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UNIVERSITIES OF SIENA, FLORENCE AND PISA
JOINT PhD PROGRAMME IN ECONOMICS
XXXV CYCLE

Essays on the role of well-being and natural capital

for a sustainable prosperity of countries

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Academic Year: 2019-2020

When I started my PhD I was wondering:

"How could I contribute to sustainability challenge?"

If I have to give an answer now, it will be

*"The best thing I can do is be actively part of society and
think of myself as a person rather than a consumer"*

SUMMARY

This dissertation, composed of three chapters, aims at highlighting the role of wellbeing and natural capital for the sustainable prosperity of countries following the "Beyond GDP" movement. The uncertainty about the interrelationship among man-made, social and natural capital and the need to measure and track the development pathways of countries, including interregional disparity, economic inequality, impact on the natural recourses and wellbeing, requires for further theoretical and empirical investigation. The emphasis of the thesis is on the empirical evidence about the different forms of capital and the fulfilment of the basic principle of economics: efficiency. The concept of efficiency means no waste of resources for attaining a given set of goals; unhappiness, economic inequality and environmental issues signal inefficiencies of our system. The ability of policy makers to propose solutions relies on understanding this complex relationship and managing its trade-offs with available economic tools. In this thesis, a novel use of datasets which combine socio-economic, wellbeing and environmental data for the UK and Italy is proposed to reflect on the empirical relationship of the forms of capital. Intentionally, the three papers focus on sub-regional and regional economic analysis to appreciate the heterogeneity of information that could be hidden in national standard macro-indicators.

The first chapter examines the relationship between self-reported wellbeing and productivity at varying geographic scales across the UK. Life satisfaction (LS) is used as a proxy of aggregated wellbeing for each unit considered (e.g. district, sub-region, region), while productivity is measured as the ratio of outputs on inputs or proxied by Gross Value Added (GVA).

The analysis employs both non-parametric (Data Envelopment Analysis) and parametric approaches (Granger causality tests) to answer the following research questions: i) is life satisfaction an input to or output from production ?; ii) do past values of life satisfaction (GVA) have any explanatory power for GVA (life satisfaction)?

The observed LS-productivity relationship is investigated by varying the spatial scale of panel dataset. All data are for 2012 – 2018. The analysis begins in Norfolk, with 7 local authorities and progressively expands the geographic scale to include East Anglia (18 local authorities), East of England (45 local authorities), England (309 local authorities or 33 sub-regions) and the UK (41 sub-regions). Results reveal that the relationship between life satisfaction and productivity varies across observations and spatial scales, and prove that the type of causality is bidirectional. In contrast to the previous firm- and national-level studies, this result reveals that life satisfaction is not only an input to production but also that the scale of analysis matter and the positive relationship between happiness and productivity may not hold at the meso-scales in which many policies are designed and implemented. Moreover, the parametric approach confirms that past values of life satisfaction affect the GVA variable and the past GVA measures have an explanatory effect on life satisfaction.

The second chapter deepens the analysis focusing on the life satisfaction and Gross Domestic Product (GDP) nexus using a simultaneous equation model (SEM). This method is chosen to complement the modelling approach of chapter 1 and overcome the endogeneity issue. The model equations are designed to be interdependent meaning that capital stock, energy consumption and life satisfaction are set as driving forces of economic growth and that life satisfaction are influenced by GDP and individual and contextual determinants (e.g. hours worked, job density, level of qualification and environmental degradation). The investigation is conducted using panel data for the England local authorities over the period 2012-2019. Different specification approaches are tested to appreciate the benefit of using the SEM approach versus more traditional models. SEM estimates for studying the relationship of life satisfaction and GDP increase reliability and results contribute to the ongoing debate showing that life satisfaction has a positive impact on GDP when a high level of self-reported wellbeing is reached (above 7.8), otherwise it negatively affects GDP. For the reverse effect, it is found a negative impact of GDP on life satisfaction after a certain threshold (when a value of 4,000 million £ of GDP is reached), while it has a positive impact on

life satisfaction (below 4,000 million £ of GDP). These empirical insights might help policy maker to design policies to sustain economic development considering the trade-off of growth with the difference forms of capitals and increase awareness of people feelings for productivity.

The third chapter revamps the need to rethink the development pathway and measure it. One of the alternative indexes of sustainability proposed is the Genuine Saving or also called Adjusted Net Saving. Expanding the current knowledge of the regional Italian Genuine Saving, three new factors are included in the index to capture nuances: flood control, water purification ecosystem services and poverty gap. The adjusted Genuine Saving estimates are computed for 2006, 2012 and 2015 by integrating macro and micro data and the social dimension (poverty gap) based on regional disposable equalised income for each region. While the methodological framework is applicable to other countries, Italian results report that the effect of ecosystem services and the poverty adjustment are crucial for measuring the regional development trends. Ignoring these components might lead to mismanagement of the human, natural and social capital at national and regional level.

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Exploring the life satisfaction and productivity nexus: a sub-national empirical analysis in the UK

Abstract

The role of life satisfaction (LS) into the productivity process is exanimated at varying geographic scales across the UK. The empirical investigations employ both non-parametric (Data Envelopment Analysis) and parametric (Granger causality tests) approaches. In contrast to previous firm- and national-level studies, the investigation focuses on how the observed LS-productivity relationship varies with the spatial scale under consideration. All data are for 2012 – 2018. The analysis starts with considering Norfolk, with 7 local authorities and progressively expand the geographic scale to include East Anglia (18 local authorities), East of England (45 local authorities), England (309 local authorities or 33 sub-regions) and the UK (41 sub-regions). Results show that life satisfaction can be considered both an input to and output from production depending on the spatial scales of the analysis and prove that the type of causality between GVA (Gross Value Added) and LS is bidirectional. Results call for caution when generalising from individual-, firm-, and national-level analyses to policies at other scales, such as communities and regions. The analysis highlights the need for higher spatial resolution time-series data describing the capital stock and socio-economic variables and suggests that a coherent economic theory is needed to guide empirical investigations into the spatial aspects of well-being and productivity.

Keywords: *Productivity, Efficiency, Subject wellbeing, Life Satisfaction, DEA, Geographical Scale, Economic Development*

1. Introduction

The current analysis is motivated by the intersection of three phenomena in economics and policy motivates. First, the so-called 'productivity puzzle' that has seen UK's productivity growth fell from a long-run average of 2% to an anaemic 0.3% from 2010-2019 (ONS, 2020; Royal Statistical Society, 2019; Remes et al., 2018). Second, a growing interest in the economics of happiness and the associated explosion of indicators and empirical work identifying the determinants of well-being and relating them to policy levers (Coyle, 2017; Stiglitz et al., 2009; Layard, 2006). And finally, a renewed concern for rising interregional inequalities, captured by the plight of 'left behind places' and political commitments to 'levelling-up'. The goal of this analysis is to investigate how these topics – productivity, life satisfaction, and regional economic analyses – may be related. Some of the intersections are well known, such as the negative effects of low productivity growth on wages, competitiveness, and regional disparities (van Ark and Venables, 2020). Similarly, the positive effects of employee well-being on firm performance are widely documented (Oswald et al., 2015; Krekel et al., 2019; Bellet et al., 2020; Amabile et al., 2005; Isen et al.,1987), leading to an explosion of workplace well-being programmes.

The existing evidence on the relationship between well-being and productivity suggests that there is a small to moderate, yet statistically significant positive relationship (Tenney et al., 2016). The literature is characterized by several common features. First, survey data on life satisfaction (LS) as a proxy for human well-being is widely used. Life satisfaction is inevitably an imperfect and incomplete proxy (Fabian 2021; Agarwala et al 2021), but it is pragmatic, has many conceptual advantages, and is widely employed (Diener et al., 2002; Pavot et al., 1991). Second, whilst early investigations largely described correlations, the field is increasingly able to make causal statements. For example, Oswald et al. (2015) use randomly assigned treatments in an experimental setting, and Bellett et al. (2020) exploit exogenous variation in weather in a panel analyses of the productivity of call-centre workers. A third feature is that many investigations are empirically driven with little to no

theoretical underpinning, which can undermine the robustness and feasibility of results and may lead to well-being policies that 'pull the wrong lever' (Fabian et al., 2021). Finally, the existing evidence base on LS and productivity is spatially blind. Analyses are conducted at an arbitrarily determined scale, typically the individual, firm, or national level, and tend not to consider how this decision might impact results. Firm-level studies largely show that employee's well-being positively correlates to firm performance, customer loyalty, profitability, and employee's productivity, and negatively with staff turnover (Krekel et al., 2019). Experimental studies generally find that recipients of happiness-enhancing treatments perform better in creative tasks relative to control groups (Amabile et al., 2005; Isen et al., 1987; Bryson et al., 2017).

The concern over spatial determinants of the life satisfaction-productivity relationship is particularly important for both business and policy audiences. In many instances, the well-being at work is driven largely by factors governed outside the factory gate. Housing quality, commuting and transport infrastructure, air quality, social opportunities and neighbourhood relations are important contributors to well-being and social capital, but largely they cannot be controlled by employers (Diener et al., 2018; Brereton et al., 2008; MacKerron and Mourato, 2009). From the policy side, interventions to enhance well-being, productivity, or both may operate differently at sub-national scales due to different local conditions. Given the complexity of overlapping jurisdiction and interests of local authorities, city and county councils, mayoral districts, regions, and nations within the UK, understanding how LS and productivity interact at different spatial scales is crucial for designing and evaluating the efficacy of policies around quality of life and levelling up.

The present analysis makes novel contributions in three domains: conceptually, by analysing the LS-productivity relationship at varying spatial scales and over time, empirically, by constructing novel data to support investigations at previously unexamined spatial scales, and methodologically,

by deploying both parametric (Granger causality tests) and non-parametric (Data Envelopment Analysis, DEA) techniques on the same dataset. The research design enables to investigate whether LS is best considered as an input to production or an output from it, whether LS Granger causes productivity, whether productivity Granger causes LS, and whether the structure of these relationships varies with the spatial scale of analysis.

To the best of author's knowledge, the empirical literature has never tested the relationship between life satisfaction and productivity at varying geographic scales in the UK. This gap is filled by examining the relationships within Norfolk (7 local authorities), East Anglia (18 local authorities) and the East of England (45 local authorities), England (309 local authorities and 33 NUTS2 subregions) and the UK (41 NUTS2 subregions)1. To tackle this challenge, the analyses proposed in the present work make use of novel datasets which combine the newly developed regional Gross Value Added (GVA) statistics with life satisfaction data.

Results suggest that the spatial scale of analysis may be an important driver of results, with direct implications for the external validity of previous studies and the credibility of evidence on which place-based policies for well-being and productivity are premised. Despite using a similar method and larger sample size than recent international studies (Di Maria et al., 2019), the current investigation cannot confirm their findings (that greater well-being improves productivity) hold at different spatial scales. The quality and availability of the core data required to analyse productivity at various spatial scales in the UK is a relevant concern. Specifically, official statistics describing the capital stock and the socio-economic variables at subnational scales in the UK are desperately needed. Finally, even if better data were available, a coherent economic theory relating well-being to productivity at different scales is needed.

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[1] For more information see the Open Geography portal from the Office for National Statistics (ONS) https://geoportal.statistics.gov.uk

2. Literature review

The impact on life satisfaction on productivity or economic indicators is founded at micro and macro level. Empirical findings are prominent in the well-being literature, concerning the links between subject well-being and other variables of interest relevant to productivity (see Clark et al., 2018 for a survey; Diener et al., 2018 for a summary).

Firm-level studies indicate that employee wellbeing is an important correlate of firm performance measured in terms of customer loyalty, profitability, staff turnover, and employee productivity (Oswald et al., 2015; Krekel et al., 2019; Bellet et al., 2020). Experimental studies generally find that participants who receive happiness-enhancing treatments perform better in creative tasks relative to control groups, suggesting mood may play an important role (Amabile et al.,2005; Isen et al.,1987).

On the other way, productivity and economic growth has long been the major goal for countries and an important means to increase material conditions, social welfare and more benefits leading healthier and longer lives, useful technologies, access to transport. At the national scale, papers show that well-being trends differ significantly across countries over short and long periods (Easterlin and Angelescu, 2009; Sacks et al., 2012). However, the debate on whether higher income in a country is associated with higher life satisfaction is still debated due to the lack of deeply understanding of causal mechanisms associated with socioeconomic, institutional, cultural structures and environment features (Fabian et al., 2021).

The current analysis employs both non-parametric (Data Envelopment Analysis) and parametric approaches (Granger causality tests) to answer the following research questions: i) is life satisfaction an input to production or an output from it?; ii) do past values of life satisfaction (GVA) have any explanatory power for GVA (life satisfaction)?

3. Data

In an ideal world, analysis of the spatially-specific relationship between well-being and productivity would rely on official statistical data describing GDP, the capital stock, the labour input, human well-being, and socio-economic variables at every scale of analysis from Norfolk up to the United Kingdom. In practice, these data are not all available at a granular scale at the time of writing. Data describing gross value added (GVA), number of employees (L) and life satisfaction come from the UK Office for National Statistics (ONS). Labour market statistics (population, employment, unemployment, earnings) of an area are taken from Nomis[2], a service provided by ONS that give free access to the most detailed and up-to-date UK labour market statistics from official sources.

The ONS has ongoing efforts to develop regional capital stocks, but figures are not yet publicly available. Data describing the capital stock at NUTS2 sub-regions are from Gardiner et al. (2021). All data are for 2012 – 2018. For analyses at finer resolution than the NUTS2 scale, a local authority capital stock measure (K_{LA}) is constructed. Assuming the capital to labour ratio is constant within the NUTS2 sub-region, this is computed as follows:

$$K_{LA} = \frac{L_{LA} \times K_{NUTS2}}{L_{NUTS2}}$$

where L_{LA} is the number of workers at local authority, K_{NUTS2} is the capital stock estimate at NUTS2 from Gardiner et al. (2021) and K_{NUTS2} is the number of workers at NUTS2 level.

Productivity is an apparently simple economic indicator; it describes the relationship between output and the inputs that are required to generate that output. Different concepts and measures of productivity are used in economic context. The main distinction is made between single-factor productivity or partial measures and multi-factor productivity or total measures; the former

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[2] https://www.nomisweb.co.uk

relates output to a single measure of input (the most often used is labour productivity), while the latter to a combination of inputs. Another differentiation is between productivity measures based on gross output to one or several inputs and those which use a value-added concept. A full discussion of the entire set of productivity measures is not the scope of this paper and for a in-depth explanation refer to Sharpe (2002) and the OECD Productivity Manual (2001).

Regarding the measurement of productivity in this analysis, when the non-parametric methods is applied, productivity is defined by the ratio of output set on input set of variables since the concept of the ratio between output and input is the basis of the non-parametric technique. In the parametric approach, GVA is considerate as the main variable of interest. GVA is the economic output (value added generated by the production process)[3].

4. Methods

Two distinct but complementary approaches to investigate the empirical relationship between life satisfaction and productivity are employed. First, the non-parametric Data Envelopment Analysis (DEA) following Di Maria et al. (2019) is used. Second, the Granger-causality tests is tested to determine the type of causality and their impact.

In standard productivity analysis, the output vector O is a function of a set of inputs and technological options managed by the decision-maker or decision maker unit (DMU). Formally the quantity produced is:

$$O = f(X) \tag{1}$$
$$min\ Cost(Ip, O) = min\ (Ip'X)$$

where $f(X)$ represents the production function, O is the quantity of outputs of the DMU. The decision maker explores all feasible input-output combinations

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[3] Figures 1 in Appendix A shows the positive relation between GVA and Gross Disposable Household Income (GDHI), annual earning.

and selects input quantities (as input prices are exogenous) to minimise the costs of producing output, *O*. Specifically, the set of exogenous factors that affect productivity is extended to incorporate life satisfaction.

Typically, productivity analyses would entail specifying the function form (f), a behavioural theory (e.g. profit maximization) and derive the solutions from first and second order conditions. In contrast, Data Envelopment Analysis (DEA) creates a data-driven step-wise frontier curve, making it possible to define numerically the output maximizing combination of inputs without imposing functional or behavioural assumptions (Zhu, 2001). This is a non-parametric method using a linear programming technique for assessing productive efficiency (Coelli et al., 2005) where the set of inputs and outputs of the system are driven by theory or empirical evidence.

Alternatively, the Granger causality test aims to establish a causality relationship between the output of productivity and life satisfaction and can represent the preliminary test of regression analysis. This is a parametric statistical hypothesis test for time series analysis. This causality test establishes whether the overtime distribution of LS can forecast the economic output distribution and vice versa. Combined, the non-parametric (DEA) and parametric approaches (Granger causality tests) offer complementary insights into the relationship between life satisfaction and productivity/economic performance. In the following sections each method is explained in detail.

4.1 Data Envelopment Analysis

DEA is a method for evaluating the performance of homogeneous DMUs and assessing their efficiency in combining multiple inputs to produce multiple outputs. In this analysis, the DMU are in turn local authorities and subregions considering different spatial scales. The linear programming method relies on the specification of a set of inputs and outputs driven by the economic theory or the research question and, through a numerical procedure, the relative efficiency level is established and used to score the performance of DMU. DEA is widely applied in management and economic studies at the firm and

industry level (e.g. Odeck 2007, Emrouznejad et al 2008) but it has been also applied to study productivity at the country level (e.g. Färe et al., 1994; Lafuente et al., 2016; Kumar and Russell, 2002).

Di Maria et al. (2019) use DEA to demonstrate a positive relationship between LS and total factor productivity across 20 European countries. We employ a similar approach, but apply DEA at different geographic scales, ranging from a small area (Norfolk) up to the entire UK. In our case study, O in eq. 1 represents the possible outputs of each DMU (e.g. local authorities, NUTS2) and X is the matrix of inputs each area employs in production. The main result of interest is the change in productive efficiency scores (θ) when life satisfaction is included or excluded from the model.

Given the matrix of inputs **X** and the vector of outputs **Y** selected by the analyst in accordance with the research question, the DEA determines for every DMU the level of efficiency score (θ) defined as the distance from the DMU's observed productivity and the data-driven frontier curve. For each DMU the numerical procedure (in a DEA input-oriented model[4]) reduces the quantity of input x_i (keeping o_i fixed) and projects the ideal combination point ($\mathbf{X}\lambda, o\lambda$) in the multidimensional space defined by all other units and the data driven frontier curve is identified. Formally, the linear problem is:

$$\min_{\theta, \lambda} \theta \qquad\qquad (2)$$

$$\text{subject to} \quad -o_i + Y\lambda \geq 0 \,,$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

λ is a vector of constants to be numerically determined and for each *i-th* observational unit the θ score is calculated. If θ is 1 the observational unit is on the efficient frontier and hence it is technically efficient, (1- θ) is the level of inefficiency.

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[4] The DEA output-oriented model measure technical inefficiency as a proportional increase in output, with input levels held fixed

Prior to calculating the θ score (eq. 2) DEA enables us to test whether a variable is an input to or output from the production process, overcoming the reverse causality issue in standard econometric analysis. The steps of the analysis are summarized in Figure 1. Initially, through a set of average productivity indices (see Appendix B for details on the Malmquist Index) it is possible to test the role of variables in the production process specifying the X matrix as [K,L] and then as [K,L,LS] and similarly the output matrix Y as [GVA] and then as [GVA, LS]. In both cases, the average productivity Malmquist Index is produced with and without the LS variable and the rank-correlation Spearman test assesses the association of these two distributions[5]. A significant rank-correlation test signals that LS plays a role in the production process (see Appendix B, Step 1 section 1).

Assuming constant returns to scale (CRS), DEA is applied and efficiency scores are computed considering the ratio of efficiency (R_i) produced by the additional factor LS. Empirically the θ is calculated with and without LS and the difference in efficiency is summarized in the R_i ratio (see Appendix B stage II section 2).

The crucial assumption is that the life satisfaction variable can be treated as a conventional production factor which can be under the control of decision-makers. This is admittedly a strong assumption, but a growing body of interdisciplinary research suggests that it is possible for policy and firm actions to improve people's well-being in organisation and countries (for a review see Bartolini, 2014; Silva and Caetano, 2007; Nakamura and Otsuka, 2007; Bartolini and Sarracino, 2007; Crawford and Holder, 2007; Haybron, 2011; Rogers et al., 2011).

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[5] This is a non parametric form of correlation which overcomes the assumption of linear association and measures strength and direction of association of two variables.

Figure 1 Flow chart of steps taken in the DEA
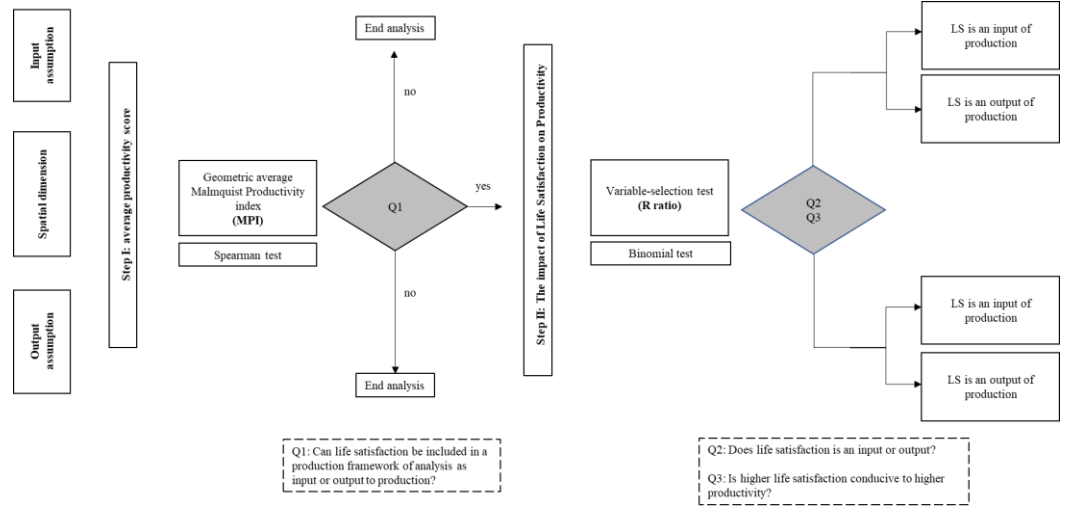
4.2 Granger-causality test

A Granger causality test is used to investigate the probabilistic causality between life satisfaction (LS) and GVA. This is a parametric test based on a vector autoregression to test whether past values of *LS* have any explanatory power for *P* and to check for reverse causality (Granger 1969 and Xiao et al. 2021).

Formally, the regression is as follows:

$$Z_{i,t} = \alpha_i + \sum_{k=1}^{K} \beta_{ik} Z_{i,t-k} + \sum_{k=1}^{K} \gamma_{ik} W_{i,t-k} + \varepsilon_{i,t}$$

where $Z_{i,t}$ can take the value of $LS_{i,t}$ or $GVA_{i,t}$ and W is $GVA_{i,t}$ if $Z=LS_{i,t}$ and vice versa. Z and W are the observations of two stationary variables for DMU i in period. Coefficients are allowed to differ across units but are assumed to be time invariant. The lag order K is assumed to be identical for all i and the panel must be balanced.

The null hypothesis is defined as:

$$H_0: \gamma_{i1} = \ldots = \gamma_{iK} = 0 \qquad \forall\, i = 1, \ldots, N$$

which implies the absence of causality for all units in the panel; in other words, the null hypothesis is that Z does not Granger-cause W.

The test assumes there can be causality for some units but not necessarily for all. Indeed, the alternative hypothesis is:

$$H_1: \gamma_{i1} = \ldots = \gamma_{iK} = 0 \forall i = 1, \ldots, N_1$$
$$\gamma_{i1} \neq 0 \ or \ldots or \ \gamma_{iK} \neq 0 \forall i = N_1 + 1, \ldots, N$$

where $N_1 \in [0, N-1]$ is unknown. If $N_1 = 0$, there is causality for all units in the panel. N_1 is strictly smaller than N, otherwise there is no causality for all units and H_1 reduces to H_0.

5. Results

Given the level of data aggregation (local authority or sub-regions), the analysis considers Norfolk, East of Anglia, the East of England, England and the UK. Table 1 reports the main summary statistics.

Table 1 Descriptive statistics of dataset variables (average for 2012-2018)

Area	Obs	GVA	Capital stock	Labour	LS	GDHI	Annual Earning
Unit	*#*	*million of £*	*£2018 million*	*thousands of workers*	*scale 1-10*	*million of £*	*thousands of £*
Norfolk[a]	49	2,469.02 (723.1628)	465.60 (166.91)	51.61 (17.47)	7.74 (0.20)	2,178.02 (398.70)	28,955.65 (2,481.11)
East of Anglia[a]	126	3,207.92 (1,341.56)	552.67 (243.30)	56.36 (24.51)	7.70 (0.20)	2,516.25 (817.39)	30,518.44 (4,032.16)
East of England[a]	315	3,207.34 (1,341.56)	569.21 (245.40)	57.28 (23.36)	7.65 (0.22)	2,682.86 (935.94)	32,179.11 (4098.85)
England[a]	2,163	4,766.97 (5,901.97)	906.79 (802.17)	81.93 (74.50)	7.60 (0.23)	3,474.93 (2362.98)	31,878.44 (6394.20)
England[b]	231	43,643.81 (30,076.95)	8,385.506 (5,040.56)	804.49 (386.60)	7.60 (0.16)	-	-
UK[b]	287	40,678.72 (28,147.38)	9,594.195 (8,743.75)	759.65 (373.85)	7.61 (0.16)	-	-

Standard Deviation in parenthesis
[a] data refers to local authority
[b] data refers to NUTS2 (sub-regionals)

Results are mixed. Ultimately, the positive relationship between life satisfaction and productivity found in previous studies is not confirmed at all scales of analysis. Our findings suggest that the spatial level of data aggregation plays a key role in understanding the LS-productivity nexus.

Table 2 summaries this finding. Starting from the non-parametric approach and when evaluating aggregations of local authorities, DEA indicates that the

causality is not homogenous and local and national level results are not convergent. For example, for some local authorities LS results as input to production and others as output from production when aggregating to the East of England (18 local authorities). Considering England (309 local authorities), LS should be considered an output from production.

When evaluating at the NUTS2 level, DEA indicates that LS is an output from production for England and the UK. For, England (n=33) and the UK (n=41), the sample of NUTS2 subregions compares favourably to the sample of 20 countries analysed in Di Maria et al (2019). Except for the East Anglia (18 local authorities), all results hold at the 1% significative level.

Results of the Granger causality tests do not fully reinforce those of the DEA as do not exclude a reverse causality when both local authorities and NUTS2 data are used. Although Granger results are not encouraging, we explore several regression models.

Table 2 Summary of key findings

			Non-parametric (DEA)		Parametric (Granger test)	
Local Authority	Norfolk (SMALL area)	7	LS is an **output** from production Significant	Norfolk (SMALL area)	-	NA
	East Anglia (MEDIUM area)	18	For some local authorities LS is an **input** to production, for others LS is an **output** from production Not significant	East Anglia (MEDIUM area)	-	NA
Level of data aggregation	East of England (LARGE area)	45	For some local authorities LS is an **input** to production, for others LS is an **output** from production Significant	East of England (LARGE area)	315 (45 LAs x 7 years)	**Bidirectional**
	England	309	LS is an **output** from production Significant	England	2163 (309 LAs x 7 years)	**Bidirectional**
	England	33	LS is an **output** from production Significant	England	231 (33NUTS2 x 7 years)	**Bidirectional**
NUTS2 (Sub-regions)	UK	41	LS is an **output** from production Significant	UK	287 (41 NUTS2 x 7 years)	**Bidirectional**

5.1 DEA results

Before conducting the efficiency analysis, we first test whether life satisfaction is a *nuisance variable* – one that has no effect on the production process. The results of the Spearman rank-correlation between the average productivity scores with and without LS factor are calculated and reveal that LS can be used in the Step II of the DEA as it can be either input or output factor of the production process depending on the geographic scale. Appendix C Tables 7 (A, B, C, D, E, F) report details of the average productivity changes and ranks.

Stage II results refer to the efficiency analysis and report the R_i ratios (the ratios of equation 8 in Appendix B) which provide the contribution of LS to productivity. Table**s** 3-5 report R_i ratios respectively for Norfolk (7 local authorities), East Anglia (18 local authorities), Est of England (45 local authorities), England (309 local authorities and 33 subregions) and UK (41 subregions). Each table reports the average R_i ratios over time considering LS first as an input to production and subsequently as an output. A ratio of 1 signals a null effect of LS.

For Norfolk, Table 3 shows that life satisfaction should be regarded as an output from production; the average efficiency contribution over period of LS is 14% and 23% in Great Yarmouth and North Norfolk respectively.
For the other local authorities, the average efficiency gains generated by life satisfaction is less then 10%. Result is significant at 1% level.

