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THE DETERMINANTS OF INNOVATIVE CAPACITY IN THE MEDICAL SECTOR IN CENTRAL EUROPE AND ACROSS THE EUROPEAN UNION

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Abstract. The recent COVID-19 crisis, as well as the resulting international response, have demonstrated the importance of medical innovation in meeting current and future health challenges. Yet capacity for innovation differs from country to country, and policymakers are wise to find ways to increase each nation's ability to generate new solutions. This study examines medical innovation, measured as patents per capita, for 27 EU countries from 2004 to 2018. Modelling innovation as a function of international and domestic macroeconomic variables, government and private-sector R&D, the rate of return to physical and human capital, and a measure of risk, a dynamic panel analysis finds that real-exchange-rate volatility reduces patent applications for some countries, particularly in Central and Eastern Europe. The response to the explanatory variables differs by countries' overall innovation levels, with innovation in weaker innovators reduced by risk and increased by higher education levels. In stronger innovators, the internal rate of return most strongly drives innovation, suggesting that this process more closely resembles "traditional" investments.

Keywords: medical innovation, innovative capacity, sectoral innovation system, European Union, Central and Eastern Europe.

JEL Classification: O31, C1, P33.

Introduction

Health-related issues and medical sector advancement have long been important for economic and social development, and have attracted the attention of policymakers all over the world. Aging populations and the rise of noncommunicable diseases have caused a shift towards promoting overall well-being in the long term. The COVID-19 pandemic has increased awareness across society about the important role played by medical innovation.

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The intensive research on vaccines and new medicines against COVID-19 has led to improved discourse about the innovative capacity of the medical sector, the costs and benefits of medical science research and development (R&D), and measures that can boost medical innovation.

While there is a wide range of empirical evidence on the national determinants of innovative capacity, the number of studies devoted to innovation in medical sector is still limited. An exploratory bibliometric analysis of the existing studies on medical innovation published in scientific journals listed in the Web of Science core collection shows that, since 2010, only 91 papers have been published, out of which only 13 are in Economics. These papers deal with the diffusion of medical innovations (e.g. Grebel & Wilfer, 2010; Frankovic et al., 2020), their value (e.g. Chan et al., 2016; Jeon & Pohl, 2019; Levaggi & Pertile, 2020), and costs (van de Wetering et al., 2012; Willemé & Dumont, 2015).

Innovation capacity in the medical sector, which has attracted attention during the COVID-19 pandemic, has not yet been studied in depth. Only a few studies include a wider macroeconomic perspective, however, with the focus on the broadly understood health innovation systems (Consoli & Mina, 2009) or covering just one country – namely the U.S. (Frankovic et al., 2020). Our paper addresses this research gap aiming at identifying the determinants of innovation at the sectoral level with a focus on medical science innovation. We analyze EU countries from Central Europe, comparing them with other Member States. The focus is on the issues that are important for the "smart" recovery from COVID-19 pandemic and resilience of sectors and countries to similar crises. The impact of COVID-19 on economic outcomes has eroded over time, in particular with regard to growth rates, trade flows, or breaks in global value chains as well as to R&D investment (Ketels & Clinch, 2020). The COVID-19 pandemic also caused an abrupt transition to remote teaching, and it is estimated that, on average, students will suffer learning loss (Di Pietro et al., 2020). Furthermore, the COVID-19 pandemic has created new risks (technological, financial, organizational, and social), or made existing ones more severe. In this context, there are a few questions which we bring to the research agenda:

Which of various elements of the general macroeconomic environment (e.g. GDP growth, real exchange rates, trade openness, education) have the strongest impact on the creation of medical innovation?

- How does the global context shape the innovation capacity of the medical sciences?
- How does risk perception impact medical innovation?
- What is the importance of industry-specific characteristics for innovation?
- What are the differences in medical innovative capacity between various groups of EU countries (Central and Eastern Europe, or the strongest and weakest innovators)?

1. The determinants of innovative capacity – a conceptual framework

What kind of conceptual frameworks may constitute a useful tool for the identification of the factors affecting the innovation performance of countries in the different sectors, as well as for the development of new policy directions? An appropriate approach to the topic of medical innovation need to meet a few important criteria. It should cover the overall innovation environment in the country as well as sector specific features, allow for cross-country comparisons, and make it possible to operationalize innovation determinants in a quantitative way.

To satisfy these criteria, we extend and modify the framework of national innovative capacity developed by Furman, Porter, and Stern (2002) integrating it with the sectoral innovation system approach (Breschi & Malerba, 1997; Malerba, 2005). Furthermore, as the healthcare sector has experienced huge turbulence during the COVID-19 pandemic, key factors that could affect medical innovation in times of the crisis caused by the pandemic outbreak have also been included in the analysis.

According to Furman, Porter, and Stern (2002) factors that determine the innovative capacity of a country can be divided into three broad categories: (1) resources, institutions and policies supporting innovation in the country, constituting innovation infrastructure, (2) the microeconomic environment for innovation offered within country's industrial clusters, (3) linkages between the two above-mentioned groups of determinants. However, the type of innovation, its rate and the way innovative activities are organized differ significantly across sectors. Therefore, when modeling innovation at the sectoral level, both macro- (country-level) factors and meso- (sector-specific) ones that constitute the sectoral system of innovation need to be considered.

There are three main components of sectoral innovation systems: (1) the knowledge base and technologies available in specific sectors, (2) actors and networks; and (3) institutions underpinning innovative activities at the sectoral level (Malerba, 2005). Merging national innovative capacity and sectoral innovation system concepts enables one to get a complete picture of innovation in the medical sector. Key determinants that need to be analyzed are financial resources available in the whole country and in the analyzed sector, overall and sector-specific human capital, the environment for investment in innovation, and linkages reflected in openness to international connections.

