How do dimensions of institutional quality improve Italian regional innovation system efficiency? The Knowledge production function using SFA

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Abstract
This paper investigates the contribution of different dimensions of institutional quality on the efficiency of the Italian regional innovation system (RIS) through the application of a knowledge production function estimated within a Stochastic Frontier Analysis environment. Though most of the dimensions of institutional quality considered in the analysis are found to play no role in affecting RIS efficiency, we detect a positive and highly significant impact of government effectiveness on the variable of interest. This result is robust to different assumptions about the underlying technology, to alternative lag structures between R&D and patenting activities and to the application of different R&D inputs. Moreover, this evidence is confirmed once instead of the RIS efficiency, we appraise the impact of institutional quality on the amount of registered patents, through the application of a canonical knowledge production function. In terms of policy implications, our analysis indicates that measures that strengthen the endowment of regional socio-economic structures are highly recommended as they enhance the efficiency of the RIS and stimulate patenting activities. Finally, interventions for Southern regions should be designed to reduce the technological and efficiency gap with the most advanced regions in the country.

Keywords Regional innovation system efficiency · Knowledge production function · SFA · Institutional quality · Knowledge spillover

JEL Classification O31 · C14 · C67 · R12
1 Introduction and related literature

Over time, an increasingly amount of economic literature has been devoted to embed regional innovation systems (RISs) within the perspective of evolutionary economics.

Several contributions, see for instance Cooke et al. (1997, 1998), Lambooy and Boschma (2001), Iammarino (2005), Morgan (2007), Uyarra (2010) and Gunnarson and Wallin (2011), have therefore attempted to link regional science to evolutionary economics, sharing two main features.

On the one hand, indeed, these papers are concerned with the role of regional policies in shaping the innovative performance of regions.

According to Cooke et al. (1997, 1998), three main policy instruments can be employed by regional authorities to enhance regional innovation.

Specifically, regional policies can enhance innovation by increasing the amount of financial resources devoted to innovative projects, by financing infrastructures-intended as both telecommunications infrastructures and network links-and, finally, by favouring regional cooperation and learning.

Lambooy and Boschma (2001), instead, emphasise the relevance of policies aimed at creating a favourable environment for the creation, the diffusion and the adoption of new technologies, though they warn, in our opinion correctly, that these policies are destined to fail if they deviate from the local context.

Gunnarson and Wallin (2011), on the other hand, suggest that the regional governance can control the development path of innovation by facilitating cooperative and interactive behaviours and by coordinating public investments devoted to the creation of knowledge.

The second, and most important for the purposes of this paper, common element shared by these contributions, is instead represented by the explicit acknowledgment of the relevance of local institutions in explaining the dynamics of regional innovation systems.

In particular, the co-evolution of institutions and innovation is assumed to be a key factor in explaining the trajectories of regional innovation systems.

As notably remarked by Cooke et al. (1998, page 1580) “the systematic dimension of innovation at regional level relies upon a combination of a well-endowed organisational infrastructure and an associative superstructure composed of an embedded civil society capable of activating social capital. Institutionally speaking, embeddedness will reside in the collective social order which evolves according to an informal microconstitution composed of microregulatory conventions, habits, routines, and rules of the game. Systematic innovation is facilitated by the constructive interaction of the institutional order and the organisation infrastructure”.

Morgan (2007), on the other hand, stresses that, given the evolutionary nature of capitalism, the relevance of the quality of institutions lies in their ability to reduce the uncertainty and the instability faced by innovative entrepreneurs.

Haschka and Herwartz (2020), propose a Bayesian stochastic frontier approach to assess the determinants of innovation efficiency in four high-technology sectors.
in Europe (i.e. chemicals, general electronics, pharmaceutical products and rubber and plastic products). Although their evidence indicates that R&D investments represent the major driver of innovation activities, a key role found for the flows of knowledge from neighbour areas or firms. Specifically, the geographical closeness to universities and competitors are found to stimulate the creation and the development of local networks and, through that, to promote and improve innovativeness. In particular, they show that firm-level innovation increases with the level of market competition, as the latter incentivises firms to undertake innovative activities to avoid other firms to prevail in the market. Further, their evidence points out to a differentiated effect of knowledge spillovers, which crucially depend on the sector examined. Indeed, firms operating in highly competitive sectors, such as pharmaceutical and chemicals, are more incentivised to pursue firm-level efficiency compared to general electronics and rubber and plastic products, where the degree of competition is lower.

Though these contributions explicitly acknowledge that the regional institutional environment can play a key role in affecting regional innovation systems, little is said on how institutional quality affects their efficiency.

In this paper, using regional data from Italy over the 2004–2011 period, we investigate the effects of local institutional quality on the regional innovation system (hereafter RIS) efficiency. In particular, we believe that an analysis based on Italy represents a promising field of analysis for various different reasons. The first, and somewhat more obvious, is represented by the persistent and large regional divides, in terms of both economic outcomes and institutional quality, between the core areas of the Centre-North and the peripheral regions of the South. However, beyond the persistent regional dualism, whose roots can be found in the different effectiveness and efficiency of the institutional environment (Tabellini, 2010; D’Agostino and Scarlato, 2015), there are other reasons which make, in our opinion, the Italian context particularly appealing. Indeed, two peculiar aspects of the Italian economy are respectively represented by the prevalence of Small and Medium firms (SMEs) (Cucculelli and Peruzzi, 2020a; Cisi et al., 2020) and by a concentrated ownership structure, as a large share of firms are owned and managed at the family level (Carletti et al., 2020; Cucculelli and Peruzzi, 2020b).

Moreover, compared to other industrialised economies, Italy has historically exhibited a poor performance in terms of R&D intensity, whose levels did not converge to the ones registered by other OECD countries (Awaworyi Churchill et al. 2020). Further, as shown by Borin et al. (2014), the lower effectiveness and efficiency of the Italian institutional environment significantly constrained its growth, as it halted Foreign Direct Investments (FDI), which have been proven to be a relevant source of technological transfer and productivity. Given these considerations, we therefore believe that assessing the efficiency of the Italian RIS and evaluating how the quality of institutions affects the efficiency with which the RIS converts inputs into output, and hence, knowledge, is of significance importance for both scholars and policy-makers. It must be also clarified that the definition of institutional quality employed in this paper follows the approach of Kaufmann et al. (2010). Accordingly, governance is broadly defined as “the traditions and institutions by which authority in a country is exercised. This includes (a)
the process by which governments are selected, monitored and replaced; (b) the
capacity of the government to effectively formulate and implement sound poli-
cies; and (c) the respect of citizens and the state for the institutions that govern
economic and social interactions among them.” (Kaufmann et al., 2010 page 4).

For the empirical purposes of the paper, we propose the application of a
knowledge production function, estimated through a Stochastic Frontier Analysis
(SFA). In particular, although the previous literature on the Italian economy has
proven that the quality of institutions has some role in stimulating both Total Fac-
tor Productivity (TFP) (Lasagni et al., 2015; Albanese et al., 2020) and patenting
activities (D’Ingiullo and Evangelista, 2020), we believe that the SFA methodology,
compared to these approaches, offers various different advantages. Specif-
ically, the application of the SFA approach allows us to evaluate the efficiency
with which the RIS converts inputs into output and to appraise how far the RIS is
relatively to its best practices, summarised by the stochastic frontier (Triebs and
Kumbhakar, 2018), something which cannot be directly captured neither by the
TFP, nor by the amount of registered patents. Another advantage of the SFA com-
pared to these alternative approaches lies in the fact that, through its application,
it is possible to evaluate whether an improvement in the quality of institutions
favours a more efficient use of resources, hence moving the RIS closer to its best
practices. Following this discussion, this contribution aims at testing the follow-
ing hypothesis: H1) the evolution of the institutional environment enhances RIS
efficiency.

Beyond providing an empirical analysis of the interactions between the quality of
institutions and the RIS efficiency, this paper also employs a Fixed Effects estima-
tor to investigate whether the benchmark results differ once a traditional knowledge
production function is considered.

We believe, hence, that our contribution is relevant even once we move away from
the evolutionary perspective, where the nexus between the quality of institutions and
RIS efficiency has received little attention, both theoretically and empirically.

Indeed, the theoretical literature has been mostly concerned with the impact of
institutional quality upon growth and innovation.

Specifically, Rivera-Batiz (2002) proposes an endogenous growth model aimed
at assessing the relationship between democracy, governance and innovation. The
main theoretical prediction of this model is that improved democracy promotes
innovation, provided that such an improvement is accompanied by a corresponding
strengthening of governance. The latter, in particular, discourages corruption among
public officials and makes innovative projects relatively more profitable, hence stim-
ulating economic growth.

Tebaldi and Elmslie (2008), on the other hand, developed a theoretical setting to
investigate the relationships between institutional quality and long-run growth. To
theoretically evaluate the impact of institutions upon economic growth, they propose
a composite index of institutional quality which includes factors like control of cor-
rupation, pro-market regulations, the perceived effectiveness of the judiciary system
and of the public administration and, finally, contract and property rights enforce-
ment. According to their findings, countries with weak institutions exhibit low rates
of technological change and output growth, a result which is essentially driven by
the fact that countries with weak institutions generate an inefficient allocation of the available human capital in the economy.

Aghion et al. (2016), within a Schumpeterian growth model,\(^1\) assess the relationship between taxation, corruption and innovation. They show that increased corruption decreases the optimal tax revenues which, in turn, diminishes the investment in public infrastructures, hence discouraging innovation. At the same time, they show that increased corruption reduces the entrance in the market of potential innovative entrepreneurs.

From an empirical perspective, though an abundant literature has investigated the impact of the quality of institutions upon the innovative performance of countries and firms, see for instance Giménez and Sanaú (2007), Asongu et al. (2018), Cahn et al. (2019) and Clò et al. (2020),\(^2\) just a limited amount of papers has instead analysed how institutions interact with efficiency.

Examples of this limited literature are, to the best of our knowledge, the contributions of Méon and Weill (2005), Castiglione et al. (2018) and Aldieri et al. (2020), which show unanimous consensus in ascertaining that increased quality of institutions is associated with higher efficiency.

In particular, Méon and Weill (2005), identify three main channels through which bad governance is translated into lower efficiency.

These channels can be summarised as follows: a) bad governance acts like a tax on innovators and diverts resources from productive activities. This, in turn, has a detrimental effect on both the accumulation of productive resources and the efficiency with which they are employed. From this perspective, typical examples are corruption and political instability. In particular, while corruption discourages productive activities as it acts like a tax on innovators that reduces the expected gains from investments, increased political instability heightens the risks related to productive economic activities, hence preventing them; b) bad governance reduces the incentives to invest in innovation. In particular, a weak rule of law forces innovative entrepreneurs to invest in property right protection, while an inefficient regulatory distorts entrepreneurs’ incentives, as they might find more profitable to take advantage of weak property rights and engage litigation, rather than innovating. An ineffective government, on the other hand, is assumed to stimulate rent-seeking rather than productive activities; c) bad governance hampers the diffusion of knowledge as it promotes the accumulation of generic rather than specific capital and discourages foreign direct investments.

To anticipate our findings, the empirical evidence reported in this paper indicates that most of the institutional factors considered in the analysis play no role in affecting RIS efficiency, as we find a positive and highly significant impact for government effectiveness only, which drives the positive effect detected for one of the two composite indices of institutional quality employed in the paper. This result is robust

\(^1\) See for instance Schumpeter (1934; 1942).

\(^2\) To assess the impact of institutions on innovation, these papers rely on the six pillars of governance identified by the World Bank, see for instance Kauffman et al. (2010). A similar set of institutional quality indicators is also employed in the following contribution.
to different assumptions about the underlying technology, to alternative lag structures between R&D and patenting activities and to the application of different R&D inputs. Moreover, this evidence is confirmed once instead of the RIS efficiency, we appraise the impact of institutional quality on the amount of registered patents, through the application of a canonical knowledge production function.³

Two main policy prescriptions can be drawn from the empirical analysis performed in this paper. On the one hand, measures that improve and strengthen the endowment of regional socio-economic structures are highly desirable, as they enhance both RIS efficiency and patenting activities. Further, interventions for Southern regions should be designed to reduce the technological and efficiency gap with the core regions of the country.

The paper is organised as follows: Section 2 introduces the methodology used to estimate RIS efficiency. Section 3 describes the data, the production set and the empirical specifications proposed in the paper. The empirical evidence is described in Section 4, while Section 5 provides a sensitivity analysis. Section 6 concludes and discusses the main policy implications.

## 2 Measuring the Regional Innovation System (RIS) efficiency

Following Fritsch and Slavtchev (2011) and Barra and Zotti (2018), we propose to measure RIS efficiency through the concept of technical efficiency, as introduced by Farrell (1957), in which a given unit is technically efficient if it is able to produce the possible maximum output from a given amount of input. To empirically deal with the relationship between inputs and outputs of innovation, a KPF,⁴ based on a Cobb–Douglas production function formulation (see Griliches, 1979 and Jaffe, 1989), is employed.

Measuring the performances of given economic unit crucially depends on the possibility that the unit under scrutiny (i.e. regions) is characterised by inefficiencies in production. It turns out that the econometric specification of production and cost functions must take into account the possibility that a given unit is likely to produce using its inputs in a sub-optimal way. One possible approach to incorporate inefficiency into the estimation of a production function is the application of a Stochastic Frontier Analysis (SFA), proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). Empirically, this method assumes that the error term is divided into two components with different distributions (see Kumbhakar and Lovell (2000) for analytical details on stochastic frontier analysis). The first component, the “inefficiency”, is asymmetrically distributed (typically as a semi-normal), while the second, i.e. the “error”, is distributed as a white noise and both these components are assumed to be uncorrelated to avoid distortions in the estimates. Though some contributions, see for instance Broekel (2015), have emphasised that non-parametric

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³ For the empirical analysis of the conventional knowledge production function, please refer to the estimates reported in the Appendix at the end of the paper.

