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The economics of Smart City policies

Abstract

A remarkable academic interest and consistent funding from national and supranational bodies has been concentrating on the topic of Smart Cities; consequently, Smart City policies have attracted relevant funding. However, no empirical evidence is to date available on the economic rationale of these policies. In particular, while few studies deal with the impact of smart urban characteristics and policies on urban performance, to date the link between smart features and policies on the one hand, and urban performance on the other hand, has never been explored.

In this paper we address this gap by empirically verifying whether smart urban policies foster urban economic growth, resting on the assumption that smart urban characteristics, while being growth-enhancing in the long run, have only an indirect effect on urban performance. This assumption is tested by means of a Instrumental Variables approach whereby urban performance is explained by Smart Urban Policies, along with a set of control variables. The model is tested on a data base of 309 European metropolitan areas, collected for this analysis and containing information both on smart urban characteristics and the intensity of smart policies.

Our empirical results suggest that Smart City policy intensity is associated with a better urban economic performance. Instrumenting smart policies with smart urban characteristics, besides, suggests that the causality direction goes from policy intensity to growth, and not vice versa (thus ruling out reverse causality). Policy suggestions based on these findings are finally provided.

Keywords: Smart City, Smart Urban Policy, Urban Growth, Instrumental Variables

JEL Classification codes: R11, R58

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1. Introduction

The literature on Smart Cities has come a long way since the early talk about the intertwined role of Information and Communication Technologies (henceforth, ICTs) and urban growth-enhancing characteristics. The famous call by Hollands (2008) for real smart cities to stand up could be now replaced, if anything, with a call for a sound and clear empirical assessment of the real smart city effect to introduce itself.

In fact, despite the to date burgeoning literature on Smart Cities (Komninos and Mora, 2017), it is often difficult to exactly pinpoint the real economic effect of being 'Smart'. The planning and geography literatures have stressed this novel concept as means to logically organize efficiency –enhancing urban features (Anthopoulos and Vakali, 2012), but the economics literature has been surprisingly scant on this front. In particular, only isolated attempts to identify correlations between Smart City characteristics and urban economic performance have been so far attempted (Caragliu and Del Bo, 2012).

The vast academic interest in the concept of Smart City has also been reflected in a number of policy initiatives aiming to build on Smart urban characteristics to foster urban efficiency and growth. The flow of money into local Smart City initiatives has also elicited a number of critiques against the predominance in the Smart City literature of a business–oriented perspective (Vanolo, 2014). In this critical view, the discussion about urban smartness would be steered by major multinational corporations, which would be biased towards suggesting to local boards the efficiency-enhancing effect of installing ICTs (sensors, communication devices etc.).

Once again, the economics literature has been shying away from empirically assessing the effect of Smart City policies, not the least because such policies have only recently been attempted, and, therefore, their effect may not have been fully reflected in economic data. In fact, to our knowledge only few attempts to link smart urban characteristics and Smart City policies have been made, without directly linking both to urban economic performance.[3]

Lastly, despite the relevant funding devoted at all territorial governance levels, an important role being played by the European Union by means of the Smart Cities and Communities (henceforth, SCC) initiative, to date not enough attention has been paid to the economic rationale underlying Smart City policies and their potential growth effects on cities.

In this paper, we exploit the early and limited evidence about the impact of Smart City policies, and the conjecture that urban smartness does not lead directly to GDP growth, as an identification strategy to assess the link between smart policies and urban growth.

The paper provides a relevant contribution to the Smart City literature. Our empirical estimates provide evidence about (i.) the existence of a positive association between Smart City policies and urban growth, measured as the growth of GDP in EU metro areas, and (ii.) the fact that this association can be interpreted in a causative sense, on the basis of the identification strategy discussed below, and the ensuing instrumental variables estimates. To the best of our knowledge, this is the first contribution to the literature systematically attempting to link smart urban policies and urban economics performance, in particular using a broad data base covering a large cross section of European cities.

The paper is organized as follows. In Section 2 we review the literature on Smart Cities with a specific focus on the economic appraisal of smart urban policies. In Section 3 we describe our empirical approach, focusing on the identification strategy underlying our estimates. In Section 4 we review the details of the data set assembled for

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[3] In one of these few contributions, positive evidence about the link between Smart Urban characteristics and Smart City policies has been identified (Caragliu and Del Bo, 2016), without actually finding a direct impact of either on urban economic performance.

our empirical exercise. Section 5 presents the empirical results, while, finally, Section 6 concludes and draws possible policy implications.

2. Smart City policies

The literature on Smart Cities has thrived over the last few years.[4] In this section, we will focus on a relatively underexplored issue, i.e. Smart City policies. In fact, while the academic world has actively participated in the debate about the definition of the concept of Smart City, it has relatively neglected the policy appraisal side.

Despite the non-negligible funding available at all spatial scales, but chiefly from the European Union through the SCC initiative, to date insufficient attention has been paid to a careful analysis of both the economic rationale for Smart City policies, as well as their potential growth-enhancing effects on cities.

Thus, two major issues seem relevant for the scope of our analysis. On the one hand, Smart City policies must show some feature that makes this specific object of policy different from other axes of intervention. In other words, the economic rationale for Smart urban policies should be clarified. This literature is summarized in Section 2.1.