For East Anglia, both test hypothesis in Table 4 (LS as input/LS as output) results not significant at 1% level[6].

When the scale of analysis expands to the East of England (Table 5), results show that for some local authorities LS is an input to production and others an output from production and both hypotheses are significant at 1% level. Contrary, LS is an output from production considering all the local authorities of England (Table 10); the same result comes both in England and the UK at the NUTS2 level.
Table 10, 11 and 12 in Appendix D report DEA results for England (309 local authorities), England (33 sub-regions) and the UK (41 sub-regions).[7]

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[6] Life satisfaction should be regarded as an output from production at 5% significant level
[7] Same results holds when DEA is applied at the UK regional level (in this application the units are the nine regions) for 2012-2018 after checking for the dynamic of GVA composition

Table 3 Average efficiency gains generated by life satisfaction in Norfolk (7 local authorities) 2012-2018

Local Authority	Test hypothesis: LS is an input	Test hypothesis: LS is an output*
Broadland	1.00	1.01
Great Yarmouth	1.00	**1.14**
Norwich	**1.32**	1.00
King's Lynn and West Norfolk	1.03	1.00
North Norfolk	1.00	**1.23**
Breckland	1.00	1.05
South Norfolk	1.02	1.03

*significant at 1% level; bold character indicates that the R_i ratio changes on average by more than 10% when life satisfaction is considered as an input (output) of the production.

Table 4 Average efficiency gains generated by life satisfaction in East Anglia (18 local authorities), 2012-2018

Local Authority	Test hypothesis: LS is an input	Test hypothesis: LS is an output
Peterborough	**1.15**	1.00
Cambridge	1.07	1.00
East Cambridgeshire	1.00	1.04
Fenland	1.00	1.05
Huntingdonshire	1.01	1.00
South Cambridgeshire	1.01	1.00
Babergh	1.00	**1.11**
Ipswich	1.00	1.00
Mid Suffolk	1.00	1.03
East Suffolk	1.04	1.00
West Suffolk	1.03	1.00
Broadland	1.00	1.02
Great Yarmouth	1.00	1.07
Norwich	1.04	1.00
King's Lynn and West Norfolk	1.00	1.01
North Norfolk	1.00	**1.21**
Breckland	1.00	1.02
South Norfolk	1.00	1.02

*significant at 1% level; bold character indicates that the R_i ratio changes on average by more than 10% when life satisfaction is considered as an input (output) of the production.

by industry in UK and comparing with cluster analysis results (see Appendix E for more details)

Table 5 Average efficiency gains generated by LS in East of England (45 local authorities), 2012-2018

Local Authority	Test hypothesis: LS is an input*	Test hypothesis: LS is an output*
Peterborough	**1.48**	1.00
Cambridge	**1.38**	1.00
East Cambridgeshire	1.00	**1.29**
Fenland	1.00	**1.29**
Huntingdonshire	**1.22**	1.00
South Cambridgeshire	**1.23**	1.00
Babergh	1.00	**1.35**
Ipswich	**1.20**	1.00
Mid Suffolk	1.00	**1.26**
East Suffolk	**1.30**	1.00
West Suffolk	**1.29**	1.00
Broadland	1.04	**1.11**
Great Yarmouth	1.01	**1.29**
Norwich	**1.30**	1.00
King's Lynn and West Norfolk	1.08	1.07
North Norfolk	1.00	**1.46**
Breckland	1.04	**1.17**
South Norfolk	1.05	**1.13**
Luton	**1.51**	1.00
Broxbourne	1.02	**1.24**
Dacorum	**1.31**	1.00
Hertsmere	**1.17**	1.00
North Hertfordshire	**1.15**	1.06
Three Rivers	1.00	1.00
Watford	**1.47**	1.00
St Albans	**1.36**	1.00
Welwyn Hatfield	**1.43**	1.00
East Hertfordshire	**1.31**	1.01
Stevenage	1.07	**1.17**
Bedford	**1.37**	1.01
Central Bedfordshire	**1.57**	1.00
Southend-on-Sea	**1.29**	1.07
Thurrock	**1.27**	1.00
Braintree	**1.18**	1.05
Colchester	**1.41**	1.00
Tendring	1.01	**1.35**
Epping Forest	**1.12**	1.02
Harlow	1.03	**1.22**
Uttlesford	1.01	**1.26**
Brentwood	1.00	1.10
Chelmsford	**1.42**	1.00
Maldon	1.00	**1.87**
Basildon	**1.43**	1.00
Castle Point	1.00	**2.01**
Rochford	1.00	**1.77**

*significant at 1% level; bold indicates that the R_i ratio changes on average by more than 10% when LS is considered as an input (output) of production.

5.2 Granger-causality test results

Before conducting the Granger-causality, a stationarity test of the variables (GVA and LS) is conducted. Using the Levin–Lin–Chu test, the null hypothesis is that the series contains a unit root, and the alternative is that the series is stationary. It rejects the null hypothesis and conclude that all series are stationary.

The hypotheses in the panel Granger-causality test are the following:

H1. GVA as dependent variable and LS as independent variable;

H2. LS as dependent variable and GVA as independent variables.

The results indicate a bidirectional relation at all scales. The past values of economic output have an explanatory power on the life satisfaction variable and vice versa. This means that the reverse causality between life satisfaction and GVA cannot be excluded. Table 6 summarises the Granger-causality test results for each geographical scale used.

Table 6 Summary of Granger-causality test for each geographical scale

Geographical scale	LAs	HPJ Wald Test	Coef.	Std. Err.	Result
Norfolk	7	-			NA
East Anglia	18	-			NA
East of England	45				**Bidirectional**
Hypothesis 1		8.09 (0.0044)	177.65 (0.004)	62.46	LS Granger-causes GVA
Hypothesis 2		38.76 (0.0000)	0.00 (0.000)	0.00	GVA Granger-causes LS
England (local authority)	309				**Bidirectional**
Hypothesis 1		2.97 (0.08)	79.78 (0.085)	46.31	LS Granger-causes GVA
Hypothesis 2		42.56 (0.0000)	0.00 (0.000)	0.00	GVA Granger-causes LS

England (subregion)	**33**				**Bidirectional**
Hypothesis 1		20.84 (0.0000)	-11089.63	2429.35	LS Granger-causes GVA
Hypothesis 2		22.29 (0.0000)	4.39e-06	9.30e-07	GVA Granger-causes LS
UK	**41**				**Bidirectional**
Hypothesis 1		14.55 (0.0001)	-2454.32	643.29	LS Granger-causes GVA
Hypothesis 2		771272.68 (0.0000)	-0.00	4.77e-06	GVA Granger-causes LS

p-value in bracket
estimates refer to lag 1 and heterogeneity correction

6. Discussion

Prior research has largely found that life satisfaction has a small to moderate, yet statistically significantly positive effect on productivity. This has been confirmed in individual, firm, and national scale studies. However, many policy interventions to enhance either well-being, productivity, or both are designed and implemented at decision making scales that fall between those examined in the research literature. Whether one calls it 'place-based policy' or 'levelling-up' a concern for economic and social policymakers is how to address the increasingly vocal and politically influential 'left behind places'. Whilst it would be a happy coincidence if the mutually reinforcing nature of productivity and life satisfaction held at all spatial scales, the evidence does not presently support such a conclusion.

In principle, there are many potential reasons why the positive relationships between life satisfaction and productivity found at the individual, firm, and national scale might not hold at other levels of aggregation. First, if previous studies evaluate the LS-productivity relationship at the mean, important variations in the tails of the distributions could be missed. If those variations entail a spatial component, then crucial details could be lost in the aggregation process. Spill over effects operating in different directions at different scales could be one mechanism. For example, a densely populated, high human capital, high productivity area such as Cambridge might also experience high levels of life satisfaction (positive local spill overs). But it may also drive a

reduction in life satisfaction or productivity in surrounding areas, if they experience a 'brain drain' effect, rising house prices, or a large inequality in incomes, skills, and opportunities (a negative regional spill over).

At present, there is not enough research at the local authority, county, or regional scale to form a strong conclusion about the relationship between life satisfaction and productivity. Our results provide evidence that economists and decision makers should not blindly assume that the positive relationships found at other scales will hold uniformly across spatial units.

Our findings rely on the data we have, rather than the data we want. A key limitation and likely reason for the lack of other meso-scale studies is the lack of official statistics describing the capital stock and other socio-economic variables at fine spatial resolution and time-series as well as a robust and valid instrumental variable to overcome the endogeneity of LS and Productivity. This should be considered a high priority for investment in the statistical infrastructure. Without this, it will be difficult to make strong claims about the effect of policy on productivity or how this affects human well-being.

Using the available data, we find that life satisfaction is a statistically significant determinant of productivity, can be either an input to or output from production, and that this directionality depends on the spatial scale of analysis. However, our results should be considered preliminary. Further investigations would benefit from a coherent theoretical foundation against which data can be fit and hypotheses tested. Methodological improvements to DEA could relax the constant returns to scale assumption. Alternative approaches to identifying causality could also be explored. Criticism of the Granger test considers it as a forecasting technique and carefully warn that Granger causality does not imply true causality (Chen and Hsiao 2010).

7. Conclusion

This paper contributes to the ongoing debate about the relationship between subject wellbeing and productivity highlighting the role of the geographical scale. Data used in the analysis are from ONS and Gardiner et al (2021) and have been scaled to the local authority and NUTS2 levels. Focusing on life satisfaction, employment, GVA, capital stocks, the paper tests if LS is an input to or output from production process at different geographical scale (Norfolk, East Anglia, East of England, England, UK) and level of data aggregation (local authority and subregional) and if past values of life satisfaction (GVA) have any explanatory power for GVA (life satisfaction).

Two approaches are applied: non-parametric DEA and parametric Granger-causality test. Results of the DEA analysis show that life satisfaction has an input role in the local production process; however, considering a larger scale including more local authorities and by subregion aggregation, life satisfaction is an output from production process rather than a production input. The parametric analysis shows a bidirectional relation between GVA and life satisfaction at all scale analysed.

Conclusions from individual, firm, and national scale studies of LS and productivity may not hold at the meso scales in which many policies are designed and implemented. The relationship between subjective wellbeing and productivity/economic output needs further research. Priorities include developing theoretical foundations and improving spatially explicit data. Such research is essential if well-being and productivity policies are intended to support left behind places and the levelling-up agenda.

8. List of abbreviations

DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
GVA	Gross Value Added
LAD	Local Authority District
LS	Life Satisfaction
NUTS	Nomenclature of Territorial Units for Statistics
SWB	Subject wellbeing

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Appendix A Correlation between income, earning and GVA

Figure 2 confirms a strong correlation between income, earning and GVA and we conclude that our productivity proxy can be our variable of interest.

Figure 2 GDHI and GVA relation (right side) and Annual earning and GVA relation (left side) average over period (2012-2018) all Local Authorities
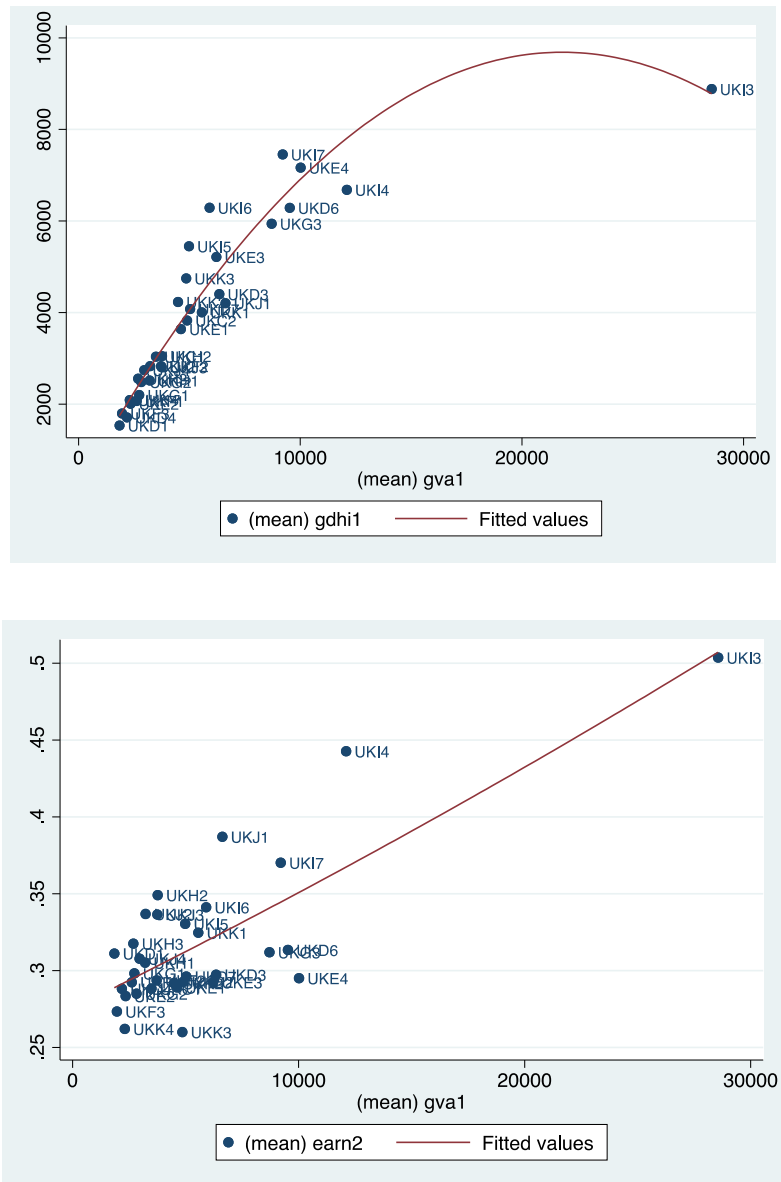
Appendix B DEA empirical strategy

Step I: average productivity score

Before exploring the role of life satisfaction on productive efficiency performance, it is necessary a preliminary step to test if productivity measures computed including LS variable in the inputs or outputs sets play a role in the productivity process[8]. The measure of productivity is referred to the average productivity change over years computed using a geometric average of the Malmquist Productivity index. Formally, it is defined as follows:

$$MPI^G = [(MPI^t)(MPI^{t+1})]^{1/2} \qquad (2)$$

where

$$MPI^t = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \qquad (3)$$

and

$$MPI^{t+1} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \qquad (4)$$

MPI^t and MPI^{t+1} are the Malmquist Productivity index computed setting the frontier (the technology) at a certain point in time to which they refer (respectively *t* and *t+1*). In theory, the Malmquist Productivity index is calculated by linking the efficiency scores of two adjacent time periods and it is the ratio of the distances to the efficient frontier at time chosen computed comparing output and input of two subsequent periods. This idea was suggested by Caves et al (1982) developing the study of Malmquist (1953); see Lee et al. (2011) for more details.

Following the Färe et al. (1994) approach, the MPI^G is used to compute the productivity change for each unit and over years under different assumptions on the role of life satisfaction in production, namely life satisfaction as an input, output, or none of the two. Then, the average productivity change is calculated and ranked from the highest to the lowest productivity growth. The ranks obtained under the three assumptions are subsequently compared using the Spearman rank test correlation for the ordinal variable. The intuition behind this is that if the ranks are correlated, the adjusted efficiency scores – those that include the life satisfaction variable - are statistically significant and Ls plays a role in the productivity process.

This preliminary step is necessary because *nuisance* variables - variables that are not linked with the production process - could be added and a "spurious" measure of productivity could be obtained. Thus, if life satisfaction were a legitimate (valid) input or output of production, we would expect that the ranking of average productivity measures with and without LS adjusted should be similar. This preliminary test is conducted for each geographical scale considered.

Step II: The impact of Life Satisfaction on Productivity

The second step of the empirical analysis aims to test whether life satisfaction can be included as an input or an output in a production framework and if it has a significant effect on productive efficiency using the geographical areas previously identified as decision-maker units. Starting from a small area (Norfolk) and then including all the local authority districts of the region (East of England), the analysis investigates the effect of the spatial dimension on the relationship between life satisfaction and productive efficiency.

The variable selection test for DEA models proposed by Pastor et al. (2002) is applied for this purpose and it consists in the computation of a ratio between the efficiency score computed when Ls is or is not included in the input (output) set. The current section presents a detailed description of it.

DEA permits to compute measures of the productive efficiency for DMU by solving linear programs. The resulting efficiency scores are "distances" from an efficient frontier, which depicts the maximum amount of output that can be produced given a certain level of input as determined by all DMUs in the analysis. Here, DMUs are assigned efficiency scores in the interval between zero and one (where a score equal to one that the DMU is on the production frontier). As an example, a score of 0.5 means that the units could double its output by using its inputs more efficiently.

The test works as follows: assume the hypothesis that life satisfaction is an input to production. First, the efficiency score, θ^{-1}, for each unit i and year t is computed by comparing output (GVA) to inputs used in production, namely labour (L), capital expenditure (K), and life satisfaction (LS). Formally, the efficiency score is as follows:

$$\boldsymbol{\theta_i^{-1}} = D_i\,(K,\,L,\,LS;\,GVA) \qquad (5)$$

where D denotes the distance of unit *i* from the efficiency frontier; note that the variables in the inputs and output set are in brackets and, in this case, life satisfaction is included in the input set.

Second, we compute efficient levels of output, that is, the output that units would produce if they were efficient. This is achieved by dividing local authority *i*'s GVA by the efficiency score obtained in the previous step, as follows:

$$GVA_i^* = \frac{GVA\,(observed)}{\theta_i^{-1}} \qquad (6)$$

Here, GVA_i^* denotes the efficient value of GVA for local authority *i*; $GVA\,(observed)$ is unit's *i* observed

output; θ_i^{-1} is the local authority's *i* efficiency score. Note that, if unit *i* is efficient and $\theta_i^{-1} = 1$, then

$GVA_i^* = GVA\,(observed)$; in contrast, if units *i* is inefficient and $\theta_i^{-1} < 1$, then $GVA_i^* > GVA\,(observed)$.

Third, the new efficiency score is computed by comparing the efficient value of output GVA_i^* to an input set that omits life satisfaction. Formally,

$$\theta_i'^{-1} = D_i\,(K,\,L;\,GVA_i^*) \qquad (7)$$

Pastor et al. (2002) argue that the comparison of the efficiency score from Eq. 5 with the measures computed using the rescaled outputs from Eq. 7 permits to estimate the contribution of life satisfaction to productivity. Formally, the ratio is computed as follows

$$R_i = \frac{D_i(K,\,L,LS;\,GVA_i^*)}{D_i(K,\,L;\,GVA_i^*)} = \frac{1}{\theta_i'^{-1}} \qquad (8)$$

The numerator in Eq. 8 is, by construction, always equal to one. This is because rescaling the GVA amounts to impose that all units are efficient when life satisfaction belongs to the input set. The denominator can take any value between zero and one. As a result, R_i will take values greater or equal to one. Values of R_i equal or close to one suggest that life satisfaction does not affect local unit *i*'s productivity performance; in contrast, values well above one indicate that life satisfaction has a significant effect on productive efficiency. If, after omitting life satisfaction from the input set, a unit remains close to the frontier, then life satisfaction does not generate significant efficiency gains for that local productivity efficiency. Otherwise, if a unit is displaced from the frontier and experiences "large" efficiency losses, then life satisfaction plays a significant role in the production process of that local authority.

The same procedure detailed above is repeated including life satisfaction in the output set to test whether life satisfaction is an output to production and to investigate, in this framework, a test of reverse causality of the relationship between life satisfaction and production efficiency considering different local geographic scales. Table 1 shows the variable selection test procedure for input and output assumption.

The binomial test is used to compare the significance difference of the ratio of Eq. 8; the test requires an improvement in efficiency by at least 5% in at least 15% of decision-maker units for not rejecting the null hypothesis at 1% significance level.

Appendix C The Spearman rank-correlation

Table 7
A. Average productivity change and local authority rankings for Norfolk.

Assumption on the role of life satisfaction in production	neither inputs nor outputs	life satisfaction as input	life satisfaction as output			
FID	DMU	Average Productivity change			rank	rank input	rank output
149	Broadland	1.01	1.01	1.01	1	1	2
150	Great Yarmouth	1.01	1.00	1.00	6	6	6
151	Norwich	1.01	1.00	1.01	4	5	4
152	King's Lynn and West Norfolk	1.01	1.01	1.01	3	4	3
153	North Norfolk	1.00	1.00	1.00	7	7	7
154	Breckland	1.01	1.01	1.01	2	2	1
155	South Norfolk	1.01	1.01	1.01	5	3	5
	Spearman					**0.89**	**0.96**

B. Average productivity change and local authority rankings for East Anglia.

Assumption on the role of life satisfaction in production	neither inputs nor outputs	life satisfaction as input	life satisfaction as output			
FID	DMU	Average Productivity change			rank	rank input	rank output
138	Peterborough	1.01	1.01	1.01	6	9	7

139	Cambridge	1.01	1.00	1.01	15	16	15
140	East Cambridgeshire	0.99	0.99	0.99	18	18	18
141	Fenland	1.01	1.00	1.01	11	15	13
142	Huntingdonshire	1.01	1.01	1.01	4	2	8
143	South Cambridgeshire	1.01	1.01	1.01	13	12	11
144	Babergh	1.01	1.00	1.01	17	14	17
145	Ipswich	1.01	1.01	1.01	3	11	3
146	Mid Suffolk	1.01	1.01	1.01	1	5	10
147	East Suffolk	1.01	1.01	1.01	7	4	6
148	West Suffolk	1.01	1.01	1.01	12	10	9
149	Broadland	1.01	1.01	1.01	2	1	4
150	Great Yarmouth	1.01	1.00	1.01	16	17	16
151	Norwich	1.01	1.01	1.01	10	7	12
152	King's Lynn and West Norfolk	1.01	1.01	1.01	9	6	2
153	North Norfolk	1.01	1.01	1.01	8	13	1
154	Breckland	1.01	1.01	1.01	5	3	5
155	South Norfolk	1.01	1.01	1.01	14	8	14
	Spearman					**0.77**	**0.77**

C. Average productivity change and local authority rankings for East of England.

Assumption on the role of life satisfaction in production	neither inputs nor outputs	life satisfaction as input	life satisfaction as output			
FID	DMU	Average Productivity change			rank	rank input	rank output
72	Peterborough	1.03	1.05	1.03	15	5	5
73	Cambridge	1.00	1.02	1.00	37	29	35
74	East Cambridgeshire	0.98	0.98	0.96	43	44	44
75	Fenland	1.03	1.04	1.00	6	18	34
76	Huntingdonshire	1.00	1.01	1.00	34	33	36
77	South Cambridgeshire	1.00	1.02	0.99	36	25	37
78	Babergh	1.01	1.01	1.01	32	36	18
149	West Suffolk	0.99	1.01	0.84	41	34	45
212	Ipswich	1.03	1.04	1.02	17	14	10
214	Mid Suffolk	1.02	1.02	1.01	25	31	22
226	East Suffolk	1.01	1.01	1.00	33	37	28
232	Broadland	1.12	1.12	1.06	2	2	1
236	Great Yarmouth	1.00	1.00	1.01	38	39	24
240	Norwich	1.01	1.03	1.01	28	22	25
277	King's Lynn and West Norfolk	0.99	0.99	1.00	39	42	29
309	North Norfolk	1.03	1.02	1.00	13	27	32
312	Breckland	0.99	0.99	1.01	42	40	15
315	South Norfolk	0.95	0.97	0.97	45	45	43
318	Luton	1.04	1.05	1.03	5	10	3

321	Broxbourne	1.03	1.02	1.03	16	30	4
324	Dacorum	1.02	1.04	1.01	19	16	23
344	East Hertfordshire	1.03	1.05	1.01	10	11	21
345	Hertsmere	1.02	1.04	1.02	23	19	7
346	North Hertfordshire	0.99	1.02	0.99	40	28	40
347	St Albans	1.03	1.04	1.01	11	12	13
348	Stevenage	1.01	1.02	1.01	27	32	20
349	Three Rivers	1.00	0.99	0.99	35	41	38
350	Watford	1.01	1.05	1.01	29	9	26
351	Welwyn Hatfield	1.02	1.05	1.00	26	7	30
352	Bedford	1.02	1.03	1.01	21	23	14
353	Central Bedfordshire	1.02	1.04	1.02	24	15	9
354	Southend-on-Sea	1.02	1.02	1.01	18	26	11
355	Thurrock	1.03	1.05	1.01	9	8	16
356	Braintree	1.03	1.04	1.00	14	17	33
357	Colchester	1.02	1.02	1.01	22	24	12
358	Tendring	1.01	0.99	1.01	31	43	19
359	Epping Forest	1.03	1.05	1.01	12	6	27
360	Harlow	1.03	1.03	1.02	8	21	8
361	Uttlesford	1.01	1.01	0.99	30	35	41
362	Brentwood	1.04	1.06	1.04	4	4	2
363	Chelmsford	0.97	1.00	0.97	44	38	42
364	Maldon	1.03	1.04	0.99	7	13	39
365	Basildon	1.02	1.03	1.02	20	20	6
366	Castle Point	1.08	1.08	1.01	3	3	17
367	Rochford	1.13	1.13	1.00	1	1	31

| | | | Spearman | | 0.83 | | 0.55 | |

D. *Average productivity change and local authority rankings for England.*

	Assumption on the role of life satisfaction in production		neither inputs nor outputs	life satisfaction as input	life satisfaction as output			
							rank	rank
id	region	name	Average	Productivity change		rank	input	output
1	North East	Hartlepool	1.04	1.04	1.04	59	63	49
2	North East	Stockton-on-Tees	1.03	1.03	1.01	112	115	186
3	North East	Middlesbrough	1.04	1.04	1.05	55	58	39
4	North East	Redcar and Cleveland	1.00	1.00	1.04	237	231	50
5	North East	Darlington	1.02	1.02	1.00	132	136	224
6	North East	County Durham	1.01	1.01	1.01	222	219	202
7	North East	Northumberland	2.86	3.13	2.81	1	1	1
8	North East	Newcastle upon Tyne	1.01	1.00	1.02	210	232	119
9	North East	North Tyneside	1.01	1.01	1.00	224	220	212
10	North East	South Tyneside	1.05	1.05	1.09	38	38	17
11	North East	Gateshead	0.99	0.99	0.98	285	285	276
12	North East	Sunderland	1.19	1.21	1.19	7	7	9
13	North West	Allerdale	0.96	0.96	0.98	303	303	280
14	North West	Barrow-in-Furness	1.04	1.04	1.04	51	54	55
15	North West	Copeland	1.14	1.14	1.28	9	10	4
16	North West	Carlisle	1.02	1.01	1.01	172	183	192
17	North West	Eden	1.05	1.05	1.04	41	43	61
18	North West	South Lakeland	1.04	1.04	1.01	49	52	161
19	North West	Manchester	1.02	1.02	1.02	163	163	145
20	North West	Salford	1.05	1.07	1.05	39	27	41

21	North West	Trafford	1.08	1.09	1.08	18	17	19
22	North West	Stockport	1.02	1.02	1.02	144	124	122
23	North West	Tameside	1.03	1.04	1.03	77	62	78
24	North West	Bolton	1.02	1.02	1.02	168	175	131
25	North West	Wigan	1.03	1.03	1.02	92	94	101
26	North West	Bury	1.02	1.02	1.00	166	166	242
27	North West	Oldham	1.07	1.08	1.08	25	20	20
28	North West	Rochdale	1.01	1.01	1.02	227	223	100
29	North West	Blackburn with Darwen	1.04	1.04	1.05	68	72	46
30	North West	Blackpool	1.03	1.03	1.02	103	106	129
31	North West	Lancaster	1.03	1.03	1.01	113	118	172
32	North West	Wyre	1.04	1.04	1.03	54	57	67
33	North West	Fylde	0.90	0.90	0.94	309	309	307
34	North West	Preston	1.04	1.04	1.03	64	67	66
35	North West	Ribble Valley	1.04	1.04	1.02	52	55	105
36	North West	South Ribble	1.06	1.06	1.05	27	30	40
37	North West	Burnley	1.01	1.01	1.03	184	182	71
38	North West	Hyndburn	1.00	1.00	1.01	246	244	184
39	North West	Pendle	1.21	1.21	1.17	5	6	10
40	North West	Rossendale	0.98	0.98	1.06	287	286	28
41	North West	Chorley	1.00	1.00	0.99	249	247	252
42	North West	West Lancashire	1.02	1.02	1.05	156	159	47
43	North West	Warrington	1.01	1.01	1.01	198	196	176
44	North West	Cheshire East	1.01	1.01	1.01	186	199	163
45	North West	Cheshire West and Chester	1.01	1.01	1.01	187	187	162
46	North West	Halton	1.02	1.02	1.02	171	170	137
47	North West	Knowsley	1.03	1.03	1.02	78	83	132
48	North West	St. Helens	1.02	1.02	1.03	179	177	83

