🏆 *reviewed paper*

Smart Cities: a Policy Tool for City Efficiency?

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1 ABSTRACT

The level of interest in smart cities has been growing during these last years. The academic literature (Hollands, 2008; Caragliu et al., 2009, Nijkamp et al., 2011 and Lombardi et al., 2012) has identified a number of factors that characterise a city as smart, such as economic development, business-friendly, environmental sustainability, social innovation, information and knowledge process, and human and social capital. Thus, the smartness concept is strictly linked to urban efficiency in a multifaceted way as well as to citizens' wellbeing through the use of appropriate technologies. Instead, from a "political perspective" smartness is mainly related to the ability of using ICT as instrument to strengthen economic growth. A research by Giffinger et al. (2007) to support European policy has defined the concept of smart city on the basis of several intangible indicators (such as a smart economy, smart mobility, smart environment, smart people, smart living, and smart governance) and has become a benchmark for European policy makers (European Parliament's Committee on Industry, Research and Energy, 2014). Following this influential research, the aim of our paper is to verify how much that smartness definition can influence the efficiency and indirectly the growth of the cities. Using the concept of output maximising, we built a stochastic frontier function in terms of urban productivity and/or urban efficiency by assessing the economic distance that separates cities from that frontier. Our conclusions highlight that not all the six indicators defined in the Giffinger et al. (2007)' analysis contribute to strength the city efficiency.

2 INTRODUCTION

With half of the world's current population living in cities, the urbanisation process is still present in all countries. At the beginning of the 20th century, cities with 8 or 10 million inhabitants were unimaginable, as well as unmanageable. Sociologists and urban planners believed that the growth of cities should be limited and alternative solutions should be offered. These hypotheses, however, have been overridden by reality as city populations continue to increase. More recently, some scholars, such as Sassen (2004), emphasise the phenomena of the irreversibility of a city's growth and of the centrality of cities as the engine of development. Nonetheless, there are negative aspects regarding cities. First, they consume approximately 80% of the energy produced in a country. Second, they represent the place where the majority of communication occurs. Third, they are the primary source of pollution. For all of these reasons, making cities more liveable and more efficient is rapidly becoming the most important, and no-longer postponable, objective of policy makers.

In recent years transforming cities into "smart cities" has emerged as the main way to achieve this target. From the academic point of view, the smart city notion is not so recent and can be subdivided into two main streams. The first one is based on the debate of Smart Growth and new Urbanism Movements. Even if these two movements are characterized by some differences, they present a common aim: the opposition to urban sprawl. These movements in fact consider that cities should be more compact, walkable, mixed-uses, transit-friendly and finally should create a range of housing opportunities and choices (Knaap and Talen, 2005; Bohl, 2000; Burchell et al., 2000; Gibbs et al., 2013). The second is based on innovation as the engine for development with economic, social and environmental sustainability as targets to aim for. These targets are strongly intertwined with human capital and education – or, following Florida (2002), with the creative class – in the urban context, as pointed out by Berry and Glaeser (2005, 2006) who show that innovation is driven by industries and products that require an increasingly more skilled labour force. Following this line Caragliu et al. (2009) and Nijkamp et al. (2011) include human and social relations, intellectual capital, health and governance concepts within a triple helix model (Etzkowitz and Lydesdorff, 2000). In their perpective, the city is called "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., 2009, p.6). "Furthermore, cities can become

ISBN 978-3-9504173-0-2 (CD), 978-3-9504173-1-9 (print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI, Clemens BEYER

"smart" if universities and industry support government's investment in the development of such infrastructures" (Nijkamp et al., 2011, p.3).

In line with this literature, Kanter and Litow (2009) define smart cities only the cities that create the necessary conditions of governance, infrastructure, and technology to produce social innovation. In other words, smart cities can solve social problems related to growth, inclusion and quality of life by involving various local actors including citizens, businesses, and associations. Moreover, Dirks and Keeling (2009) focus the attention on the way information and knowledge are produced, collected, and shared to raise the process of innovation. Regardless of the type of communication (financial, economic, social or cultural), cities are increasingly active nodes of these intangible flows in addition to the physical flows.

Finally, more recently, Neirotti et al. (2014) provides a taxonomy of application domains of the smart city concept, namely: natural resources and energy, transport and mobility, buildings, living, government, and economy and people.