⁴ This is based on the assumption that R&D activities are the main source of inventions and innovation.
approaches offer a number of advantages and avoid critical assumptions (such as homogeneous elasticities), the literature has identified various drawbacks related to the application of this approach and such to justify the empirical methodology employed in this paper. As notably remarked by Méon and Weill (2005) and by Castiglione et al. (2018), two-stages approaches, such as Data Envelopment Analysis (DEA), are inconsistent. Specifically, these procedures are based on the computation of efficiency scores in the first stage and on the regression of these scores on some exogenous variables in the second stage. These methods are therefore inconsistent as they assume that the inefficiency component, in the first stage, is independently and identically distributed (i.i.d.), but this assumption is then violated in the second stage regression. Castiglione et al. (2018) further highlight that another advantage of the SFA, compared to the DEA, is that the it allows to deal with the presence of random shocks which are not controlled by the producer but that can affect the production output. Moreover, various contributions in the literature, see for instance Kneip et al. (1998), Park et al. (1998) and Gijbels et al. (1999), have emphasised that non-parametric approaches lead to bias estimates of the parameters of interest in presence of small samples, as it is the case of the current contribution. Finally, as shown by Koop et al. (1999), Simar (2003) and Simar and Zelenyuk (2011), the performance of non-parametric approaches is particularly poor in the presence of outliers, while the assumptions concerning the distribution of the error term in the parametric approach make it less sensitive to the presence of extreme values (Pereira de Souza et al., 2010). Formally, 6 taking logarithms, the KPF is described as follows:

\[
y_{it} = \alpha_i + f(x_{it}, \beta)\exp\{v_{it} - u_{it}\}
\]

where \(\alpha_i\) allows for regional-specific time-invariant unobserved heterogeneity, being disentangles from time varying inefficiency (Belotti et al., 2013; Greene 2005), \(y_{it}\) is the output of region \(i\) at time \(t\); \(x_{it}\) is a vector of input quantities of region \(i\) at time \(t\) (see Section 3.1 for more details on the input–output framework used in the production set); \(\beta\) is a vector of unknown parameters; \(f(x_{it}, \beta)\) is the production function or conventional regression model; \(v_{it}\) is a vector of random variables related to the idiosyncratic or stochastic error term of region \(i\) at time \(t\), assumed to be independently and identically distributed (i.i.d.) as \(N(0, \sigma^2_v)\) and independent of the \(u_{it}\), while \(u_{it}\) is a vector of non-negative random variables measuring the inefficiency term of region \(i\) at time \(t\) and assumed to be independently but not identically distributed. They are obtained from the truncation to zero of the distribution \(N(m_{it}, \sigma^2_u)\), where \(m_{it} = \mu + z_{it}z\), where \(\mu\) denotes the location parameter, \(z_{it}\) is a vector of determinants of (technical) inefficiency of region \(i\) at time \(t\) (see Section 3.2. for more details on the variables used in the inefficiency component), and \(z\) is a vector of

5 It also true, however, that more recent developments in non-parametric approaches, such as conditional non-parametric efficiency analysis (Daraio and Simar 2006) and robust approaches, such as order-m and order-a frontiers (Cazals et al. 2002), overcome many of the drawbacks of non-parametric methods.

6 Moreover, in order to solve some possible criticisms related to the imposition of critical assumptions, such as homogenous elasticities (see e.g. Broekel 2015), we also estimate the stochastic frontier relaxing this assumption. The effect of quality of institutions upon efficiency is confirmed (see Table 7, 8 and 9).
unknown coefficients. In sum, as notably argued by Liu and Myers (2009), the SFA model assumes that $u_{it}$ and $v_{it}$ are independent of each other and that $u_{it}$ is independent of the input vector, $x_{it}$, conditional on $z_{it}$. Furthermore, the assumption of independence between the stochastic term ($v$) and the inefficiency term ($u$) prevents that unobserved factors could have an adverse effect on the territorial determinants and then on the components of institutional quality. If this assumption were relaxed, the effect of the unobserved factors could strongly affect the performance (i.e. efficiency scores) and therefore the ranking (in terms of performance) of the regions. Same goes for $u$, where we assume that inefficiency of region $i$ does not depend on the inefficiency of region $j$, with $i \neq j$. This leads us to assume that the inefficiency component should not be identical between regions, while as regards the unobserved factors ($v$), we assume that the factors of region $i$ do not influence the factors of region $j$, but that they are distributed identically.

In addition, time dummies have been included in the model to capture exogenous factors that might affect the production set and to provide a measure of technological change; time trend and macro-area dummies have also been included in the inefficiency component to capture how time and geographical areas affect inefficiency.

We assume that all the regions are initially endowed with the same level of technology but that this technology varies over time. For this reason, we do not consider a single time trend but a set of time-dummies.

All the parameters in Eq. (1) and efficiency scores are estimated through a maximum likelihood estimator (MLE) using the STATA 14 software. Following Kalirajan and Shand (1999), we estimate the technical efficiency assuming that the output elasticity associated to any input (i.e. $\beta_i$) is identical for all Italian regions ($i = 1, \ldots, 20$). In other words, the produced output may fall systematically below the maximum, not because of lower output elasticities of the factors of production, but because of a lower level of the function.

3 Data, production set and model specification

3.1 The production set

The empirical analysis proposed in this paper is developed by combining data collected from the Italian National Institute of Statistics (ISTAT) with information concerning the quality of regional institutions drawn from the Institutional Quality Index (IQI) dataset developed by Nifo and Vecchione (2014), over a 8 years-period (from 2004 to 2011). The estimated technology is specified using six inputs (both regarding

7 The ISTAT (http://www.istat.it/) is an independent statistical office and represents the major provider of regional statistics in Italy (i.e. NUTS2 level). The virtue of ISTAT regional data lies in the fact that they provide information on Higher Education Institutes (HEIs), private and public sector investments in R&D activities-in terms of expenditures and number of employees- and on the relevant innovative output employed in this paper.

8 The choice of the sample period is driven by data availability.
Table 1 Specification of inputs, outputs and exogenous factors in SFA models

| Model A | Model B |
|--------|--------|
| **Output** | PAT |
| **Inputs** | RD_EXP_PUBL; RD_EXP_HEI; RD_EXP_PRIV |
| **Determinants of RIS efficiency** | KS1; PD; EP; UR; SERV; IND; CORR; GOV; REG; RULE_LAW; VO; IQI; PCA |

- The output used is the number of disclosed regional patents applications (PAT). The first set of inputs (Model A) consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). The second set of inputs (Model B) consists of the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV). All controls are reported in order to explain RIS efficiency. KS1: Knowledge spillovers (measured as RD_EXP_PRIV*W, where RD_EXP_PRIV is in log and W is the inverse distance weighted matrix); KS2: Knowledge spillovers (measured as RD_EMP_PRIV*W, where RD_EMP_PRIV is in log and W is the inverse distance weighted matrix); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as a percentage of exports); IND: % of employment in the industry sector; CORR: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); GOV: measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, productivity, trial times, the degree of tax evasion and the shadow economy (Nifo and Vecchione, 2014 page 1633); REG: “measures the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops” (Nifo and Vecchione, 2014 page 1633); IQI: composite indicator of institutional quality using principal component analysis. See Table 2 for additional details about statistics of these variables.
the R&D expenditures and the number of R&D employees in different sectors) and one output (number of disclosed regional patent applications in the years 2004–2011). See Table 1 below for more details on the model specification. Specifically, the first set of inputs consists of the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). See Bottazzi and Peri (2003), Fritsch and Franke (2004), Buesa et al. (2010) and Tavassoli and Carbonara (2014), for the use of similar innovation inputs. The second set of inputs, instead, is based on the amount of R&D employees in the public sector (RD_EMPL_PUBL), in the higher education institutions (RD_EMPL_HEI) and in the private sector (RD_EMPL_PRIV). See Fritsch and Slavtchev (2011) and Buesa et al. (2010) for the use of this type of innovation inputs. As highlighted by Buesa et al. (2010, page 724), the choice of these inputs depends on the conclusion that “innovatory outputs depend in the first place on the effort made in allocating resources, regardless of whether the latter is measured via expenditures or staff employed in R&D”. For this reason, the two set of inputs are alternatively used in the knowledge production function to explore potential differences determined by the way in which R&D is measured (i.e. R&D expenditures or employees).

With respect to the output, we propose to adopt, as a measure of innovation, a standard variable, represented by the number of disclosed regional patent applications registered at the European Patent Office (PAT) over the 2004–2011 period. In particular, patents are territorially assigned on the basis of the postal code of the inventor’s residence. If the invention is the work of several authors, the patent is divided equally between all of them and therefore between their respective places of residence. For this reason, the reported data contain decimal values. Although the application of the number of patents as a measure of innovation output is not immune from limitations, they can be used as a good approximation for innovative ideas (see Bottazzi and Peri, 2003; Buesa et al. 2010; Fritsch and Slavtchev, 2011; Tavassoli and Carbonara 2014). Following Fritsch and Slavtchev (2011), we assume that a certain amount of time is required before R&D activities will result in a patent. Several months (usually from 12 to 18) are therefore needed for patents’ applications to be published.

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9 In order to make the results easier to interpret and read, we report the coefficients of interest in terms of RIS efficiency.

10 The number of R&D expenditures is expressed in thousands of Euros. We decided to separate out R&D expenditures in the universities from those in the public sector in order to further analyse the contribution higher education institutions to RIS efficiency.

11 The number of R&D employees refers to the researchers, technical employees and any other operator in R&D activities, respectively in the public sector, in the universities and in the private sector. It is expressed as full time equivalent units. We decided to separate out R&D employees in the universities from those in the public sector in order to further analyse the contribution of the higher education institutions to RIS efficiency.

12 First, patents are granted for an invention, but that invention is not necessarily transformed into an innovation, i.e., a new product or production technology. Second, patents are for products rather than for processes. Third, because there are other ways besides patenting to appropriate the returns of successful R&D activities, the number of patents might underestimate actual innovation output (see, among others, Cohen et al. 2000 and Cohen et al. 2002 on this points).

13 This corresponds to the amount of time the patent office needs to verify whether an application fulfills the basic preconditions for being granted a patent and to complete the patent documents (Greif and Schmiedl, 2002).
and a time lag between innovation inputs and the output of at least one or two years should be assumed. The time lag between R&D inputs and patent applications also depends on the reliability of the data and, to deal with this issue, different solutions have been exploited in the literature. Acs et al. (2002) report that innovation records result from inventions made 4 years before. Fritsch and Slavtchev (2007) propose a time lag of three years between patent applications and innovation input, while Fischer and Varga (2003) relied on a two-year lag. Fritsch and Slavtchev (2011), on the other hand, reduced the time lag to a period of one year. Given both the data constraints and the main literature and also in order to take into account the time required to transform competences into concrete innovation, as well as innovation into patents, we follow Fischer and Varga (2003) and assume a time lag of two years between innovation inputs and outputs. Data for Italian regional governance quality are taken from Nifo and Vecchione (2014). Taking inspiration upon the World Governance Indicator (WGI) developed by Kauffman et al. (2010), they provide information for six different measures of regional institutional quality. Specifically, beyond considering five elementary dimensions of institutional quality, namely corruption, government effectiveness, regulatory quality, rule of law, voice and accountability, they further exploit these five dimensions of governance to construct an overall index of institutional quality. Beyond the application of the full set of indicators developed by Nifo and Vecchione (2014), we propose an additional aggregate index of institutional quality, obtained through the application of the Principal Component Analysis (PCA) to the afore-mentioned five elementary dimensions. This procedure seems to be suitable for our purposes, as the institutional quality indicators employed in the paper exhibit strong linear correlations. According to Ariu et al. (2016), if the indices of governance exhibit strong linear correlations, it is then hard to empirically quantify their impact. Accordingly, the application of the PCA has the advantage to shrink the dimension of the governance indicators and to deal with the existing variability in the data. It is worth noting that in the literature that has investigated the impact of institutional quality upon efficiency, while Méon and Weill (2005) and Aldieri et al. (2020) have taken advantage of the full set of governance quality indicators identified by Kauffman et al. (2010), hence relying on a set of governance indices which is close to the one employed in this paper, the empirical analysis of Castiglione et al. (2018) only exploits the composite institutional quality indicator of Nifo and Vecchione (2014) and not just explores the potential contribution of each individual measure of institutional quality upon efficiency. All inputs and the output variables are in log-levels so that the overall positive skewness of the variables is reduced.

Descriptive statistics disaggregated by the four main Italian regional macro-areas are reported in Table (2). What clearly emerges is the large dual structure of

14 Assuming such a time lag also helps to avoid potential problems of endogeneity between R&D inputs and outputs.
15 Differently from Kauffman et al. (2010), Nifo and Vecchione (2014) do not provide any measure of political stability and absence of violence as the latter is assumed to be irrelevant in the Italian context.
16 For the sake of the convenience, pairwise correlations are not reported in the paper but available upon request.
the Italian economy, which is visible not only considering the production function parameters, but also the variables related to the determinants of efficiency and the quality of institutions. Indeed, the descriptive statistics reveal that North-Western regions show a higher degree of economy activity, as signaled by the level of patents and R&D expenditures, while Southern regions\textsuperscript{17} are characterised by a lower degree of R&D intensity, implying that regions in the North are the most innovative in the country. A similar picture emerges when considering the descriptive statistics related to the efficiency components, with North-Western regions which outperform all the others. Once again, the Southern part of the country registers the worst performance, displaying statistics which are indicative of an economy that did not achieve high levels of socio-economic development and a catching-up process with the most developed macro-areas of the country.\textsuperscript{18} The same holds once we focus on the quality of regional institutions, with the Southern regions that exhibit weaker governance relatively to Center and Northern regions.

### 3.2 Determinants of RIS efficiency

In a stochastic frontier environment characterised by heterogeneity, omission of relevant exogenous factors may determine bias estimates of the production frontier parameters and of the level of technical efficiency, therefore leading to poor policy conclusions (e.g. Caudill and Ford, 1993; Caudill et al., 1995; Hadri 1999; Wang 2003). Differences in the economic environment, indeed, might have a relevant impact upon RIS efficiency. To empirically deal with the issues determined by the omission of relevant exogenous factors, various control variables could be used. These variables are considered exogenous in the sense that they influence the production process but are not themselves either inputs or outputs. They, in fact, influence the efficiency with which inputs are converted into outputs. Allowing efficiency to depend on regional environmental characteristics enables researchers to examine the determinants of efficiency, and to suggest policy interventions to enhance it. In other words, the basic assumption of the model is that institutional and environmental factors influence the degree of technical efficiency. For this reason, the innovation production function must include these variables, as they directly influence the efficiency component. We therefore apply a single stage approach (see, for example Battese and Coelli, 1995) where environmental factors are assumed to directly affect technical efficiency. This procedure, indeed, is preferred to a two-stage approach since the latter may determine inconsistent estimates of the main parameters of interest (Kumbhakar and Lovell, 2000).

Following the empirical procedure proposed by Barra and Zotti (2018), we explore whether the institutional factors, related to quality of government, affect RIS efficiency. We then introduce seven different indicators related to the quality of government.\textsuperscript{17}

\textsuperscript{17} Southern regions comprise the Islands as well.