49	North West	Liverpool	1.01	1.00	1.00	234	238	211
50	North West	Sefton	1.03	1.03	1.03	114	103	99
51	North West	Wirral	1.01	1.00	1.00	228	233	226
52	Yorkshire and The Humber	Kingston upon Hull, City of	1.01	1.01	1.01	199	197	179
53	Yorkshire and The Humber	East Riding of Yorkshire	1.02	1.02	1.02	162	162	144
54	Yorkshire and The Humber	North East Lincolnshire	1.01	1.01	1.02	212	208	108
55	Yorkshire and The Humber	North Lincolnshire	1.02	1.02	1.01	121	123	194
56	Yorkshire and The Humber	York	1.00	1.00	1.00	251	248	228
57	Yorkshire and The Humber	Craven	0.95	0.95	0.96	306	306	297
58	Yorkshire and The Humber	Hambleton	0.94	0.94	0.95	307	307	303
59	Yorkshire and The Humber	Harrogate	1.03	1.03	1.00	79	77	235
60	Yorkshire and The Humber	Richmondshire	1.03	1.03	1.11	116	119	13
61	Yorkshire and The Humber	Ryedale	1.08	1.08	1.05	20	22	45
62	Yorkshire and The Humber	Scarborough	0.99	0.99	0.99	279	280	245
63	Yorkshire and The Humber	Selby	0.98	0.98	1.00	291	290	214
64	Yorkshire and The Humber	Barnsley	1.00	1.00	1.01	242	240	203.5
65	Yorkshire and The Humber	Doncaster	1.03	1.03	1.03	97	100	88
66	Yorkshire and The Humber	Rotherham	1.02	1.02	1.03	161	143	82

67	Yorkshire and The Humber	Sheffield	1.20	1.25	1.20	6	5	8
68	Yorkshire and The Humber	Bradford	1.00	1.00	1.01	243	260	207
69	Yorkshire and The Humber	Leeds	1.01	1.01	1.01	217	186	196
70	Yorkshire and The Humber	Calderdale	1.03	1.03	1.02	81	85	116
71	Yorkshire and The Humber	Kirklees	1.03	1.03	1.03	99	110	84
72	Yorkshire and The Humber	Wakefield	1.02	1.01	1.02	153	184	150
73	East Midlands	Derby	0.99	0.99	0.99	276	275	263
74	East Midlands	Bolsover	1.03	1.03	1.05	80	84	44
75	East Midlands	Chesterfield	1.03	1.03	1.01	90	92	191
76	East Midlands	North East Derbyshire	1.08	1.08	1.22	16	18	7
77	East Midlands	Amber Valley	1.03	1.03	1.02	88	87	141
78	East Midlands	Derbyshire Dales	1.03	1.03	1.06	87	89	37
79	East Midlands	Erewash	1.04	1.04	1.03	57	60	77
80	East Midlands	High Peak	1.00	1.00	1.01	248	246	193
81	East Midlands	South Derbyshire	1.08	1.08	1.05	19	21	38
82	East Midlands	Nottingham	1.04	1.04	1.03	61	65	69
83	East Midlands	Ashfield	1.01	1.01	1.00	232	227	219.5
84	East Midlands	Bassetlaw	1.01	1.01	1.01	205	203	181
85	East Midlands	Mansfield	1.01	1.01	0.98	203	202	284
86	East Midlands	Newark and Sherwood	1.05	1.05	1.06	44	45	26
87	East Midlands	Broxtowe	1.02	1.02	1.01	122	126	198
88	East Midlands	Gedling	1.03	1.03	1.01	104	107	199
89	East Midlands	Rushcliffe	1.05	1.05	1.06	40	41	25
90	East Midlands	Leicester	1.04	1.04	1.04	67	70	63

91	East Midlands	Rutland	1.00	1.00	1.04	244	241	58
92	East Midlands	Blaby	1.00	1.00	1.00	262	257	225
93	East Midlands	Charnwood	1.03	1.03	1.03	115	117	96
94	East Midlands	Harborough	0.99	0.99	0.99	278	279	248
95	East Midlands	Hinckley and Bosworth	1.04	1.04	0.99	60	64	246
96	East Midlands	Melton	1.02	1.02	1.03	120	122	86
97	East Midlands	North West Leicestershire	1.01	1.01	1.01	185	185	208
98	East Midlands	Oadby and Wigston	1.02	1.02	0.99	145	149	266
99	East Midlands	West Northamptonshire	1.02	1.03	1.02	158.5	116	112
100	East Midlands	North Northamptonshire	0.99	0.99	1.00	268	283	215
101	East Midlands	Boston	1.02	1.02	0.95	176	174	304
102	East Midlands	East Lindsey	0.97	0.97	0.97	294	294	287
103	East Midlands	Lincoln	1.01	1.01	0.99	233	228	261
104	East Midlands	North Kesteven	1.00	1.00	0.99	258	255	247
105	East Midlands	South Holland	1.02	1.02	0.99	146	150	254
106	East Midlands	South Kesteven	0.99	0.99	0.99	273	272	253
107	East Midlands	West Lindsey	0.89	0.89	0.80	310	310	310
108	West Midlands	Herefordshire, County of	1.03	1.03	1.03	98	101	97
109	West Midlands	Bromsgrove	1.05	1.05	1.02	35	39	147
110	West Midlands	Malvern Hills	1.00	1.00	0.99	259	258	251
111	West Midlands	Redditch	1.05	1.05	1.06	34	37	29
112	West Midlands	Worcester	1.00	1.00	0.98	264	256	285
113	West Midlands	Wychavon	0.97	0.97	0.98	296	297	279
114	West Midlands	Wyre Forest	1.00	1.00	0.98	267	262	282
115	West Midlands	North Warwickshire	1.03	1.03	1.02	76	82	134

116	West Midlands	Nuneaton and Bedworth	1.03	1.03	1.00	84	86	213
117	West Midlands	Rugby	1.04	1.04	1.06	48	51	34
118	West Midlands	Stratford-on-Avon	1.05	1.06	1.06	37	32	31
119	West Midlands	Warwick	1.03	1.03	1.03	86	97	85
120	West Midlands	Telford and Wrekin	1.03	1.03	1.02	91	93	113
121	West Midlands	Shropshire	1.16	1.18	1.16	8	8	11
122	West Midlands	Stoke-on-Trent	1.02	1.02	1.02	149	153	139
123	West Midlands	Cannock Chase	1.03	1.03	1.01	73	79	183
124	West Midlands	East Staffordshire	1.13	1.15	1.12	10	9	12
125	West Midlands	Lichfield	1.00	1.00	1.00	241	239	232
126	West Midlands	Newcastle-under-Lyme	1.08	1.08	1.07	17	19	22
127	West Midlands	South Staffordshire	1.02	1.02	1.03	142	147	90
128	West Midlands	Stafford	0.99	0.99	0.99	283	284	258
129	West Midlands	Staffordshire Moorlands	1.04	1.04	1.08	58	61	18
130	West Midlands	Tamworth	1.06	1.06	1.04	29	33	56
131	West Midlands	Birmingham	1.03	1.03	1.03	106	108	91
132	West Midlands	Solihull	1.03	1.03	1.02	105	109	102
133	West Midlands	Coventry	1.02	1.02	1.02	147	151	149
134	West Midlands	Dudley	1.02	1.02	1.02	138	142	142
135	West Midlands	Sandwell	1.05	1.05	1.05	33	36	43
136	West Midlands	Walsall	1.02	1.02	1.03	125	129	95
137	West Midlands	Wolverhampton	1.02	1.02	1.02	157	160	136
138	East of England	Peterborough	1.01	1.01	1.02	216	212	111
139	East of England	Cambridge	0.99	0.99	0.99	271	268	267
140	East of England	East Cambridgeshire	0.95	0.95	0.98	304	304	270
141	East of England	Fenland	1.01	1.01	1.01	213	209	209
142	East of England	Huntingdonshire	1.00	0.99	0.98	265	270	275

143	East of England	South Cambridgeshire	0.97	0.97	1.00	298	298	234
144	East of England	Babergh	1.00	1.00	0.96	252	249	294
145	East of England	Ipswich	1.01	1.01	1.00	226	222	239
146	East of England	Mid Suffolk	1.01	1.01	0.98	231	226	283
147	East of England	East Suffolk	1.00	0.99	1.01	260	276	177
148	East of England	West Suffolk	0.97	0.96	0.98	299	300	274
149	East of England	Broadland	1.10	1.11	1.04	12	14	51
150	East of England	Great Yarmouth	0.98	0.98	0.99	292	292	259
151	East of England	Norwich	1.01	1.01	0.99	218	213	262
152	East of England	King's Lynn and West Norfolk	0.99	0.99	0.97	277	277	290
153	East of England	North Norfolk	2.11	2.14	1.60	2	2	2
154	East of England	Breckland	1.01	1.01	1.00	193	192	237
155	East of England	South Norfolk	0.97	0.97	0.96	293	293	295
156	East of England	Luton	1.04	1.04	1.03	70	74	64
157	East of England	Broxbourne	1.01	1.01	1.00	209	206	238
158	East of England	Dacorum	1.02	1.02	1.02	129	133	138
159	East of England	Hertsmere	1.04	1.04	1.00	69	71	221
160	East of England	North Hertfordshire	1.05	1.05	1.02	36	40	126
161	East of England	Three Rivers	1.00	1.00	1.00	256	253	244
162	East of England	Watford	1.03	1.03	0.99	83	90	260
163	East of England	St Albans	1.01	1.01	1.03	204	214	72
164	East of England	Welwyn Hatfield	1.01	1.01	0.99	229	224	256
165	East of England	East Hertfordshire	0.99	0.99	0.99	282	278	265
166	East of England	Stevenage	1.02	1.02	1.02	139	144	106
167	East of England	Bedford	1.02	1.02	1.01	154	157	169
168	East of England	Central Bedfordshire	1.02	1.02	1.02	152	156	128
169	East of England	Southend-on-Sea	1.02	1.02	1.02	158.5	161	103
170	East of England	Thurrock	1.03	1.03	1.02	93	95	151

171	East of England	Braintree	1.02	1.02	1.02	123	127	146
172	East of England	Colchester	1.02	1.01	1.02	177	178	156
173	East of England	Tendring	1.03	1.03	0.99	94	96	264
174	East of England	Epping Forest	1.02	1.02	1.01	130	134	205
175	East of England	Harlow	1.03	1.03	1.03	74	80	92
176	East of England	Uttlesford	0.99	0.99	1.03	281	282	79
177	East of England	Brentwood	1.07	1.07	1.02	22	25	143
178	East of England	Chelmsford	1.00	0.99	0.98	263	264	277
179	East of England	Maldon	1.06	1.06	1.00	26	28	233
180	East of England	Basildon	1.03	1.04	1.02	75	73	104
181	East of England	Castle Point	1.06	1.06	1.06	31	34	27
182	East of England	Rochford	1.07	1.07	1.06	21	23	36
183	London	City of London	1.01	1.06	1.01	196	31	171
184	London	Camden	1.06	1.05	1.06	30	35	35
185	London	Westminster	1.01	0.99	1.01	223	267	203.5
186	London	Hammersmith and Fulham	1.05	1.05	1.04	43	46	48
187	London	Kensington and Chelsea	1.01	1.01	1.01	206	218	189
188	London	Wandsworth	1.02	1.02	1.02	126	131	114
189	London	Hackney	1.02	1.02	1.02	137	141	123
190	London	Newham	1.00	1.00	1.00	254	236	227
191	London	Tower Hamlets	1.09	1.09	1.09	15	16	16
192	London	Haringey	1.02	1.02	1.02	136	140	120
193	London	Islington	1.00	0.99	1.00	250	265	219.5
194	London	Lewisham	1.01	1.01	1.01	221	217	200
195	London	Southwark	1.01	1.01	1.01	189	189	168
196	London	Lambeth	1.02	1.02	1.02	175	173	155
197	London	Bexley	1.00	1.00	1.00	240	235	217

198	London	Greenwich	1.00	1.00	1.00	239	234	216
199	London	Barking and Dagenham	1.00	1.00	1.00	261	259	236
200	London	Havering	1.02	1.02	1.02	150	154	152
201	London	Redbridge	1.01	1.01	1.01	181	180	185
202	London	Waltham Forest	1.01	1.01	1.01	208	205	190
203	London	Enfield	1.03	1.03	1.03	110	114	98
204	London	Bromley	1.01	1.01	1.01	197	194	166
205	London	Croydon	1.02	1.02	1.02	131	135	115
206	London	Kingston upon Thames	1.01	1.01	1.01	194	193	187
207	London	Merton	1.09	1.11	1.11	14	13	15
208	London	Sutton	1.02	1.02	1.01	167	167	206
209	London	Barnet	1.01	1.01	1.01	188	188	178
210	London	Brent	1.02	1.02	1.02	141	146	124
211	London	Ealing	1.03	1.03	1.03	96	99	87
212	London	Harrow	1.03	1.03	1.02	109	112	110
213	London	Hillingdon	1.03	1.03	1.04	72	105	62
214	London	Hounslow	1.02	1.02	1.02	148	152	133
215	London	Richmond upon Thames	1.10	1.11	1.11	13	12	14
216	South East	Bracknell Forest	1.02	1.02	1.01	164	164	164
217	South East	West Berkshire	1.33	1.35	1.32	3	4	3
218	South East	Reading	1.23	1.47	1.23	4	3	6
219	South East	Slough	1.00	1.00	1.00	245	243	230
220	South East	Windsor and Maidenhead	1.01	1.01	1.00	219	215	223
221	South East	Wokingham	1.01	1.01	1.01	207	204	201
222	South East	Milton Keynes	1.03	1.03	1.03	102	104	89
223	South East	Buckinghamshire	1.01	1.00	1.01	191	252	174
224	South East	Cherwell	1.04	1.04	1.04	50	50	60

225	South East	Oxford	0.99	0.98	0.99	284	291	249
226	South East	South Oxfordshire	1.10	1.11	1.07	11	11	21
227	South East	Vale of White Horse	1.03	1.03	1.03	111	78	75
228	South East	West Oxfordshire	1.07	1.07	1.06	24	26	30
229	South East	Brighton and Hove	1.04	1.04	1.03	65	69	65
230	South East	Eastbourne	1.02	1.02	0.99	170	169	255
231	South East	Hastings	1.03	1.03	0.97	119	121	289
232	South East	Lewes	1.02	1.02	0.99	128	132	250
233	South East	Rother	1.00	1.00	0.96	247	245	292
234	South East	Wealden	1.01	1.01	1.01	190	190	158
235	South East	Elmbridge	1.04	1.04	1.04	53	56	54
236	South East	Guildford	1.00	1.00	1.00	257	254	231
237	South East	Runnymede	1.03	1.03	1.01	89	91	170
238	South East	Spelthorne	0.97	0.97	0.98	295	295	278
239	South East	Surrey Heath	1.02	1.04	1.01	160	53	165
240	South East	Waverley	1.01	1.01	1.03	200	200	76
241	South East	Woking	1.02	1.02	1.01	133	137	180
242	South East	Epsom and Ewell	1.03	1.03	1.02	95	98	118
243	South East	Mole Valley	0.99	0.99	0.98	275	274	281
244	South East	Reigate and Banstead	0.93	0.93	0.92	308	308	308
245	South East	Tandridge	1.03	1.03	0.98	101	102	272
246	South East	Adur	0.98	0.98	0.92	288	287	309
247	South East	Arun	0.98	0.98	0.96	290	289	298
248	South East	Chichester	1.06	1.06	1.03	28	29	73
249	South East	Worthing	1.02	1.02	1.03	151	155	80
250	South East	Crawley	1.01	1.01	0.99	211	207	257
251	South East	Horsham	0.96	0.96	0.96	301	301	296
252	South East	Mid Sussex	1.04	1.05	0.97	66	42	286

253	South East	Portsmouth	1.03	1.03	1.02	108	111	117
254	South East	Southampton	1.02	1.02	1.01	140	145	173
255	South East	Isle of Wight	1.02	1.02	1.02	134	138	140
256	South East	Eastleigh	1.04	1.04	1.02	62	66	135
257	South East	Fareham	1.04	1.04	1.02	63	68	125
258	South East	Gosport	1.03	1.03	1.07	118	120	24
259	South East	Havant	1.05	1.05	1.03	46	48	74
260	South East	East Hampshire	0.99	0.99	0.95	280	281	302
261	South East	New Forest	1.00	1.00	1.04	236	230	59
262	South East	Test Valley	0.98	0.98	0.98	289	288	271
263	South East	Winchester	1.00	1.00	1.00	238	242	241
264	South East	Basingstoke and Deane	0.95	0.95	0.95	305	305	300
265	South East	Hart	1.01	1.01	1.02	201	201	154
266	South East	Rushmoor	1.02	1.02	1.02	169	168	109
267	South East	Medway	1.02	1.02	1.02	155	158	121
268	South East	Dartford	1.02	1.02	1.01	135	139	197
269	South East	Gravesham	0.99	0.99	0.96	274	273	291
270	South East	Swale	0.97	0.97	0.95	300	299	301
271	South East	Canterbury	1.02	1.02	0.98	173	171	269
272	South East	Dover	1.00	1.00	0.97	266	261	288
273	South East	Folkestone and Hythe	1.02	1.02	1.02	124	128	148
274	South East	Thanet	1.01	1.01	1.04	192	191	57
275	South East	Ashford	0.99	0.99	0.96	272	271	299
276	South East	Maidstone	1.02	1.02	1.00	127	130	240
277	South East	Sevenoaks	1.01	1.01	0.99	195	198	268
278	South East	Tonbridge and Malling	1.03	1.03	1.02	100	113	130
279	South East	Tunbridge Wells	1.01	1.01	1.00	214	210	222
280	South West	Bristol, City of	1.01	1.01	1.01	180	179	160

281	South West	Bath and North East Somerset	1.00	1.00	1.00	253	250	243
282	South West	North Somerset	1.00	1.00	1.03	255	251	94
283	South West	South Gloucestershire	1.06	1.07	1.06	32	24	33
284	South West	Cheltenham	1.02	1.02	0.98	165	165	273
285	South West	Cotswold	1.04	1.04	1.06	47	49	32
286	South West	Forest of Dean	1.01	1.01	1.03	215	211	70
287	South West	Gloucester	1.03	1.02	1.02	117	125	107
288	South West	Stroud	1.04	1.04	1.07	56	59	23
289	South West	Tewkesbury	0.96	0.96	0.94	302	302	306
290	South West	Swindon	1.01	1.01	1.01	183	181	167
291	South West	Wiltshire	1.01	1.01	1.00	235	229	210
292	South West	Mendip	1.03	1.03	0.96	107	81	293
293	South West	Sedgemoor	1.03	1.03	1.04	71	75	52
294	South West	South Somerset	0.99	0.99	0.95	286	269	305
295	South West	Somerset West and Taunton	1.01	1.01	1.00	220	216	218
296	South West	Bournemouth, Christchurch and Poole	1.01	1.01	1.01	182	195	159
297	South West	Dorset	1.07	1.10	1.05	23	15	42
298	South West	Cornwall	1.03	1.03	1.03	85	88	81
299	South West	Isles of Scilly	1.05	1.05	1.24	42	44	5
300	South West	Plymouth	1.02	1.02	1.02	143	148	157
301	South West	Torbay	1.01	1.01	1.01	225	221	182
302	South West	East Devon	0.99	0.99	1.01	269	263	195
303	South West	Exeter	1.01	1.00	1.02	202	237	153
304	South West	Mid Devon	1.01	1.01	1.04	230	225	53
305	South West	North Devon	1.05	1.05	1.01	45	47	175
306	South West	South Hams	1.02	1.02	1.02	174	172	127

307	South West	Teignbridge	1.02	1.02	1.00	178	176	229
308	South West	Torridge	0.97	0.97	1.03	297	296	68
309	South West	West Devon	0.99	0.99	1.01	270	266	188
		Spearman					**0.9879**	**0.7412**

E. Average productivity change and NUTS2 rankings for England.

Assumption on the role of life satisfaction in production		neither inputs nor outputs	life satisfaction as input	life satisfaction as output			
ID	NUTSname	Average Productivity change			rank	rank input	rank output
UKC1	Tees Valley and Durham	1.010267	1.010267	1.005333	29	29	22
UKC2	Northumberland and Tyne and Wear	1.010573	1.010573	1.006053	28	28	21
UKD1	Cumbria	1.013055	1.013055	1.001649	16	17	30
UKD3	Greater Manchester	1.011502	1.012629	1.008247	22	18	14
UKD4	Lancashire	1.020392	1.020392	1.011921	4	4	7
UKD6	Cheshire	1.012142	1.012142	1.004263	17	19	25
UKD7	Merseyside	1.009015	1.009015	1.006307	30	30	20
UKE1	East Yorkshire and Northern Lincolnshire	1.007993	1.007993	1.000659	31	31	31
UKE2	North Yorkshire	1.011709	1.011709	1.003555	20	22	28
UKE3	South Yorkshire	1.013532	1.013532	1.004033	14	15	27
UKE4	West Yorkshire	1.01088	1.01088	1.006745	25	25	19
UKF1	Derbyshire and Nottinghamshire	1.015582	1.015582	1.011653	10	10	8
UKF2	Leicestershire, Rutland and Northamptonshire	1.013338	1.013338	1.00717	15	16	18
UKF3	Lincolnshire	1.011539	1.011539	1.003226	21	23	29
UKG1	Herefordshire, Worcestershire and Warwickshire	1.016958	1.016958	1.00991	9	9	11

NUTScode	NUTS2						
UKG2	Shropshire and Staffordshire	1.011778	1.011778	1.005187	19	21	23
UKG3	West Midlands	1.022005	1.022005	1.0171	1	1	1
UKH1	East Anglia	1.011455	1.011455	1.007731	23	24	16
UKH2	Bedfordshire and Hertfordshire	1.020286	1.020286	1.012007	5	5	6
UKH3	Essex	1.020453	1.020453	1.013198	3	3	3
UKI3	Inner London - West	1.010895	1.01526	1.010959	24	14	10
UKI4	Inner London - East	1.005454	1.007957	1.004207	32	32	26
UKI5	Outer London - East and North East	1.002883	1.002883	0.9975566	33	33	32
UKI6	Outer London - South	1.017666	1.017778	1.009217	7	7	12
UKI7	Outer London - West and North West	1.021588	1.021588	1.015695	2	2	2
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	1.010826	1.010826	1.008081	26	26	15
UKJ2	Surrey, East and West Sussex	1.015323	1.015323	1.012332	13	13	5
UKJ3	Hampshire and Isle of Wight	1.015346	1.015346	1.01253	12	12	4
UKJ4	Kent	1.01726	1.01726	1.011359	8	8	9
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area	1.010649	1.010649	1.0073	27	27	17
UKK2	Dorset and Somerset	1.01198	1.01198	1.00457	18	20	24
UKK3	Cornwall and Isles of Scilly	1.018068	1.018068	0.9955733	6	6	33
UKK4	Devon	1.01544	1.01544	1.008652	11	11	13
	Spearman					0.9766	0.6116

F. Average productivity change and NUTS2 rankings for UK.

ID	NUTScode	NUTS2	Assumption on the role of life satisfaction in production					
			neither inputs nor outputs	life satisfaction as input	life satisfaction as output	rank	rank input	rank output
			Average Productivity change					
1	UKC1	Tees Valley and Durham	1.0103	1.0103	1.0060	36	36	28
2	UKC2	Northumberland and Tyne and Wear	1.0106	1.0106	1.0067	35	35	25

3	UKD1	Cumbria	1.0131	1.0131	1.0023	21	22	37
4	UKD3	Greater Manchester	1.0115	1.0126	1.0083	27	23	19
5	UKD4	Lancashire	1.0204	1.0204	1.0105	5	5	15
6	UKD6	Cheshire	1.0121	1.0121	1.0075	22	24	23
7	UKD7	Merseyside	1.0090	1.0090	1.0063	37	37	27
8	UKE1	East Yorkshire and Northern Lincolnshire	1.0080	1.0080	1.0009	38	38	38
9	UKE2	North Yorkshire	1.0117	1.0117	1.0029	25	27	36
10	UKE3	South Yorkshire	1.0135	1.0135	1.0041	19	20	33
11	UKE4	West Yorkshire	1.0109	1.0109	1.0082	31	31	20
12	UKF1	Derbyshire and Nottinghamshire	1.0156	1.0156	1.0119	13	13	10
13	UKF2	Leicestershire, Rutland and Northamptonshire	1.0133	1.0133	1.0076	20	21	22
14	UKF3	Lincolnshire	1.0115	1.0115	1.0032	26	28	34
15	UKG1	Herefordshire, Worcestershire and Warwickshire	1.0170	1.0170	1.0118	11	11	11
16	UKG2	Shropshire and Staffordshire	1.0118	1.0118	1.0053	24	26	29
17	UKG3	West Midlands	1.0220	1.0220	1.0179	1	1	1
18	UKH1	East Anglia	1.0115	1.0115	1.0072	28	29	24
19	UKH2	Bedfordshire and Hertfordshire	1.0203	1.0203	1.0125	6	6	8
20	UKH3	Essex	1.0205	1.0205	1.0137	4	4	5
21	UKI3	Inner London - West	1.0109	1.0153	1.0110	30	17	13
22	UKI4	Inner London - East	1.0055	1.0080	1.0042	40	39	32
23	UKI5	Outer London - East and North East	1.0029	1.0029	0.9972	41	41	40
24	UKI6	Outer London - South	1.0177	1.0178	1.0092	9	9	17
25	UKI7	Outer London - West and North West	1.0216	1.0216	1.0149	2	2	3
26	UKJ1	Berkshire, Buckinghamshire and Oxfordshire	1.0108	1.0108	1.0086	32	32	18
27	UKJ2	Surrey, East and West Sussex	1.0153	1.0153	1.0128	16	16	7

28	UKJ3	Hampshire and Isle of Wight	1.0153	1.0153	1.0131	15	15	6
29	UKJ4	Kent	1.0173	1.0173	1.0123	10	10	9
30	UKK1	Gloucestershire, Wiltshire and Bristol/Bath area	1.0106	1.0106	1.0079	34	34	21
31	UKK2	Dorset and Somerset	1.0120	1.0120	1.0046	23	25	30
32	UKK3	Cornwall and Isles of Scilly	1.0181	1.0181	0.9956	8	8	41
33	UKK4	Devon	1.0154	1.0154	1.0067	14	14	26
34	UKL1	West Wales and The Valleys	1.0149	1.0149	1.0109	18	19	14
35	UKL2	East Wales	1.0113	1.0113	1.0030	29	30	35
36	UKM5	North Eastern Scotland	1.0056	1.0056	1.0044	39	40	31
37	UKM6	Highlands and Islands	1.0107	1.0107	0.9978	33	33	39
38	UKM7	Eastern Scotland	1.0205	1.0205	1.0164	3	3	2
39	UKM8	West Central Scotland	1.0150	1.0150	1.0100	17	18	16
40	UKM9	Southern Scotland	1.0184	1.0184	1.0111	7	7	12
41	UKN0	Northern Ireland	1.0168	1.0168	1.0146	12	12	4
	Spearman						0.9814	0.6761

Appendix D The average efficiency gains generated by life satisfaction in England (309 local authorities)

Table 8 *Average efficiency gains generated by LS in the England (309 local authorities), 2012-2018*

Local Authority	Test hypothesis: LS is an input	Test hypothesis: LS is an output*
Hartlepool	1.00	1.07
Stockton-on-Tees	1.00	1.02
Middlesbrough	1.00	1.03
Redcar and Cleveland	1.00	1.05
Darlington	1.00	1.03
County Durham	1.00	1.01
Northumberland	1.00	1.02
Newcastle upon Tyne	1.00	1.01
North Tyneside	1.00	1.02
South Tyneside	1.00	1.05
Gateshead	1.00	1.02
Sunderland	1.00	1.01
Allerdale	1.00	1.05
Barrow-in-Furness	1.00	1.06
Copeland	1.00	1.06
Carlisle	1.00	1.03
Eden	1.00	1.07
South Lakeland	1.00	1.04
Manchester	1.02	1.00
Salford	1.00	1.01
Trafford	1.00	1.01
Stockport	1.00	1.02
Tameside	1.00	1.03
Bolton	1.00	1.02
Wigan	1.00	1.02
Bury	1.00	1.04
Oldham	1.00	1.03
Rochdale	1.00	1.03
Blackburn with Darwen	1.00	1.03
Blackpool	1.00	1.04
Lancaster	1.00	1.03
Wyre	1.00	1.06
Fylde	1.00	1.04
Preston	1.00	1.02
Ribble Valley	1.00	1.05
South Ribble	1.00	1.03
Burnley	1.00	1.05

