teachers. It also mentions that the Department of Education sees "a record number of highly qualified teachers being attracted to the profession".

14 (Figure 4).[28] As mentioned, the fact that the UK did not experience deep cuts in employment may have contributed to the cyclical weak labor productivity growth, on the one hand, and also in part supported the increase in outputs and efficiency in core sectors on the other.

The rest of this paper is organized as follows. Section II lays out the evidence-based empirical strategy, data and measurement issues and Section III reports the baseline results on sub-regional public sector efficiency. Section IV presents robustness checks and Section V draws conclusions and policy implications.

II. Empirical Strategy, Data and Measurement

Given the importance of public services to economic performance, this paper next combines official public spending data and sectoral output measures from various government departments to estimate an index of public productivity or efficiency at the sub-regional English level. The methodology used follows Simar and Wilson (2007), with the approach being related to Giordano and Tommasino (2013) and Giordano et al. (2015) who empirically estimate an index of public service efficiency across Italian provinces. The latter studies do not, however, differentiate between performance pre and post the GFC, for example, when austerity led to large spending cuts. This is one of the novelties of this paper. In particular, it constructs from scratch a sub-regional multi-sector public service (education, health and economic services) database, aggregating (weighted from the town or local level upward) to the NUTS2 sub-regional level, and then matching these with NUTS1 regional public spending data. It then uses a regression framework to empirically estimate public sector efficiency over two non-overlapping period averages: pre (2003–07) and post (2010–14) the GFC, using annual data. This allows for an analysis of the evolution and variation of public service delivery across England and its sub-regions (excluding London).[29]

A. Measuring public sector efficiency

Relation to the literature

Recent studies build on the microeconomic literature in measuring technical efficiency of a unit of production, by establishing the difference between an actual and a potential unit of output in relation to a unit of input—operational Pareto Optimality. Generalizing to all "input-output pairs" allows the construction of an efficient production frontier that connects or "envelopes" these combinations of input-output pairs, building on the idea of relative efficiency (Farrell, 1957) using non-parametric linear programming—the so-called Data

[28] See IMF 2016 and references therein for explanations and an analysis of this weak productivity growth.

[29] Including London narrows variation across sub-regions vis-à-vis each other, but widens it vis-à-vis London.

Envelopment Analysis (DEA) developed by Charnes et al. (1978) and extended by Simar and Wilson (2007).[30] DEA allows multiple input-output pairs to be considered at the same time without any assumption on data distribution. The relationship between spending (input) and performance (output) is thus benchmarked despite its drivers not having been directly observed.

Cross-country studies on public service efficiency or productivity using this approach include Afonso et al. (2003 and 2007), Gupta et al. (2007), Verhoeven et al. (2007), and Grigoli (2013). At the regional or local level, studies include Borge et al. (2008) for Norway, Revelli (2010) for the UK, and Giordano and Tommasino (2013) for Italy. However, no study has yet examined how public sector efficiency has changed sub-regionally post the GFC following a large fiscal consolidation episode and across most spending categories or sectors.[31] This is one of the contributions of this paper.

Methodology

A sub-regional index of public sector efficiency is constructed using DEA regression analysis based on total (central, regional, county, local) spending data on the three key public services across the English regions: education, health, economic affairs (including transport and housing).[32] The regional spending data is complemented by sub-regional "control" variables, e.g., changes in private spending on the examined public services, income per capita, population density and its age-profile, and capital stocks, among others.

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[30] Non-parametric techniques, such as the Data Envelopment Analysis (DEA), typically do not control for the diverse set of factors that influence outputs or outcomes—such as educational attainment, urbanization, private spending on services, income, etc.—and thus collinearity arises. To control for the bias in the resultant efficiency scores, the so-called "second stage" regression analysis (which simply refers to the inclusion of control variables along with inputs on the left hand side of the regression equation (5) above) mitigates measurement error and bias. See Ray (2004) for a comprehensive review of DEA. As a robustness, two separate parametric stochastic frontier analysis (SFA) regressions are carried out in Section IV and thus complement the DEA estimation.

[31] Analysis of public sector performance has been carried out either at the UK national level following the 2005 Atkinson Review (e.g., ONS, 2017) or at the local spending level using only local spending, (e.g., Revelli 2010), which represents a small fraction of total spending—unlike this paper which covers total spending.

[32] Other studies have estimated more aggregated measures of public sector efficiency across countries or regions. For example, Charron (2013) estimated a quality of governance for all EU economies available at the NUTS1 level. However, the measure suffers from some shortcomings (see Giordano et al. 2015). Aggregating sub-regional public sector efficiency scores estimated in this paper to the regional level does suggests a statistically significant (at the 5 percent level) and positive correlation with the Charron (2013) quality of governance index for some periods. Afonso et al. (2007) also estimate a measure of public sector efficiency and show that although the UK ranked seventh out of 23 OECD economies in terms of overall public sector efficiency, output efficiency ranked 16th (out of 23).

Non-parametric treatment of the efficiency frontier does not assume a particular functional form, but relies instead on the general regularity properties, such as monotonicity, convexity, and homogeneity. The DEA is based on a linear programming algorithm,[33] constructing an efficiency frontier from the data in all "single decision units"—here being a sub-region or county, such as the Greater Manchester Combined Authority. A DEA model can be sub-divided into an input-oriented model (which minimizes inputs and controls while satisfying at least a given level of output) or an output-oriented model (which maximizes outputs without requiring more of any of the observed input or control values). The latter is chosen in this paper, as these models are the most frequently used because the quantity and quality of inputs (public spending and other controls defined here) are assumed to be fixed exogenously, hence the sub-regional authorities cannot influence these, at least not in the short-run.[34]

DEA models can also be subdivided in terms of returns to scale by adding weight constraints. Constant returns to scale are chosen here as the baseline, as there is no conclusive evidence to suggest that the production of public services (whether in health, education or economic services) varies in technology across English regions or sub-regions outside Greater London—particularly during the past four decades since the creation of the National Health Service and the state school system, unlike firms. However, variable returns to scale technologies (i.e., increasing or decreasing) were also estimated but do not suggest a material change to the results.[35] A specific sub-region is called efficient when the DEA score equals to one and slack is zero. Inefficiency can be seen in terms of how much the inputs and control variables must contract along a ray from the origin until it crosses the frontier (Ji and Lee, 2010).

Spending on the three categories of education, health, and economic affairs represents over 50 percent of total public spending over the past decade, with all three having been shown in the literature to influence economic prospects over time (Afonso et al. 2003), and the

[33] Limitations arise from the assumption of linearity in the production function. This is mitigated in part through the use of parametric stochastic frontier analysis with a Cobb-Douglas technology in Section IV.C.

[34] Input-oriented results are also estimated and shown in the appendix, yielding similar results (in terms of the order or ranking of sub-regional performance).

[35] The Attlee government centralized health spending in the 1940s and the Callaghan government did the same for education in the mid-70s onward. Hence the delivery of these public services have become standardized, broadly speaking, nation-wide since the post-war era, with limited variation by region or sub-region, and with only about a quarter of this spending being local. Nevertheless, variable returns to scale technologies (i.e., increasing or decreasing) in the production of these services are also estimated (see appendix Table A.4) in case there could be some regional variation, e.g., between the north and south of England, given differing population densities, incomes, and other factors. No material change is evident (Table A.4).

remainder largely being spending on pensions and social protection.[36] [37] The assumption is that this spending does not vary within each region, only across regions (Giordano and Tommasino 2013, Giordano et al. 2015).[38] By and large, all regions experienced public spending cuts post crisis, with the exception of health—where spending per head rose across regions with limited (NUTS1) regional variation (Figure 3 and Table A.1). On the other hand, spending cuts in education (which offset the health spending increases), were large with considerable variation across regions. For example, the North experienced cuts per pupil between three to 8½ times more than the South (Figure 3 and Table A.1).

Performance outputs and other control variables vary within regions—in other words they are available and have been collected from various government departments at the sub-regional (NUTS2) level (see the data appendix). Two cross-sections are examined to compare the pre- and post-crisis average performance (2003–07 vs. 2010–14) given data availability.[39] This allows for the coefficients to vary between the pre- and post-crisis periods, capturing the dynamic changes. Outputs are those of the 28 English counties.[40] [41]

B. Estimation

The DEA regression is estimated, for each of the two non-overlapping period averages, pre- and post-crisis. The production process is constrained by the production set:

$$\Psi = \{(x, y) \in R_{+}^{N+M}|_{x}\ can\ produce\ y\} \quad (1)$$

where x represents a vector of N inputs (public spending by sector and controls as specified below for each sector) and y the vector of M outputs by sector (as shown in more detail below). Three separate production processes are estimated for each sector. Each production frontier is the boundary of Ψ. In the interior of the Ψ there are units that are technically

[36] In this paper, all non-health and non-education spending is considered other than social protection (largely pensions), defense and international chapters, to represent spending that influences "economic services".

[37] Arguably, social protection spending can also influence public sector efficiency, economic performance and productivity—since caring for the elderly or disadvantaged can impact labor productivity if such labor is fully or partly engaged in this type of care.

[38] In practice targeting of under-privileged schools or hospitals in some sub-regions has taken place and may result in variation within a sub-region. However, data is unavailable to test this at the sub-regional level.

[39] The years 2008-09 are excluded owing to the global financial crisis and the consequent small fiscal stimulus. Results are available upon request.

[40] All English countries excluding the five parts of Greater London are shown—common practice in the literature given London's outlier and global city status.

[41] See the Appendix for data specification and sources.

inefficient while technically efficient ones operate on the boundary of Ψ, i.e., the technology frontier. If the production set is described by its sections, then the output requirement set is described for all $x \in R_+^N$:

$$Y(x) = \{y \in R_+^M | (x, y) \in \Psi\} \tag{2}$$

The output-oriented efficiency boundary $\partial Y(x)$ is defined for a given $x \in R_+^N$ as:

$$\partial Y(x) = \{y | y \in Y(x), \lambda y \notin Y(x), \forall \lambda > 1\} \tag{3}$$

and the output measure of efficiency for a production unit located at $(x, y) \in R_+^{N+M}(x, y)$ is:

$$\lambda(x, y) = sup\{\lambda | (x, \lambda y) \in \Psi\} \tag{4}$$

Because the production function set Ψ is unobserved, in practice efficiency scores $\lambda(x, y)$ are obtained by DEA estimators, for example, for output orientation with constant returns to scale, and the solution is found through the linear program:

$$\hat{\lambda}_{CRS}(x, y) = sup\{\lambda | x, \lambda y \leq \sum_{i=1}^{n} \gamma_i y_i x \geq \sum_{i=1}^{n} \gamma_i x_i \, for \, (\gamma_1, \ldots \gamma_n)\} \tag{5}$$

such that: $\gamma_i \geq 0, i = 1, \ldots, n$

The three sectors are:

- **Education.** *Input*: Real public expenditure on education per pupil; *Other inputs or control variables*: Private spending on education and education attainment by income level per head; *Output*: High school (GCSE) achievement.[44]

- **Health.** *Input*: Real public expenditure on health per head; *Other inputs or control variables*: Adjusted for population's age structure (i.e., ratio of population over 65);[45] and the prevalence of obesity. *Output*: Life expectancy at the age of 65 years.[47]

- **Economy.** *Input*: Real public expenditure on economic services, including transport and housing, normalized by lagged population size; *Other inputs or control variables*: Lagged stock of capital; *Output*: Number of active enterprises.[48]

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[44] Alternative outputs and control variables are examined for robustness in Section IV.B, as well as the issue of lags in public spending.