In order to include in the analysis the impact of the COVID-19 pandemic on in-novation activity, it is important to look back on past crises and their impact on innovation. On the one hand, an economic crisis can lead to "creative destruction" as de-scribed by Schumpeter (1950), and thus, as the innovation acceleration hypothesis assumes, new innovative trajectories and radical innovations emerge (Mensch, 1979). On the other hand, an economic crisis creates a risk of facing financial constraints for innovative and R&D performing firms, which may cause significant R&D investment cuts (Clark et al., 1981). Financial barriers that intensify during the crisis may cause a delay in introducing innovations (Francois & Lloyd-Ellis, 2003) and may slow down knowledge transfer and adoption along value chains. Innovation is per se a risky activity, there are several types of risks associated with in-novation, such as technological, market, financial, organizational, and social risks, as well as the risk of unforeseen events. This may potentially lead to difficulties in introducing innovation, and has significant implications for financing innovative activities and the application of innovative policy tools. The COVID-19 pandemic, similar to other crises, has increased the risk of doing business and conducting research and development activity.

In view of the diverse and ambiguous impact of crises on innovation that has been pointed out in the literature, coupled with the huge risk pressure imposed by the COVID-19 pandemic, we include the international risk climate as an important factor determining innovation in the times of crisis, such as COVID-19 pandemic. Risk is de-fined in the literature in multiple ways (Willet, 1951; Knight, 1964; Adams, 2000; Rosa et al., 2014). According to a very broad definition risk is objectified uncertainty of the occurrence of an undesirable event, but this uncertainty is not determined by the level of probability (Willet, 1951). As it is difficult to operationalize the risk understood in this way, we assume, following the literature (Holton, 2004; Rosa et al., 2014), that what can be measured is a perception of uncertainty.

Having scratched the surface of the conceptual framework, the determinants of innovation capacity in medical science and their proxies need to be discussed. First, in order to perform the analysis, observable measures of new-to-the-world innovations must be identified. Consistent with prior research, we recognize that there is no perfect measure in precisely characterizing innovation performance in an economy or its sectors. As many studies suggest (Pavitt, 1985; Griliches, 1990; Nagaoka et al., 2010; Kelly et al., 2020) we assume that innovation can be measured by patent applications, bearing in mind however that advantages and disadvantages of this measure and its limitations have been pointed out in the literature (e.g. Furman et al., 2002; Nagaoka et al., 2010; Dziallas & Blindt, 2019).

Second, our conceptual framework discussed above implies that there are two sets of medical innovation determinants that should be included in the analysis: (i) the ones that reflect the macroeconomic environment for innovation as pointed out in national innovation capacity concept and (ii) sector-specific ones reflecting the sectoral innovation system approach. Therefore, the next step in our analysis is to answer the question of how exactly conceptually described determinants of innovation capacity are found significant the empirical literature.

When it comes to macroeconomic environment, Furman and Hayes (2004) conducted an empirical study of national innovative capacity in 29 selected developed countries and found that increasing investment in R&D supported by innovation-oriented policy commitments determines innovation in these countries, but the role of both determinants differ depending on the level of innovativeness of the countries, with the former being relatively more important for countries that are at a moderate level of innovativeness, and the latter is more important for economies with al-ready well developed innovative capacities. For minor innovators, improvements are needed in both dimensions. Similar findings have been achieved for five East Asian countries by Hu and Mathews (2005), who additionally proved that public R&D expenditure has been important for catching up with innovation leaders. They have also been confirmed for a sample of 23 small developed economies from all over the world (Doyle & O'Connor, 2013). The econometric model employing a panel dataset for 15 Asian countries for of the period 2008–2017 confirmed these results, also indicating positive impact of institutional quality, education and trade openness on innovation capacity (Malik, 2020).

Moving to sectoral perspective, it should be pointed out that only a few studies on innovative capacity of medical sector exist. Innovative capacity is explained for a broadly understood health innovation, which is a bundle of medical technologies and clinical services, with the analysis centered around health innovation system without offering an empirical framework for its quantitative analysis (Consoli & Mina, 2009).

The majority of existing studies that focus on various aspects of medical innovation, but not on its determinants, which is a core of our study. Major research problems examined by scholars in recent years include the diffusion of new medical technologies (Grebel & Wilfer, 2010; Frankovic et al., 2020), the economic benefits of new treatment methods (Jeon and Pohl, 2019), the cost of ensuring efficiency of different regulation regimes for the reimbursement of medical innovations (Levaggi & Pertile, 2020), or the impact of new medical technologies on health spending (Willemé & Dumont, 2015).

Therefore, in order to shed some light on innovative capacity seen from the sectoral perspective, it is worth reviewing previous studies devoted to innovation in different sectors, A study of a sample of 32 developed and emerging economies on financial market development and its effect on innovation proved that the role of equity and credit markets in driving innovation varies depending on the type of industry and its technological capacity (Hsu et al., 2014). Private R&D funding and government R&D grants, as well as human capital, were found to play a role in the innovation capacity of the high-tech industry in China (Hong et al., 2015). In turn, a comparative assessment of innovative capacity of the water sector in China and Europe revealed a strong relationship between innovation in this sector and national innovative capacity, with environmental regulations, R&D expenditure, and international collaboration being key determinants for both Europe and China, and for the latter direct investments as well as private R&D were found to be also significant.

Summing up a review of existing evidence of macroeconomic factors that determine innovation capacity, it should be observed that key factors are as follows: R&D expenditure (both public and private), human capital development (measured by education and the availability of R&D personnel), openness to the world, and innovation-oriented policy.

In turn, the review of selected previous studied on sectoral innovative capacity can be summarized by a list of various determinants that have been identified to matter for innovation at sectoral level. These are: private and government R&D, financial market development, specific sectoral regulations, and international collaboration.

2. Methodology and data

The variable of interest in this study is the number of medical patent applications at the country level, scaled by population. Application data for "PCT publications by IPC class" for all EU countries are taken from the World Intellectual Property Organization (WIPO) database, covering the years 2004 to 2018. Within item A61 (medical technology), we aggregate items B, C, F, G, H, K, L, M, N and P to create a single annual measure of medical patent applications. These are then scaled by population (in millions) using data from Eurostat. These subgroups, as well as the other variables in the model, are explained in the Appendix.