From the political point of view, instead, the smart city concept was introduced within the SET (Strategic Energy Technology) Plan by the European Union in 2009 to foster economic growth. The SET Plan indicates that a smart city is a city or a large conglomerate that aims to improve energy efficiency by undertaking as target the double level, i.e., 20/20/20, as determined by the EU. Moreover, the EU 2020 strategy (see the Horizon 2014-2020 programme) has emphasized this concept focusing especially on the use of ICT within cities and assuming the definition developed by the University of Vienna and Ljubliana with the work of Giffinger et al. (2007) (European Parliament, 2014).

"A smart city is a city well performing in six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"

This definition identifies six dimensions or characteristics: economics, people, governance, mobility, environment, and quality of life. They, in turn, are broken down into 31 major factors and 74 indicators. This definition has allowed, for the first time, a classification of cities according to their level of smartness.

As shown, the smart city concept, first related to energy saving and efficiency use issues, has been developed to include different aspects such as the quality of life, the environment and so on. As a consequence, smart city has become more close to and, for some authors (Audirac, 2005; Herrschel, 2013), has joined with the smart growth concept. In the urban planning debate, smart growth is mainly related to urban sprawl and its negative impacts on physical form and on urban life. Besides, the concept of smart city means even the possibility of creating an urban context identity of protecting natural contexts, reducing the car use, and supporting the urban "mixity".

The smart city concept, however, is not generally accepted as a new urban economic paradigm because some authors (Hollands, 2008; Greenfield, 2013; Söderström et al., 2014; Vanolo, 2014) consider this concept as empty and ambiguous based more on an imaginary and discursive level. In other words, the underlying thought is the risk within the smart city vision of reducing the democratic process the specific conflicts in favour of a well-organized and ordered city.

Despite the variety of specifications, features and pros and cons defining a smart city, the Giffinger et al. (2007) definition has become the main benchmark at the political level. Given that the European Union has considered the "smart city" as one of its main policies for the 2014-2020 programming period, the central issue is to understand whether this definition is coherent with the EU's goal, which consists in improving growth (namely GDP) of the European cities.

In order to answer that question, the aim of our paper is to verify the robustness of the Giffinger et al. (2007) smartness indicators in explaining city efficiency and city growth using the same sample of European cities from Eurostat Urban Audit dataset. Applying the stochastic frontier approach (SFA), we can estimate a production function distinguishing between production inputs and inefficiency factors and hence we can rank the European cities using technical inefficiency values.

3 THE METHODOLOGY

As we have already emphasised, cities as well as countries must face the challenge of improving their performance. In other words, cities must become more efficient. According to the neoclassical economic theory, two agents having the same information on the production function could maximise their profits and thus be efficient in an identical way. We apply the same hypothesis to those cities chosen by Giffinger et al. (2007).

In reality, however, two cities – even if identical in terms of "inputs" used – can produce only a similar output. In other words, two cities can be different because of unforeseen exogenous shocks and the analysis of efficiency through the SFA can allow explaining these dissimilarities (Desli et al., 2002).

Traditionally, the empirical analysis of production functions has focused on the standard econometric approach based on the OLS model that incorporates a random error term that can take both positive and negative values. However, a simple OLS regression is not sufficient for estimating the relationship between output and inputs, as described in Feld et al. (2004) because of the impossibility to measure the distance of each unit of analysis from the efficient frontier for a given production function. Consequently, in recent years, several new econometric techniques have been developed to estimate the frontier of a production function that better corresponds to the economist's theoretical definition (Kalirajan and Shand, 1999 and Kumbhakar and Knox-Lovell, 2000).

To estimate a production function frontier, either parametric or nonparametric techniques, can be applied (Coelli et al., 1998). The parametric model SFA chosen,[1] firstly developed by Aigner et al. (1977) and Meeusen and van den Broeck (1977), allows to distinguish between production inputs and inefficiency factors and to disentangle distances from the efficient frontier between those due to systematic components and those due to noise. Through the systematic component, that is an additional error term, exogenous shocks beyond the control of cities are captured and technical inefficiency[2] is estimated.