\textsuperscript{18} For a comprehensive discussion concerning the evolution and the causes of regional divides in Italy and the role of innovation and institutions in explaining regional disparities, please refer to Capello (2016).
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Table 2 Descriptive statistics by macro areas

| Variables     | North-Western | North-Eastern | Central  | Southern | Total   |
|---------------|---------------|---------------|----------|----------|---------|
| Output        |               |               |          |          |         |
| PAT           | 506.9806      | 394.0744      | 165.6728 | 36.3831  | 227.8988|
| Inputs        |               |               |          |          |         |
| RD_EXP_PUBL   | 90.166.1389   | 97.754.8228   | 312.568.4523 | 46.867.4978 | 118.844.8819 |
| RD_EXP_HEI    | 263.400.4545  | 240.341.0735  | 329.068.4868 | 185.863.3452 | 240.907.3410 |
| RD_EXP_PRIV   | 1,033,408.2051 | 482,548.0830  | 335,290.2406 | 101,378.3396 | 410,800.6416 |
| RD_EMP_PUBL   | 1387.5625     | 1407.2969     | 4340.4313 | 784.7281 | 1740.9494|
| RD_EMP_HEI    | 4152.5344     | 3602.6031     | 4717.1594 | 2737.9609 | 3589.6438|
| RD_EMP_PRIV   | 10,766.8656   | 6776.3625     | 3698.9969 | 1147.4328 | 4707.4181|
| Determinants of RIS efficiency |           |               |          |          |         |
| PD            | 224.3095      | 169.6999      | 182.5639 | 159.3725 | 179.0636|
| EP            | 26.57         | 20.27         | 27.02    | 30.95    | 27.15   |
| UR            | 4.3041        | 3.5445        | 5.4198   | 10.6562  | 6.9162  |
| SERV          | 0.6814        | 0.6273        | 0.6703   | 0.6825   | 0.6688  |
| IND           | 0.2888        | 0.3327        | 0.3004   | 0.2438   | 0.2819  |
| Institutional quality |           |               |          |          |         |
| CORR          | 0.8574        | 0.9025        | 0.9202   | 0.6871   | 0.8108  |
| GOV           | 0.4232        | 0.5105        | 0.3846   | 0.2207   | 0.3519  |
| REG           | 0.5820        | 0.6253        | 0.5774   | 0.3114   | 0.4815  |
| RULE_LAW      | 0.5469        | 0.5641        | 0.6911   | 0.4878   | 0.5555  |
| VO_ACC        | 0.5626        | 0.4839        | 0.4954   | 0.2968   | 0.4271  |
| IQI           | 0.6816        | 0.7355        | 0.7209   | 0.3815   | 0.5802  |
| PCA           | 1.0662        | 1.3159        | 1.1595   | -1.7708  | 0.0000  |
| Observations  | 32            | 32            | 32       | 64       | 160     |

Patents (PAT) represents the output, i.e. the number of disclosed regional patents applications. The first set of inputs consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). The second set of inputs, instead, consists in the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV). PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the values of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions: a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveli-
of institutions. Specifically, beyond the five elementary dimensions of government quality identified by Nifo and Vecchione (2014) and their composite measure of institutional quality, we propose an additional composite indicator, computed by applying the Principal Component Analysis (PCA) to the five elementary dimensions discussed below. Accordingly, Nifo and Vecchione (2014), for the Italian context, identify the following five elementary dimensions of institutional quality, namely: a) Corruption (CORR): “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works” (Golden and Picci, 2005, p. 37)” (Nifo and Vecchione, 2014 page 1633); b) Government effectiveness (GOV): “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment” (Nifo and Vecchione, 2014 page 1633); c) Rule of law (RULE_LAW): “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy” (Nifo and Vecchione, 2014 page 1633); d) Regulatory quality (REG): “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity” (Nifo and Vecchione, 2014 page 1633); finally, e) Voice and accountability (VO_ACC): “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops” (Nifo and Vecchione, 2014 page 1633). Nifo and Vecchione (2014) then combine these five elementary dimensions of governance to obtain an overall measure of institutional quality, namely the Institutional Quality Index (IQI). The IQI is the outcome of 3 different stages, respectively represented by normalisation, weight assignment and aggregation. Specifically, the normalisation process, based on the distance from the ideal point, serves to transform each elementary dimension in an indicator bounded in the [0,1] interval, while the weighting scheme is based on the analytic hierarchy process (AHP) developed by Saaty (1980, 1992). The last stage instead consists in the aggregation of the elementary dimensions of institutional quality to obtain the IQI index. Nevertheless, beyond the six indices of institutional quality provided by Nifo and Vecchione (2014), we propose an alternative aggregation of the five elementary dimensions discussed below.

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19 All the indices are constructed in a way that the higher is their score, the higher is the quality of institutions.
elementary dimensions, based on the application of the Principal Component Analysis (PCA). As stated before, the PCA allows to shrink the dimensions of governance and to better deal with the existing variability in the data.

Finally, we include in the inefficiency component\(^{20}\) (see Section 2 for more analytical details) the following variables: knowledge spillovers (labelled as KS1 and KS2, respectively), population density (PD); export (EP); unemployment rate (UR); employment in services (SERV) and in industry (IND) sectors.

Relatively to the role of knowledge spillovers, which are expected to be positively correlated with the RIS efficiency, their relevance has been remarked by various contributions in the literature (see for instance Bode, 2004; Cabrer-Borrás and Serrano-Domingo, 2007; Aldieri et al., 2018; Agasisti et al., 2019). As notably emphasised by Bode (2004), the higher is the geographical proximity among regions, the higher is the intensity of the knowledge transferred from one region to another. The measurement of knowledge spillovers requires, however, some considerations. Indeed, a popular approach adopted in the literature to capture knowledge spillovers consists in the application of patent citations, see for instance Jaffe et al. (1993), Jaffe et al. (2000) and Thompson and Fox-Kean (2005). Other contributions, like Acs et al. (2002) and Grafnström (2018), have instead proposed the application of the amount of patents, as the latter represent a good proxy of knowledge (Acs et al., 2002), though they warn that the application this measure must be taken with caution. Other possibilities, however, have been exploited in the literature and other variables have been employed to capture knowledge spillovers. These alternative approaches consider, among others, the amount of R&D expenditures (Fritsch, 2000; Grilliches, 2007; Autant-Bernard and LeSage, 2011), and the amount of R&D employees (Bloch, 2013; Zemstov and Kotsemir, 2019). At the same time, some contributions have emphasised that knowledge spillovers mostly occur in the private sector (Greunz, 2003; Wenner et al., 2011; Autant-Bernard and LeSage, 2011). For this reason, we measure knowledge spillovers by alternatively considering the amount of R&D expenditures in the private sector (KS1) and the amount of R&D employees in the private sector\(^{21}\) (KS2), depending on whether the inputs of the model consist of R&D expenditures or R&D employees. It must be also specified that knowledge spillovers, in line with other contributions in the literature, see for instance Fritsch and Franke (2004) and Zemstov and Kotsemir (2019), have been treated as an explanatory variable of the RIS efficiency. In line with other studies in the literature devoted to assess the role of different types of spillovers, (see, among others, Pacheco and Tyrrell, 2002; Moreno et al., 2005; Kelejian et al., 2013; George and Sandler, 2018; Agasisti et al., 2019), we rely on the application of an inverse distance weighted matrix. More specifically, the amount of R&D expenditures and R&D employees in the private sector have been respectively weighted by a spatial

\(^{20}\) For a similar approach see Barra and Zotti (2018).

\(^{21}\) Note that other measures were employed to capture the impact of knowledge spillovers. These measures include the amount of registered patents, the amount of employees and expenditures in the public sector and in the higher education. The overall amount of R&D expenditures and of R&D employees were used as well. The application of these measures, however, does not alter the main findings. The estimates performed, not reported in the paper, are available upon request. Patents’ citations were not used to capture knowledge spillovers as this information is not available.

\(^{22}\) For a comprehensive overview of spatial econometrics methods and models, which includes the inverse distance function as well, please refer to Anselin (1988).
matrix, $W$, with the implication that the interaction between the two different measures of R&D and the spatial matrix allows us to capture the effects of knowledge spillovers of region $k$ on its neighbour $i$.\(^{23}\)

With respect to the other determinants of RIS efficiency, population density (PD), measured as the number of inhabitants in the region by squared kilometres, aims at measuring the effects of urbanisation. High population density should boost RIS efficiency as it provides opportunity for intensive contacts and cooperation (for a similar view, see Feldman, 2000 and Fritsch, 2000). The unemployment rate (UR), measured as the number of people actively looking for a job as a percentage of the labour force, is intended to capture, in line with Srholec (2010), the impact of structural factors and socio-economic conditions on RIS efficiency and to appraise, in line with Crescenzi and Rodríguez-Pose (2013) and Hajek et al. (2014), how the lack of labour demand and the lack of adequate skills in the local markets affect the RIS efficiency. Additional channels, however, might operate. In particular, as emphasised by Rodríguez-Pose and Di Cataldo (2015), the unemployment rate reflects the structural rigidities of the local labour markets which, in turn, halt the generation of knowledge. Cunningham et al. (2019), on the other hand, emphasise that dynamic and flexible labour markets represent a fundamental ingredient for innovation and technology transfer to take place.\(^{24}\) Although this literature points out to an inverse relationship between the unemployment rate and innovative activities, the expected sign of this variable is a priori ambiguous. Indeed, while on the one hand it can be argued that regions with high socio-economic standards should exhibit more efficient RISs, as they are better able to accumulate and retain human capital, hence favouring the generation of knowledge and to easily absorb the knowledge created elsewhere, on the other it might be argued that higher unemployment could exert a positive effect on innovation (Crescenzi and Rodríguez-Pose, 2013), as it might stimulate R&D expenditures (Ceh and Gatrell, 2006) or encourage entrepreneurship (Lee et al., 2004),\(^{25}\) hence implying that unemployment and RIS efficiency could be directly correlated. Taking into account regional differences in the industry structure is crucial since patenting propensity differs across industries, see for instance Griliches (1990) and Broekel et al. (2018). In order to control for the impact of regional specialisation in certain industries, following Bottazzi and Peri (2013), we use two variables, namely the percentages of employment in services (SERV) and in industry (IND) sectors. Specifically, SERV and IND are measured, respectively, as

\(^{23}\) Information concerning regional latitudes and longitudes come from the ISTAT website (http://www.istat.it/it/strumenti/cartografia). The “spwmatrix” module by Jeanty (2010a) has instead been employed to obtain the spatial weights matrix, which is row-standardised. This implies that that its row-elements sum up to 1. The “splagvar” module proposed by Jeanty (2010b) has instead been employed to construct the spatial lagged variables used in the analysis.

\(^{24}\) The causality between the unemployment rate and the output variable has been assessed through the application of Granger causality tests (Granger, 1969; 1980. The p-values of the tests, not reported in the paper for the sake of convenience but available upon request, indicate that the unemployment rate Granger-causes the amount of patents issued.

\(^{25}\) In particular, the positive relationship found by Ceh and Gatrell (2006) between unemployment and R&D might essentially reflect the fact that increases in R&D expenditures mostly took place in regions experiencing process of industrial restructuring and consequent increases in unemployment.
the number of employees in services and industry sectors over the number of total employees in each region. A priori, we expect these variables to be directly correlated with RIS efficiency. In particular, the assumption behind the expected sign of these variables is that that the higher is the degree of regional specialisation in the industrial and in the service sector, the higher is the RIS efficiency. We further use a variable aimed at assessing the impact of export (EP), measured as the value of exports as a percentage of the Gross Domestic Product, on RIS efficiency. As higher export stimulates patent applications (Salomon and Shaver 2005), R&D investments (Baldwin and Gu, 2004; Yang, 2018) and the introduction of new products and technologies (Gorodnichenko et al., 2010), a positive sign is expected for this variable as well, as it seems plausible to assume that the higher is the propensity of the RIS towards export activities, the higher is its efficiency. Finally, a time trend to control for exogenous effects is included in our preferred specifications. See Tables 3 for the definition and the expected sign of these variables.

4 Empirical evidence

4.1 Investigating the endogeneity issues using an IV approach: A preliminary check

Before discussing the evidence of the SFA approach, the issue of endogeneity requires some considerations and needs to be addressed. Indeed, the evidence reported in this paper might be confounded by the presence of endogeneity, which might be driven by reverse causality among the main variables employed the paper. It turns out that that ruling out the possibility of endogeneity is thus necessary not only to appraise the feasibility of the SFA approach, but also to avoid that the estimates might be biased, hence leading to poor policy conclusions.

To appraise the issue of endogeneity, the analysis reported in this section closely mirrors the one performed Haschka et al. (2020). In their contribution aimed at assessing the relationship between health care infrastructure and health outcome, Haschka et al. (2020) propose, prior to the SFA, to appraise the existence of reverse causality by relying on an approach based on the Hausman test (Hausman, 1978). Specifically, to assess whether the SFA approach is suitable or not for their analytical purposes, they propose to estimate their production technology using the Ordinary Least Squares (OLS) and two alternative Instrumental Variable (IV) models. In particular, in the two IV models Haschka et al. (2020) treat their inputs as endogenous and propose to instrument them using the lagged first differences and through the application of heteroscedasticity-based instruments.26 For the purposes of our paper, we therefore follow the latter approach and propose a set of specifications, with both one and two-year lag between inputs and output, where the set of inputs of our technology are assumed to be endogenous.

26 In our specific case this approach is particular suitable because there are sub-samples (i.e. 20 regions) that have a different variance, where therefore it is better to assume that the residuals of the regression depend on the explanatory variables.
| Symbol     | Description                                                                 | Source                        | Expected sign |
|------------|-----------------------------------------------------------------------------|-------------------------------|---------------|
| **Output** |                                                                             |                               |               |
| PAT        | Number of disclosed regional patents applications (in log)                  | ISTAT                         |               |
| **Inputs** |                                                                             |                               | +             |
| RD_EXP_PUBL| R&D expenditures in the public sector (in log)                               | ISTAT                         |               |
| RD_EXP_HEI | R&D expenditures in higher education institutions (in log)                  | ISTAT                         |               |
| RD_EXP_PRIV| R&D expenditures in the private sector (in log)                               | ISTAT                         |               |
| RD_EMP_PUBL| Number of R&D employees in the public sector (in log)                        | ISTAT                         |               |
| RD_EMP_HEI | Number of R&D employees in higher education institutions (in log)            | ISTAT                         |               |
| RD_EMP_PRIV| Number of R&D employees in the private sector (in log)                       | ISTAT                         |               |
| **Determinants of RIS efficiency** |                                                                      |                               |               |
| KS1        | Knowledge spillovers (RD_EXP_PRIV (in log)*W)                              | ISTAT                         | +             |
| KS2        | Knowledge spillovers (RD_EMP_PRIV (in log)*W)                              | ISTAT                         | +             |
| PD         | Population density (in log)                                                | ISTAT                         |               |
| EP         | Export (in log)                                                            | ISTAT                         | +             |
| UR         | Unemployment rate (in log)                                                 | ISTAT                         | ±             |
| SERV       | Percentage of employees in the services sector                              | ISTAT                         | +             |
| IND        | Percentage of employees in the industry sector                              | ISTAT                         | +             |
| CORR       | “Summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (...) and the amounts of money cumulatively allocated by government to create these public works””, (Nifo and Vecchione, 2014 page 1633) | Nifo and Vecchione (2014)      | +             |
| GOV        | “Measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633) | Nifo and Vecchione (2014)      | +             |
How do dimensions of institutional quality improve Italian...