On the other hand, once the nature of such policies has been defined, their expected impact on urban growth should be discussed, possibly with an eye on a possible empirical strategy to appraise the impact. This second type of literature is critically discussed in Section 2.2.

2.1 The economic rationale of Smart City policies

The notion of Smart City is intended as a way to logically organize a set of growth-enhancing urban factors that have already been discussed in the economics, planning, and geography literatures. Among the many definitions of this concept, in this paper we follow the one provided in Caragliu et al. (2011), whereby a city is defined as smart when "*investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance*" (Caragliu et al., 2011, p. 70). This definition follows on the seminal ranking by Giffinger and coauthors (Giffinger et al., 2007), where urban performance is ranked along six axes including Smart Economy, Smart Mobility, Smart Environment, Smart People, Smart Living, and Smart Governance.

In this stream of literature, what distinguishes urban smartness from other germane definitions is in fact the synergic interplay between tangible and intangible features. Each of the growth enhancing factors, categorised under the six axes definition of the Giffinger path, has in fact been individually linked to urban productivity growth. In this section, the link between each of the axis comprised in the adopted definition of Smart City and urban economic performance will be reviewed, with the aim to lay down the foundations for the subsequent empirical analyses.

Human capital has been recently found to play a crucial role in determining urban growth (a literature originated from the seminal work by Berry and Glaeser, 2005). More educated and more productive people tend to sort in cities (Combes et al., 2008), and the localised accumulation of human capital engenders positive externalities at the urban level not only in terms of higher productivity, but also in terms of social capital (in particular, lowering criminal participation and improving citizenship's political behaviour: Moretti, 2004). It thus comes as no

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[4] The scope of this section is not to review the generic literature on Smart Cities, and in particular on the way this concept can be defined. The interested reader is referred to Caragliu et al. (2015) for a broad overview of this type of literature; to Angelidou (2015) for a classification of the existing literature in terms of *urban futures* and the *knowledge and innovation economy*; to Nijkamp and Kourtit (2017) for a Regional Science perspective on this topic; to Giffinger and Haindlmaier (2010, 2017) for a review of the use of rankings in the Smart City literature; and to Komninos and Mora (2017) for a bibliographic analysis of the literature, with a geographic and thematic breakdown.

surprise that cities with higher levels of social capital are also found to overperform with respect to similarly endowed cities where social capital, mostly by shaping different returns to human capital (Glaeser and Redlick, 2009). An additional channel that engenders creative resonance here is due to the fact that physical proximity enhances social interactions, thereby maximising the potential returns from social capital (Glaeser and Sacerdote, 1999).

Earlier literature has also shown that thicker and more efficient transportation networks both internal as well as external to the city make cities more productive. For instance, Duranton and Turner (2012) show that a 10 per cent increase in a city’s stock of highways is in the medium run associated to a 1.5 per cent increase in employment, while Höll (2016) finds that manufacturing firms become more productive the easier their access to transportation networks. Often, investment in transport infrastructure changes the structure of spatial incentives and exposes weaker urban areas to increased competition from more productive ones, which may in the long run prove an unsustainable challenge for lagging regions (Capello, 2016; Faber, 2014); and relevant spatial spillovers are found to characterise the impact of the creation of infrastructure, with a heterogeneous distribution of the benefits accruing to local actors (Del Bo and Florio, 2012).

More recently, the widespread availability of Information and Communication Technologies (henceforth, ICTs) has prompted the emergence of a vast literature discussing the productivity enhancing role played by digital infrastructure at different spatial scales. Basu et al. (2003) find overwhelming evidence that the divergence of productivity growth between the US and UK can be explained on the basis of different ICTs adoption rates. Given its early focus on the role of ICTs in explaining urban development, the Smart City literature has often provided evidence about the (on average) higher endowment with ICTs of Smart Cities w.r.t. cities of comparable size (Baucells et al., 2016). Clearly, the widespread diffusion of ICTs is not exempt from major drawbacks and side effects: fir instance, Audirac (2005) finds a strong negative effect of the diffusion of ICTs on compact urban form, while Graham (2002) discusses the potential redistribution and income polarization effects exerted by the unequal diffusion of ICTs among the urban population.

Urban locations are often associated with higher quality of life. This is testified both in spatially aggregate empirical (e.g. Shapiro, 2006), whereas urban productivity growth is associated to higher quality of life measures, as well as in a recent and promising stream of literature which uses micro data to explore the association between urban features and individual life satisfaction (see for instance Lenzi and Perucca, 2016 for a recent example). A classical stream of studies, based on the traditional Rosen-Roback spatial equilibrium setting, has also used hedonic price models to identify the quality-of life premium associated to urban locations (see e.g. Blomquist et al., 1988).

The issue of urban sustainability has also gained much attention over the last two decades (Maclaren, 1996). A sustainable and wise management of natural urban resources is in fact a necessary condition for achieving long run economic success. The depletion of natural resources can in fact seriously affect the availability of production factors for future generations. In empirical terms, this point has been captured mostly by a burgeoning literature dealing with the impact of urban form, and in particular sprawl, on economic performance and social sustainability. Most literature typically finds that a compact urban form is more sustainable, and, therefore, conducive to a better long run economic performance (Camagni et al., 2013). However, fewer yet strong advocates (e.g. Glaeser and Kahn, 2004) exist of the opposite case, viz. that sprawl makes urban dwellers better off, also thanks to the technological change that reduced the costs associated to a dispersed urban form.