This estimation is based on a single stage maximum likelihood approach in which exogenous variables were incorporated directly into the inefficiency error component as developed first by Kumbhakar et al. (1991). The subsequent development is the Battese and Coelli (1995) model where the allocative efficiency is imposed, the first-order profit maximising conditions removed, and panel data are permitted.

Following this last model, the production function can be expressed as:

$$Y_{it} = x_{it}\beta + (v_{it} - u_{it}) \qquad i=1,...,N,\ t=1,...,T \quad (1)$$

where Y_{it} is (the logarithm of) the production of the *i-th* city in the *t-th* time period; x_{it} is a $k\times1$ vector of (transformations of the) input quantities of the *i-th* city in the *t-th* time period; β is a vector of unknown parameters. The unobserved random noise is composed of a first component v_{it}, which are random variables following the assumption of normally distributed error terms [iid $N(0, \sigma_V^2)$], and a second independent component to capture the effects of technical inefficiency defined as u_{it}, which are non-negative random variables assumed to be independently distributed as truncated normal $N(m_{it}, \sigma_U^2)$ distribution.

The mean of this truncated normal distribution is a function of systematic variables that can influence the efficiency of a city:

$$m_{it} = z_{it}\delta + \varepsilon_{it}, \quad (2)$$

where z_{it} is a $p\times1$ vector of variables that may have an effect on the production function of a city and δ is a $1\times p$ vector of parameters to be estimated.

Following Battese and Corra (1977), the simultaneous maximum likelihood estimation of the two equation system is expressed in terms of the variance parameters $\sigma^2=\sigma^2_v+\sigma^2_u$ and $\gamma=\sigma^2_u/(\sigma^2_v+\sigma^2_u)$ to provide asymptotically efficient estimates. Hence, the acceptance of the null hypothesis that the true value of the parameter γ equals zero implies that σ^2_u, the non-random component of the production function residual, is zero.

The technical efficiency of the *i-th* city in the *t-th* time period is given by:

[1] A number of comprehensive reviews of this literature are now available see, for example Coelli et al. (1998) and Kumbhakar and Knox-Lovell (2000).

[2] We follow the Farrel (1957) measure of a firm's efficiency consisting of two components: technical and allocative. The former reflects the ability of a firm to obtain maximal output from a given set of inputs, while the latter reflects the ability of a firm to use the inputs in optimal proportions given their respective prices. These considerations are obviously true also at the country level considering that the aggregate output comes from the sum of national producers.

$$TE_i = e^{(-u_i)} = e^{(-z_{it}\delta - \varepsilon_{it})} \quad (3)$$

The technical inefficiency values oscillate between 0 and 1, being the latter the most favourable case. If $TE_{it}<1$ then the observable output is less than the maximum feasible output, meaning that the statistical unit is not efficient.

4 THE EMPIRICAL MODEL

Using the 1995 Battese and Coelli' specification and an unbalanced panel dataset, we perform the SFA to analyse the efficiency of several European cities. Data have been drawn from the Urban Audit dataset of Eurostat. This dataset, however, presents several limitations. Data are collected every three years and many variables have missing values. Even if there are several waves of the survey,[3] due to comparability we use only three out of the six waves: 1999-2002, 2003-2006 and 2007-2009. As regards the choice of cities, we select the same 70 European cities considered in the ranking developed by Giffinger et al. (2007) (see Table in Appendix).

The production of each city is measured by the proxy GDP in PPS of NUTS 3 region (in euro) (Y_{it}) and, as usual, is assumed to be a function of three inputs: physical capital (K_{it}), labour (L_{it}) and human capital (H_{it}). Typically, the value of the physical capital should comprise buildings (dwellings, warehouses and other buildings), transport equipment and other machinery and equipment. Because a city is not a firm, assessing city's physical capital is a challenge especially when data are lacking[4]. The only thing to do is to use as proxy two available variables: i) houses, measured by the number of dwellings, and ii) transport, measured by the length of the public transport network (km)[5]. The second input, labour variable, is represented by the number of employees. As regards the third input, human capital is measured by the number of students (aged 15-64) with ISCED level 3 or 4.