After examining their time-series behavior and statistical properties, the macroeconomic determinants of these per-capita medical patent applications are estimated using dynamic panel methods first introduced by Arellano and Bond (1991). This well-known method both includes lagged values of the dependent variable and help control for endogeneity. Given the "short" time series, traditional time-series methods are not applicable. Dynamic panel approaches are preferred to "static" panel approaches, particularly due to the relationship between present and past innovation. A number of panel approaches were estimated during this analysis, including fixed and random effects models, with and without time dummies.

The dynamic approach performs well, whie taking into account autocorrelation in the time series. The significance of the lag variable in the models presented here confirm this finding.

Patent data values (plus one, to control for zero values) are log-transformed and used as the dependent variable; the model also includes time dummies. Robust standard errors are calculated throughout (which, however, precludes the use of the Sargan test for overidentification).

Based on the literature (particularly the studies mentioned above by Hong et al., 2015 and Malik, 2020), key macroeconomic determinants are included in the model. These variables are also grounded in economic theory, both in terms of the underlying economic environment and investment climate, as well as specific policies to promote medical research. Because the samples can be relatively small in this study, care must be taken to limit the number of explanatory variables, while still capturing the effects we seek to evaluate. Unless indicated, all of the following variables are taken from Eurostat, and transformed (often as log changes or as ratios) as necessary.

Economic connections are captured both by (log changes in) the real effective ex-change rate (REER; source: Eurostat), and by economic openness (exports and imports as a share of GDP, source: Penn World Table). The share of the population with at least a secondary education and the internal rate of return (source: Penn World Table) proxy the returns to human and physical capital. The ratios of Government and Business R&D (as a share of the total, source: Eurostat), and the growth rate (log changes in real GDP) are included as well. Economic risk is calculated here as the within-year standard deviations of the 12 monthly log changes in the log REER.

A pair of additional variables – the percentage of medical science R&D, both as a share of all R&D and of GDP, as well as medical employment as a share of the total, are only available for a small handful of countries. Since most of these countries lie in the same region, eight CEE countries are first estimated with each variable included in a separate specification. While the results appear interesting, it is not possible to extend the model without excluding this measure. As a result, a total of eight explanatory variables are included.

The resulting panel is first estimated for 27 countries that comprise the European Union. Malta is excluded due to the lack of continuous data for the patent data used here. After estimating it for this group (and the sets of countries that follow), various combinations are removed based on the insignificance of their coefficients. A “final” model is included alongside the “full” model in our results table. Here, EU-level results can be compared with high-and low innovation countries, as well as the 11 CEE EU member states.

The countries examined here are split into two groups based on the 2018 European Innovation Scoreboard Summary Innovation Index (European Commission, 2018). Among the most innovative countries, six “Innovation Leaders” (Denmark, Finland, Germany, Netherlands, Sweden, United Kingdom) are combined with six “Strong Innovators” (Austria, Belgium, France, Ireland, Luxembourg, and Slovenia). In the second subset, 13 “Moderate Innovators” (Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Slovakia, and Spain) are grouped with two “Modest Innovators” (Bulgaria and Romania). Four sets of countries – the EU-27, 12 strong innovators, 15 weak innovators, and the CEE-11, can therefore be compared in a way that can help drive policy decisions. Our results are provided in the next section.

3. Results

Figure 1 depicts patent applications (per million inhabitants) for 27 EU nations (including the UK, but excluding Malta). There are clear increases for some countries (such as Poland and the Netherlands), and decreases for others (such as Sweden); many more have flatter patterns.

A look at Table 1, which provides summary statistics for each medical patent series, shows the overall levels to be much higher in Western Europe than in the South or East. One exception in the CEE region is Slovenia; this is likely due to the country's longstanding connections to the West. Long before its inclusion in the former Yugoslavia, the country was a part of the Austrian (rather than the Ottoman) Empire. The country's early euro accession reflects this status.

Table 1. Summary statistics for medical patent application series (source: authors' elaboration)

	Mean	SD	Median	Min	Max
Belgium	29.961	6.274	27.94	19	42.947
Bulgaria	0.519	0.310	0.557	0	1.131
Czech Republic	4.586	1.906	3.948	2.191	8.534
Denmark	69.999	13.578	66.426	46.957	90.784
Germany	28.827	2.733	30.276	23.632	33.46
Estonia	4.060	2.568	3.712	0.738	8.975
Ireland	40.715	8.721	40.01	27.729	60.608
Greece	2.082	0.944	1.996	0.822	3.898
Spain	9.217	1.787	9.444	3.984	11.594
France	21.654	3.375	22.481	12.122	26.184
Croatia	3.723	2.726	2.554	0.951	9.045
Italy	9.938	1.333	10.062	6.015	12.231
Cyprus	16.039	8.461	14.648	1.238	27.133
Latvia	4.136	2.697	4.593	0	9.805
Lithuania	1.555	1.315	1.265	0	4.184
Luxembourg	127.146	84.057	91.674	57.126	343.804
Hungary	5.128	0.979	5.353	3.376	6.663
Netherlands	53.197	9.944	56.139	27.761	65.053
Austria	15.816	2.061	16.78	10.524	18.685
Poland	1.588	0.856	1.573	0.419	2.922
Portugal	3.449	1.464	3.220	0.572	5.421
Romania	0.243	0.175	0.233	0	0.645
Slovenia	15.415	7.626	14.549	4.340	29.417
Slovakia	0.703	0.343	0.558	0	1.116
Finland	21.232	4.217	21.353	15.289	29.774
Sweden	63.018	26.371	49.634	37.231	117.174
United Kingdom	21.491	3.375	21.983	16.468	26.238

The next step, before estimating the patent models that are the main focus of this paper, is to generate an appropriate measure of economic risk. As is mentioned above, this is done by taking the series of monthly log changes in each country's REER, and calculating within-year standard deviations to create annual measures. This measure proxies overall risk, but is based on variability in international competitiveness. These series are plotted in Figure 2. Events such as Brexit are clearly depicted, but relevant events also appear to increase all countries' risk levels. Summary statistics for each country's measure are provided in Table 2.