A final an interesting element of novelty in the Smart City definition adopted in this paper is that of participated governance. In the Smart City literature, participatory governance is often found to make cities smarter and, thus, more efficient. Participated governance also means that cities that foster the co-participation of public and private institutions in Smart projects makes such projects more prone to success (Rodríguez Bolívar, 2017); in fact, recently a holistic approach to the evaluation of smart city performance, in the light of a bottom-up participatory approach oriented towards the creation of public value has been advocated in Castelnovo et al. (2016).

2.2 The expected impact of Smart City policies

As for the expected impact of Smart City policies, recent evidence convincingly shows that Smart City policies tend to be undertaken by urban areas that already score high in one or more of the axes of the definition used in this paper (Neirotti et al., 2014). As also documented in Caragliu and Del Bo (2016), "*Smart City policies are more likely to be designed and implemented in cities that are already endowed with smart characteristics*" (Caragliu and Del Bo, 2016, p. 657). The complexity of Smart City policies impact is clarified in Angelidou (2014), who provides a useful classification of Smart City policies along four main axes, i.e. whether Smart policies:

- are undertaken at the local or the national level;
- are applied to existing cities or geared towards the creation of brand new ones;
- focus on hard or soft infrastructure;
- are organised along a sector-oriented or place-specific axis.

In turn, local context conditions are also a crucial determinant of Smart City policy effectiveness (Neirotti et al., 2014); and a shared, bottom-up approach in integrating infrastructure is often a critical factor for maximising these policies (Lee et al., 2014).[5]

Given the structural multifaceted nature of smart cities, the economic impact of the adoption of Smart City policies is in turn expected to be complex. In this subsection such impact will be analysed in terms of the channels through which it may possibly happen.

The first and most straightforward channel through which Smart City policies may work is through enhancing urban efficiency (Chourabi et al., 2012). This happens by means of financing one or more of the axes described in Subsection 2.1. For instance, Smart city policies have often stimulated the widespread availability of knowledge and information, especially in terms of big data (Kitchin, 2014).

A second major channel through which Smart city policies may act is through increased citizens participation. As stressed in the definition of Smart City adopted in this paper, participation of various social groups to the construction of Smart Cities is one of the most notable elements differentiating this concept from other similar notions in the literature. In fact, the literature is replete with calls for paying attention to the redistributional effects possibly engendered by enacting Smart City policies focusing just on the technological contents, and ignoring the soft factors needed for urban dwellers to fully absorb such new technologies. For instance, Coe et al. (2001) suggest that in the absence of a careful attention being paid to soft infrastructure, risks of unequal Smart City policies effects may be relevant.

A third and last relevant way of fostering urban efficiency when Smart City policies are enacted is through an increase in business opportunities. Despite the relatively young literature on this topic, in fact, evidence is quite strong in suggesting that cities investing in Smart City policies also tend to be more proactive in attracting productive workers and firms (Bowerman et al., 2000). Nam and Pardo (2011) suggest that technology-intensive companies involved in the application of Smart technologies may engender local spillovers that can trigger positive feedback effects; and this may even prove a strategic way out of the economic crisis, as argued in Paroutis et al. 2014). In fact, the widespread adoption of e-technologies, sensors, and smart technological solutions has prompted many critiques against the business-oriented nature of the very notion of urban smartness (Vanolo, 2014).

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[5] This point will be taken into account in our empirical exercise, by controlling for a set of local growth-enhancing factors in our estimates.

All these points can be summarized in the expected positive relationship between the adoption of Smart City policies and urban economic performance, captured either by means of higher productivity growth, or higher GDP growth. An interesting remark to be made here is the notable absence in this literature of a direct link between urban smartness and urban economic performance. In fact, to date no attempt has been made to empirically evaluate the causal relationship between the interplay of smart urban characteristics posited in the definition of Smart City adopted in this paper and urban economic performance.[6] Instead, evidence suggests that investing in one or more of the typologies of policies here summarised is expected to stimulate urban economic growth. In this paper we will hinge on this point for our identification strategy, as further explained in Section 3.

Despite the large sums invested in Smart City policies, nevertheless, the literature on the economic impact of Smart City policies is surprisingly scant. Mostly, it focuses on case study evidence of the impacts of the adoption of one or more type of Smart City policies on overall urban efficiency. Notable examples of cities that boast effective Smart City policies include Barcelona (Bakici et al., 2013), Seoul and San Francisco (Lee et al., 2014), or Louisville and Philadelphia (Shelton et al., 2015). A grand overview of the empirical association between Smart City policies in a cross-section of cities and urban performance is instead mostly absent; this paper aims to fill this gap, by answering the following research question:

RQ *What is the economic impact of adopting Smart City policies on urban growth?*

Section 3 will explain the empirical strategy adopted to provide an empirical answer to this research question.

3. Empirical approach and identification strategy

On the basis of the literature review discussed in Section 2, and of the complex and multifaceted nature of the concept of Smart City, the indicator of urban performance that seems most appropriate to fully reflect the various impacts and channels of Smart City policies is urban GDP growth.