By assuming that the production function takes the log - linear homogeneous Cobb-Douglas form, our stochastic frontier production model is specified as follows:

$$ln(Y/L)_{it} = \beta_0 + \beta_1 ln(Kdwelling/L)_{it} + \beta_1 ln(Ktransport_{net}/L)_{it} + \beta_2 ln(H/L)_{it} + v_{it} - u_{it} \quad (4)$$

where the dependent variable is the value of the economic performance of the *i-th* city at time *t* (*i=1,...,N; t=1,....,T*) divided by a scale variable (labour force) to remove potential problems of heteroskedasticity, multicollinearity and output measurement (Hay and Liu, 1997). As independent variables, we put *Kdwelling/L* and *Ktransport_net/L* as per-worker physical capital of the *i-th* city at time *t*, and *H/L* as human capital measured by per-worker education level of residential people of the *i-th* city at time *t*.

According to the SFA, the systematic component of error includes exogenous factors that can influence city's efficiency. These factors are captured by city smartness measured by Giffinger *et al.* (2007) indictors, as shown in the following equation:

$$u_{it} = \gamma_0 + \gamma_1 Smart_{Economy_{it}} + \gamma_2 Smart_{People_{it}} + \gamma_3 Smart_{Governance_{it}} + \gamma_4 Smart_{Mobility_{it}}$$
$$+ \gamma_5 Smart_{Environment_{it}} + \gamma_6 Smart_{Living_{it}} + \sum_{k=7}^{26} \gamma_k Countrydummy + \varepsilon_{it} \quad (5)$$

where $Smart\_Economy_{it}$, $Smart\_People_{it}$, $Smart\_Governance_{it}$, $Smart\_Mobility_{it}$, $Smart\_Environment_{it}$ and $Smart\_Living_{it}$ are the Giffinger *et al*. (2007)' indicators that jointly describe a city as a smart city. On this basis researchers have ranked the 70 European medium-sized cities. The main criticism to the Giffinger et al. (2007)' analysis is based on the combined use of data at both national and local level and on the mix of timing of the different components of the six indicators. Moreover, the methodology to aggregate all factors

[3] The first three waves of the survey (1989-1993, 1994-1998, 1999-2002) can be considered as a "pilot", as the first full-scale European Urban Audit took place in 2003 for the then 15 countries of the European Union.

[4] Because the very recent literature on smart cities is not well developed, there is not an accepted measure of city physical capital. A first attempt to measure this input was conducted by the Economist Intelligence Unit (2012). Even if we are aware that this report is not academic, the authors follow a very similar method to our assumption. Another method to estimate capital stock of city production function is based on investments as in Segal (1976), but unfortunately urban audit dataset does not include this type of data.

[5] We have been obliged to use this proxy because of a lack of "length of road" variable in the Urban Audit dataset.

into six indicators is too simple[6], and it does not consider heterogeneity among cities. However, the European Union considers this approach the most relevant benchmark for defining a smart city.

Finally, to analyse a recent issue that emerged in the new economic geography literature that asserts that a city belonging to a well-developed area can perform better than a city belonging to a less developed area, we have introduced *m*-1 country dummies to capture the effect of city's geographical localisation and the heterogeneity among cities. A country in northern Europe should influence positively city's economic performance, and thus, technical inefficiency should be less with respect to other cities in other countries. In other words, the gap from the optimal stochastic frontier of this kind of city should not be very wide.

5 DESCRIPTIVE EVIDENCE AND RESULTS

Results of the stochastic frontier estimations are reported in Table 1. In the first and second model, the estimated results exclude the variable "length of the transport net" but include country dummies (as in column 2). In the third and fourth model, instead, the length of the transport net is included, and thus, the missing value problem drastically reduces the observations. Cities considered are reduced to only 54 cities in model 1 and 2 and to only 39 cities for model 3 and 4. In the Appendix, we report the differences, in terms of cities considered, among our estimation datasets, the Urban Audit dataset and the Giffinger et al. (2007) dataset.

Subdividing cities according to the country to which the city belongs, only Germany presents 6 cities in the sample, while other countries show a lesser number of cities and some others are considered because of the presence of only one city. The missing data problem is a quite serious one when the Urban Audit dataset is used and can create some comparability problems among European cities. On the basis of the Giffinger et al. (2007) smart indicators, the Scandinavian cities are highly ranked, while Germany and the United Kingdom are, more or less, in the middle of the classification.