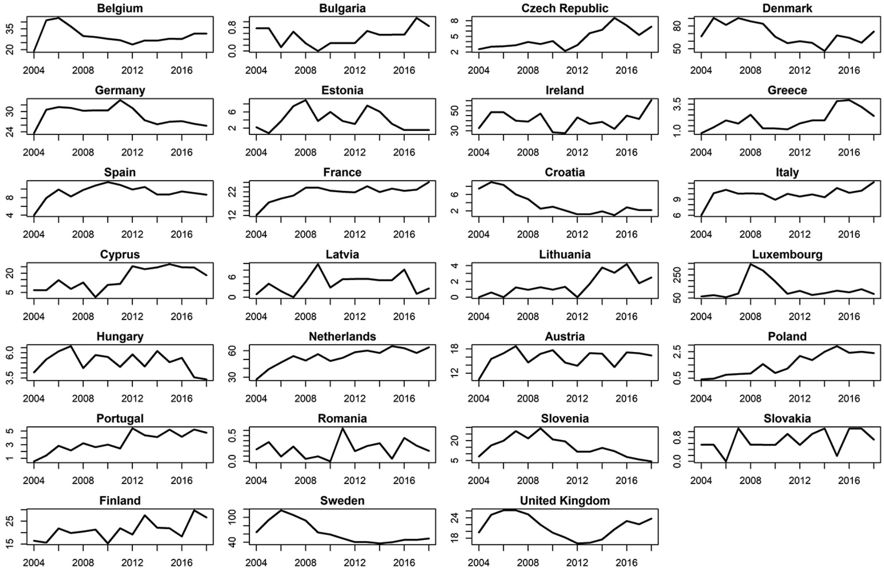

Figure 1. Medical Patent applications per 1 million inhabitants

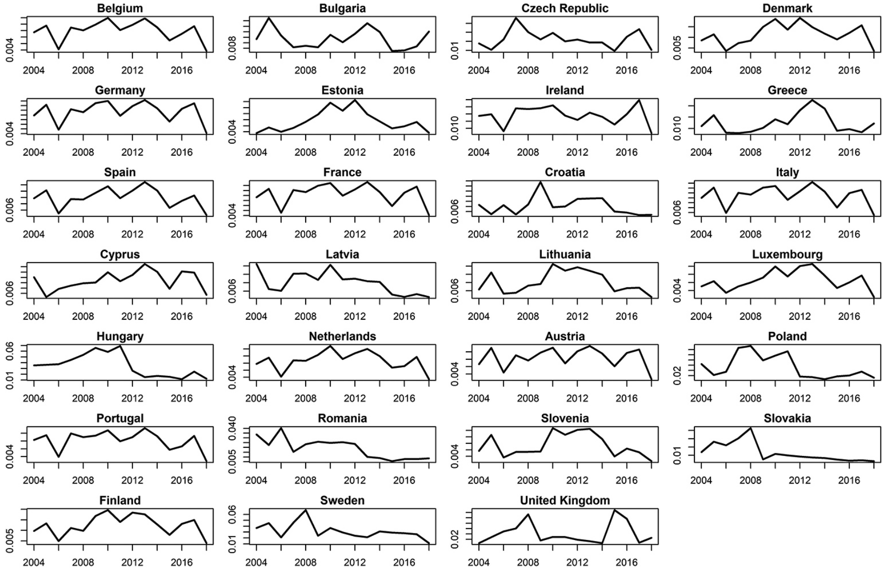

Figure 2. International risk measures, 2004–2018

Table 2. Summary statistics for REER risk (source: authors' elaboration)

	Mean	SD	Median	Min	Max
Belgium	0.010	0.003	0.011	0.004	0.014
Bulgaria	0.012	0.004	0.011	0.007	0.019
Czech Republic	0.022	0.010	0.022	0.009	0.046
Denmark	0.012	0.005	0.012	0.004	0.019
Germany	0.013	0.004	0.015	0.004	0.018
Estonia	0.008	0.003	0.007	0.004	0.015
Ireland	0.019	0.006	0.020	0.007	0.030
Greece	0.012	0.004	0.011	0.008	0.023
Spain	0.010	0.003	0.010	0.004	0.015
France	0.013	0.004	0.013	0.004	0.017
Croatia	0.008	0.004	0.008	0.005	0.018
Italy	0.013	0.004	0.014	0.005	0.018
Cyprus	0.011	0.004	0.011	0.005	0.017
Latvia	0.008	0.003	0.008	0.005	0.012
Lithuania	0.008	0.003	0.007	0.004	0.013
Luxembourg	0.007	0.002	0.006	0.002	0.011
Hungary	0.035	0.020	0.036	0.012	0.069
Netherlands	0.009	0.003	0.009	0.003	0.013
Austria	0.008	0.003	0.010	0.003	0.012
Poland	0.037	0.023	0.027	0.013	0.077
Portugal	0.008	0.002	0.009	0.003	0.011
Romania	0.019	0.011	0.023	0.006	0.040
Slovenia	0.006	0.002	0.005	0.003	0.008
Slovakia	0.013	0.012	0.008	0.003	0.043
Finland	0.013	0.005	0.013	0.004	0.020
Sweden	0.032	0.014	0.029	0.011	0.067
United Kingdom	0.031	0.020	0.024	0.013	0.074

Finally, we estimate our panel model for all countries and select subsets. We begin by including medical research (either as a percent of GDP or as a percent of total R&D) and medical employment in a preliminary model. These data are not available for all countries. While a few other EU countries have such data, we focus on eight CEE countries (Bulgaria, Czech Republic, Croatia, Estonia, Hungary, Poland, Romania, Slovenia, and Slovakia), since they fit well as a single group. The results from two models – one with all explanatory variables, and the other after certain insignificant variables are dropped – are provided in Table 3. Generally, dropping such variables does not add to the significance of the others; one exception is in column 2, where medical R&D (as a percentage of total R&D) sees its p-value fall below the critical threshold of 0.05.