The research question of this paper faces a number of relevant empirical issues. The two most relevant problems are related on the nature of Smart City policies impact (do Smart City policies directly foster GDP growth?), and the potentially relevant issue of endogeneity (do Smart City policies foster GDP growth, or do faster-growing cities tend to invest more in Smart City policies?).

These two issues are solved simultaneously with the following identification strategy. As clarified in the previous section, there is very limited evidence of a direct causal impact of smart urban features on economic performance. Individually, each axis of the adopted definition is found to be associated to economic growth, but so far no evidence exists on the synergic interplay between the six axes and economic performance. However, the literature does suggest the existence of a positive association between investing in Smart City policies and urban economic growth. We will hinge on this finding (and test it empirically) in order to identify the causal link between this type of policy and urban economic performance. The natural candidate for this type of econometric exercise is the Instrumental Variable (IV) Estimator.

Formally, our research question is translated into the following testable equation:

$$\Delta GDP_{i,T-t} = \alpha_{i,t} + \beta_{i,t} * GDP_{i,t} + \gamma_{i,t} * smart\_policies_{i,t} + \delta_{i,t} * density_{i,t} + \\ + \varphi_{i,t} * R\&D_{i,t} + \vartheta_{i,t} * institutions_{i,t} + \varepsilon_{i,t} \qquad (1.)$$

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[6] Empirically, a test of this assumption would entail the use of interactions among individual measures of the six axes comprised in the definition adopted in this paper. While potentially interesting, this exercise is not undertaken in this paper and is left as a future research avenue.

where index i indicates a city in our sample, indices t and T refer to time (here equal respectively to 2008 and 2013), ΔGDP and GDP indicate urban GDP growth and the initial level of GDP, respectively, *smart_policies* is our indicator of Smart City policy intensity, *density* is a measure of agglomeration economies (captured by population density), *R&D* stands for expenditure in Research and Development, and finally *institutions* is a measure of the local quality of institutions. Finally, $\varepsilon_{i,t}$ is the usually i.i.d. error term.

Methodologically, our IV estimates use the indicator of urban smartness described in Section 4 below for instrumenting Smart policies. The exclusionary restriction in this case therefore requires urban smartness to be associated with a higher chance to enact Smart City policies, as argued in Caragliu and Del Bo (2016), without however a direct link with GDP growth, as argued in the literature summarised in Section 2. A second instrument used for identifying the causal link between Smart City policies and urban growth is a dummy, equal to 1 when the city is the Country capital. In this case the rationale is that administrative and power centres are expected to more easily attract funds targeting the creation of Smart Cities, without however being necessarily bound to grow faster.[7]

This exclusionary restriction will be empirically tested in Section 5.

4. Data and indicators

A new data set has been used for this empirical exercise, with data covering three major axes:

- Intensity of smart urban policies;
- Socio-economic characteristics of European cities;
- Urban economic performance.

In the remain of this section we review sources and methods for each of these three dimensions.

4.1 An indicator of smart urban policies

In order to measure the intensity of Smart urban policies we refer to the approach developed in Caragliu and Del Bo (2016). Accordingly, four main data sources on policy intensity have been analysed:

- cities implementing smart policies in the list prepared by European Parliament (2014);
- cities member of the Eurocities network;[8]
- cities participating in Framework Programme 7 (henceforth, FP7) Smart City initiatives;
- cities actively cooperating with a major Multinational Company offering Smart urban services.

Each of these sources is described in detail below.

European Parliament (2014) discusses successful case studies of cities implementing Smart City policies. In this case, being successful means enjoying an alignment between city-level policy objectives and EU2020 goals. In our data base, this information translates into a dummy variable, equal to 1 if cities are included in this study 0 otherwise.

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[7] Indeed, recent evidence suggests that small and medium-sized cities may have outperformed larger urban areas, at least in the EU context (see e.g. Dijkstra et al., 2013, and Camagni et al., 2015).

[8] http://www.eurocities.eu/

The Eurocities network has been created in 1986 by eleven European cities, with the goal of enhancing networking between non-capital cities. This group now encompasses 103 members, organized in forums, working goups and projects. The goal of this network is related to the view that cities are engines of smart and sustainable growth in the EU, and the network's major working group is precisely on Smart Cities.[9] We have thus created a second indicator variable that assigns value 1 to cities belonging to this network and 0 otherwise.

Using data from the factsheets on Smart City Projects[10] and the European Commission's SCC web page,[11] which are part of the European Commission's Digital Agenda, information on public involvment and funding of municipal offices to FP7 is collected.

In order to have a more comprehensive picture of the implementation of Smart City policies, the information on participation in already funded projects is complemented by involvement in Commitments at the city level.[12]

Commitments are non-binding but represent voluntary expressions of interest of public and private partners[13] to actively and concretely support the overall objectives of the European Innovation Partnership on SCC. Commitments are expressed in different subject areas, which can be linked to the six axes of our Smart City definition (Section 2.1), while official FP7 projects are for the most part in the field of energy efficiency, following the EU's reading of Smart Cities (Crivello, 2014). From a policy perspective, this seems particularly fitting the aim of these empirical analysis; in fact, SCC is based on stakeholders' commitments, thereby allowing the matching of funding devoted to R&D with institutional budget of the involved actors,[14] very much in line with the discussion about the need for a bottom up approach in delivering Smart City solutions (Schaffers et al., 2011).