Hyndburn	1.00	1.06
Pendle	1.00	1.05
Rossendale	1.00	1.09
Chorley	1.00	1.05
West Lancashire	1.00	1.04
Warrington	1.00	1.01
Cheshire East	1.00	1.01
Cheshire West and Chester	1.00	1.01
Halton	1.00	1.03
Knowsley	1.00	1.03
St. Helens	1.00	1.04
Liverpool	1.00	1.01
Sefton	1.00	1.03
Wirral	1.00	1.02
Kingston upon Hull, City of	1.00	1.01
East Riding of Yorkshire	1.00	1.01
North East Lincolnshire	1.00	1.03
North Lincolnshire	1.00	1.02
York	1.00	1.01
Craven	1.00	1.07
Hambleton	1.00	1.04
Harrogate	1.00	1.02
Richmondshire	1.00	**1.12**
Ryedale	1.00	1.08
Scarborough	1.00	1.05
Selby	1.00	1.04
Barnsley	1.00	1.03
Doncaster	1.00	1.02
Rotherham	1.00	1.02
Sheffield	1.00	1.01
Bradford	1.00	1.01
Leeds	1.01	1.00
Calderdale	1.00	1.02
Kirklees	1.00	1.01
Wakefield	1.00	1.01
Derby	1.00	1.01
Bolsover	1.00	1.05
Chesterfield	1.00	1.04
North East Derbyshire	1.00	1.07
Amber Valley	1.00	1.04
Derbyshire Dales	1.00	1.06
Erewash	1.00	1.06
High Peak	1.00	1.06
South Derbyshire	1.00	1.04

Nottingham	1.00	1.01
Ashfield	1.00	1.03
Bassetlaw	1.00	1.04
Mansfield	1.00	1.06
Newark and Sherwood	1.00	1.04
Broxtowe	1.00	1.04
Gedling	1.00	1.06
Rushcliffe	1.00	1.04
Leicester	1.00	1.01
Rutland	1.00	**1.16**
Blaby	1.00	1.03
Charnwood	1.00	1.03
Harborough	1.00	1.05
Hinckley and Bosworth	1.00	1.04
Melton	1.00	1.08
North West Leicestershire	1.00	1.03
Oadby and Wigston	1.00	**1.12**
West Northamptonshire	1.00	1.01
North Northamptonshire	1.00	1.01
Boston	1.00	1.07
East Lindsey	1.00	1.04
Lincoln	1.00	1.03
North Kesteven	1.00	1.04
South Holland	1.00	1.05
South Kesteven	1.00	1.03
West Lindsey	1.00	1.07
Herefordshire, County of	1.00	1.02
Bromsgrove	1.00	1.03
Malvern Hills	1.00	1.06
Redditch	1.00	1.04
Worcester	1.00	1.03
Wychavon	1.00	1.04
Wyre Forest	1.00	1.07
North Warwickshire	1.00	1.04
Nuneaton and Bedworth	1.00	1.05
Rugby	1.00	1.03
Stratford-on-Avon	1.00	1.02
Warwick	1.00	1.02
Telford and Wrekin	1.00	1.03
Shropshire	1.00	1.02
Stoke-on-Trent	1.00	1.02
Cannock Chase	1.00	1.06
East Staffordshire	1.00	1.03
Lichfield	1.00	1.05

Newcastle-under-Lyme	1.00	1.06
South Staffordshire	1.00	1.08
Stafford	1.00	1.04
Staffordshire Moorlands	1.00	1.08
Tamworth	1.00	1.09
Birmingham	**1.15**	1.00
Solihull	1.00	1.01
Coventry	1.00	1.01
Dudley	1.00	1.02
Sandwell	1.00	1.01
Walsall	1.00	1.02
Wolverhampton	1.00	1.02
Peterborough	1.00	1.01
Cambridge	1.00	1.01
East Cambridgeshire	1.00	1.05
Fenland	1.00	1.05
Huntingdonshire	1.00	1.02
South Cambridgeshire	1.00	1.02
Babergh	1.00	1.05
Ipswich	1.00	1.02
Mid Suffolk	1.00	1.05
East Suffolk	1.00	1.02
West Suffolk	1.00	1.02
Broadland	1.00	1.03
Great Yarmouth	1.00	1.05
Norwich	1.00	1.02
King's Lynn and West Norfolk	1.00	1.03
North Norfolk	1.00	1.06
Breckland	1.00	1.04
South Norfolk	1.00	1.04
Luton	1.00	1.02
Broxbourne	1.00	1.04
Dacorum	1.00	1.02
Hertsmere	1.00	1.03
North Hertfordshire	1.00	1.03
Three Rivers	1.00	1.03
Watford	1.00	1.02
St Albans	1.00	1.02
Welwyn Hatfield	1.00	1.02
East Hertfordshire	1.00	1.03
Stevenage	1.00	1.04
Bedford	1.00	1.02
Central Bedfordshire	1.00	1.02
Southend-on-Sea	1.00	1.03

Thurrock	1.00	1.02
Braintree	1.00	1.03
Colchester	1.00	1.02
Tendring	1.00	1.05
Epping Forest	1.00	1.03
Harlow	1.00	1.04
Uttlesford	1.00	1.04
Brentwood	1.00	1.03
Chelmsford	1.00	1.02
Maldon	1.00	1.09
Basildon	1.00	1.02
Castle Point	1.00	**1.10**
Rochford	1.00	1.08
City of London	1.00	1.00
Camden	1.00	1.01
Westminster	**1.58**	1.00
Hammersmith and Fulham	1.00	1.06
Kensington and Chelsea	1.00	1.06
Wandsworth	1.00	1.09
Hackney	1.00	1.02
Newham	1.00	1.02
Tower Hamlets	1.00	1.00
Haringey	1.00	1.03
Islington	1.00	1.00
Lewisham	1.00	1.03
Southwark	1.00	1.00
Lambeth	1.00	1.01
Bexley	1.00	1.01
Greenwich	1.00	1.02
Barking and Dagenham	1.00	1.02
Havering	1.00	1.02
Redbridge	1.00	1.02
Waltham Forest	1.00	1.02
Enfield	1.00	1.01
Bromley	1.00	1.02
Croydon	1.00	1.01
Kingston upon Thames	1.00	1.03
Merton	1.00	1.02
Sutton	1.00	1.03
Barnet	1.00	1.01
Brent	1.00	1.01
Ealing	1.00	1.01
Harrow	1.00	1.02
Hillingdon	1.00	1.01

Hounslow	1.00	1.00
Richmond upon Thames	1.00	1.01
Bracknell Forest	1.00	1.02
West Berkshire	1.00	1.01
Reading	1.00	1.01
Slough	1.00	1.01
Windsor and Maidenhead	1.00	1.01
Wokingham	1.00	1.01
Milton Keynes	1.00	1.01
Buckinghamshire	1.00	1.00
Cherwell	1.00	1.02
Oxford	1.00	1.01
South Oxfordshire	1.00	1.02
Vale of White Horse	1.00	1.02
West Oxfordshire	1.00	1.05
Brighton and Hove	1.00	1.01
Eastbourne	1.00	**1.10**
Hastings	1.00	**1.15**
Lewes	1.00	**1.11**
Rother	1.00	**1.23**
Wealden	1.00	1.04
Elmbridge	1.00	1.02
Guildford	1.00	1.02
Runnymede	1.00	1.01
Spelthorne	1.00	1.03
Surrey Heath	1.00	1.03
Waverley	1.00	1.03
Woking	1.00	1.03
Epsom and Ewell	1.00	**1.12**
Mole Valley	1.00	1.02
Reigate and Banstead	1.00	1.01
Tandridge	1.00	1.09
Adur	1.00	**1.27**
Arun	1.00	1.06
Chichester	1.00	1.03
Worthing	1.00	1.03
Crawley	1.00	1.02
Horsham	1.00	1.03
Mid Sussex	1.00	1.03
Portsmouth	1.00	1.02
Southampton	1.00	1.01
Isle of Wight	1.00	1.04
Eastleigh	1.00	1.02
Fareham	1.00	1.03

Gosport	1.00	**1.10**
Havant	1.00	1.03
East Hampshire	1.00	1.04
New Forest	1.00	1.02
Test Valley	1.00	1.03
Winchester	1.00	1.02
Basingstoke and Deane	1.00	1.01
Hart	1.00	1.03
Rushmoor	1.00	1.03
Medway	1.00	1.02
Dartford	1.00	1.02
Gravesham	1.00	1.06
Swale	1.00	1.04
Canterbury	1.00	1.03
Dover	1.00	1.04
Folkestone and Hythe	1.00	1.04
Thanet	1.00	1.05
Ashford	1.00	1.03
Maidstone	1.00	1.02
Sevenoaks	1.00	1.03
Tonbridge and Malling	1.00	1.02
Tunbridge Wells	1.00	1.03
Bristol, City of	1.00	1.01
Bath and North East Somerset	1.00	1.02
North Somerset	1.00	1.02
South Gloucestershire	1.00	1.01
Cheltenham	1.00	1.03
Cotswold	1.00	1.03
Forest of Dean	1.00	1.10
Gloucester	1.00	1.03
Stroud	1.00	1.04
Tewkesbury	1.00	1.03
Swindon	1.00	1.01
Wiltshire	1.00	1.01
Mendip	1.00	1.04
Sedgemoor	1.00	1.04
South Somerset	1.00	1.03
Somerset West and Taunton	1.00	1.03
Bournemouth, Christchurch and Poole	1.00	1.01
Dorset	1.00	1.01
Cornwall	1.00	1.01
Isles of Scilly	1.00	**2.33**
Plymouth	1.00	1.02

Torbay	1.00	1.04
East Devon	1.00	1.04
Exeter	1.00	1.02
Mid Devon	1.00	1.08
North Devon	1.00	1.04
South Hams	1.00	1.05
Teignbridge	1.00	1.04
Torridge	1.00	**1.10**
West Devon	1.00	**1.12**

*significant at 1% level; bold indicates that the R_i ratio changes on average by more than 10% when LS is considered as an input (output) of production.

Appendix E GVA composition, DEA at UK regions level and Cluster analysis

The dynamic of GVA composition by industry in UK and in the nine regions is statistically analysed in order to check if the UK regions could have different economic performance as they differ by sectorial productivity. DEA at UK regional level and the cluster analysis are performed.

The sectorial GVA of the UK regions shows similarity excepting for the Greater London area where the primary sector is lower compared to all other regions. Economic sectors refer to the ONS National Accounts Sector Classification. Comparing DEA and cluster analysis results, it is worth noting that:

- Great London and South East England are respectively placed in clusters 1 and 2 (with high level of GVA and low value of life satisfaction) and the efficiency in productivity is not affected by the LS in DEA;

- North Ireland, Wales and North East England are included in cluster 4 (with low level of GVA and high value of life satisfaction) and they show the major impact of LS on productivity.
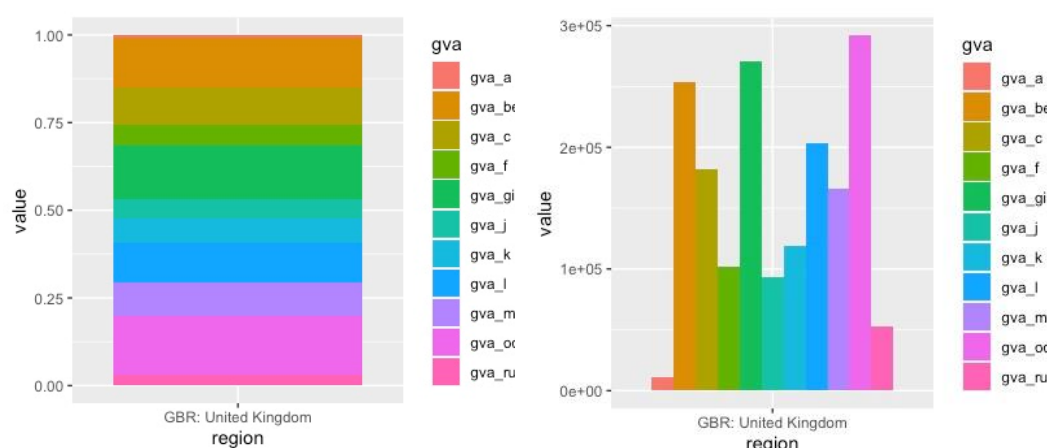
GVA composition

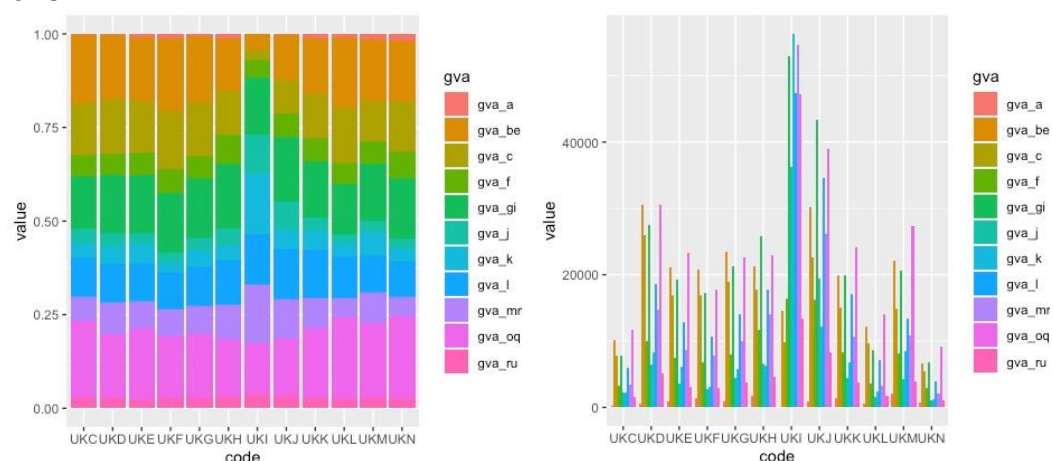**Figure 3** GVA composition

Figure 3 reports the GVA composition % and value in UK and UK regions based on value from 2000-2018. The classification of GVA by industry is from ONS industry classification and it is reported in the following table:

GVA by industry (Pound sterling, 2015)	
gva_a	GVA_IND_10_VA: GVA in agriculture, forestry and fishing (ISIC rev4)
gva_be	GVA_IND_10_VB_E: GVA in industry, including energy (ISIC rev4)
gva_c	GVA_IND_10_VC: ..Of which: GVA in manufacturing (ISIC rev4)
gva_f	GVA_IND_10_VF: GVA in construction (ISIC rev4)
gva_gi	GVA_IND_10_VG_I: GVA in distributive trade, repairs, transport, accommod., food serv. activities (ISIC rev4)
gva_j	GVA_IND_10_VJ: GVA in information and communication (ISIC rev4)
gva_k	GVA_IND_10_VK: GVA in financial and insurance activities (ISIC rev4)
gva_l	GVA_IND_10_VL: GVA in real estate activities (ISIC rev4)
gva_mn	GVA_IND_10_VM_N: GVA in prof., scientific, techn. activities, admin., support service activities (ISIC rev4)
gva_oq	GVA_IND_10_VO_Q: GVA in public admin., compulsory s.s., education, human health (ISIC rev4)
gva_ru	GVA_IND_10_VR_U: GVA in other services (ISIC rev4)

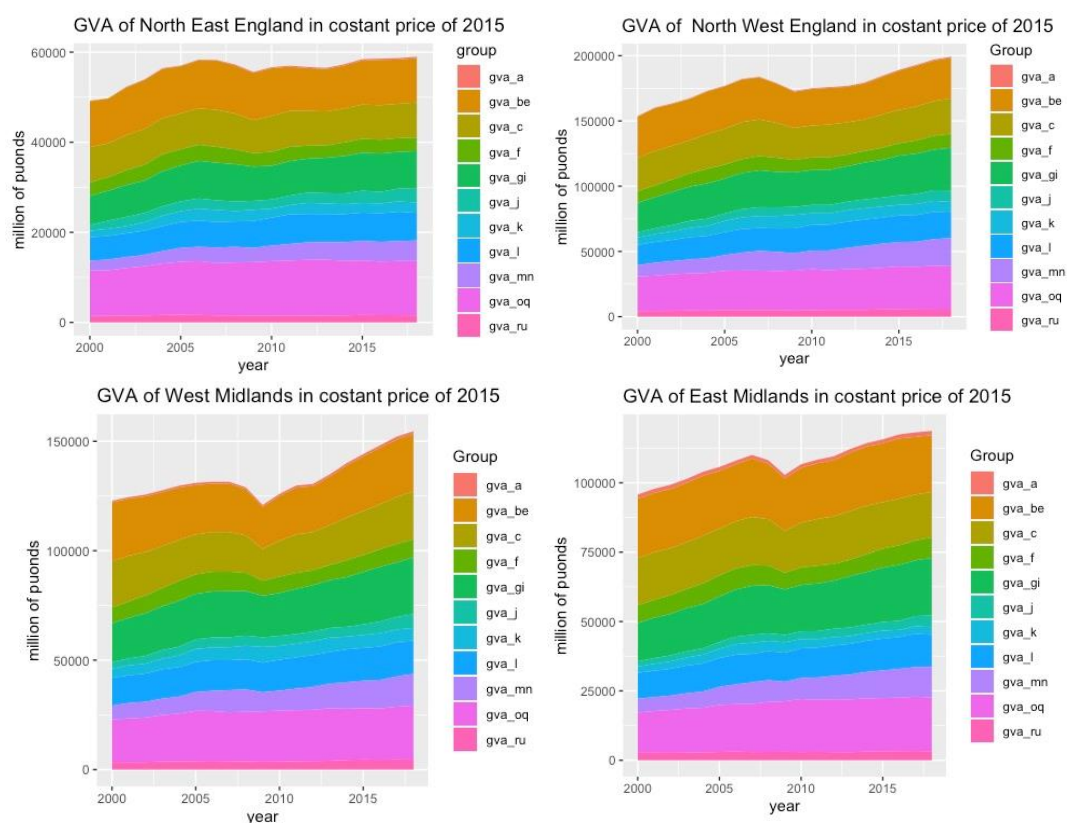GVA composition in % and value in UK based on mean value from 2000-2018

GVA composition in % and value by regions based on mean value from 2000-2018

The following graphs show the GVA composition by each region.

GVA of Yorkshire and The Humber in costant price of 2015

GVA of East of England in costant price of 2015

GVA of Greater London in costant price of 2015

GVA of South East England in costant price of 2015
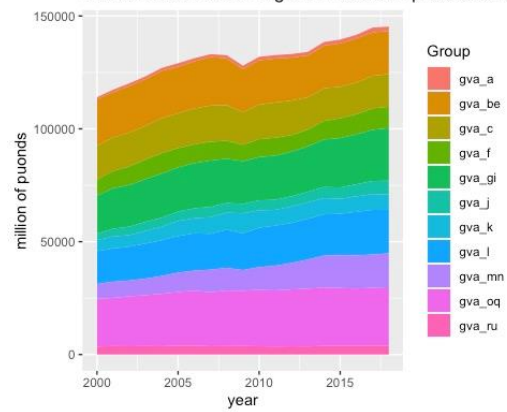
DEA results at UK regional level

DEA is applied at the UK regional level (in this application the units are the nine regions) for 2012-2018. Results show that LS should be considering as an output from production. Table below shows the R_i ratios which provide the contribution of LS to productivity; a ratio of 1 signals a null effect of LS.

In details, the effect of LS on productivity is huge in North East England, Northern Ireland and Wales. Contrary, Great London and South East England show an average R ratio near to 1.

Table 9 *Average efficiency gains generated by LS in the UK (12 regions), 2012-2018*

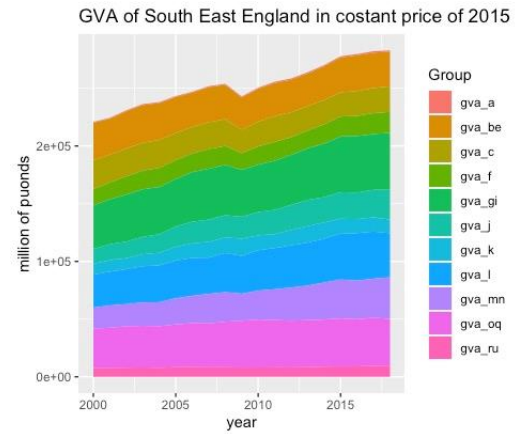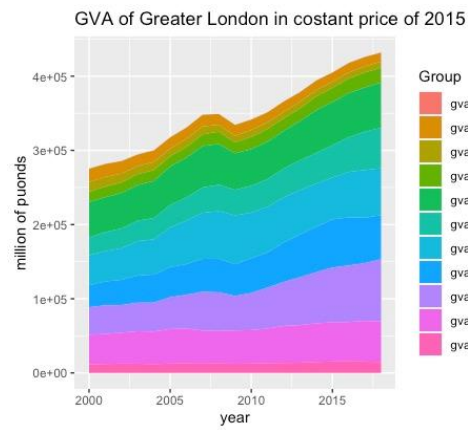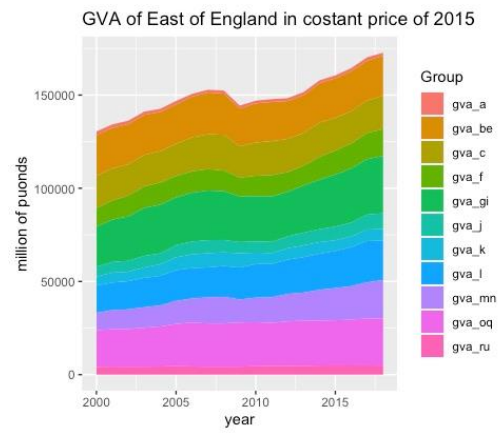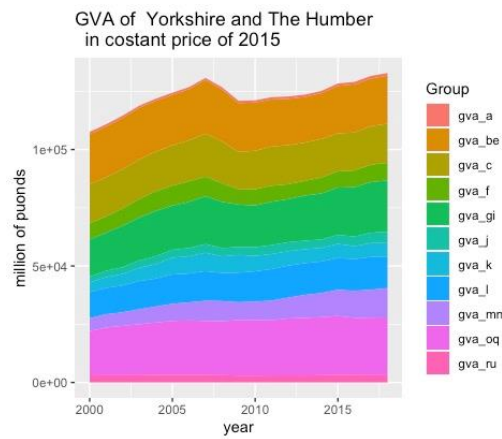| Code	Regions	Test hypothesis: LS is an input	Test hypothesis: LS is an output*
UKC	North East England	1.00	**1.70**
UKD	North West England	1.00	**1.20**
UKE	Yorkshire and The Humber	1.00	**1.27**
UKF	East Midlands	1.00	**1.35**
UKG	West Midlands	1.00	**1.22**
UKH	East of England	1.00	**1.25**
UKI	Greater London	1.00	1.00
UKJ	South East England	1.01	1.06
UKK	South West England	1.00	**1.22**
UKL	Wales	1.00	**1.59**
UKM	Scotland	1.00	**1.21**
UKN	Northern Ireland	1.00	**2.03**

*significant at 1% level

Average efficiency gains generated by life satisfaction in UK (12 regions) 2012-2018. Bold character indicates that the R_i ratio changes on average by more than 10% when life satisfaction is considered as an input (output) of the production.

Cluster analysis

A clustering approach is a well-known statistical classification technique aiming to group several observations by similar characteristics. In other word, referring to the present application, the cluster analysis allows to gather the English regions based on specific criteria.

The partitioning method is used in this application; the PAM algorithm (Partitioning Around Medoids, Kaufman and Rousseeuw, 1990) is a k-medoid type algorithm that provides clusters built around the most representative observation (one per cluster). The partitioning cluster analysis is an approach breaking the observations in k distinct non-overlapping clusters such that the observations within the same cluster are as similar as possible. For this reason, PAM is less sensitive to outliers and noise in data than other partitioning methods.

The cluster analysis is performed separately on the variables describing the economic, labour and social dimension. The preliminary step to examine the optimal number of clusters is made through the Silhouette method. A solution with five department clusters is chosen.

The dataset for the cluster analysis includes variables which describe economic, labour and social dimensions:

Economic	Labour	Social
GVA	Labour rate	Life satisfaction
Income	Employment rate	Education level
Capital stock	Unemployment rate	Leave rate
Firm density	Work population	NEET rate
Churn rate[9]	Youth unemployment	Crime

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[9] The churn rate is calculated as the sum of the employer enterprise birth rate and the employer enterprise death rate.

Figure 4 *Summary of clusters by each dimension*

Economic

Cluster1
UKI Greater London

Cluster2
UKJ South East England

Cluster3
UKM Scotland

Cluster4
UKC North East England,
UKL Wales,
UKN Northern Ireland

Cluster5
UKD North West England,
UKE Yorkshire and The Humber,
UKF East Midlands
UKG West Midlands,
UKH East of England,
UKK South West England

Labour

Cluster1
UKI Greater London

Cluster2
UKJ South East England

Cluster3
UKM Scotland,
UKD North West England,
UKE Yorkshire and The Humber,
UKG West Midlands,

Cluster4
UKC North East England,
UKL Wales,
UKN Northern Ireland

Cluster5
UKF East Midlands,
UKH East of England,
UKK South West England

Social

Cluster1
UKI Greater London

Cluster2
UKJ South East England,
UKK South West England

Cluster3
UKM Scotland

Cluster4
UKC North East England,
UKN Northern Ireland,
UKE Yorkshire and The Humber,
UKG West Midlands

Cluster5
UKD North West England,
UKL Wales,
UKF East Midlands,
UKH East of England

Cluster analysis results

Table 10 reports the main characteristics of the clusters are reported in the following table.

Table 10 Cluster results

Cluster 1	Highest level of GVA (412,268 million £), income (24,000 £), firm density (56.5%) and churn rate (27.5%); Capital stock ~36,438 million £; Highest level of labour rate (58.8%) and employment; unemployment rate ~7%; Lowest life satisfaction (7.4), high level of education and lowest rate of Early Leavers from Education and Training (7.4%), NEET rate ~14%; high crime rate 1.4%
Cluster 2	Level of GVA ~266,136 million £), firm density (45%) and churn rate (21.7%); Capital stock ~62,700 million £; level of labour rate (48.5%) and employment; unemployment rate ~4.7%; High level of LS (7.7); high level of education and lowest rate of Early Leavers from Education and Training (10.6%), NEET rate ~13%; crime rate 0.7%
Cluster 3	Level of GVA ~137,465 million £, firm density 30.6%, churn rate 21.5%; Highest Capital stock (~88,638 million £); Level of labour rate ~45% and unemployment rate ~6.6%; Level of LS ~7.6; high level of education; rate of Early Leavers from Education and Training ~12% and NEET rate ~14.8%; high crime rate 1.4%
Cluster 4	Low level of GVA ~105,000 million £, lowest income (~14,600 £), lowest capital stock (~9,000 million £); firm density 32%, churn rate 20%; Lowest level of labour rate (41%) and employment; unemployment rate 6.2%; Level of LS ~7.7; most people have non-tertiary education; Highest level of NEET (18%); crime rate 1.2%
Cluster 5	Low level of GVA (102,000 million £), income (16,700£), capital stock ~24,300 million £; firm density ~34%, churn rate ~22%; Level of labour rate ~46.6% and unemployment rate ~5.4%; Level of LS ~7.6; most people have non-tertiary education; rate of Early Leavers from Education and Training ~13% and NEET rate ~16%; lowest crime rate (1%)

Dataset variables and descriptive statistics for cluster analysis

Table 11 describes variables used for the cluster analysis. The dataset includes the following variables from 2012 to 2018 at NUTS2 and NUTS3 level.