Table 3. Arellano-Bond dynamic panel results, preliminary country group (source: authors' elaboration)

DV = Medical Patents per Capita	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)
Constant	4.695 (0.074)	4.814 (0.053)	4.196 (0.196)	5.167 (0.142)
L1.	**0.643 (0.000)**	**0.639 (0.000)**	**0.652 (0.000)**	**0.660 (0.000)**
IRR	2.103 (0.460)	2.219 (0.405)	1.668 (0.584)	
OPEN	–0.001 (0.738)		–0.002 (0.642)	
DLNREER	0.717 (0.163)	0.731 (0.124)	0.698 (0.181)	0.679 (0.155)
GROWTH	0.001 (0.956)		0.000 (0.995)	
RISK	–1.522 (0.201)	–1.448 (0.277)	–1.382 (0.216)	–1.865 (0.088)
GERDGOVRATIO	**–2.137 (0.000)**	**–2.082 (0.004)**	**–1.934 (0.000)**	**–1.580 (0.007)**
GERDBUSRATIO	**–1.414 (0.008)**	**–1.388 (0.014)**	**–1.262 (0.027)**	**–1.163 (0.030)**
SECED	–0.041 (0.160)	–0.043 (0.144)	–0.035 (0.360)	–0.048 (0.261)
MEDEMPRAT	1.017 (0.604)		0.665 (0.759)	
PERCMEDY			**1.005 (0.001)**	**1.123 (0.000)**
PERCMEDRDALL	0.009 (0.076)	**0.01 (0.018)**		
N (Obs.)	104	104	104	104
Countries	8	8	8	8

In these preliminary estimates, the government and business R&D shares both have significantly negative effects on medical patents – a finding that warrants further investigation. Perhaps this is because this precludes foreign investment (a variable which, due to lack of complete data, was not included in the estimations conducted here). While the share of medical employment has no effect, the percentage of medical R&D has a significantly positive effect on medical patents. But since these data are not available for all countries, these results cannot be extended beyond certain CEE countries.

The first extension is to the 27 EU countries (excluding Malta). The panel results are shown in Table 4. Most explanatory variables do not have a significant influence on medical patent applications, and growth rates have an unexpected negative effect. This does not disappear or turn positive, even when the explanatory variables are entered with a two-year lag. Perhaps this is because medical technology is more acyclical than other sectors, so that periods of low overall growth divert resources into this "safe" industry.

The significantly negative coefficient on the risk variable, however, is in line with theory, as risk aversion might drive a reduction on funding or research in any sector, and particularly ones with long time horizons from idea to inception.

Next, the sample is split into 12 "high innovation" countries and 15 "low innovation" countries. These results are provided in Table 5. Two interesting findings result. First, increased risk leads to reduced medical patent applications only in the weaker innovators. This suggests that institutional strength – in ways to mitigate uncertain-ty – is paramount. Policies designed to foment macroeconomic (and other types of) stability might help increase medical innovation. Second, higher internal rates of return drive innovation in the stronger group of countries, while education has a significantly positive effect only in the weaker countries. This suggests that human capital investment can have a real income on health outcomes, but not after a certain point where "diminishing returns" might take effect.

Table 4. Arellano-Bond dynamic panel results, EU-27 countries (source: authors' elaboration)

DV = Medical Patentsper Capita	Coeff. (p-val.)	Coeff. (p-val.)
Constant	–0.939 (0.278)	–0.662 (0.544)
L1.	**0.371 (0.005)**	**0.364 (0.003)**
irr	3.165 (0.254)	
open	0.003 (0.084)	0.003 (0.100)
dlnreer	–0.176 (0.752)	
growth	**–0.027 (0.000)**	**–0.023 (0.001)**
risk	**–3.205 (0.012)**	**–3.535 (0.027)**
gerdgovratio	0.045 (0.960)	–0.288 (0.64)
gerdbusratio	0.370 (0.619)	
seced	0.022 (0.184)	0.025 (0.093)
N	404	404
Groups	27	27

Table 5. Arellano-Bond dynamic panel results, EU-27 strong and weak innovators
(source: authors' elaboration)

DV = Medical Patents per Capita	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)
constant	–0.049 (0.958)	–0.079 (0.934)	–3.261 (0.072)	**–3.387 (0.045)**
L1.	**0.556 (0.000)**	**0.556 (0.000)**	0.247 (0.079)	0.239 (0.090)
irr	**4.140 (0.033)**	**4.303 (0.026)**	0.225 (0.938)	
open	0.000 (0.872)	–0.001 (0.824)	0.008 (0.087)	0.007 (0.079)
dlnreer	0.565 (0.189)		–0.518 (0.514)	
growth	**–0.026 (0.003)**	**–0.027 (0.002)**	**–0.031 (0.007)**	**–0.030 (0.008)**
risk	–0.433 (0.842)	–0.710 (0.755)	–3.827 (0.075)	**–3.739 (0.035)**
gerdgovratio	3.472 (0.288)	3.527 (0.279)	–0.304 (0.694)	–0.034 (0.948)
gerdbusratio	1.515 (0.127)	1.535 (0.131)	–0.347 (0.681)	
seced	0 (0.981)	0.001 (0.969)	**0.058 (0.021)**	**0.057 (0.015)**
N	179	179	225	225
Groups	12	12	15	15

Finally, the 11 CEE countries are examined, with results shown in Table 6. Here, too, risk lowers innovation, but most other variables have no significant effect.