[45] This adjustment is made to reflect the fact that spending on the elderly could be larger for counties that have a larger share of elderly in their total population.

[47] This output is chosen since it is more ambitious (relative to life expectancy "at birth") given the secular trend in population aging. See Section IV.B for the use of life expectancy at birth.

[48] See footnote 13 and Section IV.B for the use of labor productivity of these enterprises as an alternative output for this sector.

III. Baseline Findings

This section examines the following questions: (i) Has sub-regional public sector efficiency improved or weakened in England during the fiscal consolidation of 2010-14? (ii) What has been the pattern across different sectors and sub-regions? (iii) Have sub-regions with lower initial levels of efficiency experienced stronger gains, implying some catch up in efficiency levels? (iv) Were deeper cuts in public spending associated with stronger efficiency gains? (v) Has there been any relationship between changes in public sector efficiency and labor productivity across sub-regions?

Sub-regional efficiency scores reassuringly show stability over the estimation sub-sample periods (Table 1). The estimated efficiency scores, $\hat{\lambda}_{CRS}(x, y)$, from the DEA regression (equation 5) are presented for each sector and combined into a simple average—a weighted average produces similar results (see Section IV.A). Higher values imply higher efficiency and the score of one implies a county that was most efficient.[49] Despite large public spending cuts, overall efficiency improved post crisis (Table 1 and Figure 5). Efficiency improved most notably in the education sector, which saw the deepest cuts, followed by health (which instead saw spending increases). However, the efficiency of economic services deteriorated slightly. In terms of sub-regions, at one end, Tees Valley and Durham (UKC1) improved its efficiency post crisis, but at the other end, Devon, (UKK4), saw a deterioration (including but not limited to the reduction in public spending). The lower quartile of efficiency, however, remains a northern-county phenomenon. Determining whether the post crisis improvements in efficiency scores are statistically significant is not straightforward, however. While bootstrapping and Bayesian methods have been used to determine the statistical significance of the DEA results, none of these methodologies can estimate, with a specified probability, the confidence interval for the true efficiency scores.[50]

Sub-regions with the weakest pre-crisis levels in public sector efficiency converged the most (Figure 5 and Table 2). Worse off sub-regions achieved the largest improvements, as

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[49] Results are reported for the output-oriented DEA. Alternative results for input-oriented DEA or variable returns technologies suggest similar results (Appendix Tables A.3 and A.4, respectively).

[50] Bootstrapping methodologies do not incorporate stochastic variations in each sub-region's input-output performance. Bayesian methods are based on variations in the frontier while ignoring variations within sub-regional units. So, like bootstrapping, they can estimate the probability distribution for the efficiency of a fixed set of inputs and outputs, but cannot estimate the probability distribution for the efficiency of the individual sub-regions. Both bootstrapping and Bayesian estimation are based on one observation of each sub-region. I have two observations per sub-region, and hence it is not possible to estimate variation without more observations. Even for a cross-sectional analysis, one cannot determine whether a sub-region is efficient with a specified degree of statistical significance nor construct confidence intervals within which the sub-region's true efficiency uptrends or downtrends are statistically significant or just random variations. For more details, see Barnum, D.T., Gleason, J.M., Karlaftis, M.G., Schumock, G.T., Shields, K.L., Tandon, S. and Walton, S.M. (2011), Estimating DEA Confidence Intervals with Statistical Panel Data Analysis. *Journal of Applied Statistics*, 39, 815-828.

Table 1. Public Sector Efficiency Scores Computed by Data Envelopment Analysis for English Counties [1]

		Pre-crisis (2003-07)				Post-crisis (2010-14)			
Country (NUTS2)	Code	Education	Health	Economy	Combined Efficiency Index[2]	Education	Health	Economy	Combined Efficiency Index[2]
Tees Valley and Durham	UKC1	0.77	0.68	0.16	0.54	0.98	0.72	0.21	0.64
Northumberland and Tyne and Wear	UKC2	0.84	0.68	0.11	0.54	0.95	0.71	0.12	0.59
Merseyside	UKD7	0.88	0.81	0.16	0.61	0.96	0.84	0.18	0.66
Greater Manchester	UKD3	0.90	0.81	0.15	0.62	1.00	0.84	0.15	0.66
South Yorkshire	UKE3	0.81	0.87	0.28	0.65	0.94	0.90	0.26	0.70
East Yorkshire and Northern Lincolnshire	UKE1	0.88	0.88	0.27	0.67	0.93	0.90	0.26	0.70
West Yorkshire	UKE4	0.89	0.87	0.28	0.68	0.95	0.90	0.30	0.71
Cheshire	UKD6	0.88	0.86	0.33	0.69	0.97	0.90	0.36	0.74
West Midlands	UKG3	0.89	0.89	0.31	0.70	1.00	0.90	0.33	0.74
Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	0.86	0.94	0.31	0.70	0.89	0.96	0.32	0.72
Shropshire and Staffordshire	UKG2	0.86	0.90	0.43	0.73	0.94	0.91	0.51	0.78
Derbyshire and Nottinghamshire	UKF1	0.88	0.94	0.41	0.74	0.95	0.95	0.41	0.77
Leicestershire, Rutland and Northamptonshire	UKF2	0.86	0.96	0.44	0.75	0.89	0.96	0.46	0.77
Dorset and Somerset	UKK2	0.93	0.97	0.42	0.78	0.87	0.98	0.41	0.75
North Yorkshire	UKE2	1.00	0.93	0.43	0.79	0.98	0.96	0.38	0.77
Berkshire, Buckinghamshire and Oxfordshire	UKJ1	1.00	1.00	0.38	0.79	0.99	0.99	0.38	0.79
Herefordshire, Worcestershire and Warwickshire	UKG1	0.88	0.93	0.59	0.80	0.96	0.94	0.51	0.80
East Anglia	UKH1	0.91	1.00	0.57	0.83	0.89	1.00	0.51	0.80
Devon	UKK4	0.94	0.95	0.61	0.84	0.91	0.96	0.61	0.83
Cumbria	UKD1	0.90	0.86	0.76	0.84	0.92	0.89	0.76	0.86
Lancashire	UKD4	1.00	0.83	0.84	0.89	1.00	0.86	0.71	0.86
Bedfordshire and Hertfordshire	UKH2	1.00	0.98	0.75	0.91	1.00	0.99	0.76	0.92
Surrey, East and West Sussex	UKJ2	0.95	1.00	0.82	0.92	0.95	1.00	0.84	0.93
Hampshire and Isle of Wight	UKJ3	0.94	0.99	0.84	0.92	0.92	0.99	0.84	0.91
Cornwall and Isles of Scilly	UKK3	0.89	0.93	1.00	0.94	0.89	0.95	1.00	0.94
Essex	UKH3	0.87	0.98	1.00	0.95	0.93	0.97	1.00	0.97
Kent	UKJ4	0.94	0.96	1.00	0.97	0.95	0.97	1.00	0.97
Lincolnshire	UKF3	1.00	0.96	1.00	0.99	0.96	0.97	1.00	0.98
England average (exl. London) [2]		**0.882**	**0.916**	**0.523**	**0.778**	**0.928**	**0.930**	**0.521**	**0.796**

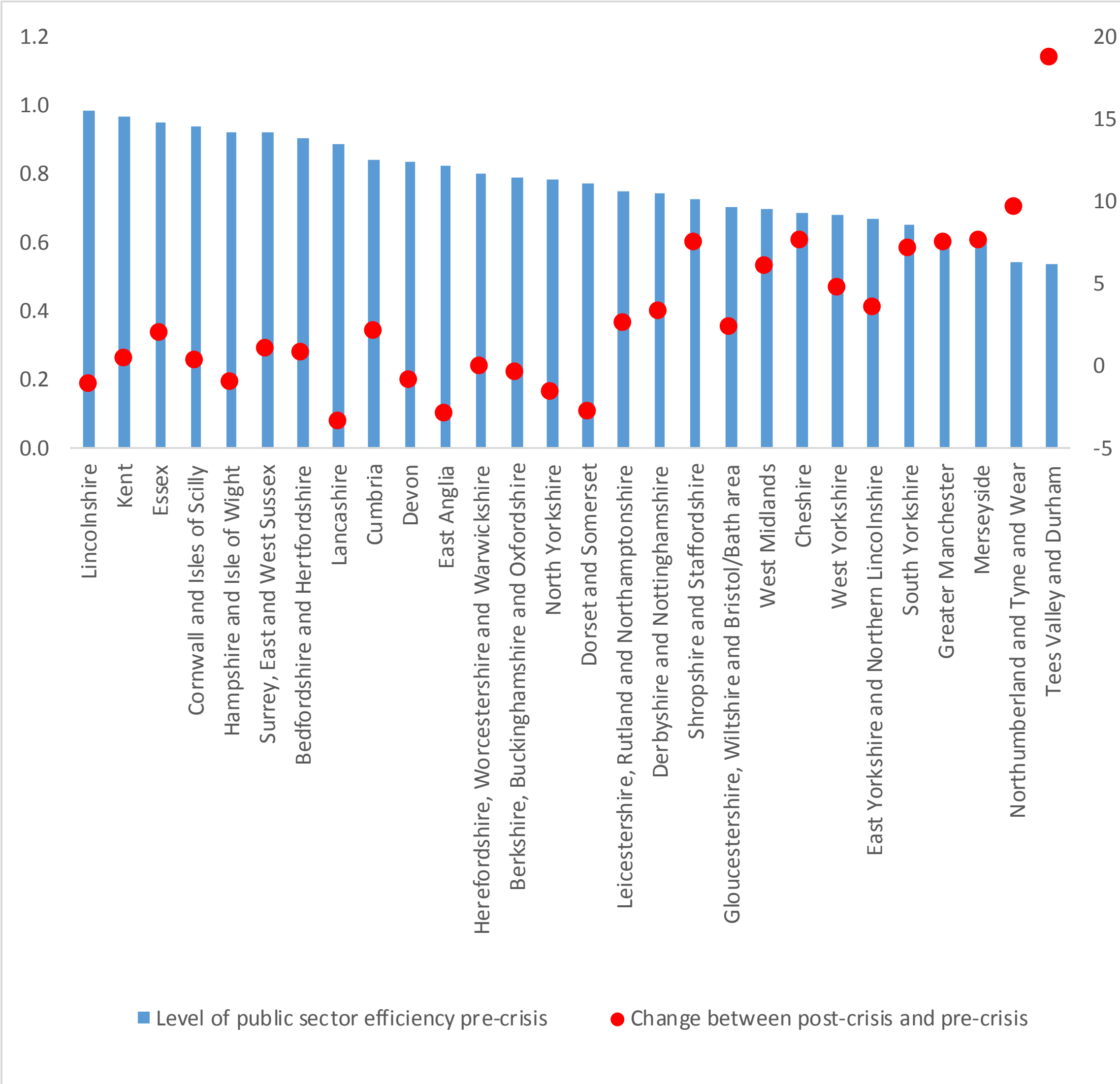
[1] Constant returns to scale.