Table 11 Variables description for cluster analysis

Variable	Unit	Description	Topic
Economy			
gva_tot1	Million Pound Sterling, 2015	total gva	economy
gva by industry			
gva_a	Pound Sterling, 2015	GVA_IND_10_VA: GVA in agriculture, forestry and fishing (ISIC rev4)	economy
gva_be	Pound Sterling, 2016	GVA_IND_10_VB_E: GVA in industry, including energy (ISIC rev4)	economy
gva_c	Pound Sterling, 2017	GVA_IND_10_VC: ..Of which: GVA in manufacturing (ISIC rev4)	economy
gva_f	Pound Sterling, 2018	GVA_IND_10_VF: GVA in construction (ISIC rev4)	economy
gva_gi	Pound Sterling, 2019	GVA_IND_10_VG_I: GVA in distributive trade, repairs, transport, accommod., food serv. activities (ISIC rev4)	economy
gva_j	Pound Sterling, 2020	GVA_IND_10_VJ: GVA in information and communication (ISIC rev4)	economy

gva_k	Pound Sterling, 2021	GVA_IND_10_VK: GVA in financial and insurance activities (ISIC rev4)	economy
gva_l	Pound Sterling, 2022	GVA_IND_10_VL: GVA in real estate activities (ISIC rev4)	economy
gva_mn	Pound Sterling, 2023	GVA_IND_10_VM_N: GVA in prof., scientific, techn. activities, admin., support service activities (ISIC rev4)	economy
gva_oq	Pound Sterling, 2024	GVA_IND_10_VO_Q: GVA in public admin., compulsory s.s., education, human health (ISIC rev4)	economy
gva_ru	Pound Sterling, 2025	GVA_IND_10_VR_U: GVA in other services (ISIC rev4)	economy
income	Pound Sterling, 2015	Disposable Household Income	economy

Capital:

cap_stock	*£2018 million*	capital stock estimates by Cambridge Econmetrics	economy

Labour:

labour_rate	%	Labour utilisation (% Total Employment over Population)	labour
empl	persons	Employment (15-64 years old)	labour
unempl	persons	Unemployment (15-64 years old)	labour
empl_rate	%	Employment Rate (% employment 15-64 over working age population 15-64)	labour
unempl_rate	%	Unemployment Rate (% unemployed over labour force 15-64)	labour
work_pop	persons	Working Age Population (15-64 years old)	labour
youth_unempl_rate1	%	Youth Unemployment Rate (% unemployment 15-24 over labour force 15-24)	labour

youth_unempl1	persons	Youth Unemployment (15-24 years old)	labour

Well-being:

ls	0-10 scale	life satisfaction	wellbeing
Education		Educational attainments are internationally standardised through the ISCED-2011 (http://uis.unesco.org/en/topic/international-standard-classification-education-isced) used to define the levels of education: ISCED 0 Early childhood and pre-primary, ISCED 1 Primary, ISCED 2 Lower secondary, ISCED 3 Upper secondary, ISCED 4 Post-secondary non-tertiary, ISCED 5 Short-cycle tertiary, ISCED 6 Bachelor or equivalent, ISCED 7 Master or equivalent, ISCED 8 Doctoral or equivalent	education
Education ISCED level		Share of population 25 to 64 year-olds by educational attainment	education
ed1level	%	Below upper secondary education	education
ed2level	%	Upper secondary and post-secondary non-tertiary education	education
ed3level	%	Total tertiary education (ISCED2011 levels 5 to 8)	education
neet	%	Share of 18-24 year-olds population not in education and unemployed or inactive (NEET)	education
leave_rate	%	Rate of Early Leavers from Education and Training (in % of the total population aged 18 to 24)	education

Business

firm_density		Density of all firms actives (number of actives firms by 1000 population)	business
churn_rate		Churn rate (births plus deaths in % of all firms - same sector, same size class)	business

Demography

pop_density	ratio	Population density (pop. per km2)	demography
mobility_rate		Inter-regional net flows mobility rate, (% net flows over population)	demography

old_pop	Share of Elderly Population (% 65+ over total population)	demography
		demography
death_rate	Crude Death Rate (deaths for 1000 population)	demography
crime	Intentional Homicide Rate (homicides for 100 000 population)	crime

Descriptive statistics

The following tables (table 12-15) show the mean and standard deviation's variable by regions.

Table 12 Descriptive statistics for economic and business variables

Region	GVA (mean St.dev)	Capital stock (mean St.dev)	Firm density (mean St.dev)	Churn rate (mean St.dev)
East Midlands	103,712.80	20,753.88	35.90	22.02
	4,436.71	271.02	1.69	1.81
East of England	150,350.90	25,601.63	42.34	22.14
	9,895.01	873.31	2.23	2.10
Greater London	412,268.80	36,438.38	56.56	27.52
	30,242.92	4,038.44	5.94	2.59
North East Engl	52,957.65	18,536.88	25.63	23.08
	1,006.00	248.29	1.43	1.84
North West Engl	171,317.90	28,043.75	34.58	23.68
	8,613.77	624.75	1.92	1.92
Northern Irelan	38,752.14	9,118.63	31.38	16.72
	1,931.68	659.26	1.19	1.42
Scotland	137,465.50	88,638.88	30.65	21.57
	4,657.69	14,695.79	1.48	1.70

79

South East Engl	266,136.40	62,700.75	45.28	21.73
	12,021.22	3,154.08	1.83	1.39
South West Engl	132,246.80	30,184.25	39.94	20.44
	5,967.95	794.50	1.29	1.79
Wales	61,984.65	15,722.38	29.88	20.67
	2,522.50	343.80	0.98	1.65

Table 13 Descriptive statistics for labour variables

Region	Labour rate	Employment	Empl. Rate	Unemployment	Unempl. Rate	Work. Pop.	Youth unempl	Youth unempl rate
	(mean St.dev)	(mean St.dev)	(mean St.dev)	(mean St.dev)	(mean St.dev)	(mean St.dev)	(mean St.dev)	(mean St.dev)
East Midlands	44.99	2,128,013.00	73.04	134,362.50	5.99	2,913,850.00	42,387.50	10.35
	0.50	59,459.79	1.62	37,189.55	1.67	24,365.61	16,462.64	5.02
East of England	46.15	2,827,988.00	76.08	152,612.50	5.03	3,717,425.00	45,837.50	9.86
	1.25	80,514.44	1.72	39,975.15	1.39	31,057.31	15,288.46	3.75
Greater London	58.78	4,156,775.00	71.30	318,825.00	7.23	5,825,500.00	88,562.50	12.69
	2.21	260,365.90	2.90	73,639.89	1.94	132,255.80	24,992.57	5.40
North East Engl	41.13	1,130,838.00	68.35	103,575.00	8.36	1,655,050.00	32,200.00	13.35
	0.40	32,226.47	2.45	26,969.12	2.12	16,017.13	9,744.60	4.69
North West Engl	45.73	3,176,188.00	70.	221,037.50	6.50	4,504,838.00	74,000.00	11.86
	1.08	93,904.23	2.20	65,312.85	1.90	31,725.88	29,661.33	5.70
Northern Irelan	42.16	791,887.50	67.14	52,400.00	6.21	1,179,538.00	18,437.50	16.51
	0.79	14,978.12	1.26	11,924.05	1.43	1,842.31	6,450.24	5.55
Scotland	46.21	2,481,825.00	72.31	163,825.00	6.20	3,432,175.00	51,600.00	10.90
	0.40	56,333.77	1.60	42,879.22	1.69	16,634.28	23,476.68	5.49
South East Engl	48.59	4,197,488.00	76.34	211,025.00	4.76	5,498,438.00	66,325.00	9.31

	0.78	124,834.90	1.77	53,953.92	1.17	43,949.29	18,301.58	3.23
South West Engl	48.15	2,510,275.00	76.08	127,350.00	4.83	3,299,038.00	41,437.50	9.38
	0.63	85,644.56	2.25	32,085.07	1.28	22,008.83	12,812.49	3.50
Wales	42.38	1,340,988.00	70.00	94,025.00	6.58	1,915,625.00	33,025.00	12.18
	0.79	36,628.93	2.17	26,987.87	1.79	13,252.36	12,195.05	5.90
West Midlands	44.66	2,502,838.00	70.19	194,325.00	6.98	3,565,538.00	61,500.00	12.41
	1.01	91,688.79	2.11	45,496.99	1.77	31,219.68	17,875.12	5.26
Yorkshire and T	45.	2,398,788.00	71.03	184,612.50	7.11	3,378,725.00	59,925.00	12.25
	1.01	75,832.64	2.37	48,317.03	2.07	18,538.28	23,723.03	5.91

Table 14 Descriptive statistics for well-being and education variables

Region	LS (mean St.dev)	ed1level (mean St.dev)	ed2level (mean St.dev)	ed3level (mean St.dev)	Leave rate (mean St.dev)	NEET (mean St.dev)
East Midlands	7.64	23.05	41.93	35.03	12.58	14.64
	0.12	1.59	0.73	1.97	2.01	2.18
East of England	7.63	21.86	40.76	37.36	13.15	14.66
	0.12	1.12	1.19	2.05	1.67	1.69
Greater London	7.44	16.14	29.20	54.66	7.41	14.04
	0.13	1.69	0.76	2.35	1.61	2.13
North East Engl	7.55	24.46	43.09	32.48	12.79	18.80
	0.11	0.94	1.76	2.46	2.17	2.26
North West Engl	7.53	23.01	40.55	36.44	12.18	16.30
	0.12	1.84	0.87	2.28	1.82	2.63
Northern Irelan	7.80	28.19	38.24	33.56	13.13	18.09
	0.13	2.46	0.76	2.43	2.51	2.86

Scotland	7.63	20.14	34.35	45.53	12.00	14.78
	0.08	0.84	1.94	2.53	1.43	2.66
South East Engl	7.68	17.65	38.00	44.36	11.03	13.31
	0.11	1.37	0.86	2.03	1.78	1.65
South West Engl	7.67	18.59	40.60	40.80	10.16	13.18
	0.10	1.62	1.09	2.49	1.71	2.37
Wales	7.57	22.39	40.55	37.06	13.75	18.23
	0.11	0.54	1.71	2.09	2.71	4.40
West Midlands	7.55	25.64	40.51	33.85	15.41	18.14
	0.15	1.76	1.08	2.21	1.95	2.67
Yorkshire and T	7.58	24.19	41.13	34.69	14.58	17.73
	0.12	1.24	1.27	2.30	1.82	2.69

Table 15 Descriptive statistics for demography variables

Region	population density (mean St.dev)	mobility rate (mean St.dev)	old_pop (mean St.dev)	death rate (mean St.dev)	crime (mean St.dev)
East Midlands	297.35	0.24	18.33	9.33	1.05
	5.96	0.11	0.77	0.28	0.20
East of England	314.66	0.24	18.76	9.11	0.88
	6.79	0.06	0.73	0.28	0.09
Greater London	5,430.46	- 0.94	11.46	5.70	1.38
	172.06	0.22	0.24	0.10	0.15
North East Engl	305.45	0.03	18.60	10.39	1.00
	2.32	0.09	0.80	0.31	0.16
North West Engl	506.73	0.03	17.75	9.77	1.26

	5.92	0.11	0.68	0.19	0.26
Northern Irelan	133.50	0.06	15.48	8.22	1.23
	1.70	.	0.63	0.24	0.22
Scotland	68.75	0.19	17.93	10.42	1.38
	0.70	.	0.68	0.25	0.34
South East Engl	465.10	0.18	18.37	8.90	0.66
	9.39	0.08	0.73	0.18	0.12
South West Engl	227.68	0.49	20.92	10.15	0.79
	4.44	0.08	0.82	0.27	0.08
Wales	149.12	0.14	19.72	10.48	0.83
	1.17	0.12	0.85	0.34	0.18
West Midlands	440.38	- 0.01	17.83	9.25	1.18
	7.79	0.07	0.55	0.27	0.16
Yorkshire and T	348.35	- 0.03	17.68	9.46	1.31
	4.32	0.06	0.68	0.19	0.70

Summary of variables by cluster

Table 16 Summary statistics of economic dimension by clusters

		Economic				
		GVA	Income	Capital stock	Firm density	Churn rate
		million £	*£*	*million*	*%*	*%*
Cluster 1		412,268.80	24,071.63	36,438.38	56.56	27.52
Cluster 2		266,136.40	20,369.38	62,700.75	45.28	21.73
Cluster 3		137,465.50	16,868.75	88,638.88	30.65	21.57
Cluster 4	*mean*	105,035.02	14,638.51	18,581.19	32.23	20.20
	min	38,752.14	14,541.13	9,118.63	29.88	16.72
	max	171,317.90	14,735.88	28,043.75	34.58	23.68
Cluster 5	*mean*	101,654.28	16,732.69	24,360.57	33.99	21.76
	min	52,957.65	15,076.00	18,536.88	25.63	20.44
	max	150,350.90	18,389.38	30,184.25	42.34	23.08

Table 17 *Summary statistics of labour dimension by clusters*

	Labour							
	Labour rate	Employment	Empl. Rate	Unemployment	Unempl. Rate	Work. Pop.	Youth unempl	Youth unempl rate
	%	*persons*	*%*	*persons*	*%*	*persons*	*persons*	*%*
Cluster 1	58.78	4,156,775.00	71.30	318,825.00	7.23	5,825,500.00	88,562.50	12.69
Cluster 2	48.59	4,197,488.00	76.34	211,025.00	4.76	5,498,438.00	66,325.00	9.31

Cluster 3	mean	45.44	2,787,488.00	71.25	192,431.25	6.66	3,941,781.50	62,800.00	11.66
	min	44.66	2,398,788.00	70.19	163,825.00	6.20	3,378,725.00	51,600.00	10.90
	max	46.21	3,176,188.00	72.31	221,037.50	7.11	4,504,838.00	74,000.00	12.41
Cluster 4	mean	41.76	1,066,437.75	68.57	77,987.50	7.29	1,547,581.50	25,731.25	14.35
	min	41.13	791,887.50	67.14	52,400.00	6.21	1,179,538.00	18,437.50	12.18
	max	42.38	1,340,988.00	70.00	103,575.00	8.36	1,915,625.00	33,025.00	16.51
Cluster 5	mean	46.57	2,478,000.50	74.56	139,981.25	5.41	3,315,637.50	43,637.50	9.87
	min	44.99	2,128,013.00	73.04	127,350.00	4.83	2,913,850.00	41,437.50	9.38
	max	48.15	2,827,988.00	76.08	152,612.50	5.99	3,717,425.00	45,837.50	10.35

Table 18 *Summary statistics of social dimension by cluster*

		Social						
		LS	**ed1level**	**ed2level**	**ed3level**	**Leave rate**	**NEET**	**Crime**
		0-10 scale	*%*	*%*	*%*	*%*	*%*	*%*
Cluster 1		7.44	16.14	29.20	54.66	7.41	14.04	1.38
Cluster 2	mean	7.68	18.12	39.30	42.58	10.60	13.25	0.73
	min	7.67	17.65	38.00	40.80	10.16	13.18	0.66
	max	7.68	18.59	40.60	44.36	11.03	13.31	0.79
Cluster 3		7.63	20.14	34.35	45.53	12.00	14.78	1.38
Cluster 4	mean	7.68	26.19	40.67	33.59	14.10	18.27	1.16
	min	7.55	24.19	38.24	32.48	12.79	17.73	1.00
	max	7.80	28.19	43.09	34.69	15.41	18.80	1.31
Cluster 5	mean	7.59	22.46	41.24	36.20	12.97	16.44	1.04
	min	7.53	21.86	40.55	35.03	12.18	14.64	0.83
	max	7.64	23.05	41.93	37.36	13.75	18.23	1.26

CHAPTER 2

Subjective wellbeing and GDP relationship: a simultaneous equation approach

Abstract

The relationship between economic growth and well-being is still hotly debated. The paper constructs a simultaneous equation model to investigate the relationship between Gross Domestic Product (GDP) and self-reported life satisfaction (LS). The investigation is conducted using panel data for the England local authorities over the period 2012-2019. Results contribute to the ongoing debate showing a bidirectional causal link of variables of interest. Results reveal that the life satisfaction has a positive impact on GDP when a high level of self-reported wellbeing is reached (above 7.8), otherwise it negatively affects GDP. For the reverse effect, it is found a negative impact of GDP on life satisfaction when the value of GDP approximates 4,000 million £, while it has a positive impact on subjective well-being below that threshold. From a policy maker point of view these empirical insights are useful to build economic policies to sustain economic development that also considers the trade-off of growth along with awareness that people feelings matters for productivity considerations.

Keywords: *life satisfaction, GDP, SEM, panel data, English local authority*

1. Introduction

The relationship between income or GDP and well-being or happiness has been a topic of interest not only for many researchers (economists, sociologists, phycologists) but it is becoming crucial for policy reasons.

The scientific debate on the relation between GDP and self-reported well-being is still open. The study of this relationship has been approached from different angles and while some studies have found a positive relationship, others have found that the relationship is not always linear and may depend on the level of country's development and other factors such as time horizon, methodology and data used for the analysis.

The paper contributes to this discussion making mainly two novel contributions: i) empirically, by analysing the Gross Domestic Product (GDP) and self-reported life satisfaction (LS) relationship at local authority district scales in England over time and by constructing novel data to support investigations at previously unexamined spatial scales; ii) methodologically, by using the simultaneous equation model to address the endogeneity between economic performance and life satisfaction. The research design enables to investigate whether LS is considered as an input to production process controlling for the determinants of well-being (individual and contextual) at local level and if a trade-off of economic growth on wellbeing exists.

To the best of our knowledge, the empirical literature has never tested the relationship between life satisfaction and GDP at local authority district scale in England. This gap is filled by examining the relationships of the newly developed regional Gross Domestic Product (GDP) statistics with life satisfaction data (locally aggregated) and adopting a simultaneous equation model approach.

The empirical evidence unravels a previously unexplored relationship between economic performance and life satisfaction since it add to the

ongoing discussion on the causal relationship between the variables under scrutiny. The results demonstrate that when a self-reported wellbeing reaches a high level (above 7.8), life satisfaction has a positive effect on GDP. However, if the level of wellbeing is lower than that, it has a negative impact on GDP. On the other hand, the study finds that GDP has a negative effect on life satisfaction when it is around £4,000 million, but a positive impact on subjective well-being when it falls below that threshold. These empirical insights could be beneficial for policymakers in developing economic policies that support economic growth while taking into account the trade-off between growth and the significance of people's happiness in productivity planning. The paper is organised as follows: Section 2 discusses the literature review, Section 3 and 4 contain respectively the description of the data and the empirical analysis. Section 5 presents the estimation results and Section 6 sets out conclusion.

2. Literature review

The relationship between GDP and subjective well-being is complex and multidimensional and a lot of attention has been devoted to its investigations from different disciplines. Most of empirical studies investigate the link ignoring the bidirectional effects either from GDP or income on life satisfaction or happiness on GDP/income.

On the one hand, the effect of income/GDP on happiness/life satisfaction seeks to answer to the following question: "Does economic growth improve societal wellbeing?" and consequently "Should policymakers work on increasing the GDP?"

These questions have been studied using various methodologies, time horizon and data sources. In the literature, one of the most interesting findings is that the outcome of the relationship depends on the time of analysis. In a recent paper, Easterlin (2023) clarifies that the relationship of happiness and income moves jointly up and down in the short-run (cyclical relationship) but happiness and income are not related if long run trends with time series

analysis are conducted (trend relationship) which is the subject of the well know Easterlin Paradox (Easterlin and O'Connor, 2022). Since the early 1970s when Easterlin's findings were published, numerous studies have been conducted to test the validity of the Easterlin Paradox, with some studies finding support for it (Bartolini and Sarracino, 2014), while others finding no evidence for it (Stevenson and Wolfers, 2008).

Bartolini and Sarracino (2014) report a positive happiness-GDP relation in the short run among and within nations but not the same direction of long term trend relation. A study by Stevenson and Wolfers in 2008 found that the relationship between GDP and happiness was positive, both within and between countries, suggesting that the Easterlin Paradox may not hold. Biswas-Diener (2018) and Diener (2006) found that, although higher levels of GDP were associated with higher levels of happiness, the relationship was not linear, and the effect of GDP on happiness declined as countries reached higher levels of income (e.g. globally it occurs at US$95,000 annual income for life evaluation and US$60,000–75,000 annual income for emotional well-being).

On the other hand, "What are the drivers of happiness?" is the question that guide the predominant happiness economics and phycological literature. Following these fields of research, policy decisions should be more heavily influenced by issues related to well-being and people's evaluations and feelings about their lives rather than economic and growth.

Many studies have focused on what are the main factors that influence subject well-being investigating socio-economic determinants (age, income, status, child, rice, religious, positional and relational goods), negative life events such as unemployment status or diseases or divorces and social capital (e.g. network of friends), on life-chances particularly at the individual level (for a summary review see Veenhoven, 1996). However, life satisfaction is influenced by individual and contextual factors (Ahmadiani et al.,2022) and only few studies focus on this prospective for example including if the economy is expanding or contracting. Proto and Rustichini (2013) give an

alternative insight analysis including the regional GDP variable to assess the impact on life satisfaction. They found a robust non monotonic relation between aggregate income (regional GDP) and average life satisfaction considering regions of 14 European Countries for five waves: 1981– 1984, 1989–93, 1994–99, 1999–04, 2005–08.

Previous findings have in common that the relationship (of life satisfaction to income and vice versa) is analysed separately only in one direction at micro or macro level keeping unexplored the finer scale. This paper fills the gap using local data and addressing the two-way relationship between life satisfaction and GDP in a short run.

3. Data

Our dataset is based on annual data from 2012 to 2019 referring to the England local authority districts (307 observations[10]). The main variables of interest for the analysis are the Gross Domestic Product (GDP) and other factors of production process (capital, labour, material inputs), and subject well-being and its determinants.

Life satisfaction is used as proxy of human well-being. In particular, life satisfaction data come from the Annual Population Survey (APS) where people are asked to respond to this question "overall, how satisfied are you with your life nowadays?" on a scale of 0 to 10, where 0 is "not at all" and 10 is "completely".

Data describing Gross Domestic Product (GDP) in million pounds 2019 and number of employees come from the UK Office for National Statistics (ONS). Additional labour market statistics (hours worked, job density, workers qualification) of local authority districts are taken from Nomis, a service provided by ONS that give free access to the most detailed and up-to-date UK labour market statistics from official sources.

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[10] City of London and Isles of Scilly are dropped and treated as outliers

The energy consumption is derived by the sum of fuels, coal, petroleum, gas and electricity consumption in thousands of tonnes of oil equivalent (ktoe) per every year of panel.

Data describing the capital stock at sub-regions (International Territorial Level 2, previously named as NUTS2) are from Gardiner et al (2021). For analyses at finer resolution than the sub-regions scale, a local authority capital stock measure is computed, K_{LA}. Assuming that the capital to labour ratio is constant within the NUTS2 sub-region, K_{LA} is obtained as follows:

$$K_{LA} = \frac{L_{LA} \times K_{NUTS2}}{L_{NUTS2}}$$

where L_{LA} is the number of workers at local authority, K_{NUTS2} is the capital stock estimated at NUTS2 from Gardiner et al. (2021) and L_{NUTS2} is the number of workers at NUTS2 level.

Table 1 in Appendix A reports the description of variables.

4. Empirical strategy

To explore the relationship between self-reported life satisfaction and economic performance, this study employs a single equation and system approach. The ordinary least squares (OLS) and fixed effect (FE) models are used as baseline; however, due to the variables of interest, they violate a key OLS assumption facing the endogeneity issue when the disturbances and the regressors are correlated producing biased estimates. The instrumental variable (IV) approach and the simultaneous equation model (SEM) are used to solve the endogeneity due to reverse causality. Using the simultaneous equations framework, the endogeneity became a fundamental part of the specification where the equations are interdependent by design (Greene, 2012). Moreover, the SEM compared with the IV allows to obtain instrumental variable estimates considering the covariances across equation disturbances as well.
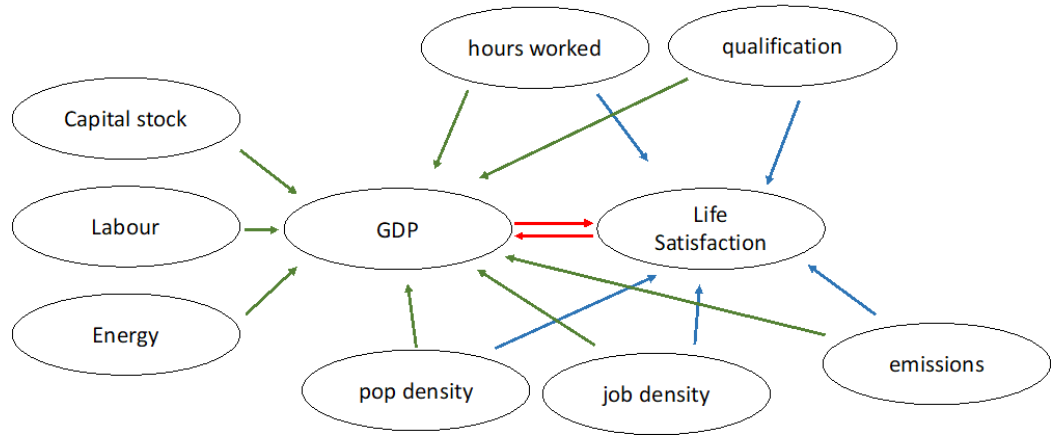
In the system approach, estimation is conducted via three-stage least squares (3SLS) following Zellner and Theil (1962). The three stage least squares

approach is a combination of multivariate regression (SUR estimation) and two stage least squares where the objective function for the three stage least squares is the sum of squared transformed fitted residuals.

Three stage least squares estimates are obtained by estimating a set of nonlinear or linear equations with imposed cross-equation constraints, but with a diagonal covariance matrix of the disturbances across equations. The derived parameter estimates are used to form a consistent estimate of the covariance matrix of the disturbances, which is then used as a weighting matrix when the model is reestimated to obtain the values of the parameters. In other words, the 3SLS requires three steps: i) first-stage regressions to get predicted values for the endogenous regressors; ii) a two-stage least-squares step to get residuals to estimate the cross-equation correlation matrix; iii) and the final 3SLS estimation step to obtain the coefficients estimates.

The figure 1 summarizes the simultaneous equation model. The first part of the system represents a production function whereby the economic output (GDP) depends on endogenous variables including life satisfaction. In particular, capital stock (K), energy (E) and labour (L) variables are included as inputs to production. Moreover, life satisfaction (LS) and its squared variables are added to test the research hypothesis; controls variables are allowed for local contextual factors such as hours worked (HW), job density (JD), population density (PD), high (HQ) and low qualification (LQ), level of pollution measured by CO_2 emissions per kilometre square (CO2) and dummies variables for area classification (e.g. countryside, London cosmopolitan, urban settlement area).

Figure 1 Graphical representation of the model

Formally:

$$
\begin{aligned}
ln(GDP)_{it} = {}& \beta_0 + \beta_1\,(LS)_{it} + \beta_2\,(LS)_{it}^2 + \beta_3\,ln(K)_{it} \\
& + \beta_4\,ln(E)_{it} + \beta_5 ln(L)_{it} + \beta_6\,HW_{it} \\
& + \beta_7 JD_{it} + \beta_8 PD_{it} + \beta_9 HQ_{it} + \beta_{10} LQ_{it} \\
& + \beta_{11} CO2_{it} + \sum_{n=1}^{7} \gamma_n (D_n)_t + \epsilon_{it}
\end{aligned}
\tag{1}
$$

The second part of the system that specify the endogeneity is constructed based on the theoretical and empirical insights from the happiness economics literature but guided by data available. In particular, Ahmadiani et al. (2022) shows that life satisfaction depends on individual determinants (e.g. socio-demographic factors such as age, education, income) and contextual determinants (e.g. economic, environmental, institutional factors and public health such as pollution, unemployment rate, corruption, life expectancy).

Formally:

$$
\begin{aligned}
(LS)_{it} = {}& \beta_0 + \beta_1 ln\,(GDP)_{it} + \beta_2\,ln(GDP)_{it}^2 + \beta_3\,HW_{it} \\
& + \beta_4 JD_{it} \\
& + \beta_5 PD_{it} + \beta_6 HQ_{it} + \beta_7 LQ_{it} + \beta_8 CO2_{it} \\
& + \sum_{n=1}^{7} \delta_n (D_n)_t + \eta_{it}
\end{aligned}
\tag{2}
$$

Equation 2 includes the local GDP and its squared variables, contextual factors and dummies for area classification as independent variables.

Equation (1) and (2) describe the simultaneous equation system where i indicates local authority and t years. In other words, Eq. (1) states that capital stock, energy consumption and life satisfaction are the driving forces of economic growth controlling for contextual factors. Equation (2) postulates that the life satisfaction can be influenced by local GDP, hours worked, job and population density, level of qualification and environmental degradation. In both equations are also included dummies variables for the type of area classified (n=8) according to the ONS (e.g. urban, countryside, London cosmopolitan).

It is worth noting that LS is kept in unit scale and GDP, K, L, E are transformed in natural logarithmic. Variables used as instruments are the exogenous variables and one year lag of logged life satisfaction (and its square when included) and logged employment for equation (1) and one year lag of logged GDP (and its squared when included) and logged energy for equation (2).

5. Results

Tables 1 reports the summary statistics of GDP and life satisfaction over time by regions. From 2012 to 2019 the average of GDP and life satisfaction in England are both increased. This is in line with the cyclical relation found by previous studies (Easterlin and O'Connor, 2022).
In particular, over time an improvement in average life satisfaction in England from 7.44 to 7.75 is noted. The increase of 0.31 on a cardinal scale might sound small; contrary, it is a substantial change if we consider that major life events like losing job and divorce have an impact of about 0.3 to 0.5 points in people's happiness.

Life satisfaction is moving upward over time across regions. However, it is worth noting that the highest productivity area (London) shows the lowest life satisfaction over year.