The output used is the number of disclosed regional patent applications (PAT) in Italy.

The first set of inputs consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). The second set of inputs, instead, consists in the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV).

KS1: Knowledge spillovers (measured as RD_EXP_PRIV*W); KS2: Knowledge spillovers (measured as RD_EMP_PRIV*W); PD: Population density (measured as the number of inhabitants in the region by square kilometer); EP: Export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labor force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees).

We include different indicators related to the quality of institutions, a) CORR: "summarizes data on crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of "the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works", (Nifo and Vecchione, 2014 page 1633); b) GOV: "measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, welfare management and the environment", (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: "summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy", (Nifo and Vecchione, 2014 page 1633); d) REG: "comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity", (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: "captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops", (Nifo and Vecchione, 2014 page 1633); f) IQI: Composite indicator of institutional quality;

g) PCA: Composite indicator of institutional quality using Principal Component Analysis (PCA)

### Table 3 (continued)

| Symbol | Description | Source |
|--------|-------------|--------|
| REG    | "Comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity", (Nifo and Vecchione, 2014 page 1633) | Nifo and Vecchione (2014) |
| RULE_LAW | "Summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy", (Nifo and Vecchione, 2014 page 1633) | Nifo and Vecchione (2014) |
| VO_ACC | "Measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, welfare management and the environment", (Nifo and Vecchione, 2014 page 1633) | Nifo and Vecchione (2014) |
| IQI | Composite indicator of institutional quality | Nifo and Vecchione (2014) |
| PCA | Composite indicator of institutional quality using Principal Component Analysis (PCA) | Own Elaboration from Nifo and Vecchione (2014) |
### Table 4: Estimates for the knowledge production function using IV approach

|                  | Model A ONE-YEAR LAG | Model A TWO-YEAR LAG | Model B ONE-YEAR LAG | Model B TWO-YEAR LAG |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| **RD_EXP_PUBL**  | -0.0330               | -0.0486               | -0.00906              | -0.00268             |
| (in log)         | [0.0584]              | [0.0519]              | [0.0632]              | [0.0664]             |
| **RD_EXP_HEI**   | 0.311***              | 0.138                 | 0.604***              | 0.903***             |
| (in log)         | [0.0800]              | [0.0796]              | [0.221]               | [0.279]              |
| **RD_EXP_PRIV**  | 0.486***              | 0.442***              | 0.585***              | 0.00339              |
| (in log)         | [0.0484]              | [0.0528]              | [0.131]               | [0.140]              |
| **RD_EMP_PUBL**  | -0.107                | -0.0416               | 0.0152                | 0.103                |
| (in log)         | [0.0517]              | [0.0600]              | [0.0576]              | [0.100]              |
| **RD_EMP_HEI**   | 0.619***              | 0.544***              | 0.567***              | -0.222               |
| (in log)         | [0.0499]              | [0.0608]              | [0.133]               | [0.200]              |
| **RD_EMP_PRIV**  | 0.257***              | 0.149*                | 0.294                 | -0.281               |
| (in log)         | [0.0718]              | [0.0840]              | [0.224]               | [0.226]              |
| **PD**           | 0.244***              | 0.358***              | 0.241***              | -9.093***            |
| (in log)         | [0.0805]              | [0.0916]              | [0.0648]              | [2.609]              |
| **EP**           | 0.0534                | -0.0407               | 0.00529               | 0.00331              |
| (in log)         | [0.0435]              | [0.0525]              | [0.0439]              | [0.0532]             |
| **UR**           | -1.223***             | -1.091***             | -1.062***             | -1.084***            |
| (in log)         | [0.0835]              | [0.0932]              | [0.0836]              | [0.0837]             |
Model A and B are estimated assuming both a one and a two-year lag between inputs and output. In Model A, the set of inputs consists of R&D expenditures. In Model B, the set of inputs consists of R&D employees. The models have been estimated either excluding Fixed Effects (Columns 1–4) and including them (Columns 5–8). R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV), number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). Robust standard errors in brackets; *, **, *** stand for significant at 10%, 5% and 1%, respectively.

|               | Model A ONE-YEAR LAG | Model A TWO-YEAR LAG | Model B ONE-YEAR LAG | Model B TWO-YEAR LAG | Model A ONE-YEAR LAG | Model A TWO-YEAR LAG | Model B ONE-YEAR LAG | Model B TWO-YEAR LAG |
|---------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| SERV          |                      |                      |                      |                      | [0.0905]            | [0.0903]            | [0.0869]            | [0.110]            |
|               | 0.128                | 2.801                | 1.239                | 4.091*               | -12.85***           | -2.013               | -9.108***           | -1.757              |
|               | [1.908]              | [2.314]              | [1.613]              | [2.063]              | [2.906]             | [2.633]             | [3.305]             | [2.524]             |
| IND           | 2.011                | 5.952***             | 1.793                | 5.146**              | -7.143**            | 5.223               | -6.395*             | 6.866**             |
|               | [1.872]              | [2.170]              | [1.591]              | [2.138]              | [3.079]             | [3.220]             | [3.375]             | [3.199]             |
| Hausman statistic | 0.6895            | 0.9289               | 0.3150               | 0.6060               | 0.9492              | 0.7811              | 0.5902              | 0.9951              |
| Hansen J statistic | 0.1458             | 0.1304               | 0.1430               | 0.1429               | 0.2711              | 0.3015              | 0.6666              | 0.8411              |
| Fixed effects | No                   | No                   | No                   | No                   | Yes                 | Yes                 | Yes                 | Yes                 |
| Time dummies  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                 | Yes                 | Yes                 | Yes                 |
| Period        | 2004–2011            | 2004–2011            | 2004–2011            | 2004–2011            | 2004–2011            | 2004–2011            | 2004–2011            | 2004–2011            |
| Observations  | 120                  | 100                  | 120                  | 100                  | 120                 | 100                 | 120                 | 100                 |
The evidence reported in Table 4 indicates that R&D expenditure and employees in higher education and in the private sector positively and significantly affect innovative activities. Among the main controls, while population density exhibits an ambiguous sign, in this environment the unemployment rate is inversely and significantly correlated with the variable of interest. On the other hand, a higher share of employees in the industrial sector seems to be significantly correlated with higher propensity towards patenting activities. Relatively instead to the main diagnostics of the model, as the Hausman test is largely above the conventional 10% threshold, the non-rejection of the null hypothesis suggests that, for the purposes of the paper, endogeneity does not represent a relevant issue and provides favourable evidence for the application of the SFA approach, hence implying that our results are unlikely to be biased by the presence of endogeneity. Moreover, according to the diagnostic statistics reported in Table 4, there is also favourable evidence for the validity of the instruments’ set, as implied by the p-values of the Hansen J-statistic, which are above the 10% level.

4.2 RIS Efficiency: The performance of Italian macro-areas

The main contribution of this paper is to shed light on the nexus between institutional quality and RIS efficiency. To achieve this goal, we start providing estimates of the efficiency scores. Specifically, we provide a comparison of the estimated parameters either when institutional factors are included or not in the proposed specifications.

The efficiency scores distributed by macro-area, based on a Cobb–Douglas KPF specification, are presented in Table 5. Results are shown either when the amount of R&D expenditures is used as input (Model A) and when R&D employees represent the relevant input variable (Model B), while the output variable is always the number of disclosed regional patents.27 In order to take into account that a certain amount of time is required before R&D activities will turn into a patent, a time lag between innovation inputs and the output of either one and two years is assumed. We report the estimated scores assuming linear homogeneity in inputs and applying robust standard errors in order to control for heteroskedasticity, whereas standard errors clustered at regional and year level. Cluster-adjusted standard errors correct for the possible correlation in innovative performances in the same region over time. The asymptotic approximation for clustered standard errors relies on a large number of clusters (see Donald and Lang, 2007). We have 160 clusters (8 years * 20 regions) which should be enough to deal with this issue. The null hypothesis that there is no heteroskedasticity in the error term has been tested and rejected at 1% significance level, using a Likelihood Ratio Test (LR), giving credit to the use of some exogenous variables, according to which the inefficiency is allowed to change. In other words, the validity of the heteroskedasticity assumption has been confirmed, leading to the significance of the inefficiency term.

27 Please refer to Table 1 for a comprehensive explanation of the models’ specification.
Table 5  RIS efficiency by macro areas according to the stochastic frontier approach

| Models         | North-West | North-East | Centre Regions | South Regions | Italy       |
|----------------|------------|------------|----------------|---------------|-------------|
|                | Model A    | Model B    | Model A        | Model B       | Model A     | Model B     |
| Lag 1 in inputs|            |            |               |               |             |             |
| NO INSTITUTIONS| 0.726      | 0.765      | 0.867          | 0.907         | 0.567       | 0.658       |
| CORR           | 0.723      | 0.768      | 0.864          | 0.911         | 0.566       | 0.659       |
| GOV            | 0.727      | 0.755      | 0.876          | 0.899         | 0.562       | 0.629       |
| REG            | 0.813      | 0.770      | 0.940          | 0.910         | 0.702       | 0.667       |
| RULE_LAW       | 0.728      | 0.768      | 0.869          | 0.909         | 0.569       | 0.661       |
| VO_ACC         | 0.732      | 0.765      | 0.870          | 0.908         | 0.572       | 0.659       |
| IQI            | 0.824      | 0.771      | 0.945          | 0.909         | 0.702       | 0.661       |
| PCA            | 0.793      | 0.766      | 0.916          | 0.906         | 0.659       | 0.659       |
| Lag 2 in inputs|            |            |               |               |             |             |
| NO INSTITUTIONS| 0.795      | 0.774      | 0.931          | 0.923         | 0.667       | 0.663       |
| CORR           | 0.796      | 0.777      | 0.933          | 0.928         | 0.667       | 0.662       |
| GOV            | 0.755      | 0.771      | 0.903          | 0.916         | 0.596       | 0.633       |
| REG            | 0.810      | 0.776      | 0.945          | 0.924         | 0.703       | 0.668       |
| RULE_LAW       | 0.815      | 0.779      | 0.947          | 0.926         | 0.705       | 0.670       |
| VO_ACC         | 0.795      | 0.772      | 0.931          | 0.924         | 0.667       | 0.662       |
| IQI            | 0.857      | 0.784      | 0.984          | 0.925         | 0.759       | 0.674       |
| PCA            | 0.808      | 0.775      | 0.938          | 0.923         | 0.693       | 0.666       |

Models with the imposition of the linear homogeneity in inputs; for more details about Model A and B see Table 1 in Section 3.1
The estimated RIS efficiency scores reported in Table 5 reveal, once again, a large dualistic structure within Italian regions. More precisely, the estimated parameters suggest that North-Western and North-Eastern regions outperform the other relevant macro-areas in terms of RIS efficiency. On the other hand, Southern regions exhibit significantly lower RIS efficiency, especially if compared to the performances registered by North-East regions. Moreover, the general picture that emerges from Table 5 is that RIS efficiency is usually higher once institutions are explicitly included in the econometric estimate, a finding which is robust to both the application of different R&D inputs and an alternative lag structure. All in all, the evidence reported in Table 5 indicates that regions with more effective institutional infrastructures exhibit significantly higher RIS efficiency scores.

4.3 RIS efficiency determinants

The discussion concerning the impact of institutional quality upon RIS efficiency begins by considering the benchmark results reported in Table 6, in which we propose a set of econometric estimates where we assume a two-year lag between R&D expenditures and patents and impose linear homogeneity in inputs. The production function parameters suggest that R&D expenditures in the public sector have a weak positive effect, while expenditures in higher education and in the private sector are found to be, as expected, positive and significant, in line with the findings of Barra and Zotti (2018).

Estimates of the efficiency component reveal that knowledge spillovers exert, in line with the expectations, a positive effect on RIS efficiency, as the parameter of interest is mostly found to be statistically significant. Both population density and export, as expected, increase RIS efficiency. The unemployment rate, in line with the expectations, is found to be detrimental for RIS efficiency, while the shares of employees in both the services and industry enter with an unexpected sign, as they inversely correlate with the variable of interest.

With respect to the impact of institutional quality, evidence reported in Table 6 indicates that government effectiveness has a positive and highly significant impact on RIS efficiency, while other dimensions of the quality of institutions are instead found to be insignificant. Relatively to the two composite indices of institutional quality employed in the paper, while the IQI of Nifo and Vecchione (2014) is positive and significant, our PCA measures plays no role in affecting the variable of interest. The positive effect found for the IQI seems therefore to suggest that the quality of institutions, as a whole, has a positive effect in stimulating RIS efficiency, though the result is driven by government effectiveness.
Table 6  Estimates for the knowledge production function and for RIS efficiency components according to the stochastic frontier approach

|                          | (A1)          | (A2)          | (A3)          | (A4)          | (A5)          | (A6)          | (A7)          | (A8)          |
|--------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| **y = Patents (in log)** |               |               |               |               |               |               |               |               |
| **Production function parameters** |               |               |               |               |               |               |               |               |
| RD_EXP_PUBL (in log)     | 0.0908**      | 0.0935*       | 0.0662*       | 0.0919**      | 0.1029**      | 0.0892*       | 0.0733*       | 0.0787*       |
|                          | [0.0451]      | [0.0496]      | [0.0379]      | [0.0403]      | [0.0432]      | [0.0479]      | [0.0388]      | [0.0403]      |
| RD_EXP_HEI (in log)      | 0.336***      | 0.335***      | 0.398***      | 0.314***      | 0.319***      | 0.337***      | 0.350***      | 0.333***      |
|                          | [0.113]       | [0.115]       | [0.0630]      | [0.0795]      | [0.111]       | [0.0509]      | [0.0769]      |               |
| RD_EXP_PRIV (in log)     | 0.573***      | 0.572***      | 0.536***      | 0.594***      | 0.578***      | 0.574***      | 0.577***      | 0.588***      |
|                          | [0.0896]      | [0.0888]      | [0.0515]      | [0.0655]      | [0.0662]      | [0.0888]      | [0.0454]      | [0.0682]      |
| **Determinants of RIS efficiency** |               |               |               |               |               |               |               |               |
| KS1 (in log)             | 0.478*        | 0.487*        | 0.152         | 0.497***      | 0.657***      | 0.476*        | 0.477***      | 0.477***      |
|                          | [0.271]       | [0.288]       | [0.106]       | [0.147]       | [0.230]       | [0.262]       | [0.0758]      | [0.159]       |
| PD (in log)              | 0.554*        | 0.556*        | 0.263**       | 0.627***      | 0.689***      | 0.556*        | 0.559***      | 0.596***      |
|                          | [0.309]       | [0.315]       | [0.122]       | [0.209]       | [0.236]       | [0.303]       | [0.104]       | [0.212]       |
| EP (in log)              | 0.291***      | 0.285**       | 0.267***      | 0.343***      | 0.392***      | 0.295**       | 0.371***      | 0.346***      |
|                          | [0.137]       | [0.129]       | [0.0760]      | [0.121]       | [0.130]       | [0.140]       | [0.0769]      | [0.126]       |
| UR (in log)              | -1.666***     | -1.697***     | -1.133***     | -1.564***     | -1.535***     | -1.657***     | -1.244***     | -1.475***     |
|                          | [0.415]       | [0.498]       | [0.310]       | [0.362]       | [0.325]       | [0.425]       | [0.272]       | [0.371]       |
| SERV                     | -7.194*       | -7.567        | -4.530        | -9.032***     | -7.524*       | -7.299*       | -8.682***     | -7.588***     |
|                          | [4.136]       | [5.159]       | [3.344]       | [3.252]       | [2.968]       | [4.023]       | [2.738]       | [2.801]       |
| IND                      | -3.471        | -3.625        | -4.846        | -5.518*       | -3.774*       | -3.584        | -7.813***     | -4.643*       |
|                          | [2.903]       | [3.291]       | [3.321]       | [3.160]       | [1.983]       | [2.833]       | [2.920]       | [2.608]       |
| CORR                     | -0.0847       |               |               |               |               |               |               |               |
|                          | [0.316]       |               |               |               |               |               |               |               |
| GOV                      |               |               |               |               |               |               | 3.088***      | [0.817]       |
| REG                      |               |               |               |               |               |               | 0.843         | [0.579]       |
| RULE_LAW                 |               |               |               |               |               |               | 0.629         | [0.492]       |
Table 6 (continued)