Considering that, in all the specifications, we reject the null hypothesis of the insignificance of the non-negative error component (γ), we conclude that the SFA is a good model to analyse the effect of smart city's indicators on cities' economic performances. The parameter (γ), meaning that a proportion of the total variance is due to inefficiency effects, is significant at the 1% level in all estimations, and varies between 0.48 and 0.80. This indicates that from 48% to 80% of the total variance of the model is explained by inefficiency effects.

As to the estimated results, they are mixed. The production functions in all models show that physical capital measured by dwellings has always a positive and significant sign, while physical capital measured by the length of the transport net has a negative, albeit insignificant, sign. Human capital has again a negative but insignificant (on three of the four models) coefficient sign. These results should be taken carefully due to the relevance of the missing data problem within the dataset as underlined by the number of observations.

When we observe the signs of the smart city's indicators in the first model, we note that only Smart People and Smart Environment show negative signs, thus indicating that both variables have a positive effect on efficiency and, hence, a negative impact on inefficiency. The other smart indicators show a vice versa effect in that they increase inefficiency and decrease efficiency. However, we must emphasise that the signs are not robust to the inclusion of other variables and that the significance of the coefficients is drastically reduced in the other model considered in Table 1.

To deepen our analysis, we have estimated technical inefficiencies for each city, using the models described in column (2) and in column (4). In both tables, we report the technical inefficiency values of European cities for three separate years - 2000, 2004 and 2008 -which represent the three different waves of the survey. We then rank the European cities according to the level of inefficiency reached in 2004.

The results confirm that the inefficient cities are those belonging to the eastern European countries, but they do not confirm that the Scandinavian cities are the most efficient. Enhancing the Giffinger et al. (2007)' analysis, a city belonging to a well-developed and best performing country such as Germany or UK can perform better than a city that belongs the other countries.

To understand and emphasise the differences better, we compare our European city rankings with that of Giffinger et al. (2007) (see Table 4). In particular, our comparison is based on the rankings resulting from

[6] They aggregate additively the factors divided by the number of values added.

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Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI, Clemens BEYER

model 4 for the year 2004 where only 36 cities are considered. The comparison highlights the gap, in the last column, between the resulting relative positions of the 36 cities. For 13 out of 36 cities, the gap is not relevant (less than 3 positions), thus suggesting that the two rankings provide similar results, while for the rest of the cities, the gap increases quickly, reaching a spread of 22 positions in the worst case (i.e. the city of Aalborg in Denmark).

dependent variable: gdp/L	1	2	3	4
Const β0	10.66***	10.82***	10.16***	10.58***
t	83.00	81.34	20.80	9.85
K dwelling/L β1	0.57***	0.51***	0.62***	0.51***
t	4.41	4.13	4.15	3.45
K_transport net/L β2			-0.11*	-0.13
t			-1.73	-1.31
H/L β3	-0.14**	-0.06	-0.08	0.16
t	-2.44	-1.06	-0.60	0.79
const γ0	-3.86***	-0.91	-3.98***	-2.22***
t	-11.13	-0.92	-5.85	-2.76
Smart Economy γ1	0.33***	0.44***	0.03	0.14
t	3.30	2.63	0.14	0.48
Smart People γ2	-0.21**	-0.17	-0.11	-0.07
t	-2.43	-0.71	-0.83	-0.16
Smart Governance γ3	0.36***	0.41	-0.07	0.21
t	2.64	1.37	-0.40	0.55
Smart Mobility γ4	0.47***	0.15	0.66***	0.58
t	3.89	0.45	3.67	1.52
Smart Environment γ5	-0.01	0.08	-0.01	-0.14
t	-0.24	0.58	-0.09	-0.57
Smart Living γ6	0.22	-0.33	0.70**	0.19
t	1.08	-1.02	1.96	0.30
Number of cities	54	54	39	39
Observations	101	101	69	69
Sigma squared	0.09***	0.04***	0.09***	0.06
t	4.76	3.09	3.75	1.57
Gamma	0.59***	0.48***	0.65***	0.80**
t	5.96	3.33	5.98	2.37
Log likelihood	-1.79	32.65	-1.35	9.28

Table 1: SFA models with GDP per-capita as the dependent variable. Note: * significant at 10%; ** significant at 5%; *** significant at 1%

6 CONCLUSION

In this paper, we analyse how a number of European cities face the challenge to be smart according to the political point of view. Using the definition of smartness developed by Giffinger et al. (2007), the European Union policy considers cities as the main engine of growth in the next future. Thus improving the efficiency of a city represents the best target to be aimed as emphasized in the EU 2020 strategy.