Table 1 Life satisfaction and GDP over time by regions

Regions	Life satisfaction							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
East Midlands	7.47	7.53	7.59	7.68	7.80	7.79	7.75	7.79
East of England	7.47	7.49	7.55	7.66	7.66	7.74	7.73	7.75
London	7.26	7.26	7.37	7.49	7.51	7.54	7.52	7.58
North East	7.42	7.40	7.47	7.57	7.62	7.61	7.64	7.65
North West	7.42	7.44	7.48	7.62	7.56	7.63	7.73	7.73
South East	7.51	7.56	7.61	7.74	7.74	7.75	7.77	7.80
South West	7.53	7.55	7.57	7.70	7.77	7.77	7.78	7.82
West Midlands	7.36	7.47	7.56	7.64	7.70	7.74	7.75	7.76
Yorkshire and The Humber	7.47	7.51	7.58	7.59	7.72	7.77	7.69	7.74
England	**7.44**	**7.48**	**7.54**	**7.65**	**7.68**	**7.71**	**7.72**	**7.75**

Regions	GDP							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
East Midlands	3,306	3,385	3,458	3,496	3,561	3,610	3,692	3,749
East of England	3,593	3,681	3,833	3,917	4,020	4,201	4,206	4,262
London	13,107	13,513	14,057	14,354	14,998	15,211	15,585	15,795
North East	4,885	4,872	4,968	5,140	5,168	5,229	5,319	5,425
North West	4,785	4,864	4,997	5,146	5,262	5,392	5,442	5,563
South East	4,440	4,528	4,668	4,809	4,853	4,929	5,060	5,184
South West	4,878	4,932	5,105	5,146	5,245	5,412	5,452	5,549
West Midlands	4,738	4,844	4,991	5,123	5,262	5,404	5,485	5,486
Yorkshire and The Humber	6,095	6,159	6,282	6,499	6,601	6,802	6,956	7,072
England	**5,359**	**5,471**	**5,649**	**5,783**	**5,929**	**6,062**	**6,171**	**6,271**

Further descriptive statistics are reported in Table 5 in Appendix B .

Table 4 and 5 contain the main results of the analysis conducted respectively for equation 1 and 2 with single equation (columns from 1 to 6) and system approach (columns 7 and 8). The research hypothesis tested is whether the level of life satisfaction affect the GDP of a local area and vice versa. For the single-equation approach, different statistical models are used: OLS, fixed effect (FE) and instrumental variables (IV). Finally, the simultaneous equation model is provided. The columns of tables show for each models the coefficient estimates using GDP or LS variable with and without its squared terms to test whether there is a turning point in the quadratic function.

For both equation (1) and (2), OLS is used as baseline model and FE is mainly used to test the area classification dummies compared with the effect of controlling for local time invariant characteristics. In general, OLS and FE estimates are biased due to endogeneity. To solve this the IV approach and the simultaneous equation are tested. The difference between these approaches is that the system estimates simultaneously the coefficients of equation (1) and (2) considering both the endogeneity problem (when the independent variable is correlated with the error term in the regression equation) and the interdependence between GDP and life satisfaction (covariates are relevant).

Referring to table 2, the colum 5 and 7 shows different sign in coefficient due to the different approaches applied keeping the same instruments. However, including the squared LS variable, the IV model loses significative compared with the model obtained by simultaneous approach. The reason is that the IV tests for column 6IVb in Table 2 show weak instruments and consequently estimation and inference become unreliable. The last column shows the estimates for the equation (1) using SEM and results reveals a U-shape curve between GDP and LS.

Considering table 3, the sign of coefficients of IV and system models are consistent, and they passed under-identification, weak-identification and

over-identification tests. Respectively, the Chi-sq(2) P-value of Anderson LM is equal to 0.000 which is significant at 1% level reject null-hypothesis, Cragg-Donald Wald F statistic is greater than 10 (in theory, if Cragg-Donald Wald F statistic is greater than 10 which means the instrument is strong), and for Hansen P- value is strongly significant at 1% level which means that the model is not over identified. The last column reports the positive sign of the first order term of GDP variable and negative sign of the quadratic ones meaning that the effect of GDP on LS is non monotonic.

Table 2 Estimates equation 1 using single equation and system approach

Estimation methods	Single equation						System	
	(1) OLSa ln_gdp	(2) OLSb ln_gdp	(3) FEa ln_gdp	(4) FEb ln_gdp	(5) IVa ln_gdp	(6) IVb ln_gdp	(7) 3SLSa ln_gdp	(8) 3SLSb ln_gdp
VARIABLES								
ls	-0.051	-0.912	0.050***	-0.384	0.413***	10.949	-0.382***	-0.775***
	(0.032)	(0.824)	(0.010)	(0.409)	(0.112)	(10.761)	(0.026)	(0.071)
ls_sq		0.056		0.029		-0.717		0.050***
		(0.054)		(0.027)		(0.721)		(0.006)
ln_cs	0.023	0.024	0.372***	0.362***	0.011	0.646	0.140***	0.105***
	(0.065)	(0.065)	(0.059)	(0.060)	(0.145)	(0.484)	(0.032)	(0.034)
ln_emp	0.829***	0.829***	-0.211***	-0.199***	-0.141	-0.495	0.630***	0.642***
	(0.080)	(0.080)	(0.065)	(0.066)	(0.094)	(0.314)	(0.039)	(0.051)
ln_energy	0.156***	0.156***	0.057*	0.053*	-0.069	0.156	0.195***	0.236***
	(0.041)	(0.041)	(0.032)	(0.032)	(0.080)	(0.169)	(0.027)	(0.028)
pop_density	0.004***	0.004***	0.007	0.007	0.004	0.003	0.008***	0.008***
	(0.002)	(0.002)	(0.005)	(0.005)	(0.004)	(0.005)	(0.001)	(0.001)
mean_hw	0.041***	0.041***	0.007***	0.007***	0.001	0.007	0.037***	0.039***
	(0.006)	(0.006)	(0.002)	(0.002)	(0.003)	(0.005)	(0.003)	(0.003)
jobdensity	0.798***	0.799***	0.449***	0.451***	0.228***	0.380***	0.767***	0.623***
	(0.116)	(0.115)	(0.038)	(0.038)	(0.070)	(0.102)	(0.053)	(0.053)
ed4	0.002	0.002	0.001**	0.001**	-0.000	0.000	0.002***	0.002***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
noedu	0.000	0.000	0.000	0.000	0.002*	0.001	-0.004**	0.000
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
emissionperkm	-0.002	-0.002	-0.001	-0.001	0.000	0.002	-0.009***	-0.005**
	(0.004)	(0.004)	(0.002)	(0.002)	(0.001)	(0.002)	(0.003)	(0.003)
2.group_code	-0.127***	-0.126***					-0.172***	-0.128***
	(0.040)	(0.040)					(0.020)	(0.018)
3.group_code	-0.231***	-0.231***					-0.248***	-0.248***
	(0.033)	(0.033)					(0.017)	(0.016)
4.group_code	-0.132*	-0.134*					-0.224***	-0.195***
	(0.077)	(0.077)					(0.041)	(0.040)
5.group_code	-0.357***	-0.358***					-0.573***	-0.527***
	(0.136)	(0.137)					(0.071)	(0.078)
6.group_code	-0.246***	-0.244***					-0.269***	-0.254***
	(0.043)	(0.044)					(0.024)	(0.022)
7.group_code	-0.199***	-0.199***					-0.201***	-0.213***
	(0.036)	(0.036)					(0.017)	(0.017)
8.group_code	-0.161***	-0.161***					-0.201***	-0.168***
	(0.042)	(0.042)					(0.022)	(0.020)
Constant	-3.629***	-0.364	5.862***	7.496***				
	(0.434)	(3.228)	(0.406)	(1.604)				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Observations	2,456	2,456	2,456	2,456	2,149	2,149	2,149	2,149
N	307	307	307	307	307	307	307	307
T	8	8	8	8	7	7	7	7
Adj R-squared	0.940	0.940	0.464	0.465	-0.515	-0.363		
ID FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No	No	No	No
Instruments					L.ls L.ln_emp	L.ls L.ls_sq L.ln_emp	L.ls L.ln_emp	L.ls L.ls_sq L.ln_emp
Anderson LM						16.278	2.770	
Cragg-Donald						14.192	0.921	
Wald F statistic								
Hansen-J Statistic						1.778	6.316	
Hansen p-value						0.182	0.012	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

*Table 3 Estimates equation 2 using single equation and system approach*

Estimation methods	Single equation						System	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	OLSals	OLSbls	FEals	FEbls	IVals	IVbls	3SLSals	3SLSbls
ln_gdp	-0.033***	-0.066	0.732***	2.844***	1.003***	3.633***	0.190***	1.650***
	(0.009)	(0.199)	(0.093)	(0.946)	(0.124)	(1.241)	(0.012)	(0.030)
ln_gdp_sq		0.002		-0.126**		-0.157**		-0.099***
		(0.012)		(0.056)		(0.073)		(0.002)
pop_density	0.001	0.001	0.016	0.019*	0.011	0.016	-0.001	0.000
	(0.001)	(0.001)	(0.010)	(0.011)	(0.012)	(0.013)	(0.001)	(0.001)
mean_hw	0.016***	0.016***	0.016***	0.016***	0.016***	0.015**	0.173***	0.018***
	(0.004)	(0.004)	(0.006)	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)
jobdensity	0.192***	0.190***	0.570***	0.573***	0.280**	0.280**	-0.132***	0.263***
	(0.048)	(0.045)	(0.114)	(0.114)	(0.131)	(0.130)	(0.042)	(0.028)
ed4	0.004***	0.004***	0.005***	0.005***	0.003**	0.003**	0.013***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
noedu	-0.012***	-0.012***	-0.008***	-0.008***	-0.006***	-0.006***	0.005*	-0.010***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
emissionperkm	-0.008***	-0.008***	-0.000	-0.002	-0.002	-0.003	-0.004**	-0.005***
	(0.003)	(0.003)	(0.005)	(0.006)	(0.006)	(0.007)	(0.002)	(0.002)
2.group_code	-0.060**	-0.060**					0.018	-0.070***
	(0.024)	(0.024)					(0.033)	(0.021)
3.group_code	0.088***	0.087***					0.429***	0.107***
	(0.019)	(0.020)					(0.026)	(0.017)
4.group_code	-0.071*	-0.072*					-0.225***	-0.077**
	(0.040)	(0.042)					(0.046)	(0.033)
5.group_code	-0.106	-0.108					-0.595***	-0.038
	(0.068)	(0.069)					(0.087)	(0.054)
6.group_code	0.037	0.036					0.116***	0.008
	(0.024)	(0.024)					(0.032)	(0.022)
7.group_code	0.054***	0.053***					0.154***	0.090***
	(0.018)	(0.018)					(0.026)	(0.016)
8.group_code	-0.033	-0.033					-0.015	-0.042**
	(0.022)	(0.021)					(0.030)	(0.020)
Constant	7.202***	7.342***	0.126	-8.676**				
	(0.139)	(0.843)	(0.776)	(3.956)				

Observations	2,456	2,456	2,456	2,456	2,149	2,149	2,149	2,149
N	307	307	307	307	307	307	307	307
T	8	8	8	8	7	7	7	7
Adj R-squared	0.338	0.338	0.256	0.259	0.193	0.194		
ID FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No	No	No	No
Instruments					L.ln_gdp L.ln_energy	L.ln_gdp L.ln_gdp_sq L.ln_energy	L.ln_gdp L.ln_energy	L.ln_gdp L.ln_gdp_sq L.ln_energy
Anderson LM					68.629	71.063		
Cragg-Donald Wald F statistic					1104.025	718.403		
Hansen-J Statistic					2.317	2.018		
Hansen p-value					0.128	0.155		

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Referring to the system results (model 8), figure 2portrays the marginal effect of LS on GDP and vice versa. In the first graph the turning point is 7.8 meaning that the marginal impact of life satisfaction on GDP varies from negative to positive after it. In the second graph the turning point is about 4,000 million £ of GDP value where the marginal impact of GDP on life satisfaction from positive become negative.

Figure 2 Marginal effect of life satisfaction on ln GDP top) and ln GDP on life satisfaction(bottom)
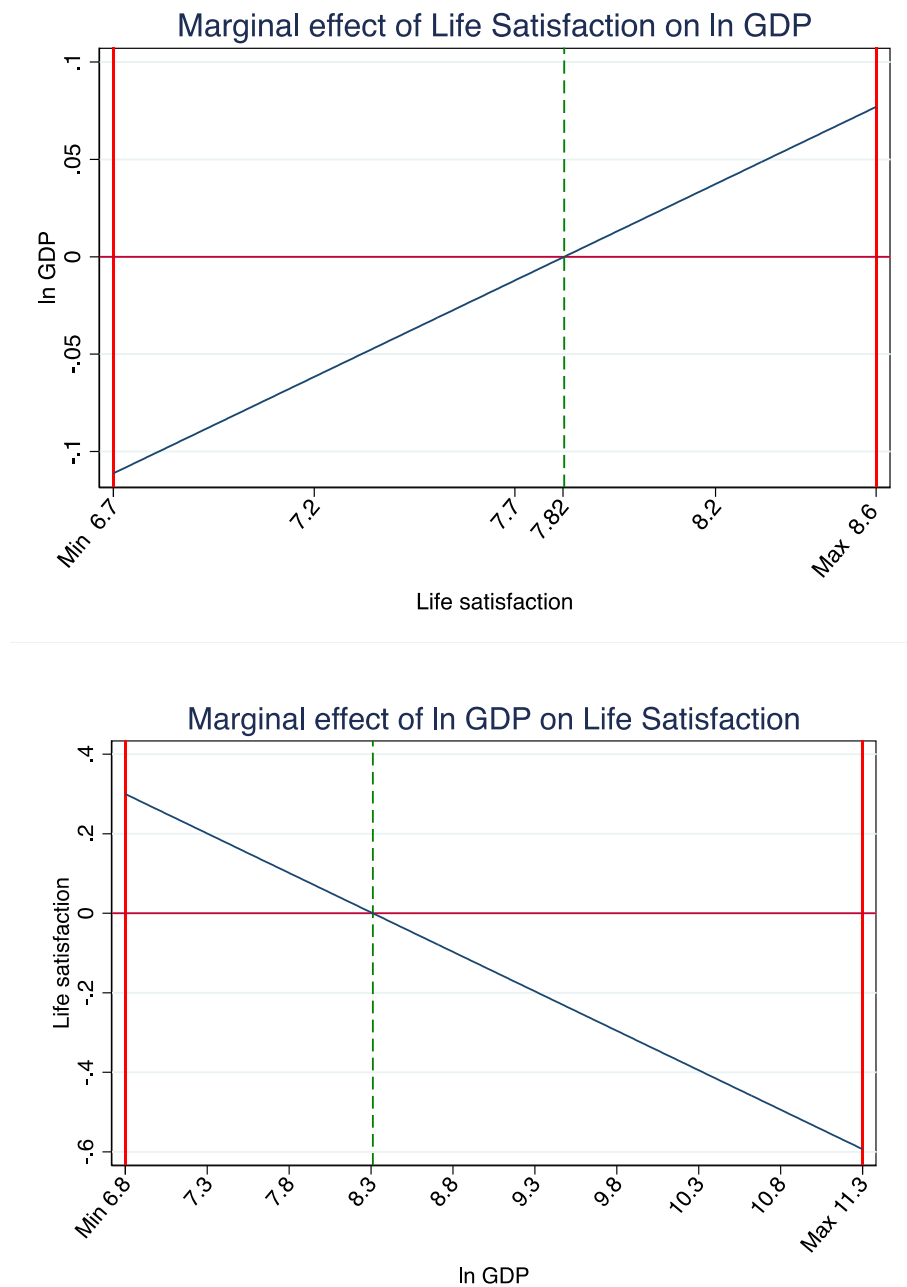
6. Conclusion

The relationship between GDP and happiness/life satisfaction is complex and multidimensional. While some studies have found a positive relationship, others have found that the relationship is not always linear and may depend on the level of development and other contextual factors as well as methodology, time horizon and data used.

Results suggests a different way of thinking about this relationship which bridge economics, psychology, and policy prospective. In the view of this analysis, findings suggest a trade-off about GDP and subject well-being in England in the short run. Life satisfaction is relevant to the GDP growth when high level of wellbeing is reached, otherwise a negative impact occurs.

On the other side, an inverse U-shape is founded meaning that GDP has a negative impact on Life satisfaction when the GDP value is greater than the threshold of 4,000 million £. The reasons cloud be several: i) when basic needs are fulfilled other factors such as social relationships and other contextual factors like enjoyment at work or living environment are more valuable; ii) higher GDP leads to higher aspirations driven by the existence of more opportunities or by comparison which leads effort and individual commitment; iii) regional negative externalities related to mobility and transports, industrial cluster effect and spatial environmental externalities (Heijman, 2007). All these mechanisms from economic growth generate a negative impact on life satisfaction.

Findings on the relationship between GDP and life satisfaction are not in contrast with the previous cross-sectional analysis. The cyclical relationship (short run) is founded and is consistent with previous findings (Easterlin and O'Connor, 2022; Bartolini and Sarracino, 2014). The peculiarity of this study compared with the literature is explained by the method and data used. When the analysis is conducted at finer scale than national level the same non monotonic relation between GDP and life satisfaction is found as in Proto and Rustichini (2013).

To conclude, results suggest a trade-off about GDP and subject well-being in England and that other factors, such as social and political conditions, cultural values, and the quality of life and environment, should be considered. For this reason, further research is needed to fully understand the relationship between GDP and well-being including the role of other factors in this relation.

7. List of abbreviations

GDP	Gross Domestic Product
LAD	Local Authority District
LS	Life Satisfaction
SEM	Simultaneous Equation Model
SWB	Subject wellbeing

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Appendix A Description of variables

Table 4 Description of variables

Variable	Variable name in the model	Description	Unit
GDP	GDP	Gross Domestic Product (GDP) chained volume measures (CVM) in 2019 money value, pounds million	Million (£2019)
Life satisfaction	LS	The personal well-being question is "overall, how satisfied are you with your life nowadays?" People are asked to respond on a scale of 0 to 10, where 0 is "not at all" and 10 is "completely".	0-10 scale
Capital stock	K	the capital stock series are computed with the Perpetual Inventory Method (PIM) by Gardiner et al (2021), whereby in each period investment is added to the capital stock in the previous period while accounting for depreciation.	Million (£2019)
Employment	L	In Employment People who did some paid work in the reference week (whether as an employee or self employed); those who had a job that they were temporarily away from (eg, on holiday); those on government-supported training and employment programmes; and those doing unpaid family work.	thousands workers
Energy consumption	E	Total final energy consumption computed by summing fuels, coal, petroleum, gas and electricity consumption in thousands of tonnes of oil equivalent (ktoe)	thousands of tonnes of oil equivalent (ktoe)
Qualification		The variables show the total number of people who are qualified at a particular level	

		and above according with the following classification: **No Qualifications** No formal qualifications held. **Other Qualifications** includes foreign qualifications and some professional qualifications. **NVQ 1 Equivalent** e.g. fewer than 5 GCSEs at grades A-C, foundation GNVQ, NVQ 1, intermediate 1 national qualification (Scotland) or equivalent. **NVQ 2 Equivalent** e.g. 5 or more GCSEs at grades A-C, intermediate GNVQ, NVQ 2, intermediate 2 national qualification (Scotland) or equivalent. **NVQ 3 Equivalent** e.g. 2 or more A levels, advanced GNVQ, NVQ 3, 2 or more higher or advanced higher national qualifications (Scotland) or equivalent. **NVQ 4 Equivalent And Above** e.g. HND, Degree and Higher Degree level qualifications or equivalent.	
	HQ	People who hold **NVQ 4 Equivalent And Above** e.g. HND, Degree and Higher Degree level qualifications or equivalent.	% on population aged 16-64
	LQ	**People who hold No Qualifications** No formal qualifications held.	% on population aged 16-64
Emission	CO2	CO_2 emissions per km^2	Kt CO_2
Job density	JD	The level of jobs per resident aged 16-64. For example, a job density of 1.0 would mean that there is one job for every resident aged 16-64. The total number of jobs is a workplace-based measure and	

		comprises employee jobs, self-employed, government-supported trainees and HM Forces. The number of residents aged 16-64 figures used to calculate jobs densities are based on the relevant mid-year population estimates.	
Hours worked	HW	Weekly paid hours worked for all employee jobs	hours
Gross Disposable Household Income	GDHI	Gross disposable household income (GDHI) is the amount of money that all of the individuals in the household sector have available for spending or saving after they have paid direct and indirect taxes and received any direct benefits. GDHI is a concept that is seen to reflect the "material welfare" of the household sector. The household sector includes residents of traditional households, as well as those living in communal establishments. GDHI also includes the business income of self-employed people.	£ million (current basic prices)
Area classification		The classification for each geography is based instead on the supergroups, groups and subgroups produced for the local authority classification[11]. The supergroups used are: Affluent England Business, education and heritage centres Countryside living Ethnically diverse metropolitan living London cosmopolitan Services and industrial Legacy Town and country living Urban settlements	
	D1	Dummy=1 if supergroup is "Affluent England", otherwise=0	

[11]https://www.ons.gov.uk/methodology/geography/geographicalproducts/areaclassifications/2011areaclassifications/abouttheareaclassifications

	D2	Dummy=1 if supergroup is ” Business, education and heritage centres“, otherwise=0	
	D3	Dummy=1 if supergroup is ” Countryside living“, otherwise=0	
	D4	Dummy=1 if supergroup is ” Ethnically diverse metropolitan living “, otherwise=0	
	D5	Dummy=1 if supergroup is ” London cosmopolitan “, otherwise=0	
	D6	Dummy=1 if supergroup is ” Services and industrial Legacy “, otherwise=0	
	D7	Dummy=1 if supergroup is ” Town and country living “, otherwise=0	
	D8	Dummy=1 if supergroup is ” Urban settlements “, otherwise=0	

Appendix B Descriptive statistics of variables by regions

Table 5 Descriptive statistics of variables by regions

East Midlands

	N	mean	sd	min	max	Median	kurtosis	skewness
area	280	44589.829	41593.587	2352	176026	29735	4.275	1.306
gdp	280	3532.039	2842.204	874	14209	2604	6.494	2.067
cs	280	7870.996	5216.848	1961.843	27578.994	6149.055	6.724	2.064
ls	280	7.673	.243	6.89	8.5	7.7	3.501	-.283
emp	280	61528.929	39448.351	15100	199300	49700	5.894	1.917
energy	280	533.996	309.365	139.338	2048.93	438.834	10.179	2.351
gdhi	280	2293.621	1426.528	742	9003	1892	9.377	2.424
pop density	280	8.935	11.824	.776	48.454	3.527	5.936	1.943
mean hw	280	32.533	1.455	28.8	37	32.5	2.906	.185
jobdensity	280	.758	.146	.45	1.11	.75	2.506	.271
ed4	280	31.821	8.165	10.2	64.9	31.8	4.225	.344
noedu	280	7.744	3.617	0	19	7.4	2.886	.503
emissionpercap	280	5.658	1.665	3.17	12.643	5.34	4.936	1.232

East of England

	N	mean	sd	min	max	Median	kurtosis	skewness
area	360	42463.089	38495.411	2142	142879	33878	2.885	.915
gdp	360	3963.936	1554.326	1210	7720	4035	2.123	.122
cs	360	8393.046	3159.791	2975.015	18809.855	8416.59	3.34	.725
ls	360	7.633	.226	6.79	8.23	7.64	3.163	-.287
emp	360	63435.556	21936.556	26800	145000	62950	4.079	.846
energy	360	509.154	213.72	190.881	1264.388	478.025	3.71	.963
gdhi	360	2735.381	962.188	1191	6471	2578.5	3.776	.836
pop density	360	10.874	13.389	1.01	49.807	4.955	4.026	1.526
mean hw	360	31.986	1.557	26.5	35.9	32.1	3.513	-.361
jobdensity	360	.82	.179	.46	1.68	.78	6.854	1.531
ed4	360	33.87	10.316	10.6	69.5	32.65	3.822	.72
noedu	360	7.744	3.235	1.6	21.9	7.2	3.678	.733
emissionpercap	360	5.222	1.264	2.904	11.074	5.084	5.039	.982

London

area	256	4903.906	3177.194	1213	15015	3821	4.734	1.437
gdp	256	12842.898	12834.91	4250	78383	9052	14.063	3.195
cs	256	18621.372	9743.193	6610.793	61364.841	17344.37	7.856	1.903
ls	256	7.441	.2	7	7.96	7.455	2.557	-.09
emp	256	132691.8	30989.857	61400	196300	132700	2.28	.051
energy	256	705.105	218.7	428.771	1554.385	686.741	5.855	1.399
gdhi	256	7258.777	2283.096	2849	14025	6862.5	3.581	.895
pop density	256	74.528	38.162	20.915	164.262	61.062	2.209	.565
mean hw	256	32.645	1.488	28.6	36.4	32.65	2.342	-.114
jobdensity	256	.91	.731	.39	4.45	.65	16.103	3.451
ed4	256	50.678	10.671	20.5	71.6	49.75	2.573	-.228
noedu	256	7.24	2.739	1.1	15.7	6.8	3.191	.59
emissionpercap	256	4.008	1.626	2.188	14.753	3.594	17.425	3.211

North East

area	96	71443.083	142684.08	5387	501302	13990.5	7.142	2.356
gdp	96	5125.531	2844.614	1559	10675	4921.5	2.119	.588
cs	96	12356.441	6861.072	4886.985	33836.605	11377.721	5.473	1.654
ls	96	7.548	.137	7.21	7.83	7.565	2.784	-.487
emp	96	94877.083	50754.158	34800	241700	86800	4.164	1.239
energy	96	915.853	523.912	335.83	2194.567	829.463	2.618	.859
gdhi	96	3478.729	1890.823	1279	8809	3109	3.665	1.174
pop density	96	13.942	9.251	.631	26.694	12.018	1.436	.043
mean hw	96	32.24	1.092	29.6	34.9	32.3	2.739	-.253
jobdensity	96	.703	.134	.51	1.02	.71	2.752	.586
ed4	96	29.539	4.423	20.9	41.9	29.65	2.715	.357
noedu	96	10.299	2.457	5.5	17	9.95	3.504	.788
emissionpercap	96	5.36	.978	3.284	7.729	5.266	2.661	.3

North West

area	312	36167.513	46922.068	3488	214236	14236	7.127	2.15
gdp	312	5181.292	4509.039	1193	27476	3640.5	9.468	2.392
cs	312	9345.701	6229.034	2447.952	28870.146	6525.175	3.91	1.28
ls	312	7.577	.24	7	8.45	7.565	3.255	.155
emp	312	82245.192	51661.68	23800	267900	60750	4.146	1.226

energy	312	734.142	525.208	192.489	3803.025	604.411	12.184	2.662
gdhi	312	3141.288	1984.507	948	9790	2266.5	3.403	1.113
pop density	312	12.919	11.422	.245	47.809	10.814	4.354	1.268
mean hw	312	32.411	1.217	28.9	36	32.4	2.735	.019
jobdensity	312	.798	.167	.54	1.18	.78	2.177	.445
ed4	312	32.172	7.664	16.8	62.7	31.15	2.898	.485
noedu	312	9.367	3.58	1.5	20.4	9.1	2.736	.253
emissionpercap	312	5.307	1.556	3.194	11.233	4.967	4.618	1.314

South East

area	512	29796.328	28462.036	2532	156495	23042.5	7.162	1.661
gdp	512	4808.867	2808.807	1172	18313	3978.5	9.681	2.155
cs	512	9331.445	6029.783	3201.306	49326.708	7749.191	21.858	3.689
ls	512	7.685	.222	7.01	8.59	7.685	3.143	.045
emp	512	66337.5	32634.57	27600	263400	58200	18.48	3.405
energy	512	532.002	363.347	163.987	2734.592	453.448	21.027	3.919
gdhi	512	3143.604	1680.474	1063	15799	2800.5	29.481	4.4
pop density	512	12.424	12.897	1.461	53.238	6.185	4.203	1.426
mean hw	512	32.138	1.394	28.1	35.7	32.2	2.71	-.163
jobdensity	512	.857	.173	.45	1.42	.85	3.458	.492
ed4	512	39.946	9.492	18.2	64.2	39.25	2.472	.169
noedu	512	5.958	2.639	.6	20	5.7	5.068	.891
emissionpercap	512	4.809	1.091	2.567	8.244	4.717	2.83	.443

South West

area	232	82947.207	87468.148	4054	354619	56436	5.91	1.846
gdp	232	5391.953	4129.33	916	17680	3668.5	3.319	1.216
cs	232	11994.887	8809.672	2917.573	36973.669	8218.627	4	1.428
ls	232	7.686	.209	6.75	8.25	7.685	4.242	-.368
emp	232	87574.138	62402.619	22400	252900	60650	3.614	1.335
energy	232	675.02	455.946	217.244	2069.159	524.124	5.137	1.685
gdhi	232	3646.371	2557.426	970	11590	2536.5	3.814	1.386
pop density	232	8.76	11.958	.465	42.278	1.92	3.419	1.377
mean hw	232	31.272	1.338	28.1	35.3	31.3	3.253	.276
jobdensity	232	.856	.126	.55	1.23	.85	3.388	.389
ed4	232	36.719	7.279	21.7	55.2	35.9	2.543	.373
noedu	232	5.665	2.051	.8	12.4	5.7	3.3	.427

emissionpercap	232	5.253	1.141	2.966	8.395	5.178	2.536	.26

West Midlands

area	240	43327.733	65600.628	3085	319730	24238	12.335	3.095
gdp	240	5166.604	5111.264	1550	31488	3547.5	18.133	3.712
cs	240	9859.247	8410.061	3154.789	52903.434	7069.098	18.041	3.683
ls	240	7.623	.244	6.74	8.36	7.64	3.796	-.499
emp	240	84584.583	75480.316	25600	476400	58100	17.753	3.638
energy	240	724.709	537.895	191.385	3301.479	647.272	16.306	3.35
gdhi	240	3232.904	2661.188	985	17547	2376.5	17.767	3.611
pop density	240	13.332	13.534	.85	42.638	5.482	2.078	.802
mean hw	240	32.478	1.298	28.6	36.5	32.4	3.361	.042
jobdensity	240	.806	.158	.51	1.36	.79	4.23	1.019
ed4	240	32.364	8.651	11	58.1	31.5	2.811	.403
noedu	240	10.387	4.808	.9	24.8	9.45	2.655	.594
emissionpercap	240	5.302	1.241	3.185	9.85	5.214	3.341	.62

Yorkshire and The Humber

area	168	73369.667	56552.945	7145	240768	55172	4.273	1.292
gdp	168	6558.286	5781.864	998	30307	5182	9.451	2.413
cs	168	13331.749	9525.224	2887.727	45699.655	11457.051	5.29	1.494
ls	168	7.635	.203	7.18	8.45	7.625	4.312	.733
emp	168	115430.95	85144.574	21700	390700	101600	4.771	1.374
energy	168	1141.801	809.542	247.899	3594.884	872.492	4.646	1.415
gdhi	168	4225.94	2926.085	913	14779	3591	5.132	1.425
pop density	168	7.319	8.151	.346	36.483	5.728	7.901	2.057
mean hw	168	32.182	1.207	28.9	35.6	32.3	2.943	.131
jobdensity	168	.809	.132	.53	1.2	.78	2.856	.576
ed4	168	31.908	8.017	19.8	50.3	31.15	2.127	.415
noedu	168	8.895	3.127	1	20.7	8.95	3.776	-.002
emissionpercap	168	5.898	1.534	3.592	10.006	5.602	2.902	.807

CHAPTER 3

Improving the Genuine Saving estimates with natural and social dimensions at the regional level in Italy

Abstract

Economic divergences between countries, interregional disparity, climate change and the growing inequality are revamping the needs to reconsider our development pathways and measures. This paper revisits the Italian Genuine Saving expanding the indicators with three new factors: flood control and water purification ecosystem services and poverty gap. The adjusted Genuine Saving estimates are computed for 2006, 2012 and 2015 at the regional level considering spatial heterogeneity and equivalised disposable income. While the methodological framework is applicable to other countries, Italian results reveal that the effect of ecosystem services and the poverty adjustment are crucial for measuring the regional trends. Ignoring these components might lead to mismanagement of the human, natural and social capital at national and regional level.