[2] Simple average.

evidenced from a regression of the efficiency gains on the initial level of efficiency.[51] Indeed, sub-regions with lower initial levels of efficiency experienced the strongest gains in each of the education, health, economic services sectors and the overall average (Table 2, columns 1, 2, 3, and 4, respectively).[52]

Figure 5. Convergence of Weaker NUTS2 Sub-regions

(DEA efficiency level during pre-crisis vs. percent change post-crisis)



[51] All regressions in this paper include an outlier truncation test (i.e. to drop outliers if needed), in order to be assured that the results are not driven by outlier sub-regions, if any.

[52] These results also hold when aggregating up to the NUTS1 level, with only 8 regions and their average (9 observations). However, in view of the small sample size resulting from the aggregation, a test of the normality of the residuals (the Shapiro-Wilk test) reveals that only the overall average was robust for inference. These results are available upon request.

What explains this strong convergence in public sector efficiency? Many factors could be at play, including fundamental covariates (e.g., sub-regional GDP per capita, other domestic sector-specific reforms, and possibly external variables, e.g. funding) and perhaps changing incentives among sub-regional authorities in the wake of spending devolution and fiscal consolidation.[53] This issue is partly examined in Section IV.

Table 2. Did sub-regions with weaker initial efficiency converge more?

Bivariate regression results

	(1)	(2)	(3)	(4)
Change in efficiency:[1]	Education	Health	Economic Services	Simple Average
Initial efficiency level:[2]				
Education	-1.366***			
	(0.174)			
Health		-0.168***		
		(0.0171)		
Economic services			-0.212*	
			(0.171)	
Simple Average				-0.391**
				(0.126)
Number of observations	29	29	29	29
adj. R-sq	0.721	0.835	0.265	0.702

Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.01

[1] Change between pre and post crisis, 2003-07 and 2010-14, respectively.

[2] Initial efficiency levels refer to 2003-07 averages.

Deeper education spending cuts are associated with large public sector efficiency gains in that sector (Table 3). When regressing the percentage change in efficiency scores, on the percentage change in public spending, for each sector as well as the simple overall average of these three sectors, deeper spending cuts only in the education sector are found to have led to larger sub-regional efficiency gains (Table 3, column 1). This suggests that the larger cuts in education may well have forced institutions across sub-regions to adapt and trim their activities with lower returns.[54] However, this is not the case for economic services and the

[53] One approach could be to regress the change in the DEA scores, $\hat{\lambda}_{CRS}(x, y)$, on potential covariates (e.g., sub-regional GDP per capita, other domestic and external variables, and dummies) with the use of a bootstrapped truncated regression (as carried out in Section IV, Table 8).

[54] As mentioned, other factors such as stable employment and lower pupil to teacher ratios or smaller class size in the sector, among others could also have contributed to this finding of increased efficiency.

simple average of the three sectors—which display the expected sign but their coefficients are statistically insignificant (Table 3, columns 3-4). The increase in spending in the health sector actually led to efficiency increases—although the coefficient is also insignificant (Table 3, column 2). This suggests that other factors have raised efficiency in the health sector (other than public spending), such as technological improvements, skill enhancements of health professionals, and other sector-specific reforms.[55]

Table 3. Did deeper spending cuts lead to larger efficiency gains?[1]

Bivariate regression results

	(1)	(2)	(3)	(4)
Change in efficiency:	Education	Health	Economic Services	Simple Average
Change in spending:				
Education per pupil	-0.733**			
	(0.301)			
Health per person		0.116		
		(0.298)		
Economic services per person			-1.102	
			(0.789)	
Simple average				-1.701
				(1.077)
Number of observations	29	29	29	29
adj. R-sq	0.512	0.344	0.167	0.453

Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.01

[1] Change between pre and post crisis, 2003-07 and 2010-14, respectively.

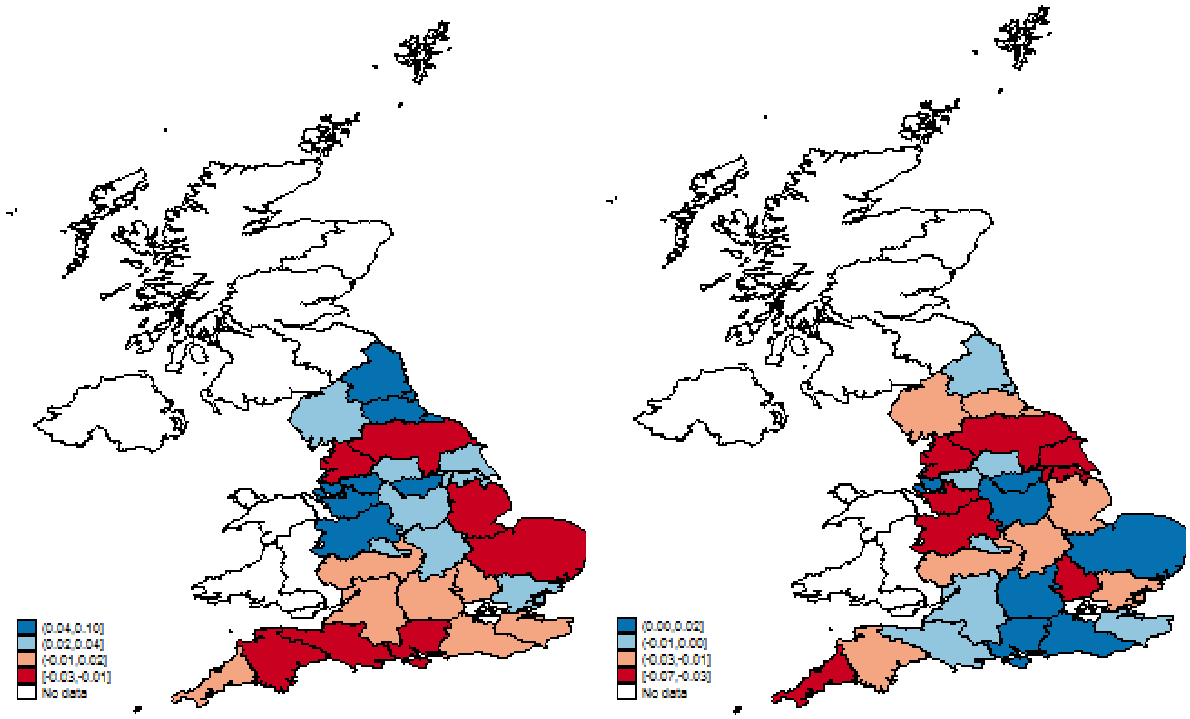
Sub-regional changes in public sector efficiency are associated with changes in sub-regional productivity. Despite considerable variation, correlation between public sector efficiency and productivity per worker is evident from a visual inspection (Figure 6). In particular, sub-regions that have improved their level of public sector efficiency or productivity in the post-crisis period also tend to have higher labor productivity growth (Merseyside, Greater Manchester, Northumberland and Tyne and Wear, West and South Yorkshire, Derbyshire and Nottinghamshire and the West Midlands), and vice versa (North Yorkshire, Lancashire, Cornwall and Devon, Bedfordshire and Hertfordshire, Leicestershire, Rutland and Northamptonshire, Herefordshire, Worcestershire and Warwickshire). A regression of the

[55] These results also hold when aggregating up to the NUTS1 level. However, in view of the small sample size resulting from the aggregation, the Shapiro-Wilk test of the normality of the residuals reveals that only the education sector result is robust for inference at the NUTS1 level. These results are available upon request.

change in sub-regional efficiency on that of labor productivity growth suggests that the coefficient is statistically significant (at the 5 percent level). However, the association between the change in public sector efficiency and that of productivity does not imply causality, as there are clearly other factors driving each despite some interrelation. Nevertheless, the positive correlation suggests that delving into this matter (e.g., using micro data) could be a fruitful direction of future research.

Figure 6. Post Crisis Change in Public Sector Efficiency and Productivity
(NUTS2 sub-regions)

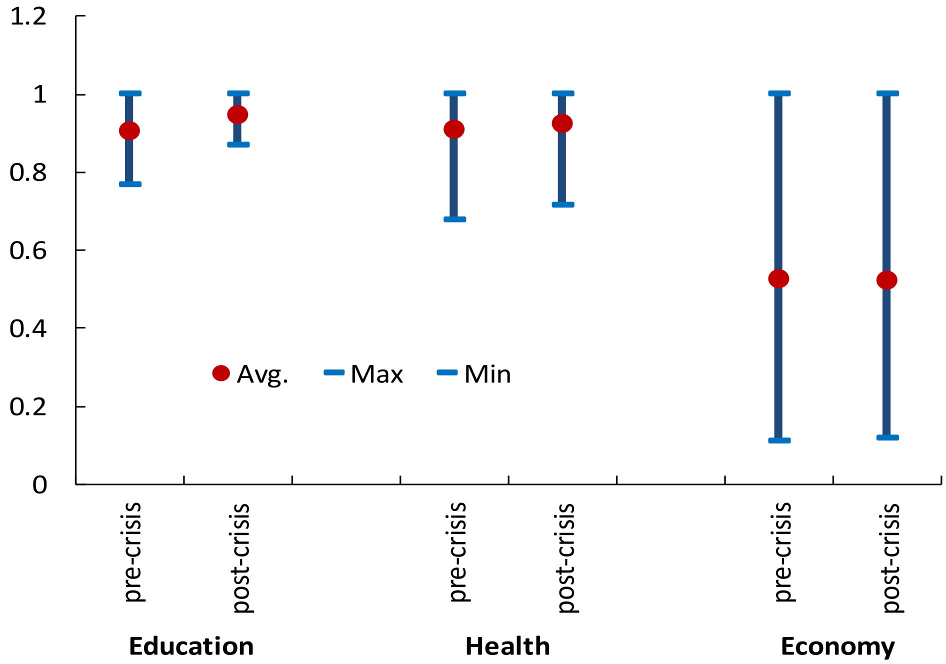
Public sector efficiency *Labor productivity*



Notes and sources: Post crisis change in sub-regional public sector efficiency is as estimated above. Labor productivity is measured as the change in real output per worker between 2003-07 and 2010-14 (ONS, 2016).