|       | (A1)         | (A2)         | (A3)         | (A4)         | (A5)         | (A6)         | (A7)         | (A8)         |
|-------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| VO_ACC| 0.0763       |              |              |              |              |              |              | 0.0801       |
|       | [0.568]      |              |              |              |              |              |              | [0.0496]     |
| IQI   | 1.492***     |              |              |              |              |              |              |              |
|       | [0.438]      |              |              |              |              |              |              |              |
| PCA   |              |              |              |              |              |              |              |              |
|       |              |              |              |              |              |              |              |              |
| σ_ν   | 0.273***     | 0.274***     | 0.238***     | 0.234***     | 0.234***     | 0.271***     | 0.044        | 0.236***     |
|       | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     |              | [0.0496]     |
| σ_σ   | 0.267***     | 0.267***     | 0.246***     | 0.281***     | 0.283***     | 0.268***     | 0.324***     | 0.279***     |
|       | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     |
| λ     | 1.021***     | 1.026***     | 0.970***     | 0.834***     | 0.826***     | 1.013***     | 0.136*       | 0.844***     |
|       | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     | [0.0496]     |              | [0.0496]     |
| Macro-area dummies in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time dummies in the frontier | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time trend in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 |
| Observations | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |

Models A1–A9 with the imposition of the linear homogeneity in inputs. The set of inputs consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). KS1: Knowledge spillovers (measured as RD_EXP_PRIV*W); PD: Population density (measured as the number of inhabitants in the region by squared kilometre); EP: export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Niño and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Niño and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Niño and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Niño and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Niño and Vecchione, 2014 page 1633); f) IQI: composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies in the frontier, a time trend and macro-area dummies in the inefficiency component. Southern regions representing the benchmark group. Constant in both frontier and inefficiency term, but not reported. σ_ν: variance of inefficiency term. σ_σ: variance of stochastic error term. λ: σ_ν/σ_σ. Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively.
Table 7 Estimates for the knowledge production function and for RIS efficiency components according to the stochastic frontier approach

| y = Patents (in log) | (B1) | (B2) | (B3) | (B4) | (B5) | (B6) | (B7) | (B8) | (B9) | (B10) | (B11) | (B12) | (B13) | (B14) |
|----------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| **Production function parameters** |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| RD_EXP_PUBL (in log) | 0.0259 | 0.0313 | 0.0424 | 0.0299 | 0.0258 | 0.0325 | 0.0302 | -0.0221 | -0.0250 | -0.0197 | -0.0207 | -0.0320 | -0.0302 | -0.0296 |
| [0.0815] | [0.0410] | [0.0379] | [0.0924] | [0.0711] | [0.0365] | [0.0423] | [0.0377] | [0.0383] | [0.0359] | [0.0377] | [0.0372] | [0.0363] | [0.0361] |
| RD_EXP_HEI (in log) | 0.404*** | 0.419*** | 0.341*** | 0.403*** | 0.406*** | 0.375*** | 0.374*** | 0.287*** | 0.321*** | 0.275*** | 0.289*** | 0.289*** | 0.30*** | 0.287** |
| [0.126] | [0.0527] | [0.0721] | [0.159] | [0.130] | [0.0625] | [0.133] | [0.105] | [0.0639] | [0.0658] | [0.112] | [0.100] | [0.0605] | [0.0757] |
| RD_EXP_PRIV (in log) | 0.570*** | 0.549*** | 0.616*** | 0.568*** | 0.593*** | 0.596*** | 0.587*** | 0.554*** | 0.603*** | 0.585*** | 0.589*** | 0.586*** | 0.595*** |
| [0.0673] | [0.0497] | [0.0641] | [0.0827] | [0.0775] | [0.0565] | [0.112] | [0.0700] | [0.0550] | [0.0517] | [0.0788] | [0.0682] | [0.0471] | [0.0559] |
| **Determinants of RIS efficiency** |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| KS1 (in log) | 0.307 | 0.160** | 0.423*** | 0.319 | 0.308 | 0.448*** | 0.383 | 0.386* | 0.178* | 0.403*** | 0.387 | 0.372** | 0.420*** | 0.390*** |
| [0.259] | [0.0766] | [0.130] | [0.483] | [0.266] | [0.136] | [0.306] | [0.167] | [0.0915] | [0.111] | [0.323] | [0.160] | [0.112] | [0.124] |
| PD (in log) | 0.325 | 0.209** | 0.501*** | 0.331 | 0.335 | 0.475*** | 0.437 | 0.530** | 0.349*** | 0.580*** | 0.527 | 0.551** | 0.558*** | 0.558*** |
| [0.364] | [0.0947] | [0.198] | [0.536] | [0.382] | [0.171] | [0.400] | [0.240] | [0.109] | [0.179] | [0.343] | [0.246] | [0.157] | [0.193] |
| EP (in log) | 0.197 | 0.219*** | 0.269** | 0.197 | 0.202 | 0.295** | 0.265 | 0.214** | 0.209*** | 0.231** | 0.209 | 0.227* | 0.247** | 0.240** |
| [0.185] | [0.0773] | [0.115] | [0.262] | [0.195] | [0.120] | [0.213] | [0.106] | [0.0747] | [0.0980] | [0.136] | [0.120] | [0.101] | [0.108] |
| UR (in log) | -1.251*** | -0.911*** | -1.242*** | -1.277*** | -1.261*** | -1.105*** | -1.178*** | -1.339*** | -0.952** | -1.291*** | -1.354*** | -1.305*** | -1.190*** | -1.237*** |
| [0.444] | [0.218] | [0.252] | [0.439] | [0.401] | [0.242] | [0.256] | [0.311] | [0.226] | [0.240] | [0.304] | [0.276] | [0.223] | [0.245] |
| SERV | -5.123 | -4.308* | -9.046*** | -5.410 | -5.844 | -8.262*** | -6.965* | -4.159 | -2.646 | -6.478* | -4.291 | -5.311* | -6.153*** | -5.182*** |
| [3.807] | [2.591] | [2.940] | [6.418] | [4.179] | [2.427] | [4.204] | [3.107] | [3.042] | [2.711] | [5.088] | [2.751] | [2.384] | [2.365] |
| IND | -3.027 | -3.806 | -5.990* | -3.141 | -3.533 | -6.218** | -4.598 | -1.035 | -1.899 | -3.223 | -1.073 | -2.002 | -3.735 | -2.386 |
| [2.723] | [2.795] | [2.850] | [4.462] | [2.887] | [2.583] | [2.831] | [2.460] | [2.901] | [2.675] | [3.682] | [2.312] | [2.495] | [2.272] |
|                  | (B1)          | (B2)          | (B3)          | (B4)          | (B5)          | (B6)          | (B7)          | (B8)          | (B9)          | (B10)         | (B11)         | (B12)         | (B13)         | (B14)         |
|------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| \( y \) = Patents (in log) |               |               |               |               |               |               |               |               |               |               |               |               |               |               |
|                  | With linear homogeneity in inputs |               |               |               |               |               |               |               |               |               |               |               |               |               |
|                  | Without linear homogeneity in inputs |               |               |               |               |               |               |               |               |               |               |               |               |               |
| CORR             | 0.104         |               |               |               |               |               |               |               |               |               |               |               |               | 0.0649        |
|                  | [0.210]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.198]       |
| GOV              | 2.455***      |               |               |               |               |               |               |               |               |               |               |               |               | 2.457***      |
|                  | [0.792]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.687]       |
| REG              | 1.008*        |               |               |               |               |               |               |               |               |               |               |               |               | 0.759         |
|                  | [0.550]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.464]       |
| RULE_LAW         | 0.0165        |               |               |               |               |               |               |               |               |               |               |               |               | -0.007        |
|                  | [0.825]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.670]       |
| VO_ACC           | 0.244         |               |               |               |               |               |               |               |               |               |               |               |               | 0.581         |
|                  | [0.483]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.463]       |
| IQI              | 1.119**       |               |               |               |               |               |               |               |               |               |               |               |               | 0.893*        |
|                  | [0.483]       |               |               |               |               |               |               |               |               |               |               |               |               | [0.463]       |
| PCA              | 0.0782        |               |               |               |               |               |               |               |               |               |               |               |               | 0.0684        |
|                  | [0.0833]      |               |               |               |               |               |               |               |               |               |               |               |               | [0.0420]      |
| \( \sigma_u \)  | 0.290***      | 0.239***      | 0.218***      | 0.290***      | 0.287***      | 0.190         | 0.241**       | 0.301***      | 0.264***      | 0.281***      | 0.303***      | 0.295***      | 0.266***      | 0.283***      |
|                  | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      | [0.0833]      |
| \( \sigma_v \)  | 0.224**       | 0.234***      | 0.273***      | 0.226         | 0.228***      | 0.279***      | 0.261***      | 0.201***      | 0.195***      | 0.215***      | 0.201***      | 0.204***      | 0.217***      | 0.211***      |
|                  | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       | [0.226]       |
| \( \lambda \)   | 1.292***      | 1.018***      | 0.799***      | 1.284***      | 1.259***      | 0.681***      | 0.920***      | 1.492***      | 1.350***      | 1.305***      | 0.507***      | 1.444***      | 1.224***      | 1.339***      |
| Macro-area       | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           |
|                  | dummies in the inefficiency term |               |               |               |               |               |               |               |               |               |               |               |               |               |
| Time             | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           | Yes           |
|                  | dummies in the frontier |               |               |               |               |               |               |               |               |               |               |               |               |               |
How do dimensions of institutional quality improve Italian...

Table 7 (continued)

| y = Patents (in log) | (B1) | (B2) | (B3) | (B4) | (B5) | (B6) | (B7) | (B8) | (B9) | (B10) | (B11) | (B12) | (B13) | (B14) |
|----------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| With linear homogeneity in inputs |      |      |      |      |      |      |      |      |      |       |       |       |       |       |
| Without linear homogeneity in inputs |      |      |      |      |      |      |      |      |      |       |       |       |       |       |
| Time trend in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 |
| Observations | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 |

Models B1-B7, with the imposition of the linear homogeneity in inputs; Models B8-B14, without the imposition of the linear homogeneity in inputs. The set of inputs consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). KS1: Knowledge spillovers (measured as RD_EXP_PRIV*W); PD: Population density (measured as the number of inhabitants in the region by squared kilometre); EP: export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Nifo and Vecchione, 2014 page 1633); f) IQI: composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies in the frontier, a time trend and macro-area dummies in the inefficiency component. Southern regions representing the benchmark group. Constant in both frontier and inefficiency term, but not reported. $\sigma_u$: variance of inefficiency term. $\sigma_v$: variance of stochastic error term. $\lambda$: $\sigma_u/\sigma_v$. Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively.
5 Sensitivity analysis

5.1 Does a different lag of R&D expenditures affect the estimates?

In Table 7 we provide, as initial robustness check, the results of our knowledge production function assuming, as suggested by the main empirical literature, a one-year lag between R&D expenditures and patent applications.

Differently from the benchmark specifications, the estimates reported in Table 7, beyond assuming an alternative lag structure between the relevant R&D input and the output, also allow-at least partially-for a different specification of the underlying technology. Specifically, though the benchmark assumption of linear homogeneity in inputs is retained (columns B1-B7), we also provide a set of empirical specifications in which this hypothesis is instead relaxed (columns B8-B14). In particular, relaxing the linear homogeneity assumption allows us to deal with the possibility of economics of scale in the underlying technology.

Under the hypothesis of linear homogeneity in input, there is evidence of a positive and highly significant effect of government effectiveness on RIS efficiency and, to a lesser extent, for regulatory quality, as the estimated coefficient is statistically significant only at the 10% level. Once the assumption of linear homogeneity is removed, while the weak positive effect of regulatory quality vanishes, the positive and highly significant impact of government effectiveness is confirmed. Moreover, both the specifications seem to suggest that the overall quality of institutions has some positive effect on RIS efficiency, as implied by the estimated coefficients of the IQI, though this effect is again mediated by government effectiveness.

5.2 Does a different measure of innovation inputs affect the estimates?

In Table 8, we assess the impact of institutional quality on RIS efficiency assuming two lags between R&D employees and patents. Specifically, we provide estimates both under the assumption of linear homogeneity in inputs (columns C1-C7) and once we relax this constraint (columns C8-C14). Again, the robustness of our findings is confirmed, hence suggesting that our results are not affected by a different set of inputs and by the underlying technology. Indeed, regardless the assumptions concerning the technology, we detect a positive and highly significant effect of government effectiveness on RIS efficiency, while all other dimensions of institutional quality are again proven to be insignificant. In line with the estimates reported so far, the direct and significant correlation between the IQI and the left-hand-side variable is confirmed, and channeled by government effectiveness (Table 9).