Since cities can be part of several EU-funded projects (EU_FP and EU_SCC, respectively) and Commitments (EU_committ), we have used a count measure of participation. The resulting variables are then standardized on a 0-1 scale, with 0 indicating cities with no participation to any of these initiatives, and 1 associated to participation in several activities.

In order to provide a complete picture of Smart City policies, the involvement of private actors is explicitly considered. In fact, as mentioned above, Smart City actions often revolve around the development and use of technological applications developed by private technological firms. As a first step in the measurement of the inclusion of private actors in the design and implementation of Smart city policies, we have considered one of the major private players, IBM, to account for this aspect. While considering a single private actor may lead us to downsize the phenomenon, the choice was driven by the fact that IBM hosts a dedicated web site[15] for its Smart City initiatives, listing current projects. Additional private actors should be included in future research on the subject. The variable private takes on value 1 if this private firm is a partner of the municipal offices in the implementation of Smart City policies and 0 otherwise.

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[9] http://www.eurocities.eu/eurocities/activities/working_groups/Smart-Cities&tpl=home. It must be acknowledged that not all Eurocities member actively engage in self-defined Smart City projects; however, it is reasonable to state that such membership closely mimics the definition of the six axes presented in Giffinger et al. (2007), and resonating in Caragliu et al. (2011). In fact, Eurocities members organise projects along the following seven axes: (i.) Culture; (ii.) Economy; (iii.) Environment; (iv.) Knowledge society; (v.) Mobility: (vi.) Social affairs; (vii.) Cooperation. Lastly, this is just one of the categorical indicators adopted in the empirical analyses to capture the extent to which cities score in terms of their *smartness* attitude. We would like to thank an anonymous referee for pointing at this possible issue.

[10] http://ec.europa.eu/digital-agenda/en/node/72869

[11] http://ec.europa.eu/eip/smartcities/index_en.htm

[12] http://ec.europa.eu/eip/smartcities/files/ifc-faq_en.pdf.

[13] Among the Commitments presented in 2014, 36 per cent of lead organizations are Public Authorities, 26 per cent Businesses and 16 per cent Academic Institutions.

[14] We would like to thank an anonymous reviewer for pointing at this relevant link between our indicators and the institutional setting of this EU initiative.

[15] http://smartercitieschallenge.org/smarter-cities.html

4.2 An indicator of urban smartness

The urban smartness indicator used in these analyses is the same calculated for the first time in Caragliu and Del Bo (2015). In that work, the six axes of the definition of a Smart City discussed in Section 2.1 and following the Giffinger et al. (2007) classification have been measured on the basis of Urban Audit data by means of a Principal Components Analysis. As illustrated in in Table 1, at least four indicators for each axis of the definition have been calculated.[16] Then, each axis is assigned a score by reducing the information of the axis indicators through a Principal Component Analysis. Finally, the six indicators are averaged to get a unique Principal Component measuring aggregate urban smartness.

The six axes selected for calculating the aggregate urban smartness indicator cover a sample of 309 EU cities for the following six dimensions:

- Human capital;
- Social capital;
- Transport infrastructure;
- ICTs;
- Natural resources;
- E-government.[17]

In order to more sensibly fill the inevitable gaps in data and maximize data availability, we have considered the mean value for the period 2008-2012, thus making use of three waves of data of the Urban Audit collection. Missing data, not negligible in some specific data vectors, were filled by different techniques:

- Whenever possible, the value of each indicator for the spatially closest urban area has been used;[18]
- In the case of specific data vectors were missing values were systematic, data from the closest hierarchical NUTS classification has been used. This is the case of the raw indicator concerning the percentage of families with internet access at home; in the absence of city-specific data, data from the corresponding NUTS1 region have been used;
- In the case of systematically varying subsamples of data for a vector with strong correlation with another vector under the same axis of data, the average ratio of the two indicators for which both data vectors were available within the same Country and axis has been calculated and this ratio applied to the observations for which data for one of the two vectors was missing. This is for instance the case of the two vectors "Proportion of solid waste arising within the boundary processed by recycling" and "Proportion of the area in green space", both falling under the *Natural resources* axis. For countries such as the Czech Republic some cities were missing data for the first indicator, but several had both available.
- Lastly, whereas none of the above solutions was possible, the average Country value, or the minimum of the Country data distribution, depending on the location of each city, has been used.

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[16] Raw data are in general obtained from Urban Audit, but additional sources also include ESPON FOCI data (Lennert et al., 2011) and EUROSTAT data at NUTS2 level.

[17] The set of six axes reflects the spirit of Giffinger et al. (2007), and is also discussed in Albino et al. (2015) as being at the forefront of means to measure Smart Cities' performance. A similar structure has also been recently adopted in Hara et al. (2016) for measuring smartness within cities.

[18] This is true for all indicators calculated as percentage or relative intensities, for which, thus, a meaningful comparison across different urban areas can be attempted.