Sectoral sub-regional disparities in the efficiency of public services narrowed post crisis (Figure 7). Variation appears widest in economic services efficiency—how spending per head (input) and capital stock (control variable) is translated into the creation of private enterprises (output). This variation persisted post crisis with very little change—likely the result of limited infrastructural spending in the post crisis period. However, sub-regional variation in the efficiency of delivering educational services (GCSE scores, in particular) was less pronounced and narrowed markedly post crisis (by 44 percent). This finding of narrower variation runs counter to the finding of Whitty (2000), who found evidence of increased polarization (variation) in examination results a decade earlier. Variation in health services was more moderate than that in economic services but still larger than in educational services, and also narrowed post crisis (by 11 percent). Once again, other factors (mentioned above) beyond the change in public spending could have contributed to the reported narrower variation findings here. Section IV.C (Table 8) picks up the issue of the drivers of sub-regional variation.

Figure 7. Disparities in Sub-Regional Public Sector Efficiency



Pre- and post-crisis refer to the 2003-07 and 2010-14 average, respectively.

IV. Robustness Checks

Three sets of robustness checks are studied in this section. First, the estimated efficiency scores are weighted by their corresponding sectoral shares of public spending. Second, alternative outputs and control variables, among others, are considered, depending on data availability. Third, as a complement to the DEA, a stochastic frontier analysis is undertaken to address some reported endogeneity difficulties when measuring efficiency in the education sector. This third check allows one to answer the following question: What are the drivers of sub-regional efficiency variation post-crisis?

A. Weighted average DEA scores

The DEA estimated efficiency scores are weighted by their corresponding sectoral shares of public spending at the NUTS1 level, in case particular NUTS1 regions' spending is concentrated in one sector more than others, so as not to under or overestimate the combined average—instead of the simple average of the three sectors shown in Table 1. The weights used are the average shares of the sectoral spending for the full sample (Table 4) and result in a similar ranking of sub-region efficiency (Table 5) with all baseline results reported in Section III holding.

Table 4. Average weights of main spending categories [1]
(£ '000)

NUTS1	Economic services	Health	Education	Total
UKC	4,225	4,898	3,511	12,635
	0.33	0.39	0.28	
UKD	11,462	12,799	9,202	33,463
	0.34	0.38	0.28	
UKE	7,567	8,881	6,876	23,324
	0.32	0.38	0.29	
UKF	5,903	6,871	5,583	18,357
	0.32	0.37	0.30	
UKG	7,547	9,422	7,261	24,230
	0.31	0.39	0.30	
UKH	7,297	8,715	6,841	22,853
	0.32	0.38	0.30	
UKJ	10,562	13,104	9,994	33,661
	0.31	0.39	0.30	
UKK	6,837	8,180	6,143	21,159
	0.32	0.39	0.29	

1 Average weights during 2003-14 of NUTS1 spending for England excluding London.

B. Alternative inputs, outputs and control variables

Alternative or additional specifications of outputs and control variables are considered next, depending on data availability, along with the issue of lags in public spending.

In the **education** sector, pupil to teacher ratios (or class size when unavailable) are used as an additional control variable (given mentioned problems associated with GCSE score inflation and other factors that could have contributed to increased education outputs post crisis), while education spending is lagged for one year due to relatively strong contemporaneous effects of public spending on achievement in the state school system, and in poorer sub-regions in particular (Jackson et al. 2016). While previously mentioned caveats still hold, including the problem of the absence of primary schooling outputs, the education sector coefficients using higher order lags of public spending in Tables 6 and 7 were insignificant albeit similar in magnitude and sign.[56] The resultant DEA scores for the education sector do not vary significantly from those shown in the baseline as a result of these robustness checks (Table 5).

[56] These results are available upon request.

Table 5. Robustness--Weighted Public Sector Efficiency Scores Computed by Data Envelopment Analysis [1]

Country (NUTS2)	Code	Pre-crisis (2003-07) Education	Pre-crisis (2003-07) Health	Pre-crisis (2003-07) Economy	Pre-crisis (2003-07) Combined Efficiency Index[2]	Post-crisis (2010-14) Education	Post-crisis (2010-14) Health	Post-crisis (2010-14) Economy	Post-crisis (2010-14) Combined Efficiency Index[2]
Tees Valley and Durham	UKC1	0.21	0.26	0.05	0.53	0.27	0.28	0.07	0.62
Northumberland and Tyne and Wear	UKC2	0.23	0.26	0.04	0.53	0.26	0.28	0.04	0.58
Greater Manchester	UKD3	0.25	0.31	0.05	0.60	0.27	0.32	0.05	0.65
Merseyside	UKD7	0.24	0.31	0.06	0.60	0.26	0.32	0.06	0.65
South Yorkshire	UKE3	0.24	0.33	0.09	0.66	0.28	0.34	0.08	0.70
East Yorkshire and Northern Lincolnshire	UKE1	0.26	0.33	0.09	0.68	0.27	0.34	0.08	0.70
Cheshire	UKD6	0.24	0.33	0.11	0.68	0.27	0.34	0.12	0.73
West Yorkshire	UKE4	0.26	0.33	0.09	0.69	0.28	0.34	0.10	0.72
West Midlands	UKG3	0.27	0.35	0.10	0.71	0.30	0.35	0.10	0.75
Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	0.25	0.36	0.10	0.71	0.26	0.37	0.10	0.73
Shropshire and Staffordshire	UKG2	0.26	0.35	0.14	0.74	0.28	0.35	0.16	0.79
Derbyshire and Nottinghamshire	UKF1	0.27	0.35	0.13	0.75	0.29	0.36	0.13	0.77
Leicestershire, Rutland and Northamptonshire	UKF2	0.26	0.36	0.14	0.76	0.27	0.36	0.15	0.78
Dorset and Somerset	UKK2	0.27	0.38	0.14	0.78	0.25	0.38	0.13	0.76
North Yorkshire	UKE2	0.29	0.36	0.14	0.79	0.29	0.36	0.12	0.78
Berkshire, Buckinghamshire and Oxfordshire	UKJ1	0.30	0.39	0.12	0.80	0.29	0.39	0.12	0.80
Herefordshire, Worcestershire and Warwickshire	UKG1	0.26	0.36	0.18	0.81	0.29	0.36	0.16	0.81
East Anglia	UKH1	0.27	0.38	0.18	0.83	0.27	0.38	0.16	0.81
Cumbria	UKD1	0.25	0.33	0.26	0.84	0.25	0.34	0.26	0.86
Devon	UKK4	0.27	0.37	0.20	0.84	0.27	0.37	0.20	0.83
Lancashire	UKD4	0.28	0.32	0.29	0.88	0.28	0.33	0.24	0.85
Bedfordshire and Hertfordshire	UKH2	0.30	0.37	0.24	0.91	0.30	0.38	0.24	0.92
Hampshire and Isle of Wight	UKJ3	0.28	0.39	0.26	0.93	0.27	0.38	0.26	0.92
Surrey, East and West Sussex	UKJ2	0.28	0.39	0.26	0.93	0.28	0.39	0.26	0.94
Cornwall and Isles of Scilly	UKK3	0.26	0.36	0.32	0.94	0.26	0.37	0.32	0.95
Essex	UKH3	0.26	0.37	0.32	0.95	0.28	0.37	0.32	0.97
Kent	UKJ4	0.28	0.37	0.31	0.97	0.28	0.38	0.31	0.97
Lincolnshire	UKF3	0.30	0.36	0.32	0.99	0.29	0.36	0.32	0.97
England average (exl. London) [2]		**0.264**	**0.348**	**0.169**	**0.780**	**0.276**	**0.354**	**0.168**	**0.797**

[1] Constant returns to scale.

[2] Weighted average.

For the **health** sector, instead of (the tougher) life expectancy at the age of 65 years, life expectancy at birth (HALE) is the main output, health spending is lagged two years to reflect some non-contemporaneous dynamics, and two additional control variables (or inputs) are added: private spending on health from household surveys, and the smoking status at the time of birth delivery.[57] [58] Despite these new variables, the output still suffers from the caveats noted earlier and thus the results should still be interpreted with some caution. The resultant DEA efficiency scores do not alter in terms of the sub-regional ranking for the health sector nor do the changes post crisis (Table 5).

As an alternative to the number of enterprises created, labor productivity is used for the output for public **economic service** spending,[59] with spending itself lagged two years. Here there were some changes in the ranking order of sub-regions, unlike other checks, however the post crisis changes remain in the same order or magnitude as those reported in the baseline (Table 5).

Using these alternative inputs, outputs and controls presented in this section, the baseline result that sub-regions with the weakest levels of public sector efficiency converged the most (when re-estimating the regression of the efficiency gains post crisis on the initial level pre crisis, for each sector as well as the weighted overall average of the three sectors) still holds, with each co-efficient displaying the same sign, similar magnitudes, and with slightly more statistical significance and larger R-square (Table 6).[60]

Turning to the robustness of the baseline results shown earlier in terms of whether deeper spending cuts have led to larger efficiency gains (when re-estimating the regression of the percentage change in efficiency on the percentage change in public spending, for each sector as well as the weighted overall average of these three sectors), the results suggest that not only are the coefficients slightly larger, but now they also gain in statistical significance and have larger R-square (Table 7).[61] Despite these results, the problem of the endogeneity of

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[57] Using household income from survey data as an alternative did not alter the results materially.

[58] As mentioned, although measuring the impact of health spending by looking at life expectancy misses the fact that much of this spending seeks to improve the quality and not the duration of life, life expectancy is often used as the main output proxy in the literature. While spending that relieves chronic pain or addresses mobility problems, which may not prolong life, is not wasteful it is still unlikely to vary significantly across sub-regions. Faster moving health outputs (surgeries performed or waiting lists) are not readily available sub-regionally.

[59] See the discussion in footnote 13.

[60] These results also hold when aggregating up to the small sample at the NUTS1 level, and are available upon request, but not all residuals pass the normalcy test. Hence the results generalized to the NUTS1 level should be interpreted with caution.

[61] These results also hold when aggregating up to the small sample at the NUTS1 level and are available from the author, but not all residuals pass the normalcy test.

Table 6. Robustness: Did sub-regions with weaker initial efficiency converge more?

Bivariate regression results

	(1)	(2)	(3)	(4)
Change in efficiency:[1]	Education[2]	Health[3]	Economic Services[4]	Weighted Average
Initial efficiency level:[1]				
Education[2]	-1.343***			
	(0.121)			
Health[3]		-0.211**		
		(0.0141)		
Economic services[4]			-1.143**	
			(0.026)	
Weighted Average				-0.677**
				(0.117)
Number of observations	29	29	29	29
adj. R-sq	0.710	0.913	0.353	0.790

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

[1] Change between weighted efficiency index pre and post crisis, 2003-07 and 2010-14, respectively. Initial efficiency levels refer to 2003-07 averages.

[2] Education spending is lagged one year (two lags were insignificant), and NUTS2 teacher-pupil ratios are included as a control variable. On the latter, data is only available since 2006.

[3] Private health spending is added as a control from household surveys, as is a mother's smoking status at time of delivery (data is only available since 2006), and life expectancy at birth (HALE) is the output.

[4] Economic service spending is lagged two years (one year lags were insignificant) and the output here is labor producivity.