As a point of comparison, the panels are estimated with all patents per million residents, instead of only medical patents. These results are presented in Table 7. Clearly, the macroeconomic determinants are much smaller for the subset of patents on which we focus in this study. Only trade openness seems to have any impact at all, in-creasing per-capita medical patents.

Table 6. Arellano-Bond dynamic panel results, CEE-11 countries (source: authors' elaboration)

DV = Medical Patents per Capita	Coeff. (p-val.)	Coeff. (p-val.)
Constant	–2.321 (0.312)	–3.072 (0.083)
L1.	**0.436 (0.003)**	**0.419 (0.005)**
irr	3.344 (0.173)	3.459 (0.127)
open	0.010 (0.104)	0.011 (0.096)
dlnreer	–0.173 (0.824)	
growth	**–0.036 (0.007)**	**–0.037 (0.012)**
risk	**–5.104 (0.009)**	**–4.872 (0.021)**
gerdgovratio	–0.582 (0.563)	0.301 (0.561)
gerdbusratio	–0.845 (0.269)	
seced	0.031 (0.296)	0.031 (0.249)
N	165	165
Groups	11	11

Table 7. Arellano-Bond dynamic panel results, total patents as dependent variable
(source: authors' elaboration)

DV = Medical Patents per Capita	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)	Coeff. (p-val.)
Constant	1.649 (0.123)	1.988 (0.282)	1.362 (0.288)	0.008 (0.541)
L1.	**0.407 (0.000)**	**0.424 (0.009)**	**0.411 (0.000)**	**0.625 (0.000)**
irr	2.118 (0.329)	0.326 (0.880)	0.023 (0.986)	1.170 (0.328)
open	**0.003 (0.011)**	0.002 (0.456)	0.000 (0.966)	0.002 (0.512)
dlnreer	0.007 (0.977)	–0.151 (0.710)	0.048 (0.874)	–0.245 (0.607)
growth	–0.005 (0.097)	–0.002 (0.645)	0.006 (0.521)	0.000 (0.915)
reersd2	–0.277 (0.583)	0.875 (0.374)	–2.007 (0.123)	–0.577 (0.573)
gerdgovratio	0.051 (0.890)	–0.668 (0.145)	5.524 (0.078)	–0.441 (0.345)
gerdbusratio	0.147 (0.572)	0.170 (0.443)	1.739 (0.055)	0.095 (0.808)
seced	0.012 (0.254)	0.005 (0.782)	0.008 (0.541)	–0.029 (0.345)
N	350	195	155	143
G	27	15	12	11

4. Discussion

In this paper we contribute to the strand of research that investigates the factors affecting innovative output produced in the medical sector. We examine the factors that determine levels of innovative output of medical science in the European Union, taking into account both the macroeconomic environment and sector-specific drivers. The novelty of this study is threefold. First, we include risk perception into the analysis, which we expect to be of high relevance in the times of crisis, such as during pandemics. Second, recognizing the heterogeneity of the EU regarding innovative capacity as pointed out by the cyclically published European Innovation Scoreboard (see the latest edition – European Commission, 2021), apart from analysis the EU as a whole, we spilt the EU region into two groups categorized by the level of innovativeness, and we conduct separate studies for each of them. We identify some differences among strong innovators (12 countries) and weak ones (15 countries) in importance of medical innovation drivers. Third, we separately analyze EU members from Central Europe, which are characterized by different technology upgrading patterns due to the disjunction between production capability, and R&D and technological capability (Kravtsova & Radosevic, 2012; Radosevic et al., 2019) and regarded as countries with emerging innovation systems (Stojčić, 2021). Our panel data-based econometric analysis provides the underpinning for understanding the factors that explain innovative productivity of the medical sector measured by patent applications. This empirical evidence may be used to design policy supporting catching up processes in medical sector.

This analysis adds to the literature by conceptualizing innovation capacity at the sectoral level. We brought a new perspective on innovation determinants, taking into account exposure to risk and the returns to human and physical capital. While the innovative capacity model developed by Furman et al. (2002) has been used as the basis for many empirical studies (e.g. Hu & Mathews, 2005; Doyle & O'Connor, 2013; Zang et al., 2019) previous studies did not analyze risk as a determinant of innovation capacity, which in our empirical analysis was proved to matter much for innovation capacity at both the national and sectoral levels. Furthermore, other papers examined innovative capacity from a national perspective and used in the analysis a smaller number of determinants (Zang et al., 2019) or were focused on a smaller sample of countries (Doyle & O'Connor, 2013). Only a few papers covered determinants of innovation attributed to specific sectors (e.g. a study on water sector) by Moro et al. (2019), while research on medical innovation was centered at other aspects not related to the determinants of innovation capacity, such as its diffusion (e.g. Frankovic et al., 2020) or its costs (Willemé & Dumont, 2015). Our paper delivers new empirical evidence regarding innovative capacity of medical sector in Europe.

There are a number of similarities, as well as certain differences, between these results and some of those mentioned in previous studies (Hong et al., 2015), for example, point to the role of both private and government R&D in China; here, these results play little role. Likewise, Hu and Mathews (2005) also found stronger evidence of government R&D playing a larger role in innovation. (Malik, 2020), on the other hand, does find that education is a key determinant; yet results are mixed because that study also showed that trade openness also plays a role. These studies, however, differ both by country of analysis and by sectr, as well as by the time period analyzed.

The current study is limited by the availability of complete data for all countries and years, even for the patent applications we study. Data on medical personnel are even more constrained, making it impossible to conduct broader comparative studies. In addition, the empirical estimation does not find that all key variables have the expected significance. Nevertheless, it highlights some useful results regarding risk, return, and innovation in the European Union.

Conclusions

As medical innovations are particularly important for rapid post-COVID recovery as well as resilience to similar crises, its support requires special attention in innovation policy, obviously with the use of horizontal policy instruments.