In the study of Giffinger et al. (2007), a city could be considered as smart on the basis of several intangible indicators. Drawing on this influential work, our aim is to verify if the Giffinger et al. (2007)' six smartness indicators are essential in explaining the efficiency and indirectly the growth of the same sample of European cities. In particular, using data of the Urban Audit Eurostat dataset and the six indicators that jointly describe a smart city, we analyse the relationship between economic performance, measured in terms of GDP, and the efficiency of these European cities through the inefficiency term. Applying the SFA approach, results show that only Smart-People and Smart-Environment have positive effects on efficiency, while the other smart indicators increase the city's inefficiency.

CITY	COUNTRY	VIENNA RANKING	2004 MODEL 4 RANKING	GAP
Liepaja	LV	33	33	0
Nijmegen	NL	8	8	0
Enschede	NL	12	12	0
Joenkoeping	SE	11	11	0
Ruse	BG	36	35	1
Pleven	BG	35	36	1
Pecs	HU	32	31	1
Kaunas	LT	31	30	1
Groningen	NL	9	10	1
Nitra	SK	27	28	1
Banska Bystrica	SK	30	29	1
Miskolc	HU	34	32	2
Kosice	SK	29	27	2
Eindhoven	NL	7	4	3
Magdeburg	DE	19	15	4
Kiel	DE	20	14	6
Ljubljana	SI	10	17	7
Goettingen	DE	13	5	8
Oviedo	ES	28	20	8
Umeaa	SE	14	22	8
Maribor	SI	17	26	9
Tartu	EE	24	34	10
Valladolid	ES	26	16	10
Erfurt	DE	18	7	11
Pamplona	ES	25	13	12
Trier	DE	16	3	13
Regensburg	DE	15	1	14
Aberdeen	UK	23	9	14
Tampere	FI	5	21	16
Portsmouth	UK	22	6	16
Aarhus	DK	1	18	17
Turku	FI	2	19	17
Oulu	FI	6	23	17
Leicester	UK	21	2	19
Odense	DK	4	24	20
Aalborg	DK	3	25	22

Table 4: Comparison between the two European city rankings

Ranking the European cities according to the level of inefficiency reached in 2004, we highlight several differences with the study of Giffinger et al. (2007). This allows us to compare different characteristics and to identify strengths and weaknesses of medium-sized cities. Among the most efficient European cities, we find some German and United Kingdom cities, while the inefficient cities are mainly located in the eastern European countries. A city belonging to a well-developed and best performing country can perform better than a city that belongs to the others European country. Comparing our European city ranking positions with that of Giffinger et al. (2007), we find that more or less one third of the sample seems to confirm the

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previous ranking while for the rest of the cities the position gap is quite relevant, suggesting that dominates dissimilarities between the two rankings.

In conclusion, we may underline that Giffinger et al. (2007)' smart city definition is not able to explain cities' efficiency and thus economic growth paths. Therefore, European policy makers should either use a different structure of indicators to foster urban efficiency and indirectly city's growth or draw on a different final target as output, i.e. European Commission should change its objectives from GDP or value added to well-being, happiness or quality of life. These different outputs are more completed and are more strictly related to the idea of urban performance. This means a more complex target where a city is smart if and only if it is able to be a focus for skilled labour force, ICT firms, honour students, tourists and to implement policies for ameliorating the business environment, reducing pollution, facilitating the development of social capital, and so on.

7 ACKNOWLEDGEMENTS

This study is supported by the MIUR (Ministry of Education, Universities and Research [Italy]) through a project entitled Governing tHe smart city: a gOvernance-centred approach to SmarT urbanism – GHOST (Project code:RBSI14FDPF; CUP Code: F22I15000070008) financed with the SIR (Scientific Independence of young Researchers) programme. We authorize the MIUR to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the MIUR.

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ISBN 978-3-9504173-0-2 (CD), 978-3-9504173-1-9 (print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI, Clemens BEYER