Table 7. Robustness: Did deeper spending cuts lead to larger efficiency gains?[1]

Bivariate regression results

	(1)	(2)	(3)	(4)
Change in efficiency:[1]	Education[2]	Health[3]	Economic Services[4]	Weighted Average
Change in spending:				
Education (per pupil)[2]	-0.728***			
	(0.301)			
Health (per person)[3]		0.166***		
		(0.268)		
Economic services (per person)[4]			-1.301*	
			(0.801)	
Weighted Average				-1.789**
				(1.078)
Number of observations	29	29	29	29
adj. R-sq	0.548	0.484	0.378	0.484

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

[1] Change between weighted efficiency index pre and post crisis, 2003-07 and 2010-14, respectively.

[2] Education spending is lagged one year (two lags were insignificant), and NUTS2 teacher-pupil ratios are included as a control variable. On the latter, data is only available since 2006.

[3] Private health spending is added as a control from household surveys, as is a mother's smoking status at time of delivery (data is only available since 2006), and life expectancy at birth (HALE) is the output.

[4] Economic service spending is lagged two years (one year lags were insignificant) and the output here is labor producivity.

public spending remains. Hence the next section attempts to address the issue through a two-stage regression framework.

C. Stochastic frontier analysis

First-stage analysis

One of the limitations of the DEA efficiency estimation is its inability to fully control for heterogeneity, for example, in terms of differences in levels of development or income (Green, 2004; Grigoli, 2014). While control variables were introduced to address sub-regional differences across England in the baseline DEA estimation (Section II and III) for robustness, a parametric stochastic frontier analysis is examined next.

Parametric techniques, including stochastic frontier analysis (SFA), are essentially econometric models requiring assumptions regarding the functional form of the production frontier. Advantages of the parametric approach relative to the non-parametric ones (as in the DEA) include controlling for a larger number of variables (that can influence each public sector output, in this case) and more limited sensitivity to outliers. Both are particularly relevant for cross-country studies, e.g., when studying differences among a heterogeneous group—such as for developing versus advanced economies. But they also are relevant to "within country" analyses—for example, here the issue of outliers was one of the reasons behind excluding Greater London in the analysis.

The SFA approach is similar to the DEA in that a technological frontier envelops all input-output pairs. In addition, from the statistical point of view, the regression model is characterized by a composite error term in which the idiosyncratic (normally distributed) disturbance capturing measurement error is included together with a one-sided disturbance which represents inefficiency.

Two SFA cross-sections are estimated using a Cobb-Douglas production function for each sector and for each of the pre- and post-crisis sub-sample averages, which are identical to those in the baseline DEA efficiency estimation. The cross-sections are estimated by maximum likelihood, with the difference from the DEA being that the estimation is carried out in two separate steps. The first step is a regression of each sector's outputs on its lagged inputs to estimate SFA efficiency scores.[62] The inputs and outputs are precisely those introduced in this section—i.e., the "alternative inputs and outputs" described on pages 23-25. As can be seen from the results of the SFA cross-sectional estimation (Figure 8),[63] the

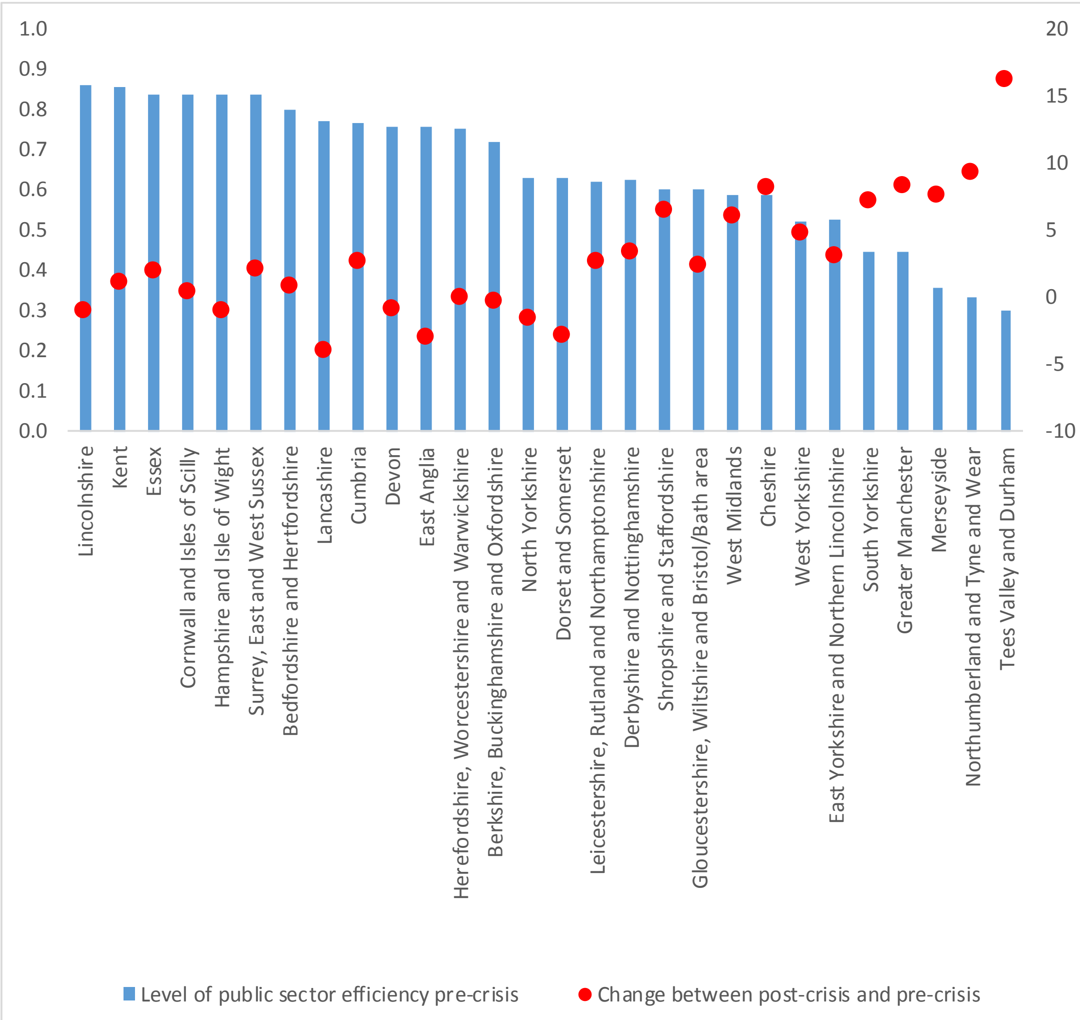
[62] For a more complete description and examples from the applied economics literature see, for example, Greene 2004 and 2008, Verhoeven et al. 2007, Fried et al. 2008, Belotti et al. 2012, Grigoli et al. 2013, and Grigoli 2014. See also Belotti et al. (2012) for SFA cross-sectional regression formulations.

[63] These results can be compared to those of the DEA estimation shown in Figure 5 and Table 5.

sub-regional efficiency scores are smaller in size but their ranking and magnitude of change post crisis (or convergence) are highly and significantly correlated to those estimated in the baseline DEA (whether for the simple or weighted average scores), despite the fact that no control variables have been included in the SFA estimation yet—although now there is more variation in the sub-regional scores (i.e., distance from the frontier).

Figure 8. Robustness: Convergence of Weaker NUTS2 Sub-regions

(Estimated SFA weighted-average efficiency pre-crisis levels vs. percent change post crisis)



Second-stage analysis

The second step estimates the determinants or covariates of sub-regional public sector spending efficiency in the three sectors of education, health and economic services and the weighted overall sectoral average. This separate second step partly addresses the problem of public spending endogeneity, particularly if using lags in public spending among other instruments. The SFA efficiency scores can be thought of as a rescaled measure of how much GSCE achievement, for example, a sub-region can achieve at the spending levels pre- or post-crisis if it were as efficient as the most efficient sub-region in England during the same periods.

Table 8. Robustness: Determinants of sub-regional (NUTS2) spending efficiency scores?[1]
Multivariate truncated regression results

	(Dependent variable: SFA efficiency scores)			
	(1)	(2)	(3)	(4)
	Education	Health	Economic Services	Weighted Average
Regressors				
Income per capita	0.012***	0.000	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Private spending on education	1.132***			
	(0.206)			
Private spending on health		0.020		
		(0.266)		
Education attainment	2.412***	3.101***	3.001***	3.000***
	(0.214)	(0.311)	(0.300)	(0.311)
Teacher to pupil ratio	0.024**			
	(0.002)			
Population density	1.362*	1.561***	1.542***	1.442***
	(0.171)	(0.180)	(0.181)	(0.172)
Smoking status		0.000		
		(0.001)		
Prevelance of obesity		0.000		
		(0.001)		
Capital stock			-0.001	-0.001*
			(0.001)	(0.001)
Active enterprises			0.012***	
			(0.022)	
Number of observations	58	58	58	58
Fixed effects	yes	yes	yes	yes

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

[1] Two sets of efficiency scores per sub-region for each of the pre- and post-crisis periods and each regressor.

A multivariate truncated regression with fixed effects is run to identify the factors that account for the sub-regional variation in the efficiency scores given that the SFA efficiency scores are bounded (between zero and one).[64] For this truncated regression, all estimated SFA scores during the pre- and post-crisis periods (28 sub-regions and their average x 2-period averages, and hence 58 observations) are included on the left hand side, and all control

[64] For more details on the estimation approach and specifications used in the literature, see Green (2004) for health, and Grigoli (2014) for education.

variables along with a fixed effect per sub-region per period average are on the right hand side. The results suggest (Table 8):

- **Income per capita.** This captures the effect of disposable income on high-school education achievement (GCSEs) and life expectancy at birth. The coefficient is positive but small as expected, and is statistically significant only in the case of education. The insignificant coefficient on health suggests that the NHS has contributed to improved sub-regional health outputs regardless of private disposable incomes.

- **Private spending on education or health.** This captures the effect of households' ability to complement public spending in achieving better high-school education and health outputs. The coefficient is positive and large in the case of education but small and statistically insignificant in the case of health. The former suggests that private spending on students during the GCSE year (and one-year prior) is important and contributed significantly to sub-regional variation in attainment. The latter suggests that while private spending on health displays the right sign, it is insignificant in terms of explaining sub-regional variation.

- **Education attainment by income level**. Higher education attainment of parents or the sub-regional population is likely to imply better GSCE achievement of their children and similarly better health and economic service outputs. All coefficients are positive, large and statistically significant, suggesting that education attainment does indeed explain a large fraction of the sub-regional variation in efficiency scores.

- **Pupil-to-teacher ratio.** In many OECD countries, a lower number of pupils per teacher (or smaller class-size) is commonly associated with more efficient public spending on high school education (Grigoli, 2014; Jackson, 2016). The coefficient is indeed positive for secondary education albeit small and is statistically significant.