We conclude our robustness analysis by proposing an alternative set of empirical specifications, in which we assume a one lag between R&D employees and patents. Specifically, we investigate the impact of institutional quality under the hypothesis of linear homogeneity (columns D1-D7) and once this hypothesis is removed (columns D8-D14). Among the institutional determinants of RIS efficiency, there is evidence of a positive and highly significant effect of government effectiveness on the variable of interest, while no significant role was detected for all other relevant
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### Table 8
Estimates for the knowledge production function and for RIS efficiency components according to the stochastic frontier approach

|                        | (C1)     | (C2)     | (C3)     | (C4)     | (C5)     | (C6)     | (C7)     | (C8)     | (C9)     | (C10)    | (C11)    | (C12)    | (C13)    | (C14)    |
|------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| **Production function parameters** |          |          |          |          |          |          |          |          |          |          |          |          |          |
| RD_EMP_PUBL (in log)  | 0.0990*** | 0.0722*  | 0.0922** | 0.0998*** | 0.0805** | 0.0902** | 0.0170   | -0.0309  | 0.00960  | 0.00924  | 0.0098   | -0.0063  | 0.00429  |
|                        | [0.0379] | [0.0375] | [0.0373] | [0.0376] | [0.0379] | [0.0376] | [0.0541] | [0.0633] | [0.0585] | [0.0571] | [0.0581] | [0.0646] | [0.0593] |
| RD_EMP_HEI (in log)   | 0.226*** | 0.270*** | 0.223*** | 0.227*** | 0.219*** | 0.226**  | 0.215**  | 0.236**  | 0.213**  | 0.220**  | 0.214**  | 0.235*** | 0.216*** |
|                        | [0.0749] | [0.0680] | [0.0735] | [0.0714] | [0.0749] | [0.0702] | [0.0608] | [0.0560] | [0.0611] | [0.0571] | [0.0608] | [0.0569] | [0.0600] |
| RD_EMP_PRIV (in log)  | 0.675*** | 0.658*** | 0.685*** | 0.680*** | 0.681*** | 0.684*** | 0.664**  | 0.659**  | 0.670**  | 0.667**  | 0.671*** | 0.665*** | 0.671*** |
|                        | [0.0657] | [0.0575] | [0.0648] | [0.0619] | [0.0649] | [0.0611] | [0.0646] | [0.0543] | [0.0519] | [0.0543] | [0.0524] | [0.0539] | [0.0521] |
| **Determinants of RIS efficiency** |          |          |          |          |          |          |          |          |          |          |          |          |          |
| KS2 (in log)           | 0.511*** | 0.140    | 0.483*** | 0.565**  | 0.504*** | 0.501**  | 0.480**  | 0.429**  | 0.0817   | 0.406*** | 0.454*** | 0.397*** | 0.407*** |
|                        | [0.176]  | [0.115]  | [0.156]  | [0.220]  | [0.169]  | [0.157]  | [0.133]  | [0.102]  | [0.126]  | [0.166]  | [0.129]  | [0.124]  | [0.125]  |
| PD (in log)            | 0.588*** | 0.320*** | 0.609*** | 0.633**  | 0.579*** | 0.613**  | 0.604**  | 0.580**  | 0.355**  | 0.585**  | 0.603**  | 0.565**  | 0.586**  | 0.587**  |
|                        | [0.183]  | [0.102]  | [0.191]  | [0.205]  | [0.181]  | [0.175]  | [0.186]  | [0.148]  | [0.0755] | [0.160]  | [0.163]  | [0.144]  | [0.143]  | [0.154]  |
| EP (in log)            | 0.247**  | 0.265*** | 0.289**  | 0.306**  | 0.255**  | 0.341*** | 0.296**  | 0.169**  | 0.180**  | 0.188**  | 0.202**  | 0.165**  | 0.224**  | 0.198**  |
|                        | [0.105]  | [0.0720] | [0.119]  | [0.130]  | [0.107]  | [0.131]  | [0.123]  | [0.101]  | [0.0750] | [0.114]  | [0.115]  | [0.098]  | [0.122]  | [0.114]  |
| UR (in log)            | -1.820*** | -1.133*** | -1.666*** | -1.638**  | -1.752*** | -1.405**  | -1.625**  | -1.765**  | -1.121**  | -1.661**  | -1.634**  | -1.715*** | -1.423*** | -1.604*** |
|                        | [0.396]  | [0.221]  | [0.322]  | [0.302]  | [0.349]  | [0.273]  | [0.325]  | [0.356]  | [0.217]  | [0.301]  | [0.286]  | [0.284]  | [0.252]  | [0.300]  |
| SERV                   | -8.320** | -4.471** | -7.321** | -7.758** | -6.253** | -7.760**  | -6.903**  | -6.757**  | -3.250   | -5.703**  | -6.283**  | -6.377**  | -6.726**  | -5.770**  |
|                        | [4.230]  | [2.470]  | [3.201]  | [3.163]  | [3.183]  | [2.666]  | [2.914]  | [3.631]  | [2.675]  | [3.081]  | [2.944]  | [1.516]  | [2.548]  | [2.697]  |
| IND                    | -4.953   | -5.967** | -4.782   | -5.384** | -3.527   | -6.603**  | -4.566   | -3.984   | -4.830** | -3.534   | -4.264   | -4.163**  | -5.865**  | -3.888   |
|                        | [3.760]  | [2.499]  | [3.264]  | [3.157]  | [3.126]  | [2.847]  | [2.917]  | [3.347]  | [2.606]  | [3.146]  | [3.049]  | [1.314]  | [2.803]  | [2.794]  |
| CORR                   | -0.376   | -0.335   | -0.354   | -0.265   |          |          |          |          |          |          |          |          |          |          |
|          | (C1) | (C2) | (C3) | (C4) | (C5) | (C6) | (C7) | (C8) | (C9) | (C10) | (C11) | (C12) | (C13) | (C14) |
|----------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| GOV      | 3.541*** | 3.379*** |       |       |       |       |       |       |       |       |       |       |       |       |
| REG      | 0.268 | 0.0436 |       |       |       |       |       |       |       |       |       |       |       |       |
| RULE_LAW | 0.414 | 0.263 |       |       |       |       |       |       |       |       |       |       |       |       |
| VO_ACC   | -0.472 | -0.081 |       |       |       |       |       |       |       |       |       |       |       |       |
| IQI      | 1.052** | 0.951** |       |       |       |       |       |       |       |       |       |       |       |       |
| PCA      | 0.0311 | 0.0289 |       |       |       |       |       |       |       |       |       |       |       |       |
| σ_u      | 0.334*** | 0.326*** | 0.328*** | 0.322*** | 0.335*** | 0.300*** | 0.326*** | 0.339*** | 0.270*** | 0.338*** | 0.334*** | 0.339*** | 0.317*** | 0.335*** |
| σ_v      | 0.191*** | 0.188*** | 0.194*** | 0.196*** | 0.191*** | 0.200*** | 0.194*** | 0.165*** | 0.160*** | 0.164*** | 0.166*** | 0.164*** | 0.167*** | 0.164*** |
| λ        | 1.745*** | 1.393*** | 1.690*** | 1.642*** | 1.754*** | 1.496*** | 1.681*** | 2.055*** | 1.695*** | 2.060*** | 2.010*** | 2.069*** | 1.901*** | 2.041*** |
| Macro-area dummies in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time dummies in the frontier | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
Table 8 (continued)

| y = Patents (in log) | (C1) | (C2) | (C3) | (C4) | (C5) | (C6) | (C7) | (C8) | (C9) | (C10) | (C11) | (C12) | (C13) | (C14) |
|---------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| With linear homogeneity in inputs |      |      |      |      |      |      |      |      |      |       |       |       |       |       |
| Time trend in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 |
| Observations | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |

Models C1-C7, with the imposition of the linear homogeneity in inputs; Models C8-C14, without the imposition of the linear homogeneity in inputs. The set of inputs consists in the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV). KS2: Knowledge spillovers (measured as RD_EMP_PRIV*W); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Nifo and Vecchione, 2014 page 1633); f) IQI composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies in the frontier, a time trend and macro-area dummies in the inefficiency component, Southern regions representing the benchmark group. Constant in both frontier and inefficiency term, but not reported. \( \sigma_u \): variance of inefficiency term. \( \sigma_v \): variance of stochastic error term. \( \lambda : \frac{\sigma_u}{\sigma_v} \). Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively.
Table 9  Estimates for the knowledge production function and for RIS efficiency components according to the stochastic frontier approach

| y = Patents (in log) | (D1) | (D2) | (D3) | (D4) | (D5) | (D6) | (D7) | (D8) | (D9) | (D10) | (D11) | (D12) | (D13) | (D14) |
|----------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
|                      | With linear homogeneity in inputs | Without linear homogeneity in inputs |
| Production function parameters | | | | | | | | | | | | | | |
| RD_EMP_PUBL (in log) | 0.0694* | 0.0637* | 0.0642* | 0.0630* | 0.0686* | 0.0525 | 0.0617* | 0.00937 | -0.0203 | 0.00624 | 0.000912 | 0.00347 | -0.0186 | -0.00220 |
| [0.0368] | [0.0344] | [0.0365] | [0.0367] | [0.0368] | [0.0371] | [0.0500] | [0.0743] | [0.0494] | [0.0515] | [0.0529] | [0.0572] | [0.0537] |
| RD_EMP_HEI (in log) | 0.224*** | 0.258*** | 0.223*** | 0.230*** | 0.221*** | 0.244*** | 0.228*** | 0.234*** | 0.266*** | 0.231*** | 0.241*** | 0.234*** | 0.261*** | 0.261*** | 0.238*** |
| [0.0660] | [0.0789] | [0.0594] | [0.0615] | [0.0654] | [0.0609] | [0.0631] | [0.0670] | [0.0651] | [0.0612] | [0.0612] | [0.0670] | [0.0600] | [0.0636] |
| RD_EMP_PRIV (in log) | 0.706*** | 0.678*** | 0.712*** | 0.707*** | 0.703*** | 0.710*** | 0.680*** | 0.663*** | 0.688*** | 0.681*** | 0.683*** | 0.683*** | 0.675*** | 0.684*** |
| [0.0657] | [0.0795] | [0.0592] | [0.0624] | [0.0648] | [0.0613] | [0.0633] | [0.0612] | [0.0602] | [0.0560] | [0.0565] | [0.0599] | [0.0534] | [0.0577] |

Determinants of RIS efficiency

|                      | (D1) | (D2) | (D3) | (D4) | (D5) | (D6) | (D7) | (D8) | (D9) | (D10) | (D11) | (D12) | (D13) | (D14) |
|----------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| KS2 (in log)         | 0.516** | 0.269* | 0.474*** | 0.547** | 0.508** | 0.491*** | 0.480*** | 0.443** | 0.171 | 0.418*** | 0.467** | 0.422** | 0.414*** | 0.410** |
| [0.207] | [0.158] | [0.172] | [0.255] | [0.198] | [0.179] | [0.184] | [0.179] | [0.146] | [0.156] | [0.213] | [0.174] | [0.154] | [0.162] |
| PD (in log)          | 0.531** | 0.362** | 0.556** | 0.558** | 0.529** | 0.538** | 0.543** | 0.523** | 0.333** | 0.545** | 0.543** | 0.529** | 0.521*** | 0.532*** |
| [0.225] | [0.143] | [0.222] | [0.247] | [0.227] | [0.221] | [0.228] | [0.196] | [0.119] | [0.202] | [0.210] | [0.201] | [0.181] | [0.199] |
| EP (in log)          | 0.223* | 0.278*** | 0.260* | 0.260* | 0.234* | 0.284* | 0.265* | 0.174 | 0.170 | 0.201 | 0.198 | 0.191 | 0.212 | 0.203 |
| [0.131] | [0.091] | [0.140] | [0.151] | [0.140] | [0.152] | [0.150] | [0.125] | [0.108] | [0.135] | [0.138] | [0.135] | [0.141] | [0.142] |
| UR (in log)          | -1.475*** | -0.862*** | -1.358*** | -1.367*** | -1.430*** | -1.184*** | -1.320*** | -1.450*** | -0.963*** | -1.344*** | -1.368*** | -1.385*** | -1.194*** | -1.312*** |
| [0.353] | [0.177] | [0.285] | [0.279] | [0.320] | [0.244] | [0.289] | [0.318] | [0.189] | [0.263] | [0.261] | [0.288] | [0.227] | [0.264] |
| SERV                 | -7.708** | -3.187* | -7.762*** | -7.404** | -6.425** | -7.753*** | -8.684** | -6.072* | -3.904 | -6.390** | -5.974** | -5.445** | -6.623** | -5.628** |
| [3.467] | [1.751] | [2.774] | [2.980] | [2.669] | [2.629] | [2.570] | [3.179] | [2.449] | [2.813] | [2.827] | [2.529] | [2.503] | [2.456] |
| IND                  | -4.193 | -2.969** | -5.134 | -4.674 | -3.403 | -6.115** | -4.327 | -3.282 | -4.217 | -4.200 | -3.824 | -3.103 | -5.583* | -3.720 |
| [3.270] | [1.252] | [3.221] | [3.086] | [2.952] | [2.969] | [2.873] | [2.993] | [2.570] | [3.172] | [3.018] | [2.784] | [2.937] | [2.757] |
| CORR                 | -0.275 | -0.247 |
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Table 9 (continued)

| y = Patents (in log) | (D1) | (D2) | (D3) | (D4) | (D5) | (D6) | (D7) | (D8) | (D9) | (D10) | (D11) | (D12) | (D13) | (D14) |
|----------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| With linear homogeneity in inputs | | | | | | | | | | | | | | |
| GOV                  | 2.824*** | [0.263] | | | | | | | | | | | |
| REG                  | 0.602 | [0.485] | | | | | | | | | | | |
| RULE_LAW             | 0.298 | [0.465] | | | | | | | | | | | |
| VO_ACC               | -0.260 | [0.563] | | | | | | | | | | | |
| IQI                  | 0.927* | [0.537] | | | | | | | | | | | |
| PCA                  | 0.040 | [0.0467] | | | | | | | | | | | |
| \( \sigma_u \)       | 0.361*** | 0.316*** | 0.352*** | 0.354*** | 0.361*** | 0.337*** | 0.353*** | 0.359*** | 0.310*** | 0.354*** | 0.355*** | 0.357*** | 0.338*** | 0.352*** |
| \( \sigma_v \)       | 0.180*** | 0.176*** | 0.182*** | 0.181*** | 0.179*** | 0.184*** | 0.181*** | 0.157*** | 0.154*** | 0.160*** | 0.158*** | 0.156*** | 0.159*** | 0.158*** |
| \( \lambda \)        | 2.004*** | 1.794*** | 0.926*** | 1.950*** | 2.010*** | 1.831*** | 1.954*** | 2.278*** | 2.007*** | 2.210*** | 2.236*** | 2.277*** | 2.123*** | 2.237*** |
| Macro-area dummies in the inefficiency terms | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time dummies in the frontier | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
Table 9 (continued)

| y = Patents (in log) | (D1) | (D2) | (D3) | (D4) | (D5) | (D6) | (D7) | (D8) | (D9) | (D10) | (D11) | (D12) | (D13) | (D14) |
|----------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
| With linear homogeneity in inputs |     |     |     |     |     |     |     |     |     |       |       |       |       |       |
| Time trend in the inefficiency term | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period                | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 | 2004–2011 |
| Observations          | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 | 140 |

Models D1-D7 with the imposition of the linear homogeneity in inputs and. Models D8-D14 without the imposition of the linear homogeneity in inputs and standard errors clustered at region and year level. The set of inputs consists in the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV). KS2: Knowledge spillovers (measured as RD_EMP_PRIV*W); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the value of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Nifo and Vecchione, 2014 page 1633); f) IQI: composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies in the frontier, a time trend and macro-area dummies in the inefficiency component, Southern regions representing the benchmark group. Constant in both frontier and inefficiency term, but not reported. σ_u: variance of inefficiency term. σ_v: variance of stochastic error term. λ: σ_u/σ_v. Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively.
dimensions of the quality of institutions employed in the paper. Again, the overall quality of institutions exhibits a positive and significant impact on the variable of interest, at least when the latter is measured through the composite indicator of Nifo and Vecchione (2014). In line with the estimates reported so far, the positive impact of the IQI on RIS efficiency is again driven by government effectiveness.