1. Introduction

A renewed concern for rising economic divergences between countries and interregional disparity has emerged leading to the need to track the development path. Further, the necessity of measuring the sustainability of economy and the distribution of well-being is an issue that has been widely discussed for years.

The world is facing several crises: climate, inequality, democracy and trust. The climate crisis worsened faster than had been expected and inequality reached new heights in the last decades (IPCC, 2022; Chancel et al., 2022). These emerging pressures stress the need for better tools to assess economic performance and social progress.

The Great Recession in 2008 let politics and citizens understand that distorted metrics can lead to misleading assessments and that what governments measure strongly influences their policies. The way economists and governments assess country's health has changed since the Commission on the Measurement of Economic Performance and Social Progress in 2009 (Stiglitz-Sen-Fitoussi Commission), the work of the High-Level Expert Group on the Measurement of Economic Performance and Social Progress (HLEG) and the following "Beyond GDP" movement. One common conclusion of these initiatives is the inadequacy of our metrics for assessing economic performance and social progress.

Growing concern about rising inequalities and global warming put an even greater emphasis on sustainability in all its dimensions, and the difficulties related to its measurement are still at the centre of the debate and remain an open question.

On the other side, economists and ecologists have worked for decades on measuring sustainability to respond to the increasing awareness of threats to humanity from environmental degradation and biodiversity loss. They have tried to incorporate values of natural capital into national economic decision-making indexes and extend traditional economic tools such as GDP and cost-benefit analysis to account for environmental values.

The complexity and the multidimensionality of sustainability and its challenge to capture all aspects in a single or a set of indicators have led to develop several tools and many indicators, both at the domestic and international level (e.g. Adjusted Net Savings, comprehensive wealth measures, the Genuine Progress Index). However, their use has remained largely academic despite efforts to revise GDP or supplement the System National Accounting (SNA) with satellite accounts to inform national-level economic decision-making.

The Adjusted Net Savings (ANS), also named Genuine Saving (GS), is the first widely accepted adjustment to national accounts. Its theorical foundation is well established and rooted in economic theory. The GS is an index of weak sustainability meaning it assumes infinitely substitutability among different form of capitals. It aims to measure the "genuine" saving that is the changes in total wealth considering not only produced capital but also natural and human capital in a specified period of time. In other words, the GS is equal to the sum of net changes in all capital stocks valued at their shadow prices.

GS is built on the framework of the green national accounting and the rearrangement of the Hartwick rule - invest resource rents in other assets - (Hartwick, 1990) and aims to trace a weak sustainable development path if it is above or equal to zero. Contrary, a persistently negative value of the GS signals an unsustainable development and an insufficient rate of produced capital accumulation.

However, the debate on which indicator, progressively constructed over past years, is the most reliable is still open. The limits of the GS have been debated since its creation and the promoter of the GS stated that the scarce availability of data in various fields (mainly environmental), makes impossible to compute the GS in the theoretically correct way, which is one of the main problematic issue. Indeed, few natural resources depletion are included in its computation yet. The World Bank (Bolt at al. 2002) provides a step-by-step calculation of GS including energy, mineral and forest depletion and damages from Carbon Dioxide emissions. Essential resources like water, soil and ecosystem services are not mentioned.

Another limitation is that the GS does not account for social disparity. Inequality and poverty are linked with productivity and environmental degradation; these interconnections affect the sustainability and the development of a region, country, or world (United Nations, 2021a). Economic inequality and poverty have a direct negative effect on the well-being of society, and this would be enough to justify the introduction of the degree of equity within an indicator like the GS.

In the last years, the attention on accounting for natural capital and ecosystem services is exponentially increased (United Nations et al.,2021b). Theoretical and practical improvements to integrate natural capital and ecosystem services into the SNA were provided by European Commission[12] as well as by

[12] For example, INCA, Integrated system for Natural Capital Accounting; KIP INCA, Knowledge Innovation Project on Integrated System for Natural Capital Accounting and LISBETH, LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging project

the UN SD guideline for natural capital accounting (United Nations, 2021b). The same has happened for the research on inequality and poverty (United Nations, 2020). Both topics are still debated but empirical applications are emerging.

Although the criticisms of GS still exist, it remains the best attempt at measuring weak sustainability. In this context, the rethinking of GS and its integration with current results for natural and social capital (ecosystem services and income inequality) represent an opportunity to widen our understanding of the development path.

In the present analysis, the national and regional GS estimates are computed referring to Italy. Biasi et al. (2019) expand the Italian GS including soil and water depletion whereas in this study we include flood control and water purification ecosystem services provided by the EU -INCA (Integrated system for Natural Capital Accounting) datasets. Subsequently, the Genuine Saving is adjusted for the social component considering the absolute Poverty Gap (PG) and the Poverty Headcount Measure (PH) at the regional level.

The paper contributes to empirically estimate the Genuine Saving for the Italian regions and to expand the indicator to accommodate ecosystem services and inequality poverty measure. The analysis at national and regional helps to investigate the heterogeneity information that could be hidden at national scale. The inequality component is based on regional disposable equalised income statistics to appreciate regional heterogeneity versus national average. Figure 1 summarizes the main steps to compute the regional genuine saving index.

The paper is structured as follow: Section 2 introduces the Genuine Saving and its link with the sustainable development concept; Section 3 explains the data and the empirical calculation of the GS focusing on the integration with ecosystem services and the social dimension; Section 4 presents and discusses results and Section 5 concludes.

Figure 1 Computation of Genuine Saving at regional level
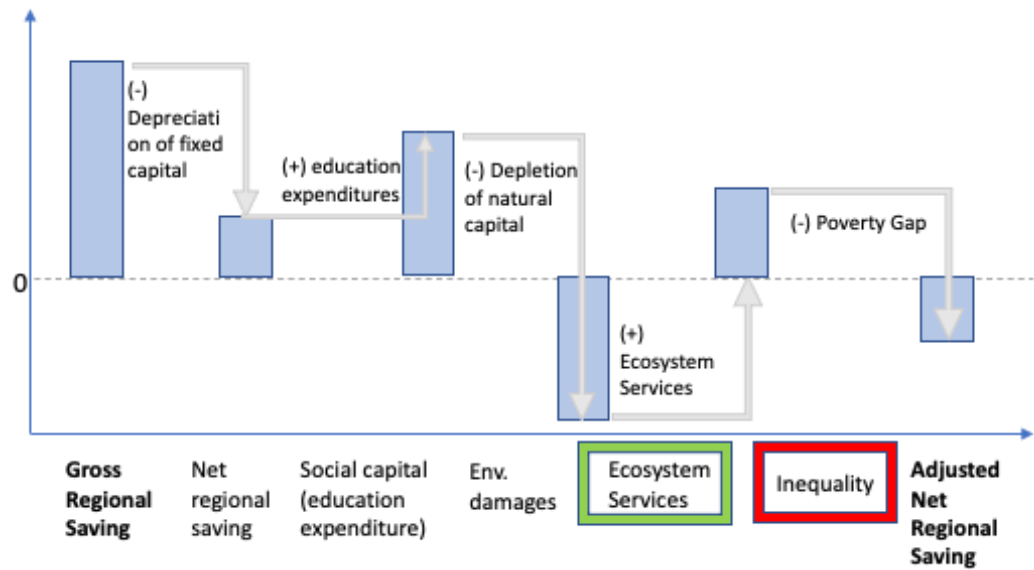
2. Genuine Saving and sustainable development

The Genuine Saving (GS), also called Adjusted Net Saving (ANS), is based on a definition of development linked with the concept of wealth: wealth accumulation is possible only through saving (Managi and Kumar, 2018). In this sense, the savings-investment process can therefore be interpreted as the dynamic behaviour that explains how an economy evolves along its development path; consequently, the national savings can be a tool to monitor and measure the development of a country.

The national saving comes from the System of National Accounting (SNA); however, it does not include other type of (inclusive) wealth. For this reason, the GS aims to transform the standard saving as measured in national accounting into "genuine savings" including natural and human capital.

The theoretical foundations of genuine savings are well established. Hamilton and Clemens (1999) developed the formal model that was revised in 2000 by Dasgupta and Maler and in 2001 by Asheim and Weitzman. Contextually, Pearce and Atkinson (1993), Hamiltom, Pearce and Atkinson (1997), and later Hamilton e Clemens (1999) proposed the cross-country estimates of GS

including man-made capital, depletion of natural and investment in human capital.

Conceptually, the GS suggests whether a country is saving for future generations by summing up total annual changes in a country's natural, human, and fixed capital. If the sum of these values is positive, then the present value of social welfare is increasing, and this means sustainable development. Contrary, if the value is negative the current generations re-depleting resources and the development is unsustainable.

The units and terms used in the computation of the GS are its advantages since they are clearly understood by economists. However, it has drawbacks and its limits have been debated from the beginning even by its creators. They state that the main limit is the scarce availability of data which hampers the possibility to produce a theoretically sounded index. In these decades, different progresses have been made, especially in measuring natural capital, and the other limits might be solved in the near future. However, a number of authors criticize the GS since it is an incomplete measure of changes in natural capital and an imprecise measure of changes in human capital (Daly and Posner, 2011; Howarth and Kennedy, 2016). Indeed, a crucial aspect of GS is about the methodological estimation of investment in human capital. To this end, public expenditure on education is added to savings; however, this simplification rises doubts on its interpretation as an investment in human capital. The reason is the vast variability in the effectiveness of public education spending: a current expenditure of one euro on education does not necessarily produce one euro of human capital. In other words, the education is measured by its cost and not by the value of its results and the actual impact on society and wellbeing.

Few natural resources depletions are included in the computation of the GS since the biophysical and/or economic quantification is currently developing. However, in the last years the attention to natural capital and ecosystem services has exponentially increased. Project like the INCA (Integrated system for Natural Capital Accounting), KIP INCA (Knowledge Innovation Project on

Integrated System for Natural Capital Accounting) and LISBETH (LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging) promoted by European Commission are theoretical and practical improvements for the integration of natural capital and ecosystem services into the SNA (Inca, K.I.P, 2021).

Another limitation is that the GS does not account for social disparity. Inequality and poverty are linked with productivity and environmental degradation (United Nations, 2021a); these interconnections affect the sustainability and the development of a region, country, or world. Inequality and poverty have a direct negative effect on the well-being of society, and this would be enough to justify the introduction of the degree of equity within an indicator such as the GS.

According to Thiry e Cassiers (2010), the lack of distribution component is due to the theoretical framework on which is based the GS, that is the maximization of societal wellbeing function. It focuses the attention on a representative individual rather than the whole community. This is a common limit that characterised other social well-being function because they do not provide any type of mechanism that attributes different weights to different interests and stakeholders.

Although we acknowledge the GS criticisms, we claim that the GS remains the best attempt at measuring sustainability, and it is an index usually adopted in economic and econometric analysis. Indeed, the World Bank uses the GS as an indicator of sustainable development and long-term well-being for a cross-country panel since 1970.

In this context, revamping the use of GS with additional adjustments (inequality and ecosystem services) can broaden the set of development path indicators and help decision maker to design their policy intervention to maximize social welfare.

The paper extends the Biasi et al. (2019)'s approach reviewing the regional GS estimates of Italy for 2006, 2012, 2015 using updated data entry, including ecosystem services and extending the indicator to account for the social impact of poverty on national and regional sustainability development analyse.

3. Data and calculations

Biasi et al. (2019) propose the regional estimate of GS in Italy adding soil and water degradation in addition to the World Bank guideline (Bolt et al., 2002). Formally, what they call "extended GS" is computed as follows:

Extended GS	=	Gross Saving
	–	Depreciation of fixed Capital
	+	Public and Private investments in Education
	–	Depletion of Energy Resources
	–	Depletion of Minerals
	–	Net Depletion of Forest[13]
	–	CO_2 Damages
	–	PM Damages
	–	Damages of soil sealing
		Damages of water losses and degradation

To compute the GS, the Net National Saving is obtained from the National Office of Statistics (ISTAT) and it is disaggregated at regional level according to Biasi and Rocchi (2016). After detecting that the Net savings and Net investment are strongly correlated, they use the ratio of regional over national investment to disaggregate the national figure.

Regional public and private expenditures in education are included as directly provided by ISTAT.

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[13] According to Biasi and Rocchi (2016) the Rent from Net Forest Depletion are excluded from the estimate of GS at the regional level because the value of this component for Italy estimated by WB is equal to zero for the years analysed

Depletions of energy resources is computed considering oil and gas extraction rent (market price minus extraction cost). Data on physical quantity extracted and the value of unit rent for oil and gas are respectively provided by the General Directorate for Energetic Resources of the Italian Ministry of Economic Development and the World Bank.

Data on CO_2 emission are calculated by ENEA (2010) and valuated at the social cost of carbon per tonne emitted (22.6 €/t in 2006, 29€/t in 2012 and 39€/t in 2015)[14]; PM Damage is estimated as the Willingness to Pay (WTP) to avoid mortality and morbidity attributable to particulate emissions by the World Bank. After computing regional PM emissions, the value of damage for each region is calculated as the contribution to national emission multiplied for the total damage.

The soil sealing is computed using the area in hectares converted into artificial surfaces valuating the loss of CO_2 sequestration potential.

Damages of water losses and degradation includes the water quality degradation due to urban and industrial pollution and the quantity of potable water lost due to inefficient distribution system. ISTAT provides data for both dimensions. Monetary values are the cost of wastewater purification and the average regional water fee.

The current analysis extends the GS computation including ecosystem services and social component as described in the following sections.

3.1 GS and ecosystem services

Ecosystem services are biophysical flows from natural capital stocks from which humans derive benefits, including provisioning, regulating, and cultural services (Fisher at al., 2008; UN2014; Potschin et al., 2016).

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[14] CO_2 valued at 37$ per ton (refer to 2015) as estimated by Office of Information and Regulatory Affairs (2013) is inflation adjusted and converted in euros; the incremental damages of CO_2 emission over the time span is accounted as well

Ecosystem services are the contributions of natural or managed ecosystems to benefits used in economic and other human activity. Benefits include provisioning (e.g., food, materials), regulating (e.g., clean air and water, protection from disasters) and cultural services (e.g., recreation). They underpin our economies and our well-being.

Similar to the national account system[15], the environmental accounting has started with the System of Environmental Economic Account Central Framework (SEEA-CF) and was integrated with the SEEA Ecosystem Accounting (SEEA EA). The SEEA-CF accounts focus on the stocks and changes in productive assets such as minerals, timber, and land, while the SEEA-EA framework measures ecosystem assets and their associated goods and ecosystem service flows. In particular, the SEEA-EA includes physical (extent, condition, services) and monetary accounts. In other words, the ecosystem accounting system is developed for multiple aims: i) to record and explore relationships and track changes in ecosystems extent (e.g. size) and condition; ii) to measure the interaction between ecosystems and the economy.

Turner et al. (2019) noted that most SEEA applications contain physical but not monetary accounts since the comprehensive environmental valuation is still difficult. Only in 2021, the Integrated system for Natural Capital Accounting (INCA) project produced the first pilot estimates of multiple ecosystem services (pollination, crop and timber provision, water purification, flood protection, carbon sequestration and recreation) for EU and they consider their possible policy use. The total EU value of these ecosystem services is estimated 172 and 234 billion euros respectively in 2012 and 2019.

Further results and technical reports of the INCA project are published on the INCA platform[16] on which data are free downloadable at fine spatial scale. The current paper uses the monetary valuation results of the INCA project and analyses them at regional Italian level. In particular, the water purification and

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[15] SNA stands for System National Accounting, the international agreed standard on how to measure and record economic activity
[16] https://ecosystem-accounts.jrc.ec.europa.eu

flood control estimates in monetary value are extracted with geographic information system[17] using the map tool and geo-located information available.

Flood control is the capacity of reducing or retaining runoff water and protect downstream infrastructure and residents from flooding. Several ecosystems such as wetlands, forest, cropland and urban area have the ability to reduce the speed of runoff water during heavy rain or store water temporarily in the soil. The physical accounts of flood control are based on a spatially explicit modelling of the water retention capacity of different ecosystem types and an assessment of the infrastructure and residential areas that are at risk (Vallecillo et al, 2020). The monetary accounts are based on avoided damage costs meaning the costs that would have been made in absence of the protective functions of ecosystems.

The water purification is the self-purifying capacity of rivers and lakes, wetlands and soils, and groundwater systems at removing excess nutrients and pollutants. In INCA estimates, a more restrictive eutrophication sustainability threshold of 1 mg of nitrogen per litre is used. This indicator is the threshold which guarantees a minimum standard to a good ecological status for rivers and lakes. The monetary accounts are based on the cost-based approach meaning the cost of replacement of water purification with an artificial constructed wetland in case ecosystems were not providing it. La Notte et al. (2017) provide details on this approach.

3.2 GS, economic inequality and poverty

A consistent question of our time is "Are country's resources managed equitably and sustainably both for present and future generations?". The awareness that a well-performing economy and society should be different from ones in which most people were doing poorly, and only few were doing

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[17] Q GIS (version 3.16), a free and open-source cross-platform desktop geographic information system, is used

great (even if the GDP increases) is widely accepted. Growing inequality in income and wealth is a global concern and accommodating distribution into development performance indicators is a timely exercise. Policies that aim to reduce inequalities require better metrics than GDP and a comprehensive view and integration with the countries' performance process and SNA.

The conceptual notions of economic inequality and poverty are generally uncontentious, and their correlation is well known. Inequality concept refers to the unevenness of resources and opportunities distribution among individuals, among groups in a population or among countries. Economic inequality generally focuses on disparities in income, wealth and consumption; although, studies suggest that same household or individual experiences disadvantage in many dimensions such as health, education, political voice, insecurity, access to justice, opportunity, and that these aspects are correlated with income inequality (Karagiannaki, 2017; Yang and Polly Vizard, 2017). Poverty is defined as the condition in which people having insufficient resources to access goods and services necessary for a minimal or socially acceptable standard of living.

Several indices and metrics have been proposed for the measurement of both inequality and poverty. The literature ranges from unidimensional monetary indicators to broader multidimensional and subjective concepts. For the aim of paper, especially for the scale of analysis, the Poverty Gap (PG) and the Poverty Headcount are used to compute the value of social dimension for each region.

The Poverty Gap is the amount of money by which each individual falls below the poverty line[18]. In other words, the PG represents how much money would be necessary to allow poor people to reach at least the level of the poverty line. In this application the PG per equivalent adult is computed following the World Bank guideline (World Bank, 2023). Formally, the PG per equivalent adult can be expressed as follows:

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[18] The poverty line is defined by the World Bank as 60% of the median households' income.

$$Poverty\ Gap = \sum_{i=1}^{M} (z_i - y_i)I(z_i, y_i)a_i$$

where i identifies the number of households, z_i is the poverty line for the i household, y_i is the disposable household income equivalent, $I(z_i, y_i)$ is a dummy variable equal to 1 for poor household, a_i is the equivalised household size and M is the total households.

The Poverty Headcount (PH) is the ratio between the number of poor people and the total population; it identifies the share of a population whose income is less than the poverty line.

$$\text{Poverty Headcount} = \frac{N_p}{N}$$

where N_p is the number of poor and N is the total population (or sample).

The poverty line for each region, on which are based the PG and PH estimates, is computed considering 60% of median disposable household income equivalent following the World Bank definition. Regional income heterogeneity is accounted by considering each region as an independent area.

The PG and PH at regional level are based on survey data on income and living condition provided by the Italian Statistics Office (ISTAT) for 2006, 2012 and 2015.

The total value of poverty by regions relies on own data elaboration of the Poverty Gap and PH using the EU SILC survey data; indeed, the PG pro poor is multiplied by the number of poor people computed using the PH and the regional population.

4. Results

Results firstly present the inclusion of ecosystem services estimates; subsequently, the Genuine Saving with and without the social adjustment both at national and regional level are presented.

4.1 GS and ecosystem services

Flood control and water purification ecosystem service provide monetary values that contribute to the regional economy and human well-being. This analysis reports a cross-region and over time assessment of essential ecosystem services reported in monetary term. Trentino Alto Adige has the greatest flood control value - which amounts yearly to about 160 million € - compared with all other regions. Lombardia and Toscana follows with respectively 102 and 95 million € per year. Sicilia, Molise and Calabria value the flood control ecosystem service respectively 0.46, 0.73 and 1.43 million which are the lowest flood control values in Italy.

Moreover, Valle d'Aosta, Molise and Emilia Romagna have a downward trend (1-2%) on flood control value, while an increase in values are recorded in Campania (6-3%) and Umbria (5-3%). Other regional overtime variations are negligible.

Considering the water purification ecosystem service, Piemonte, Trentino Alto Adige and Lombardia result in higher value than other regions and in an upward trend in percentage change overtime: the estimates amount to 585, 550 and 510 million €, and the variations range at about 1-2%.

Molise, Marche and Basilicata exhibit the lowest estimation values at 49 million €. Decreasing trends in water purification values are especially noted for the Southern regions: Sicilia (6-3%), Calabria (3-2%), Campania (4-2%) and Basilicata (3-1%).

Figures 2 and 3 report in monetary term flood control and water purification value at regional level in Italy[19] for 2006, 2012 and 2015. Tables 1 and 2 summarizes the monetary value for both ecosystem services in million € and percentage change overtime per each region.

However, monetary estimates should always be interpreted with care and contextually with physical estimates because high value of them, it is not

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[19] Puglia and Sardegna data are not available

always a good indicator of healthy ecosystem but contrary it could mean scares resources. Lange, Wodon, and Carey (2018) shows that the per capita value of a country's natural capital typically increases even as its share of total capital declines, since its value to the economy and population increases.

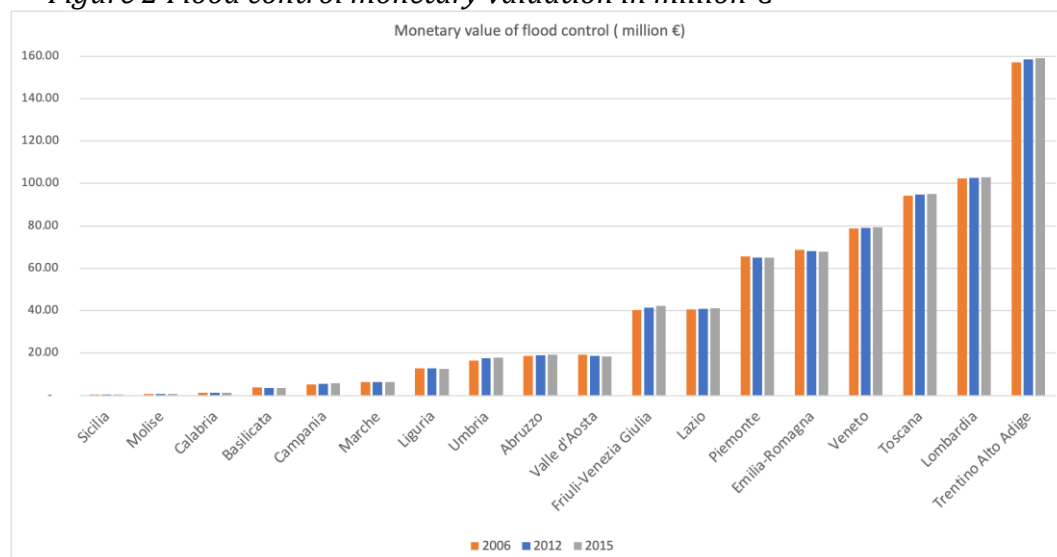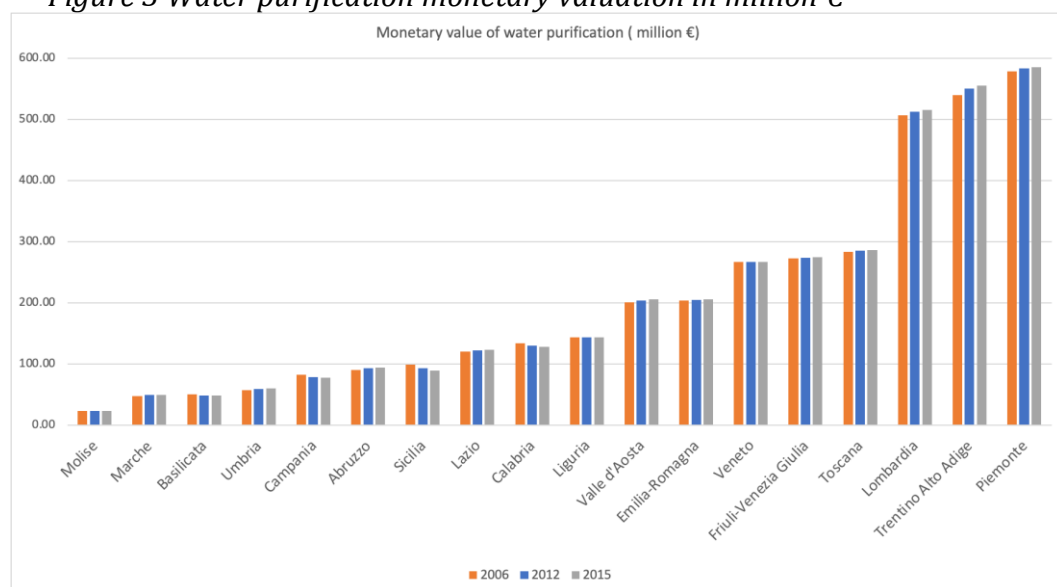*Figure 2 Flood control monetary valuation in million €*

Figure 3 Water purification monetary valuation in million €

4.2 *GS and poverty*

The contribution of the social dimension (economic inequality and poverty) is a missing component in the GS. This paper includes the social dimension of poverty into the Italian GS estimates recording the regional differences to appreciate social welfare heterogeneity.