- **Population density.** The quantity and quality of public services provided in education, health, and economic affairs is usually easier to carry out in areas that are urban or more densely populated since commuting distances are shorter and the diffusion or transfer of knowledge and innovation is faster and competition brisker than in rural areas. As expected the coefficients are positive, large and statistically significant for all sectors implying that population density (a proxy for "connectivity" perhaps) is also an important factor explaining the variation in spending efficiency across all sectors.

- **Smoking status at time of delivery.** For the health sector alone, the smoking status of the family at the time of the delivery of a birth could be associated with life expectancy at that time. The coefficient is positive but small and insignificant, implying that smoking is not an important factor explaining the variation in sub-regional public health spending efficiency.

- **Prevalence of obesity.** Once again, for the health sector alone, the prevalence of obesity in mothers at the time of the delivery of a birth could be associated with the life expectancy of the child born at that time. The coefficient is positive but small and insignificant, implying that obesity has not been an important factor explaining the variation in public health spending efficiency.

- **Capital stock.** For economic services and the weighted average alone, larger capital stocks could be associated with higher economic service efficiency scores since higher capital output ratios augment and influence labor productivity as they contribute not only to easing transportation and housing bottlenecks, but also bring in more jobs and opportunities that would increase efficiency diffusion. However, the coefficient does not display the expected sign, is small and only statistically significant in the case of the weighted average. This could reflect measurement error in the input, which is likely to be underestimated (see the data appendix).

- **Number of active enterprises.** For economic services alone, more abundant firms could be associated with higher public economic service efficiency scores; since the more abundant the firms, the more experienced and sophisticated are the public service providers in terms of the delivery of auxiliary business services offered. As expected, the coefficient is positive, large and statistically significant, suggesting that the creation of firms is an important determinant of sub-regional efficiency variation.

Overall, it appears that the most important determinant of sub-regional variation in public sector service productivity or efficiency since 2003 is education attainment, followed by population density (a proxy for urbanization or connectivity), and then private spending and class size on education.

V. Conclusions and Policy Implications

How public sector efficiency or productivity changes during large fiscal consolidation episodes is relevant since efficiency gains can help limit to some extent, along with other secular trends, the adverse impact of spending cuts on outputs. Yet, there is little evidence on how large "exogenous" fiscal consolidation episodes affect sub-regional public sector efficiency and its variation. Despite data limitations at the sub-regional level, and therefore several caveats to the paper's findings, it offers a first stab at filling the gap in terms of what has happened to sub-regional multi-sector public sector productivity post crisis. Its findings could help inform multi-sector spending reforms in the wake of fiscal spending devolution in England at this sub-regional (county or Combined Authority) level. The paper first found that the actual "quantity" of public services provided post crisis broadly has not declined with the proportional decline in education spending per pupil or spending in economic services, for example. Moreover, health spending per head and its associated outputs have increased post crisis.

While these results are encouraging, other factors could also be at play—such as technological improvements, sector reforms, stable employment and incentives of sub-regional authorities in the wake of fiscal devolution. In addition, the choice of outputs in both the education and health sectors does suffer from some shortcomings—therefore making data available on more complete (e.g., Key Stage 2 examination results) and faster moving (e.g., hospital waiting lists) outputs at the sub-regional level would aid further study. In addition, despite these assuring and somewhat unexpected findings, employers have complained about skill deficiencies among the young and those with relatively low education attainment. There is also a high proportion of negative growth firms and room to improve managerial capabilities in the economy (Heseltine 2012). Changes to the "quality of outputs" has also not been measured. Finally, the long-term impact of some of the spending cuts may not be felt for years to come, especially concerning health outputs (as this is a slow moving variable) and the impact of cuts in primary education on high school achievement and education attainment in England more broadly. Further analysis using micro data at the sub-regional level, for example, could provide a fruitful avenue of future research and complement the research undertaken in this paper.

Nevertheless, the paper sought to answer the central question of how much has public sector service efficiency or productivity in sub-regional England and its variation changed since the crisis following the large fiscal consolidation in an evidence-based (empirical) setting. After constructing a sub-regional database that combines official public spending variables matched with several leading multi-sectoral output measures used in the literature from various government departments, an index of public efficiency at the sub-regional English level is estimated.

Through a regression framework, the main empirical findings are: (i) despite large public spending cuts, most notably in the education sector, overall efficiency improved post crisis, with larger cuts yielding the highest efficiency improvements across sub-regions most notably in the education sector, although the lower quartile remains a northern-county phenomenon; (ii) notwithstanding lower initial efficiency levels, these northern counties made the largest efficiency gains post crisis, thus contributing to a narrowing in regional disparities across England; (iii) and while sectoral disparities in the efficiency of delivering public services in economic affairs were widest and remained broadly unchanged post-crisis, those for education (following spending cuts, among other factors) and health (following spending increases, among other factors) have narrowed markedly.

These results could help inform policy makers when designing fiscal spending reforms, including decentralization, across the English sub-regions. In particular, spending powers to those sub-regions that delivered the largest improvements in efficiency could be devolved first, and if the improvements persist, consideration could be given to granting revenue generation powers next, for example. However, for those which saw a deterioration, benchmarking as an incentive to improve future performance could be warranted. Robustness checks revealed that the drivers behind sub-regional variation in public sector efficiency levels since 2003 were fundamental factors such as education attainment of households, population density, private spending on high school education and class size. These could be a sign that reforms to increase sub-regional connectivity (and reduce the costs of transportation) while increasing education attainment and reforms in some sub-regions are worthwhile (for many sound economic reasons, not least) because they would help narrow sub-regional disparities in public sector productivity further.

Finally, the paper found that post-crisis sub-regional changes in public sector efficiency are associated with changes in post-crisis sub-regional labor productivity. However, given the finding that public sector efficiency has improved, this suggests that either there are lags between the two variables, with productivity possibly improving with a delay post improvement in public sector efficiency, and that there are other factors beyond the change in public sector efficiency driving the UK's weak "productivity puzzle". Exploring these factors and continuing to delve more deeply into the UK's productivity puzzle at the sub-regional level would be an important avenue for future research.

References

Afonso, A., V. Tanzi, L. Schuknecht, 2003. "Public Sector Efficiency: An International Comparison, *ECB Working Paper* No. 242.

Afonso, A., V. Tanzi, L. Schuknecht and N. Veldhuis, 2007. "Public Sector Efficiency: An International Comparison, Fraser Alert, The Fraser Institute.

Atkinson, T., 2005. "Atkinson Review: Final Report—Measurement of Government Outputs and Productivity for the National Accounts", Palgrave MacMillan.

Belotti, F., S. Daidone, and G. Ilardi, 2012. "Stochastic frontier analysis using Stata," Centre for Economic and International Studies, Research Paper Series, Vol. 10, Issue 12, No.251 (sept. 2012).

Borge, L-E., T. Falch, P. Tovmo, 2008. "Public Sector Efficiency: The Roles of the Political and Budgetary Institutions, fiscal capacity, and Democratic Participation", *Public Choice* (2008) 136: 475-495.

Boyle, S., 2011. "Health Systems in Transition", United Kingdom (England).

Charron, N., 2012. "From Aland to Ankara: European Quality of Government Index", *University of Gothenburg Working Papers* 2013:11

Evans, P., and J.E. Rauch, 1999. "Bureaucracy and Growth: A cross-National Analysis of the Effects of "Weberian" State Structures on Economic Growth," *American Sociological Review*, Vol. 64(5), pp. 748-765.

Farrell, M.J., 1957. "The Measurement of Productive Efficiency*," Journal of the Royal Statistical Society* vol. 120, pp. 253–281.

Fried, H., K. Lovell, and S. Schmidt, 2008. "The Measurement of Productive Efficiency and Productivity growth (Oxford: Oxford University press).

Giordano, R., and P. Tommasino, 2013. "Public-Sector Efficiency and Political Culture," FinanzArchiv: Public Finance Analysis, Mohr Siebeck, Tübingen, vol. 69(3), pages 289-316, September.

Giordano, R., S. Landau, P. Tommasino, P. Topalova, 2015. "Does Public Spending Inefficiency Constrain Firm Productivity: Evidence from Italian Provinces". *IMF Working Paper* 15/168.

Greene, W., 2004. "Distinguishing between Heterogeneity and Inefficiency: Stochastic Frontier Analysis of the World Health Organization's Panel Data on Health Care Systems," *Health Economics*, Vol. 13, pp. 959-80.

Green, W., 2008. *The Measurement of Efficiency*, chap. The Economic Approach to Efficiency Analysis. Oxford University Press.

Grigoli, F. and J. Kapsoli, 2013. "Waste Note, Want Not: The Efficiency of Health Expenditure in Emerging and Developing Economies." *IMF Working paper* 13/187.

Grigoli, F., 2014. "A Hybrid Approach to Estimating the Efficiency of Public Spending on Education in emerging and developing Economies." *IMF Working paper* 14/19.

Heseltine, M., 2012. “No Stone Unturned—In Pursuit of Growth.”

Hughes, A., 2008. “Entrepreneurship and Innovation Policy: Retrospect and Prospect.” *Political Quarterly* 79, 2008.

International Monetary Fund, 2016. The UK Article IV Consultation and Selected Issues Paper, 2016.

Jackson, C. K., R. C. Johnson, and C. Persico, 2016. “The Effects of School Spending on Educational and Economic Outcomes: Evidence from School Finance Reforms”, *Quarterly Journal of Economics* (2016), 157-218.

Ji, Y-b, and C. Lee, 2010. “Data Envelopment Analysis”, *The Stata Journal* (2010) 10, Number 2, pp. 267-280.

Kibblewhite, A., 2011. “Role of Public Sector Performance in Economic Growth,” Speech delivered by Mr. Kibblewhite, Deputy Chief Executive, The Treasury, at the Institute of Policy Studies, Wellington, 1 April 2011

Lloyd, T., 2015. “Historical trends in the UK: Funding Overview”, The Health Foundation.

Machin, S., 2015. “Real Wage Trends”, Understanding the Great Recession: From Micro to Macro Conference, Bank of England, Sept. 23-24 2015.

Oats, W., 1972. Fiscal Federalism (New York: Harcourt Brace Jovanovich).

Office of National Statistics, 2017. “Public service productivity estimates: total public service, UK:2104.” Office of National Statistics.

Phillips, D., 2015. “Local Government and the Nations: A Devolution Revolution?” Institute of Fiscal Studies.

Ray, S., 2004. “Data Envelopment Analysis: Theory and Techniques for Economies and Operations Research (Cambridge: Cambridge University Press).

Revelli, F., 2010. “Spend More, Get More? Any Inquiry into English Local Government Performance”. *Oxford Economic Papers* 62(2010), 185-207

Simar, L., and P. W. Wilson, 2007. “Estimation and Inference in Two-stage, Non-parametric Models of Production Processes. *Journal of Econometrics*, 136-64.

Travers, T., 2015. “A Hyper-Centralized Anomaly: why the UK Must Embrace Tax Devolution”, in *Tax for Our Times: How the Left Can Reinvent Taxation*, edited by D-R Smith, Fabian Ideas 640.