This study applies dynamic panel methods to investigate the role of investment policy and climate, as well as of macroeconomic variables on the number of medical patents in European Union countries. It finds clear differences between strong and weak innovators, as well as between CEE countries and elsewhere in Europe. One key finding is that external risk lowers innovation, especially in Central and Eastern Europe. Risk also reduces innovation in weaker innovators, but at the same time, education helps innovation only in these countries. For stronger innovators, the internal rate of return drives innovation. This distinction, between the returns to human versus "traditional" capital, both is worthy of further investigation and differs from earlier studies.

Our findings have clear implications for policy for both the EU as a whole and for the subregions that we investigated. Having identified the differences in innovative capacity to deliver medical innovation between various groups of the European Union countries, these differences should be kept in mind, when designing solutions.

Major policy goals would be to reduce risk and its perception for R&D funders and patent applicants, particularly in countries that are classified as "weak" innovators and in EU countries from Central and Eastern Europe. Support for education is also indis-pensable in EU countries that belong to the group that includes the weakest innovators. In a view of public support to creation of medical innovation, diverse innovation policy goals should be devised for individual EU countries, depending on the overall level of innovativeness of the country and dynamics of its economy.

Additional studies might also examine the time-series dynamics of each country's medical innovation measures, conditional upon the availability of quality data. The model could also be extended by adding variables for (i) previous innovation achievements (e.g., the number of patents in previous years); (ii) the diffusion of medical in-novation across the EU and beyond; and (iii) examining the institutional environment for conducting R&D (including the impact of various policy instruments on creation of medical innovations). Another research area could focus specifically on digital innovation in the medical sector. The research focus could also be shifted from product-type medical innovation, measured by patents, to process-type medical innovations (such as medical innovations in services). As the current crisis continues to unfold, this type of research has the potential to make significant contributions to public health outcomes.

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References

Adams, J. (2000). *Risk*. Routledge.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies*, *58*(2), 277–297. https://doi.org/10.2307/2297968

Breschi, S., & Malerba, F. (1997). Sectoral systems of innovation: Technological regimes, Schumpeterian dynamics and spatial boundaries. In C. Edquist (Ed.), *Systems of innovation* (pp. 139–156). Frances Pinter.

Chan, T. Y., Hamilton, B. H., & Papageorge, N. W. (2016). Health, risky behaviour and the value of medical innovation for infectious disease. *The Review of Economic Studies*, *83*(4), 1465–1510. https://doi.org/10.1093/restud/rdv053

Clark, J., Freeman, C., & Soete, L. (1981). Long waves, inventions, and innovations. *Futures*, *13*(4), 308–322. https://doi.org/10.1016/0016-3287(81)90146-4

Consoli, D., & Mina, A. (2009). An evolutionary perspective on health innovation systems. *Journal of Evolutionary Economics*, *19*, 297–319. https://doi.org/10.1007/s00191-008-0127-3

Di Pietro, G., Biagi, F., Dinis Mota Da Costa, P., Karpinski, Z., & Mazza, J. (2020). *The likely impact of COVID-19 on education: Reflections based on the existing literature and recent international datasets*. Publications Office of the European Union, Luxembourg.

Doyle, E., & O'Connor, F. (2013). Innovation capacities in advanced economies: Relative performance of small open economies. *Research in International Business and Finance*, *27*(1), 106–123. https://doi.org/10.1016/j.ribaf.2012.08.005

Dziallas, M., & Blindt, K. (2019). Innovation indicators throughout the innovation process: An extensive literature analysis. *Technovation*, *80–81*, 3–29. https://doi.org/10.1016/j.technovation.2018.05.005

European Commission. (2018). *European Innovation Scoreboard 2018*. EIS. Publications Office of the European Union, Luxembourg. Retrieved August 13, 2021, from https://data.europa.eu/doi/10.2873/66501

European Commission. (2021). *European Innovation Scoreboard 2021*. EIS. Publications Office of the European Union, Luxembourg.

Francois, P., & Lloyd-Ellis, H. (2003). Animal spirits through creative destruction. *American Economic Review*, *93*(3), 530–550. https://doi.org/10.1257/000282803322156972

Frankovic, I., Kuhn, M., & Wrzeszczak, S. (2020). Medical innovation and its diffusion: Implications for economic performance and welfare. *Journal of Macroeconomics*, *66*, 103262. https://doi.org/10.1016/j.jmacro.2020.103262

Furman, J. L., Porter, M. E., & Stern, S. (2002). The determinants of national innovative capacity. *Research Policy*, *31*(6), 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4

Furman, J. L., & Hayes, R. (2004). Catching up or standing still? National innovative productivity among "follower" countries, 1978–1999. *Research Policy*, *33*(9), 1329–1354. https://doi.org/10.1016/j.respol.2004.09.006

Grebel, T., & Wilfer, T. (2010). Innovative cardiological technologies: A model of technology adoption, diffusion and competition. *Economics of Innovation and New Technology*, *19*(4), 325–347. https://doi.org/10.1080/10438590802482019

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, *28*(4), 1661–1707. http://www.jstor.org/stable/2727442

Holton, G. A. (2004). Defining risk. *Financial Analysts Journal*, *60*(6), 19–25. https://doi.org/10.2469/faj.v60.n6.2669

Hong, J., Hong, S., Wang, L., Xu, Y., & Zhao, D. (2015). Government grants, private R&D funding and innovation efficiency in transition economy. *Technology Analysis & Strategic Management*, *27*(9), 1068–1096. https://doi.org/10.1080/09537325.2015.1060310

Hsu, P.-H., Tian, X., & Xu, Y. (2014) Financial development and innovation: Cross-country evidence. *Journal of Financial Economics*, *112*(1), 116–135. https://doi.org/10.1016/j.jfineco.2013.12.002

Hu, M.-C., & Mathews, J. A. (2005). National innovative capacity in East Asia. *Research Policy*, *34*(9), 1322–1349. https://doi.org/10.1016/j.respol.2005.04.009

Jeon, S.-H., & Pohl, R. V. (2019). Medical innovation, education, and labor market outcomes of cancer patients. *Journal of Health Economics*, *68*, 102228. https://doi.org/10.1016/j.jhealeco.2019.102228

Kelly, B., Papanikolaou, D., Seru, A., & Taddy, M. (2020). *Measuring technological innovation over the long run* (National Bureau of Economic Research, Working Paper 25266). Cambridge, MA. http://www.nber.org/papers/w25266

Ketels, C., & Clinch, J. P. (2020). *Acting now while preparing for tomorrow: Competitiveness upgrading under the shadow of COVID-19* (ISC Working Paper, April 29). Institute for Strategy and Competitiveness. Harvard Business School.