Table 3 includes the poverty line, poverty gap and poverty headcount for each region for 2006, 2012 and 2015.

Table 1 Flood control monetary value in million € and percentage change for each region

Region	2006	2012	2015	Change 2006-2012	Change 2012-2015	%Change 2006-2012	%Change 2012-2015
		Million €				%	%
Sicilia	0.46	0.47	0.47	+	+	2.7%	1.3%
Molise	0.73	0.72	0.72	-	-	-0.9%	-0.5%
Calabria	1.43	1.43	1.43	+	+	0.0%	0.0%
Basilicata	3.71	3.67	3.65	-	-	-1.0%	-0.5%
Campania	5.22	5.53	5.68	+	+	6.0%	2.8%
Marche	6.37	6.33	6.31	-	-	-0.7%	-0.3%
Liguria	12.77	12.69	12.65	-	-	-0.6%	-0.3%
Umbria	16.61	17.50	17.95	+	+	5.4%	2.6%
Abruzzo	18.72	19.00	19.15	+	+	1.5%	0.8%
Valle d'Aosta	19.15	18.76	18.56	-	-	-2.1%	-1.0%
Friuli-Venezia Giulia	40.38	41.58	42.18	+	+	3.0%	1.4%
Lazio	40.49	41.02	41.29	+	+	1.3%	0.6%
Piemonte	65.53	65.15	64.96	-	-	-0.6%	-0.3%
Emilia-Romagna	68.71	68.09	67.79	-	-	-0.9%	-0.5%
Veneto	78.66	79.15	79.40	+	+	0.6%	0.3%
Toscana	94.31	94.87	95.15	+	+	0.6%	0.3%
Lombardia	102.25	102.77	103.03	+	+	0.5%	0.3%
Trentino Alto Adige	156.97	158.35	159.04	+	+	0.9%	0.4%

Table 2 Water purification monetary value in million € and percentage change for each region

Region	2006	2012	2015	Change 2006-2012	Change 2012-2015	%Change 2006-2012	%Change 2012-2015
		Million €				%	%
Molise	23.16	23.15	23.14	-	-	-0.1%	0.0%
Marche	47.74	48.87	49.43	+	+	2.4%	1.2%
Basilicata	49.97	48.61	47.92	-	-	-2.7%	-1.4%
Umbria	57.17	59.09	60.05	+	+	3.4%	1.6%
Campania	81.99	78.79	77.19	-	-	-3.9%	-2.0%
Abruzzo	90.03	92.87	94.30	+	+	3.2%	1.5%
Sicilia	98.75	92.47	89.33	-	-	-6.4%	-3.4%
Lazio	120.38	122.17	123.07	+	+	1.5%	0.7%
Calabria	133.50	129.53	127.54	-	-	-3.0%	-1.5%
Liguria	142.92	143.02	143.07	+	+	0.1%	0.0%
Valle d'Aosta	200.26	203.70	205.42	+	+	1.7%	0.8%
Emilia-Romagna	203.93	204.75	205.16	+	+	0.4%	0.2%
Veneto	266.83	267.01	267.09	+	+	0.1%	0.0%
Friuli-Venezia Giulia	272.73	273.70	274.18	+	+	0.4%	0.2%
Toscana	283.59	285.54	286.52	+	+	0.7%	0.3%
Lombardia	506.62	512.52	515.47	+	+	1.2%	0.6%
Trentino Alto Adige	539.68	549.69	554.69	+	+	1.9%	0.9%

4.2 *GS and poverty*

The contribution of the social dimension (economic inequality and poverty) is a missing component in the GS. This paper includes the social dimension of poverty into the Italian GS estimates recording the regional differences to appreciate social welfare heterogeneity.

Table 3 includes the poverty line, poverty gap and poverty headcount for each region for 2006, 2012 and 2015.

At country level, Figure 4 reports the impact of considering the Poverty Gap in the GS measure as a percentage of GDP for the years of analysis (2006, 2012, 2015)[20]. The inclusion of poverty generates a reduction of 4% with respect to the "standard" GS in 2006, 3.6% in 2012 and 4% in 2015. This result is consistent with the increase in the national inequality from 2006 to 2015 as showed in Figure 5. The value of PG amounts approximately to 38, 53 and 61 thousand million euros for 2006, 2012 and 2015. These findings support the idea that integrating the social dimension into the GS helps to better reflect the sustainability performance of countries.

It is worth noting that the national "standard" GS reveals a huge decline from 2006 to 2012 probably due to the financial crisis of 2007-2008 and a modest improvement in 2015. Moreover, in 2012 and 2015 the GS, after the social correction, became negative because of two combined effects: the GS decrease and the poverty increase.

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[20] GDP amounts respectively to 1,552,686.8, 1,624,358.7 and 1,655,355 million € in 2006, 2012 and 2015

Table 3 Poverty line, poverty gap and poverty headcount for 2006, 2012, 2015

Region	2006			2012			2015		
	Poverty Gap	Poverty line	Poverty Headcount	Poverty Gap	Poverty line	Poverty Headcount	Poverty Gap	Poverty line	Poverty Headcount
	€	€	%	€	€	%	€	€	%
Piemonte	767,565.9	9,517.8	15.8%	1,484,733.0	11,364.0	19.2%	1,157,023.0	11,303.7	16.3%
Valle d'Aosta	155,883.1	9,864.3	13.2%	210,732.4	11,161.7	14.8%	219,185.5	11,583.6	14.6%
Lombardia	1,500,593.0	10,002.7	15.9%	1,491,745.0	11,682.8	15.9%	1,912,003.0	12,272.4	16.9%
Trentino Alto Adige	463,514.3	10,281.0	14.6%	541,191.5	11,444.7	17.1%	514,481.6	12,083.9	16.6%
Veneto	880,290.6	9,339.6	15.0%	1,057,469.0	10,899.6	16.5%	1,054,440.0	11,160.3	15.4%
Friuli Venezia Giulia	482,380.4	9,571.2	15.9%	791,114.6	10,955.1	17.3%	763,069.9	11,549.0	13.9%
Liguria	551,588.8	9,029.7	17.1%	892,761.5	10,627.5	18.5%	1,087,862.0	11,199.6	19.0%
Emilia Romagna	1,102,782.0	10,373.5	16.5%	1,050,496.0	11,684.0	15.4%	1,255,145.0	12,374.8	16.8%
Toscana	821,361.2	9,669.9	14.1%	1,113,420.0	11,071.2	16.5%	1,040,312.0	11,240.4	16.1%
Umbria	473,497.8	8,764.4	16.5%	586,063.4	10,002.4	15.7%	609,258.1	10,219.0	16.8%
Marche	601,636.5	9,137.0	16.5%	884,852.4	10,448.4	17.1%	770,771.3	10,235.6	13.2%
Lazio	1,171,957.0	8,609.4	18.4%	1,779,294.0	10,200.6	20.0%	1,822,031.0	10,000.8	21.9%
Abruzzo	268,641.8	8,053.2	15.6%	378,257.3	8,798.9	19.6%	451,941.2	8,380.8	18.5%
Molise	228,465.4	7,352.0	17.0%	269,773.3	7,828.6	17.1%	284,542.5	8,146.8	20.0%
Campania	1,181,724.0	6,724.8	18.4%	1,326,998.0	7,386.8	20.1%	1,044,137.0	7,551.0	19.1%
Puglia	592,996.6	6,561.6	16.2%	835,625.8	8,033.2	16.9%	838,888.8	8,223.7	16.8%
Basilicata	308,718.7	6,469.6	14.3%	362,472.7	7,597.0	17.8%	260,922.2	7,360.9	16.3%
Calabria	606,515.6	6,635.3	20.5%	680,475.0	7,644.8	18.9%	571,720.8	7,622.3	19.8%
Sicilia	790,403.9	5,766.6	17.5%	940,760.8	6,700.0	18.6%	1,102,612.0	7,113.8	21.8%
Sardegna	411,258.5	7,833.6	16.5%	409,930.4	8,806.3	18.7%	445,310.0	8,555.4	20.3%

Data own elaboration from on income and living condition survey provided by ISTA

Figure 4 The GS estimates with and without the social correction as percentage of GDP in Italy for 2006, 2012 and 2015
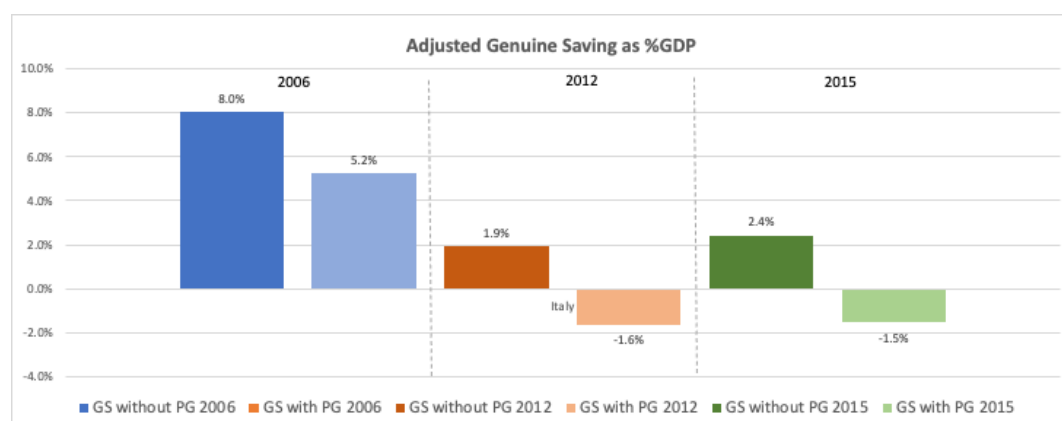

Figure 5 The national Poverty Gap as percentage of GDP in 2006, 2012, 1015

The regional analysis is conducted by disaggregating the GS with and without social correction to highlight the dynamic of changes and provides a comparison of Italian regions.

Figures 6, 7 and 8 report the GS estimates with and without the social correction in 2006, 2012 and 2015.

In 2006, the general trend of GS with and without the poverty adjustment does not change: all Italian regions report a positive standard and adjusted GS. Molise and Abruzzo have the highest performance, while Lombardia and Emilia-Romagna the lowest.

A different situation is reported in 2012 and 2015. In these years the "standard" GS are lower compering of those in 2006.

In 2012, the Trentino Alto Adige[21] is the only, of the twenty regions, that passed the weak sustainability test keeping a positive value of GS (1% of its regional GDP) despite the social adjustment. Contrary, the GS of fourteen regions on twenty became negative after the inequality correction; these regions are: Basilicata, Calabria, Campania, Emilia-Romagna, Lazio, Lombardia, Marche, Piemonte, Puglia, Sardegna, Sicilia, Toscana, Umbria, Veneto. The five remaining regions (Abruzzo, Friuli-Venezia Giulia, Liguria, Molise, Valle d'Aosta) see the negative values of the GS getting worse.

In 2015, all regions excepting Basilicata report a positive GS without the social correction. After the adjustment, only four regions present a positive GS (Campania, Friuli-Venezia Giulia, Trentino e Valle d'Aosta). The overall situation reports an improvement (more regions gain the weak sustainability) compared with the 2012, although the adjusted GS values are very close to zero (0.4%, 0.2%, 0.3% and 0.6% of respectively regional GDP),

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[21] Trentino Alto Adige is an autonomous region of Italy meaning that it owns legislative, administrative and financial powers to take into account cultural differences and protect linguistic minorities

Figure 6 Regional genuine saving with and without the Poverty Gap, 2006 (%GDP)
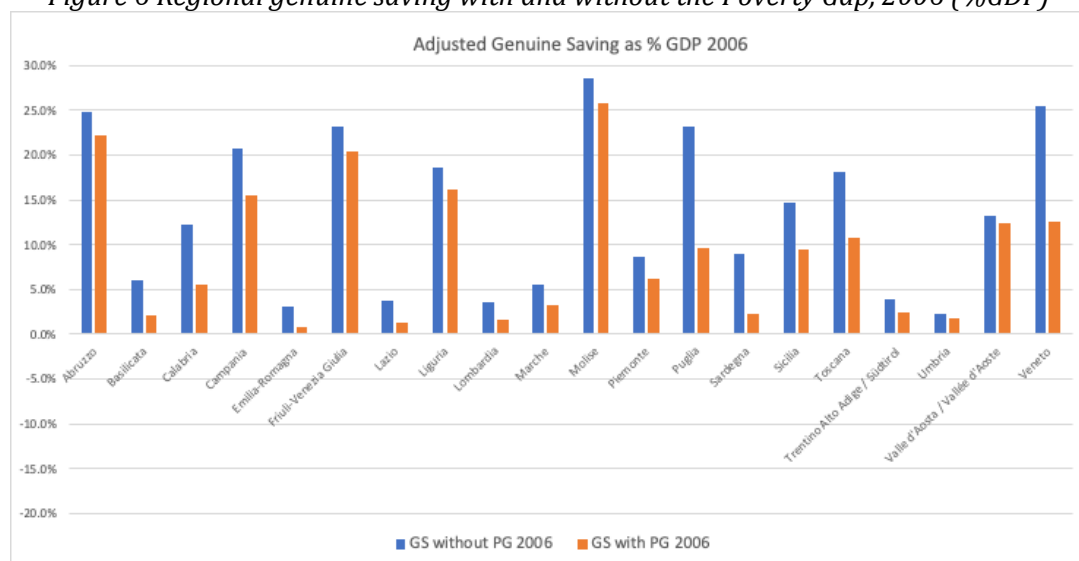
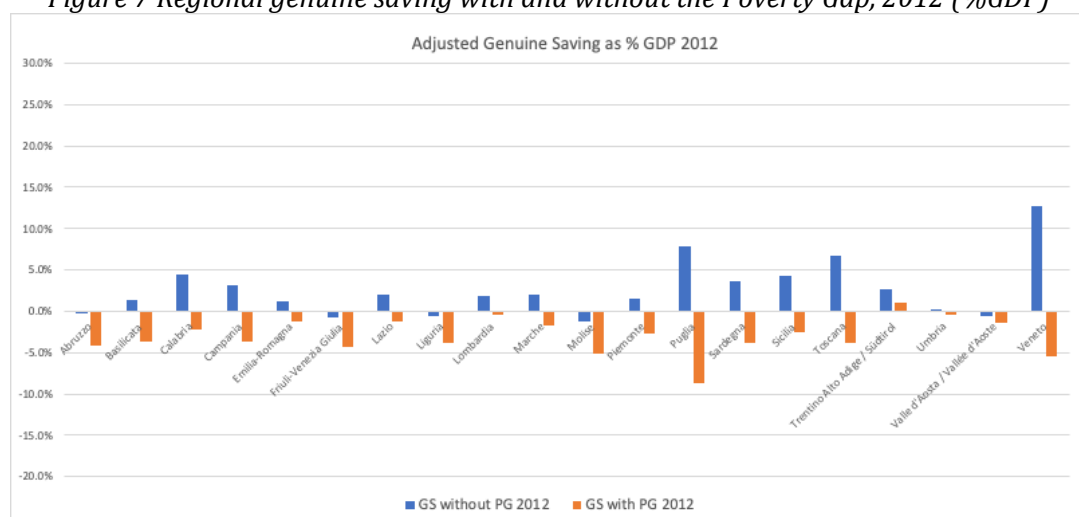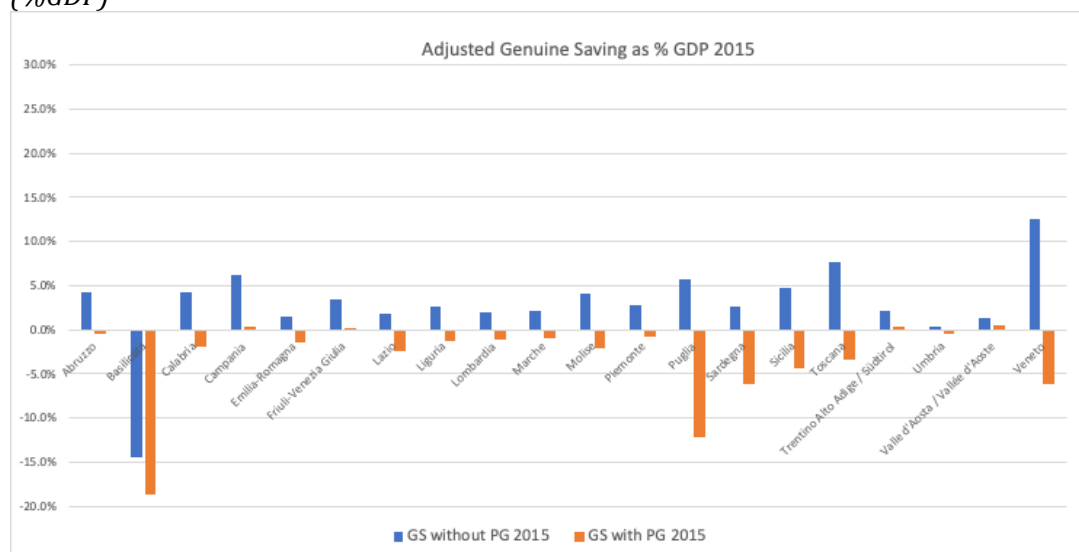*Figure 7 Regional genuine saving with and without the Poverty Gap, 2012 (%GDP)*

Figure 8 Regional genuine saving with and without the Poverty Gap, 2015 (%GDP)


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More in general, the heterogeneity of Italian regions in terms of sustainability is mainly due to the combination of two effects: the Genuine Saving decreases and the inequality increases.

On the one hand, most regions report a large increase in their regional adjusted GS from 2006 to 2012. Exceptions are Puglia, Sardegna, Trentino Alto Adige and Basilicata which had a slightly downward direction.

On the other hand, all regions had an increase in poverty from 2006 to 2012 and this trend kept in the most of regions from 2012 and 2015. Only six regions (Basilicata, Calabria, Campania, Friuli-Venezia Giulia, Marche and Piemonte) reveal a little decrease of the value of poorness.

The regional analysis investigates the intensity of poverty change overtime and figure 9 summarizes the impact of poverty from 2006 to 2012 (left hand side) and from 2012 to 2015 (right hand side).

Figure 9 Regional changes in Poverty Gap (%)
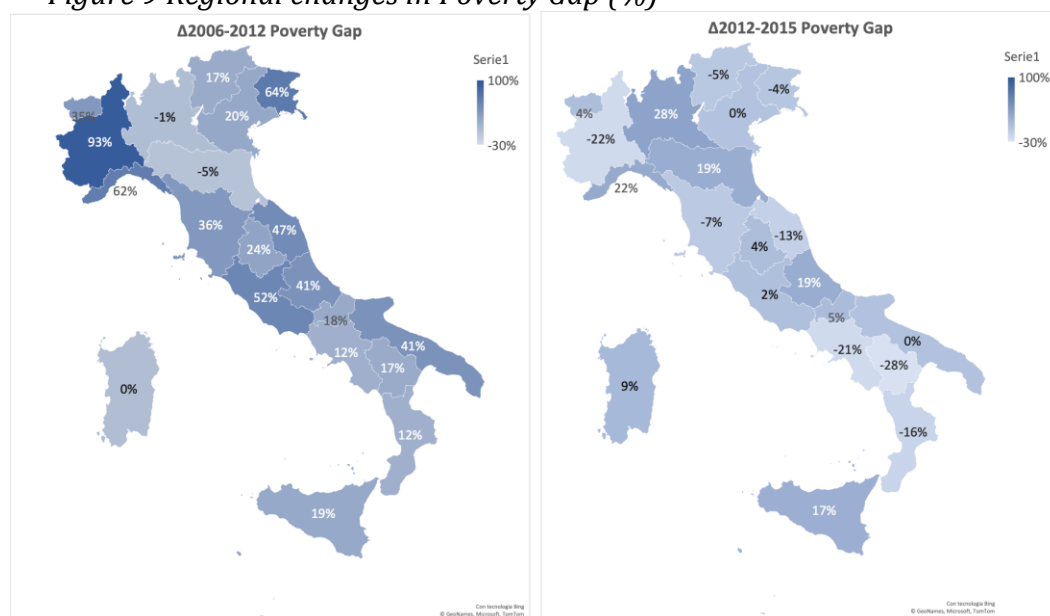
The poverty effect is particularly intense in the 2006-2012 compared to 2012-2015 probably due to the financial crisis and the longer period of analysis. In particular, the poverty gap change from 2006 to 2012 is greater than 50% in

Piemonte (93%), Friuli-Venezia Giulia (64%), Liguria (62%), and Lazio (52%); while Lombardia and Emilia Romagna have a slightly decrease trend (respectively 1% and 5%). From 2012 to 2015 results shows a reduction or a stationary poverty situation in almost half of Italian regions; an increase of the poverty gap above 15% is recorded in Lombardia (28%), Liguria (22%), Emilia Romagna (19%), Abruzzo (19%) and Sicilia (17%).

In summary, the effect of the adjustment of the regional and national GS for poverty is remarkable and the need to jointly consider produced, human and natural capital depreciation it is crucial. Results are useful to track the direction and the intensity of the poverty status and to better inform policy decision maker and resource manager to counter act the social disparity and depletion of natural resources.

5. Conclusion

Multiple factors from climate change to pressure on natural resources and exacerbation of inequality and poverty recall our attention on sustainable development concept and its measurement.

The Genuine Saving (GS) is one of the indicators proposed to assess the sustainable development of countries. This paper enriches the GS including firstly flood control and water purification ecosystem services and, subsequently, the social dimension measured by the Poverty Gap. The empirical analysis computes the regional GS for Italy for 2006, 2012 and 2015 and highlights the impact for each component (ecosystem services and poverty) across regions and over time.

Ecosystem services, the contributions of natural or managed ecosystems to benefits used in economic and other human activity, underpin our economy and well-being. The analysis reveals downward and upward trends for these services. For example, Trentino Alto Adige and Lombardia report higher monetary value of flood control and water purification compared to the rest of

Italy and their change from one year to another are positive. Contrary, Molise accounts for the lowest value of these services and decreasing monetary valuation estimates.

Secondly, the analysis integrates the social dimension (economic inequality and poverty) into the GS to better understand the sustainable pathway of Italy. Results reveal the impact of poverty on national GS estimates and disaggregates them into regional analysis with a focus on over time comparisons.

At country level, the inclusion of poverty generates a reduction of 4% with respect the "standard" GS in 2006, 3.6% in 2012 and 4% in 2015 which became negative in 2012 and 2015. This result is consistent with the increase in the national inequality from 2006 to 2015 and the huge decline from 2006 to 2012 of "standard" GS is probably due to the financial crisis of 2007-2008.

At regional level, results depend on the year of analysis. The general trend of GS with and without the poverty adjustment does not change in 2006. In 2012, the Trentino Alto Adige is the only region that passes the weak sustainability test keeping a positive value of GS (1% of its regional GDP) and the GS of fourteen regions out of twenty became negative after the inequality correction. The regions with already a negative value of GS (Abruzzo, Friuli-Venezia Giulia, Liguria, Valle d'Aosta) see the situation getting worse. In 2015, the overall situation reports an improvement - more regions have a non-negative adjusted GS - compared with the 2012.

In conclusion, the effect of the adjustment of the regional and national GS for poverty is remarkable and findings are useful to show the direction and intensity of this adjustment that should be considered for policy on sustainable development. Moreover, the integration of micro data on ecosystem services and macro data on Net Savings recommended by Stiglitz-Sen-Fitoussi Commission (Stiglitz et al., 2009) is empirical tested, and the extended GS might represent a valid substitute of the GDP.

6. Abbreviations

ANS	Adjusted Net Saving
GS	Genuine Saving
ES	Ecosystem -services
PG	Poverty Gap
PH	Poverty Headcount
SEEA-CF	System of Environmental Economic Account - Central Framework
SEEA-ES	System of Environmental Economic Account - Ecosystem Accounting
SNA	System National Accounting

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Appendix A The Genuine Saving's theoretical foundation

Hamilton e Clemens (1999) developed the formal model that was revised in 2000 by Dasgupta and Maler and in 2001 by Asheim and Weitzman. The present appendix recalls the basic model and the conceptual idea of Genuine Saving.

Assuming a simple closed economy and fixed population, the model aims to maximise the social well-being based on a representative individual.
The individual utility function is $U(C, X_i)$ where C is the consumption and X_i are the resources in the economy (e.g. know-how, health, wooden, CO_2 emissions).
The production function is $F(K, X_i, \dot{X}_l)$ and the composite good can be consumed, invested in capital K or used in quantity e_i to control other stocks; it is assumed i control functions f^i such $\dot{X}_l = f^i(X_i, e_i)$.

The social welfare V is defined as the present value of future utility as follows:

$$V = \int_t^\infty U\big(C(s), X_i(s)\big) e^{-\rho(s-t)} ds \tag{1}$$

where ρ is the fixed pure rate of time preference and $t < s < \infty$. Follow that the current utility plus the variation of welfare is equal to the return to the welfare itself. Formally:

$$U + \dot{V} = \rho V \tag{2}$$

The intertemporal optimization problem assumes that the social planner wishes to maximise wealth as follows:

$$max\ V = \int_t^\infty U\big(C(s), X_i(s)\big) e^{-\rho(s-t)} ds \tag{3}$$

subject to

$$\dot{K} = F - C - \sum e_i \tag{4}$$

$$\dot{X}_l = f^i(X_i, e_i) \tag{5}$$

The current value Hamiltonian function, which is maximized at each point in time, is given by,

$$H = U + \sum \gamma_i \dot{X}_l \tag{5}$$

where γ_i are the shadow prices in utils of resource with $\gamma_0 = U_C$. The shadow prices in consume units are computed by dividing the shadow prices for the consumer marginal utility:

$$p_i = \frac{\gamma_i}{U_C} \tag{6}$$

Rearranging the equation (5) and (6), the definition of Genuine Saving can be written as:

$$G = \sum p_i \dot{X}_l \tag{7}$$

The Genuine Saving consists, therefore, into the change in the real value of assets (e.g. human capital is valued at its marginal creation cost, pollution stocks are valued at marginal abatement costs and natural resources at the resource rental rate).

Plugging eq. (6) and (7) into eq (5) , we have

$$H = U + U_C G \tag{8}$$

The Hamiltonian can be interpreted as the sum of the current and future utility depending on the current investment. Moreover, the relation between the Hamiltonian function and the welfare in utility terms can be express as follows:

$$H = \rho V \tag{9}$$

Equations (2), (8) and (9) imply the following property:

$$U_C G = \dot{V} \tag{10}$$

This means that measuring negative genuine saving at a point in time implies that future utility is less than current utility over some period of time on the optimal path. Then, negative genuine saving serves as an indicator of non-sustainability.

ACKNOWLEDGEMENT

This thesis is the outcome of a long journey: a few years of research combined with the unpredictable up and down of life. During this time, I went through the COVID pandemic and lockdowns, the injustice of the war in Europe since 1945 and family difficulties; I grew up a lot personally and professionally thanks to many people who helped me in many ways: supporting and encouraging me, reminding me of the value of resilience and self-care in my life and the amazing beauty of the surrounding world despite unpleasant events.

The first person I need to thank is my supervisor Dr Silvia Ferrini, for her guidance and support. I am deeply and sincerely thankful that I met her during my master's degree; she has believed in my skills and abilities, raising my self-confidence at the right time. She allowed me to live my time as a PhD Student in the most complete and fulfilling way as possible, enriching my competences much beyond this thesis. She followed me in every step of my route giving me genuine advice and pushing me to improve myself and my research. At the same time, she has been trusting me and gave me all the freedom I needed. In this way, I think she allowed me to express, in the best way, my research interests and have my own PhD experience.

I would also like to thank all the board of the joint Ph.D. Program in Economics of the joint Universities of Tuscany, and in particular the Director, Prof Simone D'Alessandro and the administrative staff, Francesca Fabbri and Anna Paola Biondi for being patience every time with all the bureaucracy and my questions.

This thesis benefited from several discussions and comments; clearly, I am the only responsible for the content of it.

The first chapter of this thesis could not have been born without the kind willingness of Dr Matthew Agarwala and the useful comments of Prof Daina Coyle. I wish to acknowledge the participants of the Pontignano Annual Meeting 2021, especially Dr Chandni Dwarkasing who discussed my paper, and people of the parallel session of "Well-Being 2022: Knowledge for informed decisions" Luxemburg conference held by STATEC for their further suggestions. Moreover, I am very grateful for Prof Stefan Baumgärtner and the University of Freiburg for hosting me and giving me the opportunity to discuss my work in internal seminars and attend to lectures enriching my multidisciplinary background during my visiting period.