Urban smartness axis	Raw data
1. Human capital	Proportion of population aged 15-64 qualified at tertiary level (ISCED 5-6) living in Urban Audit cities - %
	Students in tertiary education (ISCED 5-6) living in Urban Audit cities - number of students per ,1000 inhabitants
	Proportion of employment in financial intermediation business activities
	Proportion of employment public administration health education
	Number of companies with headquarters in the city quoted on the national stock market
2. Social capital	Car thefts per 1,000 pop.
	Burglaries per 1,000 pop.
	Crimes per 1,000 pop.
	Number of elected city representatives
3. Transport infrastructure	Length of public transport network per inhabitant
	Share of restricted bus lanes from public transport network
	Number of buses (or bus equivalents) operating in the public transport per 1,000 pop
	Number of stops of public transport per 1,000 pop.
4. ICT infrastructure	Percentage of families with internet access at home
	Number of local units producing ICT products
	Number of local units producing ICT-related services
	Number of local units producing web content
5. Natural resources	Proportion of solid waste arising within the boundary processed by recycling
	Proportion of the area in green space
	Green space (in m2) to which the public has access, per capita
	Annual average concentration of PM_{10}
	Annual average concentration of NO_2
6. E-government	% of internet users who interacted via internet with the public authorities in the last 12 months (Country data)
	% of internet users who sent filled forms to public authorities in the last 12 months (Country data)
	Number of administrative forms available for download from official web site
	Number of administrative forms which can be submitted electronically

Table 1. Indicators for the 6 axes of the Smart City definition

Source: Caragliu and Del Bo (2015)

Individual indicators are now individually described. Firstly, for human capital we follow up to the definition given in Caragliu et al. (2012), which brings together education (here measured with the number of students in tertiary education per 1,000 inhabitants), the functional/sectoral component (here captured by means of the share of employment in skill-intensive industries), and the position of the city within the urban hierarchy (here proxied by the number of companies listed on a stock exchange with headquarters in the analysed city). The resulting human capital indicator thus better reflects the multifaceted nature of this concept, especially within cities.

Social capital is also a multidimensional concept. Here we follow Putnam et al.(1993), which refers to the political action component of this concept (here measured with the number of elected representatives in each city), and add to this classical contribution the work by Akçomak and ter Weel (2012), which shows that cities with lower crime rates are also characterized by higher levels of social capital. In our analyses, this issue is captured with the number of car thefts, burglaries and crimes per 1,000 inhabitants.[19]

The density of urban transport infrastructure is measured by the length of the public transport network and the number public vehicles in each city's urban fleet; the network's quality is instead proxied with the proportion of restricted bus lanes over the total street lanes and the number of stops per 1,000 inhabitants (Geurs and van Wee, 2004).

A crucial element in the measurement of the Smart City definition followed in this work is how to properly capture the quality of ICTs endowment. To this aim, we refer to OECD (2005), where ICTs have been found to be characterized both a demand side as well as a supply side. Here, we measure the demand side of ICTs with a measure of household internet access, while the supply side is proxied by in the production of ICT products, services and web contents in each city.[20]

It is worth stressing that this choice is not exempt from criticism. For instance, it has been argued that "*policy prominence retained by supply-side benchmarking of e-government has probably indirectly limited efforts made to measure and evaluate more tangible impacts. High scores in EU benchmarking have contributed to increasing the institutionally-perceived quality but not necessarily the real quality and utility of e-government services*" (Codagnone et al., 2015, p. 305). However, in the absence of city-specific comparable measures of the quality of e-government services offered by local administrative bodies, ours still appears to be the most reasonable solution to proxy for the intensity of e-government efforts of local boards.

The natural resources axis is captured by means of the percentage of waste that is disposed of by recycling, the amount of public green space in each urban area (as a share of total area)[21] and the annual average concentration of PM_{10} and NO_2, as indicators of the intensity of pollution.

Lastly, e-government is measured by the percentage of internet users who interacted with, and downloaded documents from, public authorities, as well as by the number of administrative forms that can be submitted and downloaded electronically (Welch et al., 2005). These data are only available at the country level and are thus attributed to each city in terms of the urban area's share of Country population.[22]

As anticipated above, each of these individual indicators is obtained by means of a Principal Components Analysis, using as an indicator of each axis components associated with the largest eigenvalue (Kaiser, 1961)

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[19] The causal relationship between social capital and civic participation, including involvement in local elections, has been extensively analyzed starting from the seminal work of Coleman (1988).

[20] The use of multiple indicators for measuring ICTs has also been advocated in Misuraca et al. (2013), along with the introduction of a reflexive meso level in the appraisal of the impact of ICTs in the different society's domains.

[21] See also Tajima (2003) for more details on the use of green area in similar empirical studies.

[22] Despite the two decades-long history of e-government solutions, their adoption rates are surprisingly low also in developed countries. This translates also in a relatively poor process of measuring the extent to which these solutions actually enter administrative bodies, and is typically explained with a concentration on e-government investment in technological and operational matters and by institutional and political barriers (Savoldelli et al., 2014).

and for which factor loadings are conceptually reasonable (Dunteman, 1989). The six Principal Components are finally aggregated, by simply un-weighted averaging the indicator, to finally obtain an aggregate indicator of urban smartness. The six tables with the factor loadings and the associated eigenvalues for the six axes are reported in the Technical Appendix.[23]

4.3 Indicators of other urban characteristics

All remaining data for our empirical exercise are collected at the EUROSTAT metro areas level, [24] apart from the indicator of the urban quality of institutions. For this last measure, we use the 2010 version of the data base described in Charron et al. (2015), which creates a unique indicator out of measures of the quality of governance understood in terms of low corruption, impartial public services and the rule of law. These data are collected at NUTS2 level, and the value of each NUTS2 region is assigned to the metropolitan area located in the region.