6 Summary and conclusions

Over time, an increasingly amount of economic literature, see for instance Cooke et al. (1997, 1998), Lambooy and Boschma (2001), Iammarino (2005), Morgan (2007), Uyarra (2010) and Gunnarson and Wallin (2011), has been devoted to embed regional innovation systems (RISs) within the perspective of evolutionary economics.

These contributions have therefore tried to reconcile regional science with evolutionary economics. Though these papers argue that the evolution of the institutional environment plays a crucial role in affecting the trajectories of regional innovation systems, little is said on how local institutions affect RIS efficiency.

In this paper, using Italian regional data over the 2004–2011 period, we investigate the effect of regional institutions on RIS efficiency, through the application of a knowledge production function estimated within the framework of a Stochastic Frontier Analysis.

The evidence reported in this paper confirms the dual structure of the Italian economy, with Southern regions being relatively less efficient and less innovative compared to Northern and Central regions. Further, the efficiency score parameters suggest RIS efficiency is larger once institutions are embedded in the estimation and that regions with more effective institutional environment exhibit higher RIS efficiency scores.

The empirical analysis conducted through the application of the Stochastic Frontier Analysis, however, points out to weak impact of the quality of institutions on RIS efficiency, as government effectiveness is the only dimension of governance that exhibits a positive and highly significant impact on the variable of interest. There is also evidence according to which the institutional environment, taken in its entirety, exerts a positive effect on RIS efficiency, as shown by the positive and significant coefficients of the composite measure of institutional quality proposed by Nifo and Vecchione (2014), though this result is essentially mediated by government effectiveness.

Our benchmark results are shown to be robust to different assumptions about the underlying technology, to alternative lag structures between R&D and patenting activities and to the application of different R&D inputs. Further, this evidence is confirmed once instead of the RIS efficiency, we appraise the impact of institutional quality on the amount of patents issued, through the application of a canonical knowledge production function, as government effectiveness is the only stand-alone dimension of institutional quality found to stimulate regional patents. Moreover, an evaluation of regional knowledge spillovers indicate that the latter are relatively more important in explaining RIS efficiency, while their role is
significantly weakened once the standard KPF is examined. This finding seems to suggest that, at least in the Italian case, regional spillovers do not generate new innovation but, rather, imitation.

The evidence reported in this paper, however, is not immune from limitations and three drawbacks are worth mentioning, respectively represented by the size of the sample and by the application of the application of patents in absolute values. Relatively to the first drawback, it arises from the fact that the analysis conducted in this paper relies upon a limited amount of information, as only a bit more of one hundred observations are available, with the implication that the evidence reported here does not allow us to draw strong conclusions. The second, on the other hand, is instead driven by the lack of information concerning the value/quality of the patents, such as a citation-weighted patent index, which, in turn, implies that the empirical analysis proposed in this paper is based on the assumption that all patents are equal in their value. However, as a large economic literature has shown (see, among others, Trajtenberg, 1990; Hall et al., 2005; Van Roy et al., 2018), patents significantly differ in terms of their importance and value, hence implying that the application of patents’ counts may not adequately capture the degree of innovativeness. Despite these limitations, we believe that our analysis has some relevance in terms of policy implications.

Though, in accordance with Méon and Weill (2005, page 87), we acknowledge that “Improving governance can arguably be deemed too evasive an objective to be really achievable”, the empirical evidence reported in this paper emphasises that government effectiveness plays a key role in enhancing both RIS efficiency and patenting activities. This result therefore suggests that policy measures aimed at enhancing the regional socio-economic endowment represent, in the Italian case, the priority.

More specifically, policies that strengthen physical infrastructures and facilitate the diffusion of ICT technologies would be highly desirable as they would stimulate both RIS efficiency and patents. Consistently with the regional policies identified by Cooke et al. (1997, 1998), the evidence reported here suggests that regional policies can play a key role in affecting the regional development path, through the financing of infrastructures-intended as both telecommunications infrastructures and network links-and, finally, by favouring regional cooperation and learning. At the same time, we believe, in line with Lambooy and Boschma (2001), that these measures, to be effective, must be tailored to the characteristics and the peculiarities of the local contexts.

In our opinion, these policies are relevant even though efficiency is not directly observable by policy-makers. In particular, it seems plausible to assume that measures that improve the quality of regional infrastructures and that promote the diffusion of ICT technologies would create a favourable environment for the RIS to operate efficiently and encourage the creation of knowledge.

Finally, though the main goal of this paper is to investigate the relevance of institutional quality upon RIS efficiency, the significant economic, technological and efficiency gap between Italian regions requires some State-level policy interventions. In particular, as Southern regions lack of some elementary preconditions for the diffusion of knowledge (Capello, 2016), measures aimed at strengthening the education
system in these regions and tailored programs for the promotion of entrepreneurship could spur innovation and efficiency in these peripheral areas. Moreover, as shown by Berman et al. (2020), some dynamic centres in the South, albeit less economically developed, took significant advantage of the presence of Multinational Enterprises, exhibiting a better reaching-in performance compared to the core areas of the country. It turns out that specific measures which incentivise and concentrate foreign investments in the South would be highly recommendable as they would reduce the technological and efficiency gap with the most developed regions in the country.

Moreover, we believe that the findings reported in this paper and the associated policy implications might embedded in the European context as well. Indeed, as various contributions in the literature have proven (see, among others, Wanzenböck and Piribauer, 2018; Mulligan et al., 2019; Muscio and Ciffolilli, 2020), regional R&D subsidies from the European Union foster innovative activities and facilitate technological integration, hence suggesting that the findings reported in this paper may be important for other European regions, most notably those of other Southern or Western European countries, such as Ireland, Greece, Spain and Portugal. Indeed, as pointed out in the contribution of Wagner and Zeileis (2019), the conditional convergence hypothesis in the growth of the real GDP per capita does not hold, in the European landscape, only for 13 non-costal and non-capital regions in the aforementioned countries. This result, in our opinion, seems to suggest that the proposed interventions for the less-developed regions in the Mezzogiorno might be extended to the peripheral areas of these countries, whose observed growth patterns did not converge to the ones observed for the majority of the European regions. In particular, these policies might facilitate not only the technological development of these areas but would also allow them to be embedded in the European context and to reduce the observed gap with the most developed areas.

The last drawback is instead represented by the structure of our data, which does not allow us to assess whether the impact of institutional quality upon RIS efficiency varies across different industries. As emphasised by Griliches (1990), Arundel and Kabla (1998), and Aldieri et al. (2021), industries significantly differ in the share of innovations being patented. Moreover, Malerba (2002) notably argues that the effects of national institutions on sectoral innovation depend on the sector examined. Indeed, given the presence of sectoral-specific factors, changes in the institutional environment might unevenly affect firms, depending on the sector in which they operate. It turns out that future research should assess whether the impact of institutions upon RIS efficiency varies across different industries and sectors. This empirical approach would shed additional light on the institutions-efficiency nexus and would allow to assess how the quality of local institutions shapes the efficiency of regional innovation systems in different industries and technologies, hence leading to more accurate policy implications. A second complementary line of research could instead be represented by an assessment of the role of spillovers of institutional change upon RIS efficiency. Indeed, as various contributions in the literature have proven, see for instance Seldadyo et al. (2010), de Groot (2011), Kelejian et al. (2013), Krammer (2015) and Grechyna (2018), institutions are spatially correlated, hence implying that improvements in the quality of institutions in a given country/region exert a positive effect on the governance of neighbour countries/regions. It
would be relevant, in our opinion, to assess whether these types of spillovers exist in the Italian case and whether an improvement in the quality of institutions in a region is translated into an increase in both the quality of government and in the RIS efficiency of its neighbours.

Appendix

The traditional Knowledge Production Function

To further assess the robustness of our findings and to evaluate whether the results differ once an alternative empirical approach is employed, we propose the estimation of a traditional knowledge production function—estimated through the application of a Fixed Effects estimator—in which we rely on the amount of registered patents as the dependent variable. Formally, the Fixed Effect regression is described as follows:

\[
PAT_{it} = \alpha_1 RD\_EXP_{it} + \alpha_2 IQ_{it} + \alpha_3 Controls_{it} + Time + \epsilon_{it} \tag{2}
\]

where \( PAT \) is the number of disclosed regional patents applications (in log form), \( RD\_EXP \) is the vector of the amount of R&D expenditures, which consists of R&D expenditures in public sector (\( RD\_EXP\_PUBL \)), in the higher education institutions (\( RD\_EXP\_HEI \)) and in the private sector (\( RD\_EXP\_PRIV \)), \( IQ \) is the vector of quality of institution indicators and \( Controls \) is a vector of regional characteristics (see Table 3 for more details about the description of the variables). Finally, \( Time \) denotes the time dummies capturing exogenous factors (i.e. technological changes) that might affect the number of patents. The subscripts \( i \) and \( t \) denote region and year, respectively.

Table 10 reports the estimates by assuming both two (columns E1-E7) and one-year lag (columns E8-E14) between R&D expenditures and patents, while R&D expenditures in the private sector are used to assess the impact of knowledge spillovers. Regardless the environment, we document a positive and highly significant effect of government effectiveness, while other dimensions of the quality of institutions are again found to be insignificant, hence suggesting that our results are robust even ones we move away from the perspective of RIS efficiency. However, once the Knowledge Production Function is employed, the positive and significant impact of the IQI of Nifo and Vecchione (2014) vanishes.

To conclude our econometric analysis, we propose a set of econometric estimates in which we assume both two (columns F1-F7) and one-year lag (columns F8-F14) between R&D employees and patents, with R&D employees in the private sector as a measure of knowledge spillovers.

In line with the estimates reported so far, all the stand-alone measures of institutional quality but government effectiveness are found to be insignificant. On the other hand, regardless the environment, government effectiveness is found to be positive and significant at the 1% level. The evidence reported in Table 11, in line with the
Table 10  Estimates for the knowledge production function according to the Fixed Effects estimator  

| y = Patents (in log) | (E1) | (E2) | (E3) | (E4) | (E5) | (E6) | (E7) | (E8) | (E9) | (E10) | (E11) | (E12) | (E13) | (E14) |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| RD_EXP_PUBL (in log) | -0.0125 | -0.00279 | -0.00418 | -0.00342 | 0.0152 | -0.0239 | -0.0161 | -0.0795 | -0.0517 | -0.0717 | -0.0721 | -0.0664 | -0.0807 | -0.0811 |
| [0.0487] | [0.0477] | [0.0472] | [0.0470] | [0.0499] | [0.0468] | [0.0480] | [0.0569] | [0.0488] | [0.0555] | [0.0559] | [0.0563] | [0.0567] | [0.0573] |
| RD_EXP_HEI (in log) | 0.278*** | 0.0561 | 0.231** | 0.234*** | 0.241** | 0.319*** | 0.293*** | 0.317*** | 0.153* | 0.290*** | 0.261*** | 0.298*** | 0.345*** | 0.333*** |
| [0.0901] | [0.101] | [0.104] | [0.0855] | [0.0954] | [0.0890] | [0.0915] | [0.0797] | [0.0843] | [0.0876] | [0.0747] | [0.0847] | [0.0783] | [0.0802] |
| RD_EXP_PRIV (in log) | 0.478*** | 0.413*** | 0.448*** | 0.462*** | 0.463*** | 0.485*** | 0.480*** | 0.528*** | 0.450*** | 0.507*** | 0.512*** | 0.514*** | 0.523*** | 0.528*** |
| [0.0521] | [0.0449] | [0.0542] | [0.0477] | [0.0475] | [0.0490] | [0.0516] | [0.0517] | [0.0433] | [0.0516] | [0.0464] | [0.0466] | [0.0487] | [0.0515] |
| KS1 (in log) | 0.115 | -0.106 | 0.109 | 0.0681 | 0.146* | 0.141* | 0.116 | 0.116* | -0.0468 | 0.112 | 0.0582 | 0.126* | 0.134*** | 0.117* |
| [0.0828] | [0.103] | [0.0846] | [0.0980] | [0.0816] | [0.0800] | [0.0826] | [0.0867] | [0.0848] | [0.0682] | [0.0731] | [0.0675] | [0.0646] | [0.0665] |
| PD (in log) | 0.340*** | 0.446*** | 0.383*** | 0.359*** | 0.372*** | 0.320*** | 0.329*** | 0.287*** | 0.376*** | 0.312*** | 0.308*** | 0.304*** | 0.278*** | 0.276*** |
| [0.106] | [0.0876] | [0.116] | [0.104] | [0.110] | [0.0994] | [0.105] | [0.0829] | [0.0729] | [0.0889] | [0.0811] | [0.0866] | [0.0793] | [0.0820] |
| EP (in log) | 0.0931 | 0.130*** | 0.0817 | 0.0760 | 0.104 | 0.113* | 0.0964 | 0.0616 | 0.0920 | 0.0539 | 0.0359 | 0.0615 | 0.0760 | 0.0650 |
| [0.0655] | [0.0632] | [0.0667] | [0.0661] | [0.0637] | [0.0653] | [0.0645] | [0.0602] | [0.0597] | [0.0626] | [0.0604] | [0.0595] | [0.0610] | [0.0608] |
| UR (in log) | -1.171*** | -0.823*** | -1.296*** | -1.260*** | -1.212*** | -1.038*** | -1.133*** | -1.042*** | -0.773*** | -1.125*** | -1.150*** | -1.080*** | -0.963*** | -1.004*** |
| [0.245] | [0.152] | [0.269] | [0.253] | [0.243] | [0.231] | [0.244] | [0.184] | [0.134] | [0.208] | [0.186] | [0.184] | [0.182] | [0.188] |
| Variable  | (E1)     | (E2)     | (E3)     | (E4)     | (E5)     | (E6)     | (E7)     | (E8)     | (E9)     | (E10)    | (E11)    | (E12)    | (E13)    | (E14)    |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|           | TWO-YEAR LAG | ONE-YEAR LAG |        |          |          |          |          |          |          |          |          |          |          |          |
| SERV      | 2.061    | 5.415*** | 3.790    | 2.992    | 3.699    | 0.557    | 1.365    | 0.308    | 3.564a   | 1.058    | 1.332    | 0.970    | -0.566   | -0.391   |
|           | (2.421)  | [2.123]  | [3.200]  | [2.432]  | [3.122]  | [2.446]  | [2.657]  | [2.073]  | [1.920]  | [2.477]  | [2.020]  | [2.563]  | [2.146]  | [2.208]  |
| IND       | 3.066    | 4.405*** | 4.990    | 4.112    | 4.800^   | 1.358    | 2.347    | 1.260    | 3.290^   | 2.220    | 2.460    | 2.073    | 0.331    | 0.571    |
|           | (2.344)  | [1.854]  | [3.214]  | [2.304]  | [2.872]  | [2.613]  | [2.744]  | [2.180]  | [1.874]  | [2.633]  | [2.113]  | [2.561]  | [2.413]  | [2.450]  |
| CORR      | 0.113    |          | 0.161    |          |          |          |          |          |          |          |          |          |          |          |
|           | (0.244)  | [0.197]  |          |          |          |          |          |          |          |          |          |          |          |          |
| GOV       |          |          | 3.693*** |          |          |          |          |          | 2.815*** |          |          |          |          |          |
|           |          |          | (0.809)  |          |          |          |          |          | [0.688]  |          |          |          |          |          |
| REG       | -0.414   |          |          | -0.179   |          |          |          |          |          |          |          |          |          |          |
|           | (0.447)  |          |          | [0.340]  |          |          |          |          |          |          |          |          |          |          |
| RULE_LAW  | -0.229   |          |          | -0.283   |          |          |          |          |          |          |          |          |          |          |
|           | (0.226)  |          |          | [0.189]  |          |          |          |          |          |          |          |          |          |          |
| VO_ACC    | -0.473   |          | -0.160   |          |          |          |          |          |          |          |          |          |          |          |
|           | (0.469)  |          | [0.381]  |          |          |          |          |          |          |          |          |          |          |          |
| IQI       | 0.543    |          | 0.397    |          |          |          |          |          |          |          |          |          |          |          |
|           | (0.364)  |          | [0.323]  |          |          |          |          |          |          |          |          |          |          |          |
| PCA       | 0.0270   |          | 0.0308   |          |          |          |          |          |          |          |          |          |          |          |
|           | (0.0402) |          | [0.0348] |          |          |          |          |          |          |          |          |          |          |          |
| Fixed effects | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  | Yes  |