Knight, F. (1964). *Risk, uncertainty and profit.* Augustus M. Kelley.

Kravtsova, V., & Radosevic, S. (2012). Are systems of innovation in Eastern Europe efficient? *Economic Systems*, *36*(1), 109–126. https://doi.org/10.1016/j.ecosys.2011.04.005

Levaggi, R., & Pertile, P. (2020). Which valued-based price when patients are heterogeneous? *Health Economics*, *29*(8), 923–935. https://doi.org/10.1002/hec.4033

Malerba, F. (2005). Sectoral systems of innovation: A framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technology*, *14*(1–2), 63–82. https://doi.org/10.1080/1043859042000228688

Malik, S. (2020). Macroeconomic determinants of innovation: Evidence from Asian countries. *Global Business Review*, 1–15. https://doi.org/10.1177/0972150919885494

Mensch, G. (1979). *Stalemate in technology: Innovations overcome the depression*. Cambridge, MA: Ballinger.

Moro, M. A., Andersen, M. M., Smets, B. F., & McKnight, U. S. (2019). National innovative capacity in the water sector: A comparative assessment between China and Europe. *Journal of Cleaner Production*, *210*, 325–342. https://doi.org/10.1016/j.jclepro.2018.10.329

Nagaoka, S., Motohashi, K., & Goto, A. (2010). Patent statistics as an innovation indicator. In H. Bronwyn & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (vol. 2, pp. 1083–1127). Elsevier. https://doi.org/10.1016/S0169-7218(10)02009-5

Pavitt, K. (1985). Patent statistics as indicators of innovative activities: Possibilities and problems. *Scientometrics*, *7*(1–2), 77–99. https://doi.org/10.1007/BF02020142

Radosevic, S., Yoruk, D. E., & Yoruk, E. (2019). Technology upgrading and growth in Central and Eastern Europe. In G. Gorzelak (Ed.), *Social and economic development in Central and Eastern Europe. Stability and Change after 1990* (pp. 178–204). Routledge. https://doi.org/10.4324/9780429450969

Rosa, E., Renn, O., & McCright, A. (2014). *The risk society revisited: Social theory and governance*. Temple University Press.

Schumpeter, J. (1950). *Capitalism, socialism and democracy* (3rd ed.). Allen & Unwin.

Stojčić, N. (2021). Collaborative innovation in emerging innovation systems: Evidence from Central and Eastern Europe. *The Journal of Technology Transfer*, *46*, 531–562. https://doi.org/10.1007/s10961-020-09792-8

van de Wetering, G., Woertman, W. H., & Adang, E. M. (2012). Time to incorporate time in cost-effectiveness analysis. *The European Journal of Health Economics*, *13*, 223–226. https://doi.org/10.1007/s10198-011-0374-3

Willemé, P., & Dumont, M. (2015). Machines that Go "Ping": Medical technology and health expenditures in OECD countries. *Health Economics*, *24*(8), 1027–1041. https://doi.org/10.1002/hec.3089

Willet, A. (1951). *The economic theory of risk and insurance*. University of Pennsylvania Press. https://doi.org/10.9783/9781512808995

Zang, L., Xiong, F., Lao, X., & Gao, Y. (2019). Does governance efficiency matter for national innovative capacity? One tale from different countries. *Technology Analysis & Strategic Management*, *31*(2), 239–252. https://doi.org/10.1080/09537325.2018.1493450

APPENDIX

Table A1. Data description

Types of Medical patents	
A61B	DIAGNOSIS; SURGERY; IDENTIFICATION
A61C	DENTISTRY; APPARATUS OR METHODS FOR ORAL OR DENTAL HYGIENE
A61F	FILTERS IMPLANTABLE INTO BLOOD VESSELS; PROSTHESES
A61G	TRANSPORT, PERSONAL CONVEYANCES, OR ACCOMMODATION SPECIALLY ADAPTED
A61H	PHYSICAL THERAPY APPARATUS
A61K	PREPARATIONS FOR MEDICAL, DENTAL, OR TOILET PURPOSES
A61L	METHODS OR APPARATUS FOR STERILISING MATERIALS OR OBJECTS N GENERAL
A61M	DEVICES FOR INTRODUCING MEDIA INTO, OR ONTO, THE BODY
A61N	ELECTROTHERAPY; MAGNETOTHERAPY; RADIATION THERAPY; ULTRASOUND THER
A61P	SPECIFIC THERAPEUTIC ACTIVITY OF CHEMICAL COMPOUNDS OR MEDICINAL PREPS

Macroeconomic Variables	Description	Source
IRR	Internal Rate of Return	PWT
Economic Openness	Exports plus Imports as share of GDP	PWT
IRR	Internal Rate of Return on Investment	PWT
DLNREER	Log Changes in Real Effective Exchange Rate	EuroStat
GROWTH	% change in Real GDP	EuroStat
RISK	Within-year standard deviation of monthly DLNREER	Author's calc.
GERDGOVRATIO	Government R&D as a share of Total R&D	EuroStat
GERDBUSRATIO	Business R&D as a share of Total R&D	EuroStat
SECED	% of Population with at least a secondary education	PWT
MEDEMPRAT	Medical employment as a share of total employment	EuroStat
PERCMEDY	Medical R&D as a share of GDP	EuroStat
PERCMEDRDALL	Medical R&D as a share of total R&D	EuroStat