Verhoeven, M., V. Gunnarsson, and S. Carcillo, 2007. “Education and Health in G7 Countries: Achieving Better Outcomes with Less Spending,” *IMF Working paper* 07/263.

Whitty, G., 2000. “Education reform and education politics in England: A Sociological Analysis”. Institute of Education.

Witty, A., 2013. “Encouraging a British Invention Revolution: Review of Universities and Growth”. Final report and Recommendations.

APPENDIX

The NUTS2 statistical classification of the United Kingdom, including all its regions:

NUTS 2 Code	Region Description
UKC1	Tees Valley and Durham
UKC2	Northumberland and Tyne and Wear
UKD1	Cumbria
UKD3	Greater Manchester
UKD4	Lancashire
UKD6	Cheshire
UKD7	Merseyside
UKE1	East Yorkshire and Northern Lincolnshire
UKE2	North Yorkshire
UKE3	South Yorkshire
UKE4	West Yorkshire
UKF1	Derbyshire and Nottinghamshire
UKF2	Leicestershire, Rutland and Northamptonshire
UKF3	Lincolnshire
UKG1	Herefordshire, Worcestershire and Warwickshire
UKG2	Shropshire and Staffordshire
UKG3	West Midlands (county)
UKH1	East Anglia
UKH2	Bedfordshire and Hertfordshire
UKH3	Essex
UKI3	Inner London – West
UKI4	Inner London – East
UKI5	Outer London – East and North East
UKI6	Outer London – South
UKI7	Outer London – West and North West
UKJ1	Berkshire, Buckinghamshire and Oxfordshire
UKJ2	Surrey, East and West Sussex
UKJ3	Hampshire and Isle of Wight
UKJ4	Kent
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area
UKK2	Dorset and Somerset
UKK3	Cornwall and Isles of Scilly
UKK4	Devon
UKL1	West Wales and The Valleys
UKL2	East Wales
UKM2	Eastern Scotland
UKM3	South Western Scotland
UKM5	North Eastern Scotland
UKM6	Highlands and Islands
UKN0	Northern Ireland

Data and sources

A schematic of the data used in this paper, brief definitions and sources is as follows:

	Inputs (NUTS1)	Controls (NUTS2)					Outputs (NUTS2)	
		Baseline			*Robustness*		*Baseline*	*Robustness*
Sectors: Education	real public spending per pupil	private spending	income per capita	education attainment	teacher-to-pupil ratio/class size		GCSE scores (Key stage 4)	
Sectors: Health	real public spending per person	private spending	income per capita	population age structure (ratio of pop >65)	prevalence of obesity	smoking status at time of birth	life expectancy at 65	life expectancy at birth
Sectors: Economic services	real public spending per person	capital stock	income per capita				number of active enterprises	labor productivity

Real public spending is available by NUTS1 level based on devolved administration spending and the subset of departmental spending that can be identified as benefiting the population of individual regions, combined with the known spending of local government (accounted for by the Department for Communities and Local Government). The data cover central government, local government and public corporations, with some caveats—see next. Source: *Her Majesty's Treasury*, "Public Expenditure by Country, Region and Function" Chapter 9. November 2015.

Real sectoral NUTS1 spending on economic affairs, transport and housing. Spending on economic affairs and housing is the sum of the following HMT budget chapters: Public and common services; Public order and safety; Economic affairs including enterprise and economic development, science and technology, employment policies, agriculture, fisheries and forestry, transport; Environment protection; and Recreation, culture and religion. It should be noted that much of rail and air transport spending cannot be apportioned on a regional basis and is thus likely to be an underestimate. Source: *Her Majesty's Treasury*, "Public Expenditure by Country, Region and Function" Chapter 9. November 2015.

Real NUTS1 private spending on public services (e.g., education and health) is from the household survey. Source: *Office of National Statistics*.

Real gross disposable income is available by NUTS1 and 2. Source: *Office of National Statistics*.

Number of pupils is available at the school level and aggregated up to NUTS2 level using the ONS Geography and GIS & Mapping's keys for local administrative units. Source: *Department of Education*.

Education achievement is GCSE of 5 or more A*-C grades at GCSE or equivalent, including English and Maths, at Key Stage 4 as a percentage of the number of pupils at the end of KS4. It should be noted that since 2012/13 evidence points to score inflation in part attributed to increases in the number of non-GCSE results and hence do not reflect a change in education output. However, the historically consistent Level 2 attainment is used here. Scores are weighted by the number of pupils for aggregation to the NUTS 2 level using the ONS geography and GIS & Mapping Unit keys. Source: *Department for Education*.

Pupil teacher ratio for secondary is available at the NUTS1 level and for years where the data is missing, the series is spliced with the change in secondary **class size** from the same source but at the local school level upward to aggregate up to NUTS1 level using the ONS geography and GIS & Mapping Unit keys. Source: *Department of Education*.

Population at NUTS2: Total resident population (midyear population estimates). The estimated resident population of an area includes all people who usually live there, whatever their nationality. Members of UK and non-UK armed forces stationed in the UK are included and UK forces stationed outside the UK are excluded. Students are taken to be resident at their term time address. The data reflect the new methodology used to calculate migration. Source: *Office of National Statistics*.

Life expectancy at birth and the age of 65 or at birth. Data is derived from the NUTS2 Annual Population Survey (APS). Source: *Office for National Statistics*.

Population age structure (i.e., ratio of population over 65) and density. Data is from the NUTS2 Annual Population Survey (APS) and *EuroStat Population Database*. Source: *Office for National Statistics and http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_statistics_at_regional_level*

Number of active enterprises: Active enterprises at the NUTS2 level are defined as those that had either turnover or employment at any time during the reference period. This is a count of active enterprises in the area. This indicator is a refinement of the indicator covering the number of VAT-registered businesses at the start of the year: for instance, it recognizes business activity occurring at any point in the year and it picks up PAYE-registered business as well as VAT-registered businesses. As a result of this being a more comprehensive measure, the figures are slightly higher than for the VAT-registered businesses measure. Source: *Office for National Statistics*. The data is augmented by splicing with growth rates from the ORBIS firm level database by Bureau van Dijk covering over one million firms, aggregated up to NUTS2 via a matching of city postcodes.

Regional Gross Fixed Capital Formation. Initial stock of capital for transport and housing is provided at the NUTS2 level and includes an industry breakdown. Source: *Office for National Statistics*.

Labor productivity at NUTS2 level is measured as the change in real output per worker between 2010-14 and 2003-07. Source: *Office for National Statistics*.

Smoking status at time of delivery. Data is from the website of *Public Health of England*, www.phoutcomes.info at the NUTS2 level.

Prevalence of obesity. Data source is the *Public Health of England*, www.phoutcomes.info at the NUTS2 level.

Tables

Table A.1. Real public spending pre- and post-crisis [1]

(Per head for health and economy and per pupil for eduction)

	Pre-crisis (2003-07)	Post-crisis (2010-14)	Change *(percent)*
North East			
Education	1.80	1.41	-22
Health	2.03	2.65	31
Economic services	2.02	1.95	-4
North West			
Education	1.74	1.32	-24
Health	1.60	2.02	27
Economic services	1.58	1.61	1
Yorkshire and the Humber			
Education	1.59	1.42	-11
Health	1.49	1.86	25
Economic services	1.42	1.40	-2
Derbyshire and Nottinghamshire			
Education	1.60	1.40	-13
Health	1.33	1.69	27
Economic services	1.29	1.28	0
West Midlands			
Education	1.60	1.34	-16
Health	1.45	1.92	32
Economic services	1.36	1.28	-6
East of England			
Education	1.54	1.32	-14
Health	1.31	1.66	26
Economic services	1.19	1.26	6
South East			
Education	1.44	1.33	-7
Health	1.33	1.70	27
Economic services	1.21	1.20	-1
South West			
Education	1.47	1.42	-3
Health	1.38	1.71	23
Economic services	1.27	1.27	0

Author's estimates based on official and indexed UK data.

1 Aggregated up from NUTS-2 or 3 to NUTS-1 level.

Table A.2. Outputs pre- and post-crisis [1]
(Per head for health and economy and per pupil for eduction)

	Pre-crisis (2003-07)	Post-crisis (2010-14)	Change *(percent)*
North East			
Education	38	58	53
Health	18	19	7
Economic services	6	6	8
North West			
Education	46	58	27
Health	18	19	6
Economic services	16	17	4
Yorkshire and the Humber			
Education	44	57	30
Health	19	19	5
Economic services	14	14	4
Derbyshire and Nottinghamshire			
Education	46	58	26
Health	19	20	5
Economic services	22	23	3
West Midlands			
Education	44	58	33
Health	19	20	6
Economic services	19	20	3
East of England			
Education	52	59	14
Health	19	20	4
Economic services	34	38	12
South East			
Education	50	60	21
Health	19	20	5
Economic services	36	38	6
South West			
Education	46	57	25
Health	20	20	4
Economic services	18	19	1

Author's estimates based on official UK data.

1 Aggregated up from NUTS-2 or 3 to NUTS-1 level.

Table A.3. Robustness: Alternative Public Sector Efficiency Indicators [1]