*Note: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01.
Models E1-E7, with the imposition of a two-year lag between R&D expenditures and patents. Models E8-E14, with the imposition of a one-year lag between R&D expenditures and patents. The set of inputs consists in the amount of R&D expenditures in the public sector (RD_EXP_PUBL), in the higher education institutions (RD_EXP_HEI) and in the private sector (RD_EXP_PRIV). KS1: Knowledge spillovers (measured as RD_EXP_PRIV*W); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the values of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR:: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Nifo and Vecchione, 2014 page 1633); f) IQI: composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies. Constant in all models but not reported. Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively
Table 11  Estimates for the knowledge production function according to the Fixed Effects estimator

\[ y = \text{Patents (in log)} \]

|          | (F1)     | (F2)     | (F3)     | (F4)     | (F5)     | (F6)     | (F7)     | (F8)     | (F9)     | (F10)    | (F11)    | (F12)    | (F13)    | (F14)    |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| TWO-YEAR LAG |         |          |          |          |          |          |          |          |          |          |          |          |          |
| RD_EMP\_PUBL (in log) | -0.0480  | -0.0391  | -0.0388  | -0.0487  | -0.0199  | -0.0850  | -0.0614  | -0.0881  | -0.0863  | -0.0848  | -0.0875  | -0.0742  | -0.111   | -0.0980  |
| [0.0760] | [0.0617] | [0.0764] | [0.0763] | [0.0762] | [0.0787] | [0.0802] | [0.0790] | [0.0675] | [0.0773] | [0.0811] | [0.0808] | [0.0817] |          |          |
| RD_EMP\_HEI (in log) | 0.276*** | 0.0617   | 0.234**  | 0.275*** | 0.246**  | 0.347*** | 0.298*** | 0.280*** | 0.122    | 0.249**  | 0.266*** | 0.264*** | 0.334*** | 0.298*** |
| [0.104]  | [0.106]  | [0.116]  | [0.102]  | [0.106]  | [0.108]  | [0.107]  | [0.0873] | [0.0962] | [0.101]  | [0.0800] | [0.0910] | [0.0841] | [0.0873] |          |
| RD_EMP\_PRIV (in log) | 0.596*** | 0.536*** | 0.569*** | 0.597*** | 0.592*** | 0.634*** | 0.612*** | 0.600*** | 0.533*** | 0.580*** | 0.599*** | 0.599*** | 0.621*** | 0.613*** |
| [0.0804] | [0.0628] | [0.0896] | [0.0804] | [0.0748] | [0.0832] | [0.0848] | [0.0846] | [0.0703] | [0.0921] | [0.0792] | [0.0781] | [0.0808] | [0.0858] |          |
| KS2 (in log) | 0.113    | -0.152   | 0.110    | 0.110    | 0.157*   | 0.144*   | 0.112    | 0.0974   | -0.113   | 0.0946   | 0.0787   | 0.122    | 0.118    | 0.0962   |
| [0.0825] | [0.0941] | [0.0822] | [0.0874] | [0.0908] | [0.0741] | [0.0815] | [0.0810] | [0.0961] | [0.0809] | [0.0818] | [0.0863] | [0.0772] | [0.0809] |          |
| PD (in log) | 0.308*** | 0.381*** | 0.346*** | 0.307*** | 0.330*** | 0.268*** | 0.291*** | 0.299*** | 0.362*** | 0.329*** | 0.302*** | 0.312*** | 0.272*** | 0.286*** |
| [0.100]  | [0.0764] | [0.111]  | [0.0982] | [0.101]  | [0.0957] | [0.100]  | [0.0983] | [0.0808] | [0.112]  | [0.0956] | [0.100]  | [0.0928] | [0.0983] |          |
| EP (in log) | 0.0728   | 0.106*   | 0.0662   | 0.0723   | 0.0898   | 0.0987   | 0.0768   | 0.0414   | 0.0645   | 0.0369   | 0.0636   | 0.0519   | 0.0634   | 0.0460   |
| [0.0679] | [0.0585] | [0.0681] | [0.0680] | [0.0663] | [0.0681] | [0.0683] | [0.0732] | [0.0647] | [0.0739] | [0.0721] | [0.0724] | [0.0737] | [0.0735] |          |
| UR (in log) | -1.174***| -0.760***| -1.269***| -1.172***| -1.179***| -0.967***| -1.111***| -1.107***| -0.752***| -1.190***| -1.118***| -1.104***| -0.953***| -1.051***|
| [0.198]  | [0.135]  | [0.212]  | [0.204]  | [0.201]  | [0.191]  | [0.190]  | [0.193]  | [0.135]  | [0.226]  | [0.188]  | [0.187]  | [0.184]  | [0.194]  |          |
| SERV     | 1.214    | 4.302**  | 2.913    | 1.260    | 2.918    | -1.198   | 0.403    | 0.646    | 3.738    | 1.830    | 0.963    | 1.647    | -0.898   | 0.0622   |
| [2.545]  | [2.099]  | [3.397]  | [2.540]  | [3.077]  | [2.609]  | [2.792]  | [2.585]  | [2.288]  | [3.332]  | [2.505]  | [3.065]  | [2.536]  | [2.761]  |          |
Table 11 (continued)

|        | (F1) | (F2) | (F3) | (F4) | (F5) | (F6) | (F7) | (F8) | (F9) | (F10) | (F11) | (F12) | (F13) | (F14) |
|--------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|
|        |      |      |      |      |      |      |      |      |      |       |       |       |       |       |
|        |      |      |      |      |      |      |      |      |      |       |       |       |       |       |
| IND    | 0.994 | 2.177 | 2.916 | 1.014 | 2.706 | -2.098 | -0.0499 | 0.448 | 2.204 | 1.760 | 0.750 | 1.410 | -1.593 | -0.343 |
|        | [2.848] | [2.195] | [3.933] | [2.932] | [3.264] | [3.273] | [3.376] | [2.786] | [2.387] | [3.679] | [2.722] | [3.216] | [2.951] | [3.156] |
| CORR   | -0.0297 |      |      |      |      |      |      |      |      | -0.0515 |      |      |      |      |
|        | [0.236] |      |      |      |      |      |      |      |      | [0.229] |      |      |      |      |
| GOV    | 3.929*** |      |      |      |      |      |      |      |      | 3.145*** |      |      |      |      |
|        | [0.717] |      |      |      |      |      |      |      |      | [0.731] |      |      |      |      |
| REG    |       | -0.440 |      |      |      |      |      |      |      | -0.351 |      |      |      |      |
|        |       | [0.453] |      |      |      |      |      |      |      | [0.421] |      |      |      |      |
| RULE_  |       | -0.0132 |      |      |      |      |      |      |      |      | -0.0879 |      |      |      |      |
| LAW    |       |      | [0.252] |      |      |      |      |      |      |      |      | [0.207] |      |      |      |
| VO_ACC |       | -0.556 |      |      |      |      |      |      |      | -0.322 |      |      |      |      |
|        |       | [0.440] |      |      |      |      |      |      |      | [0.398] |      |      |      |      |
| IQI    |       |      |      | 0.751* |      |      |      |      |      |      |      | 0.553 |      |      |
|        |       |      | [0.418] |      |      |      |      |      |      |      |      | [0.357] |      |      |
| PCA    |       | 0.0278 |      |      |      |      |      |      |      |      |      |      | 0.0216 |      |
|        |       | [0.0434] |      |      |      |      |      |      |      |      |      |      | [0.0391] |      |
| Fixed  | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| effects|       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Time   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| dummies|       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Period | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– | 2004– |
|        | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  | 2011  |
Models F1-F7, with the imposition of a two-year lag between R&D employees and patents. Models F8-F14, with the imposition of a one-year lag between R&D employees and patents. The set of inputs consists in the number of R&D employees in the public sector (RD_EMP_PUBL), in the higher education institutions (RD_EMP_HEI) and in the private sector (RD_EMP_PRIV). KS2: Knowledge spillovers (measured as RD_EMP_PRIV*W); PD: Population density (measured as the number inhabitants in the region by squared kilometre); EP: export (measured as the values of exports as a percentage of the Gross Domestic Product); UR: Unemployment rate (measured as the number of people actively looking for a job as a percentage of the labour force); SERV: % of employment in the services sector (measured as the number of employees in the services sector over the total number of employees); IND: % of employment in the industry sector (measured as the number of employees in the industry sector over the total number of employees). We include different indicators related to the quality of institutions, a) CORR: “summarizes data on a crimes committed against the Public Administration (PA), the number of local administrations overruled by the federal authorities and the Golden-Picci Index, measuring the corruption level on the basis of “the difference between the amounts of physically existing public infrastructure (…) and the amounts of money cumulatively allocated by government to create these public works”, (Nifo and Vecchione, 2014 page 1633); b) GOV: “measures the endowment of social and economic structures in Italian provinces and the administrative capacity of provincial and regional governments in relation to policies concerning health, waste management and the environment”, (Nifo and Vecchione, 2014 page 1633); c) RULE_LAW: “summarizes data on crime against persons or property, on magistrate productivity, trial times, the degree of tax evasion and the shadow economy”, (Nifo and Vecchione, 2014 page 1633); d) REG: “comprises information concerning the degree of openness of the economy, business environment and, hence, the ability of local administrators to promote and protect business activity”, (Nifo and Vecchione, 2014 page 1633); e) VO_ACC: “captures the participation in public elections, the phenomenon of associations, the number of social cooperatives and cultural liveliness measured in terms of books published and purchased in bookshops”, (Nifo and Vecchione, 2014 page 1633); f) IQI: composite indicator of institutional quality; g) PCA: composite indicator of institutional quality using principal component analysis. All models consider time dummies. Constant in all models but not reported. Standard errors clustered at region and year level in brackets. *, **, *** stand for significant at 10%, 5% and 1%, respectively.

| y = Patents (in log) | (F1) | (F2) | (F3) | (F4) | (F5) | (F6) | (F7) | (F8) | (F9) | (F10) | (F11) | (F12) | (F13) | (F14) |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| TWO-YEAR LAG        | 120  | 120  | 120  | 120  | 120  | 120  | 120  | 140  | 140  | 140  | 140  | 140  | 140  | 140  |
| ONE-YEAR LAG        | 120  | 120  | 120  | 120  | 120  | 120  | 140  | 140  | 140  | 140  | 140  | 140  | 140  | 140  |
results of Table 10, indicates that the positive and significant effect found for the IQI on RIS efficiency vanishes once we rely on the Knowledge Production Function.

All in all, the application of the standard KPF confirms the findings of the paper, though two things are worth mentioning. The first concerns the role of knowledge spillovers. Indeed, their role becomes significantly weaker once we consider the traditional Knowledge Production Function, while they are found to be significant once the analysis is focused on the RIS efficiency.

This evidence is, at least partially, in line with the theoretical predictions of Mukoyama (2003), and consistent with the empirical findings of März et al. (2006) and Wang et al. (2013). According to März et al. (2006) and Wang et al. (2013), in order to improve their technological levels, firms might find more profitable to imitate rather than engage in independent innovation. In the specific context of this paper, knowledge spillovers seem to enhance technological levels via imitation—which is translated into higher RIS efficiency—but do not generate a higher propensity towards patenting activities.

The second is that though our results are confirmed, we believe that the approach of the Stochastic Frontier Analysis is, for the purposes of this paper, relatively more suitable and provides relatively more insights compared to the Knowledge Production Function approach. Indeed, though it is true that through the KPF it is possible, to some extent, to capture the impact of the quality of regional institutions on the degree of innovativeness of the RIS, its major limitation lies in the fact that through its application it is not possible to infer how the quality of institutions interacts with the RIS efficiency and, hence, with the efficiency with which the RIS converts inputs into outputs, which represents the main goal of the current contribution. On the other hand, this can be done through the application of the SFA approach, which allows to appraise how the different dimensions of the quality of institutions affect the RIS efficiency and to evaluate how distant is the RIS relative to its best practice, summarised by the efficiency frontier (Lanskin et al., 2001; Murillo-Zamorano, 2004).

At the same time, the application of the SFA approach further allows us to assess whether an improvement in the quality of institutions moves the RIS closer to the efficiency frontier, hence determining a more efficient allocation of resources.

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**Data Availability** The data that support the findings reported in this paper are available from the corresponding author upon request.

**Declarations**

**Ethical Conduct** The authors declare that they have no conflict of interest.
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