5. Empirical results

Table 2 shows the empirical estimates of Eq. (1), based on the Instrumental Variables regressions based on the identification strategy described in Section 3.

In Table 2, columns differ in that additional regressors are progressively added to our estimates. Thus, potential differences across columns is meant to highlight possible multicollinearity issues. It is worth stressing that our estimates display no such behavior – magnitudes and significance of the estimated parameters do not vary significantly across columns. The only exception is represented by the initial level of GDP, initially estimated to be negatively and significantly correlated to GDP growth as in the traditional conditional convergence literature. This variable becomes insignificant after including a dummy for cities located in New member States.[25] Besides, all regressors are standardised. Hence estimated coefficients can be interpreted as elasticities.

Across all model specifications, the indicator of Smart City policies is positively and significantly associated to a higher GDP growth. In the last column, which encompasses the full set of control variables in our model, the estimated coefficient suggests that a one standard deviation increase in policy intensity is associated, all else being equal, to a .16 standard deviation increase in GDP growth. All standard IV tests are significantly passed. Both the underidentification and the weak identification tests are confidently rejected. Besides, Hansen's statistic suggests that instruments are not over identified, which strengthens the case for our identification strategy.

Finally, all control variables are positively and significantly associated to urban GDP growth, with the only exception of density, which is puzzingly found to be negatively associated to economic performance.

These analyses make a quite strong case for a positive and causative association between Smart City policies and urban growth. It must be acknowledged, however, that the economic sphere could not be the only one positively affected by investing in such policies; a holistic approach to the appraisal exercise here discussed, as advocated in castelnovo et al. (2016) could provide further insight into the complex mechanisms at play.

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[23] The interested reader is referred to Caragliu and Del Bo (2015) for more details on this urban smartness measure, where it has been first shown.

[24] "*Metropolitan regions are NUTS3 regions or a combination of NUTS3 regions which represent all agglomerations of at least 250 000 inhabitants. These agglomerations were identified using the Urban Audit's Functional Urban Area (FUA). Each agglomeration is represented by at least one NUTS3 region. If in an adjacent NUTS3 region more than 50% of the population also lives within this agglomeration, it is included in the metro*" (EUROSTAT, 2013).

[25] New Member States in this case include all Countries accessing the EU from 2004 onwards.

Dependent variable	*Metro area GDP growth rate, 2008-2013*				
Model	(1)	(2)	(3)	(4)	(5)
Constant term	0.08***	0.10***	0.24***	0.09**	0.02
	(0.00)	(0.00)	(0.02)	(0.04)	(0.03)
Initial per capita GDP	-0.02***	-0.02***	-0.03***	-0.04***	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Intensity of Smart City Policies	0.11***	0.23***	0.22***	0.24***	0.16***
	(0.00)	(0.00)	(0.00)	(0.06)	(0.06)
Population density	-	-0.01***	-0.01***	-0.01***	-0.01***
		(0.00)	(0.00)	(0.00)	(0.00)
R&D expenditure	-	-	0.03***	0.02***	0.02***
			(0.00)	(0.00)	(0.00)
Quality of local institutions	-	-	-	0.04***	0.04***
				(0.01)	(0.01)
Dummy New Member States	-	-	-	-	0.05***
					(0.01)
Number of obs.	309	309	309	309	309
R^2	0.26	0.28	0.28	0.29	0.32
Joint F test	51.42***	30.94***	46.43***	40.32***	56.52***
Estimation method	IV	IV	IV	IV	IV
Variable insturmented	Intensity of Smart City Policies				
Instruments used	Urban smartness; dummy, equal to 1 if the city is the Country capital				
Underidentification test (Kleibergen-Paap rk LM statistic)	46.13***	34.17***	34.03***	30.65***	21.41***
Weak identification test (Cragg-Donald Wald F statistic)	50.47***	33.23***	32.61***	31.11***	19.12***
Hansen J statistic (overidentification test of all instruments)	19.24***	6.33**	2.41	0.36	0.48

Table 2. Empirical estimates of Eq. (1): Smart City policies and urban economic performance.
Note: heteroskedastic-robust standard errors in brackets.
, **, and * indicate significance at the 90%, 95%, and 99%, respectively.*

6. Conclusions and policy implications

This paper entered the growing debate on the economic impact of Smart City policies. Our contribution offers for the first time to our knowledge an empirical assessment of this impact. Our empirical exercise uses a new data set covering a wide range of urban characteristics and merging information from EUROSTAT's Urban Audit and regional quality of institutions data set.

Our findings provide strong evidence of a positive association between investing in Smart City policies and Urban GDP growth. Moreover, our empirical estimates suggest that this association is causal, or, in other words, Smart City policies foster economic performance, thus ruling out reverse causality.

Given the remarkable amount of richly-funded projects on this topic, this assessment exercise is of paramount importance for policymakers at all spatial scales. Yet, several questions remain unanswered and a number of details could be improved.