		Pre-crisis (2003-07)				Post-crisis (2010-14)			
Country (NUTS2)	Code	Education	Health	Economy	Combined Input-oriented Efficiency Index	Education	Health	Economy	Combined Input-oriented Efficiency Index
Lincolnshire	UKF3	1.00	0.96	1.00	**0.987**	0.96	0.97	1.00	**0.975**
Kent	UKJ4	0.94	0.95	1.00	**0.963**	0.95	0.97	1.00	**0.972**
Essex	UKH3	0.87	0.93	1.00	**0.934**	0.93	0.97	1.00	**0.969**
Cornwall and Isles of Scilly	UKK3	0.89	0.89	1.00	**0.926**	0.89	0.95	1.00	**0.945**
Surrey, East and West Sussex	UKJ2	0.95	0.95	0.82	**0.908**	0.95	1.00	0.84	**0.933**
Bedfordshire and Hertfordshire	UKH2	1.00	1.00	0.75	**0.916**	1.00	0.99	0.76	**0.916**
Hampshire and Isle of Wight	UKJ3	0.94	0.92	0.84	**0.898**	0.92	0.99	0.84	**0.914**
Cumbria	UKD1	0.90	0.92	0.76	**0.861**	0.92	0.89	0.76	**0.858**
Lancashire	UKD4	1.00	1.00	0.84	**0.945**	1.00	0.86	0.71	**0.858**
Devon	UKK4	0.94	0.91	0.61	**0.823**	0.91	0.96	0.61	**0.829**
East Anglia	UKH1	0.91	0.89	0.57	**0.790**	0.89	1.00	0.51	**0.802**
Herefordshire, Worcestershire and Warwickshire	UKG1	0.88	0.96	0.59	**0.811**	0.96	0.94	0.51	**0.802**
Berkshire, Buckinghamshire and Oxfordshire	UKJ1	1.00	0.99	0.38	**0.788**	0.99	0.99	0.38	**0.787**
Shropshire and Staffordshire	UKG2	0.86	0.94	0.43	**0.744**	0.94	0.91	0.51	**0.785**
North Yorkshire	UKE2	1.00	0.98	0.43	**0.803**	0.98	0.96	0.38	**0.774**
Leicestershire, Rutland and Northamptonshire	UKF2	0.86	0.89	0.44	**0.730**	0.89	0.96	0.46	**0.772**
Derbyshire and Nottinghamshire	UKF1	0.88	0.95	0.41	**0.747**	0.95	0.95	0.41	**0.768**
Dorset and Somerset	UKK2	0.93	0.87	0.42	**0.741**	0.87	0.98	0.41	**0.753**
Cheshire	UKD6	0.88	0.97	0.33	**0.728**	0.97	0.90	0.36	**0.743**
West Midlands	UKG3	0.89	1.00	0.31	**0.734**	1.00	0.90	0.33	**0.741**
Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	0.86	0.89	0.31	**0.685**	0.89	0.96	0.32	**0.720**
West Yorkshire	UKE4	0.89	0.95	0.28	**0.705**	0.95	0.90	0.30	**0.714**
South Yorkshire	UKE3	0.81	0.94	0.28	**0.677**	0.94	0.90	0.26	**0.699**
East Yorkshire and Northern Lincolnshire	UKE1	0.88	0.93	0.27	**0.689**	0.93	0.90	0.26	**0.697**
Greater Manchester	UKD3	0.90	1.00	0.15	**0.681**	1.00	0.84	0.15	**0.663**
Merseyside	UKD7	0.88	0.96	0.16	**0.665**	0.96	0.84	0.18	**0.662**
Tees Valley and Durham	UKC1	0.77	0.98	0.16	**0.636**	0.98	0.72	0.21	**0.637**
Northumberland and Tyne and Wear	UKC2	0.84	0.95	0.11	**0.632**	0.95	0.71	0.12	**0.594**
England average					**0.791**				**0.796**

1/ A constant returns to scale technology is assumed in the estimation of the technical efficiency of the production function.

Table A.4. Robustness: Alternative Public Sector Efficiency Scores Using a Variable Returns Technology

		Education			Health			Economy			Combined Efficiency Index	Education			Health			Economy			Combined Efficiency Index
		Pre-crisis (2003-07)										Post-crisis (2010-14)									
Country (NUTS2)	**Code**		SCALE			SCALE			SCALE				SCALE			SCALE			SCALE		
Essex	UKH3	0.93	0.93	irs	1.00	0.98	irs	1.00	1.00	-	**0.977**	1.00	0.93	irs	1.00	0.97	irs	1.00	1.00	-	**1.000**
Surrey, East and West Sussex	UKJ2	1.00	0.95	irs	1.00	1.00	-	0.98	0.84	irs	**0.994**	1.00	0.96	irs	1.00	1.00	-	1.00	0.84	irs	**0.998**
Berkshire, Buckinghamshire and Oxfordshire	UKJ1	1.00	1.00	-	1.00	1.00	irs	0.98	0.38	irs	**0.993**	1.00	0.99	irs	1.00	0.99	irs	1.00	0.38	irs	**0.998**
Hampshire and Isle of Wight	UKJ3	1.00	0.94	irs	1.00	0.99	irs	0.98	0.85	irs	**0.993**	1.00	0.92	irs	1.00	0.99	irs	1.00	0.84	irs	**0.998**
Kent	UKJ4	1.00	0.94	irs	1.00	0.97	irs	1.00	1.00	-	**0.999**	1.00	0.95	irs	1.00	0.97	irs	1.00	1.00	-	**0.997**
Lincolnshire	UKF3	1.00	1.00	-	1.00	0.96	irs	1.00	1.00	-	**1.000**	0.97	0.99	drs	1.00	0.97	irs	1.00	1.00	-	**0.989**
Bedfordshire and Hertfordshire	UKH2	1.00	1.00	-	1.00	0.98	irs	1.00	0.75	irs	**1.000**	1.00	1.00	-	1.00	0.99	irs	0.96	0.80	irs	**0.986**
East Anglia	UKH1	0.96	0.95	irs	1.00	1.00	-	1.00	0.57	irs	**0.987**	1.00	0.89	irs	1.00	1.00	-	0.95	0.54	irs	**0.985**
Shropshire and Staffordshire	UKG2	0.97	0.88	irs	0.96	0.94	irs	0.89	0.49	irs	**0.940**	0.98	0.96	irs	0.95	0.95	irs	0.97	0.52	irs	**0.970**
Herefordshire, Worcestershire and Warwickshire	UKG1	0.93	0.95	irs	0.96	0.97	irs	0.90	0.66	irs	**0.929**	0.98	0.97	irs	0.95	0.98	irs	0.97	0.53	irs	**0.969**
Dorset and Somerset	UKK2	0.98	0.95	irs	1.00	0.97	drs	0.96	0.44	irs	**0.980**	0.93	0.94	irs	1.00	0.98	drs	0.98	0.42	irs	**0.969**
Cornwall and Isles of Scilly	UKK3	1.00	0.89	irs	0.95	0.98	irs	1.00	1.00	-	**0.983**	0.93	0.96	irs	0.97	0.97	irs	1.00	1.00	-	**0.967**
Derbyshire and Nottinghamshire	UKF1	0.97	0.90	irs	1.00	0.94	irs	0.92	0.45	irs	**0.966**	0.96	0.99	irs	1.00	0.95	irs	0.94	0.43	irs	**0.966**
Leicestershire, Rutland and Northamptonshire	UKF2	0.94	0.91	irs	1.00	0.96	irs	0.92	0.48	irs	**0.956**	0.95	0.94	irs	1.00	0.96	irs	0.95	0.48	irs	**0.965**
West Midlands	UKG3	1.00	0.89	irs	0.96	0.93	irs	0.87	0.35	irs	**0.944**	1.00	1.00	-	0.95	0.94	irs	0.94	0.35	irs	**0.964**
Devon	UKK4	1.00	0.94	irs	0.96	1.00	drs	0.97	0.64	irs	**0.975**	0.93	0.98	irs	0.97	0.99	irs	0.98	0.63	irs	**0.961**
South Yorkshire	UKE3	1.00	0.81	irs	0.95	0.92	irs	0.87	0.32	irs	**0.937**	0.99	0.95	irs	0.97	0.92	irs	0.89	0.29	irs	**0.952**
Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	0.98	0.88	irs	0.95	0.99	irs	0.94	0.33	irs	**0.956**	0.93	0.95	irs	0.97	0.99	irs	0.94	0.34	irs	**0.948**
North Yorkshire	UKE2	1.00	1.00	-	0.95	0.99	irs	0.85	0.50	irs	**0.932**	1.00	0.98	drs	0.98	0.98	irs	0.87	0.44	irs	**0.947**
East Yorkshire and Northern Lincolnshire	UKE1	0.99	0.88	irs	0.95	0.93	irs	0.88	0.30	irs	**0.939**	0.96	0.96	irs	0.97	0.93	irs	0.90	0.29	irs	**0.946**
West Yorkshire	UKE4	0.98	0.90	irs	0.95	0.92	irs	0.84	0.34	irs	**0.923**	0.97	0.98	irs	0.97	0.92	irs	0.87	0.34	irs	**0.937**
Cumbria	UKD1	0.93	0.97	irs	0.90	0.95	irs	0.80	0.95	irs	**0.879**	1.00	0.92	irs	0.93	0.95	irs	0.79	0.96	irs	**0.908**
Lancashire	UKD4	1.00	1.00	-	0.90	0.92	irs	0.85	0.99	drs	**0.917**	1.00	1.00	-	0.93	0.92	irs	0.78	0.91	irs	**0.905**
Cheshire	UKD6	0.89	0.98	irs	0.90	0.95	irs	0.78	0.42	irs	**0.861**	1.00	0.98	irs	0.93	0.96	irs	0.78	0.46	irs	**0.905**
Merseyside	UKD7	0.96	0.91	irs	0.90	0.89	irs	0.77	0.21	irs	**0.880**	1.00	0.96	irs	0.93	0.90	irs	0.78	0.24	irs	**0.904**
Greater Manchester	UKD3	0.96	0.94	irs	0.90	0.89	irs	0.75	0.19	irs	**0.872**	1.00	1.00	irs	0.93	0.90	irs	0.75	0.20	irs	**0.893**
Tees Valley and Durham	UKC1	1.00	0.77	irs	0.76	0.90	irs	0.62	0.26	irs	**0.792**	0.98	1.00	drs	0.79	0.91	irs	0.65	0.32	irs	**0.809**
Northumberland and Tyne and Wear	UKC2	0.97	0.86	irs	0.76	0.89	irs	0.61	0.18	irs	**0.781**	0.95	1.00	drs	0.79	0.90	irs	0.64	0.19	irs	**0.795**
England average											**0.939**										**0.947**

Table A.5. Public Sector Efficiency Indicators Aggregated to the Regional NUTS1 Level

Period [2]	NUTS1 Region	Code	Education	Health	Economy	Combined	Change post-crisis *(in percent)*
Pre-crisis	North East	UKC	0.80	0.68	0.14	**0.54**	
Post-crisis	North East	UKC	0.96	0.72	0.17	**0.62**	**14.1**
Pre-crisis	North West	UKD	0.92	0.82	0.36	**0.70**	
Post-crisis	North West	UKD	0.98	0.86	0.34	**0.73**	**3.9**
Pre-crisis	Yorkshire and the Humber	UKE	0.88	0.88	0.30	**0.69**	
Post-crisis	Yorkshire and the Humber	UKE	0.95	0.91	0.29	**0.72**	**4.0**
Pre-crisis	Derbyshire and Nottinghamshire	UKF	0.89	0.95	0.52	**0.79**	
Post-crisis	Derbyshire and Nottinghamshire	UKF	0.93	0.96	0.52	**0.80**	**2.1**
Pre-crisis	West Midlands	UKG	0.88	0.90	0.41	**0.73**	
Post-crisis	West Midlands	UKG	0.98	0.91	0.42	**0.77**	**4.9**
Pre-crisis	East of England	UKH	0.92	0.99	0.75	**0.89**	
Post-crisis	East of England	UKH	0.94	0.99	0.73	**0.89**	**(0.0)**
Pre-crisis	South East	UKJ	0.96	0.99	0.74	**0.90**	
Post-crisis	South East	UKJ	0.95	0.99	0.75	**0.90**	**0.1**
Pre-crisis	South West	UKK	0.90	0.95	0.47	**0.77**	
Post-crisis	South West	UKK	0.89	0.96	0.47	**0.77**	**0.0**
Pre-crisis	England average excl. London		0.894	0.896	0.462	**0.751**	
Post-crisis	England average excl. London		0.947	0.911	0.463	**0.774**	**3.63**

1/ Constant returns to scale and output oriented-DEA analysis.

2/ Pre- and post-crisis refer to the average of 2003-07 and 2010-14, respectively.