First of all, the existence of a direct link between Smart urban features, and the possible synergic role they may play in stimulating economic growth, is yet to be inspected. Ideally, this exercise would require longer time spans in the data, in order to uncover possible long run effects that the data base collected for this paper cannot capture.

Secondly, our dependent variable is measured at a very specific point in time, which in Europe marked the most relevant economic downturn since 1929 (Capello et al. 2015). Thus, our findings would need to be corroborated on a different frame, closer to a situation of long term equilibrium. Presently, our findings suggest that Smart City policies can play an important role in abating crisis effects, but their long run effect still calls for further empirical research.

Lastly, a sound conceptual classification of existing Smart City policies could also be beneficial. Presently, these policies comprise a wide range of measures, both spatially and sectorally heterogeneous. A rigorous survey of their extent, main purpose and economic rationale would offer a great deal of information for those interested in identifying their real effect.

From a policy perspective, the existence of scientific evidence on the impact of Smart city policies should not be underestimated and would ideally elicit a process of monitoring of the diffusion and intensity of these policies in European cities. The current panorama of Smart City policies is scattered in terms of responsibility and effectiveness, and a better coordination at the supranational scale could maximise the impact of these policies, avoiding overlappings and inefficiencies.

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Technical Appendix

	Component1	Component 2	Component 3	Component 4
Students in tertiary education (ISCED 5-6) living in Urban Audit cities - number of students per 1000 inhabitants	-0.08	0.81	0.55	-0.19
Proportion of employment in financial intermediation business activities	0.70	0.16	0.10	0.69
Proportion of employment public administration health education	-0.42	-0.41	0.69	0.42
Number of companies with headquarters in the city quoted on the national stock market	0.57	-0.38	0.46	-0.56
Eigenvalue	1.34	1.02	1.00	0.65
Difference	0.32	0.02	0.35	*na*
Proportion	0.33	0.25	0.25	0.16
Cumulative	0.33	0.59	0.84	1.00

Table A1. Results of PCA for the human capital component

	Component1	Component 2	Component 3	Component 4
Car thefts per 1,000 pop.	0.58	0.08	-0.17	-0.79
Burglaries per 1,000 pop.	0.53	-0.33	-0.60	0.49
Crimes per 1,000 pop.	0.52	-0.31	0.78	0.18
Number of elected city representatives	0.33	0.89	0.06	0.32
Eigenvalue	1.74	0.95	0.70	0.61
Difference	0.79	0.25	0.09	*na*
Proportion	0.43	0.24	0.18	0.15
Cumulative	0.43	0.67	0.85	1.00

Table A2. Results of PCA for the social capital component

	Component1	Component 2	Component 3	Component 4
Length of public transport network per inhabitant	0.69	0.04	0.03	0.72
Share of restricted bus lanes from public transport network	-0.34	0.62	0.66	0.27
Number of buses (or bus equivalents) operating in the public transport per 1,000 pop	0.07	0.76	-0.64	-0.09
Number of stops of public transport per 1,000 pop.	0.64	0.21	0.39	-0.63
Eigenvalue	1.29	1.07	0.90	0.74
Difference	0.21	0.17	0.16	na
Proportion	0.32	0.27	0.22	0.18
Cumulative	0.32	0.59	0.82	1.00

Table A3. Results of PCA for the transport infrastructure component

	Component1	Component 2	Component 3	Component 4
Percentage of families with internet access at home	-0.13	0.99	0.01	-0.03
Number of local units producing ICT products	0.52	0.06	0.83	0.18
Number of local units producing ICT-related services	0.61	0.05	-0.22	-0.76
Number of local units producing web content	0.58	0.10	-0.51	0.62
Eigenvalue	2.13	0.98	0.58	0.30
Difference	1.15	0.40	0.28	*na*
Proportion	0.53	0.25	0.14	0.08
Cumulative	0.53	0.78	0.92	1.00

Table A4. Results of PCA for the ICTs component

	Component1	Component 2	Component 3	Component 4
Proportion of solid waste arising within the boundary processed by recycling	0.31	0.61	-0.62	0.38
Proportion of the area in green space	0.09	0.64	0.75	0.11
Annual average concentration of PM10	0.59	-0.46	0.23	0.63
Annual average concentration of NO2	0.74	0.03	-0.01	-0.67
Eigenvalue	1.35	1.25	0.82	0.58
Difference	0.10	0.43	0.24	*na*
Proportion	0.34	0.31	0.21	0.14
Cumulative	0.34	0.65	0.86	1.00

Table A5. Results of PCA for the natural resources component

	Component1	Component 2	Component 3	Component 4
% of internet users who interacted via internet with the public authorities in the last 12 months	-0.19	0.68	0.70	0.00
% of internet users who sent filled forms to public authorities in the last 12 months	0.08	0.72	-0.68	0.03
Number of administrative forms available for download from official web site	0.69	0.07	0.12	-0.71
Number of administrative forms which can be submitted electronically	0.69	0.04	0.15	0.70
Eigenvalue	1.94	1.34	0.61	0.11
Difference	0.61	0.72	0.50	*na*
Proportion	0.49	0.33	0.15	0.03
Cumulative	0.49	0.82	0.97	1.00

Table A6. Results of PCA for the e-government component