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Knowledge creation: new frontiers for public investment

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1 | INTRODUCTION: THE PANDEMIC AS A DRIVER OF CULTURAL CHANGE

The COVID-19 pandemic is an unexpected driver of cultural change. Science and the role of governments in promoting investment in knowledge creation are now prominent in the public discourse. Suddenly, laypeople who never paid attention to newspaper articles on scientific discoveries, funding of scientific work, the socio-economic impact of research and development (R&D), realized that our life literally depends upon esoteric knowledge. For example we had to learn that virus existence is based on molecules of ribonucleid acid (RNA), that innovative vaccines can be based on messenger RNA, that fast-track sequencing of the genome of the tiny SARS COV-2 virus and early detection of its mutations are of the essence. We have been exposed to a wealth of information about "spike" proteins, antibody testing, manufacturing technologies of vaccines and drugs, software for tracking contagions, statistical models for forecasting them, and much more. Never have scientists been so much on prime-time television and never has news from the laboratories been so quickly disseminated by all kind of media, including blogs and social media.

At a deeper level of understanding of current trends, many people now have a better grasp of the interrelation between the cumulative process of knowledge creation in different fields, such as medicine, genomics, physics, information technology, data science and economics. Experts of all these disciplines are needed to study strategies and tools to fight the pandemic, and to advise policy makers. Governments in a matter of weeks had to reinvent some of their established tenets, quickly adjusting their budgets and debts, their decision-making processes and regulatory mechanisms. Governments had to hire personnel in the somewhat previously neglected public health systems, but also needed to find new ways to target funds to private enterprises and to public bodies. For example, Operation Warp Speed by the US government, managed by BARDA (Biomedical

Advanced Research and Development Authority), channelled 18 billion USD to pharmaceutical companies for R&D on the new vaccines.

Are there more general lessons to be learned from the pandemic about the role of governments and knowledge creation? In this special issue the authors explore some crucial research questions with interesting science policy implications.

Some of the papers here published draw from the XVIII Milan European Economy Workshop on the socio-economic impact of large-scale science projects, an online event co-organized by the University of Milan, the Italian Space Agency, and CIRIEC International (June 25–26, 2020). Other articles were submitted following an open call for papers by this journal. I am grateful to all the authors, including those whose papers have not been accepted because of space constraints, and to the over twenty anonymous reviewers who generously helped the Editor-in-Chief, Professor Marco Marini, to reach his final decisions.

After a brief presentation and discussion of each of the seven papers included in this special issue, I suggest topics for future research in my concluding remarks.

2 | REDEFINING THE CONCEPT OF PUBLIC INFRASTRUCTURES

We are accustomed to the notion that an infrastructure is a form of investment supporting a wide scope of services for a range of users, from firms to households. Water, transport, energy, telecommunications are easily identified as sectors where essential infrastructures have a long history. In all these sectors, governments played a pivotal role in promoting capital formation because private investors have often been reluctant to take long-term risks, or because, if they took such risks, the investors aimed at establishing monopolistic positions in order to protect their interests (Picot et al., 2015).

Knowledge in our economies and societies is a production factor of paramount importance, it is as pervasive as electricity or transport in our ability to transform economic inputs in outputs. However its measurement and the mechanisms of its creation and appropriation are not yet fully understood. Particularly, we need to better understand fundamental market failures in R&D. The current pandemic is such a failure, not just an "Act of God".

The lack of preparedness by both the pharma industry and governments for the COVID-19 pandemic is the starting point for the article by Florio and Gamba. The disconnection between the long-term public health agenda (that had long identified pandemic risks) and the investment priorities of the pharma industry suggests the need of a new public policy approach. The authors propose a public infrastructure for R&D in the biomedical field, aiming at discovering drugs, vaccines and other innovations that are considered less profitable or too risky by private investors, but are crucially important for public health, such as for antibiotic resistant bacteria or for orphan drugs. The authors propose "an international, interconnected, transparent, science-informed and publicly funded research infrastructure for pharmaceutical and biomedical research combined with a public enterprise: Biomed Europa". The model they have in mind is inspired by research infrastructures such as CERN, the highly successful European Council for Nuclear Research (Geneva), or by the EMBL (European Molecular Biology Laboratory, Heidelberg), but also by a knowledge-intensive enterprise with an industrial policy mission, such as the ESA (European Space Agency). In fact, looking at these organizations suggests that both the concept of infrastructure and of public enterprise can be redefined and rejuvenated when knowledge creation is conceived as the production of a public good. I will discuss again this point in my concluding remarks.

3 | EXTENDING TO SCIENCE THE CONCEPT OF PUBLIC PROCUREMENT FOR INNOVATION

The economic impact of public infrastructures through procurement is well known and often cited as an ingredient of Keynesian-type policies to counteract recessions (Seccareccia, 2011). However, it is increasingly understood that public procurement may have more structural effects by actively promoting technological innovations. When research infrastructures are considered in this perspective, we can observe that they also activate a supply chain of firms. These are challenged to supply hi-tech components of scientific equipment such as using special materials, advanced electronics, or innovative software, having frequently to solve new problems. Castelnovo and Dal Molin study the supply chain of the Italian Institute for Nuclear Physics (INFN), a set of public sector laboratories for advanced research. After having built a unique database of hundreds of firms working with INFN, they provide both qualitative evidence from case studies, and quantitative analyses by respectively an econometric and a Bayesian Network approach (Salini & Kennett, 2009). Data from a survey are then complemented by data from company accounts. They find clear evidence that the cooperation between firms and the INFN has an impact on innovation, learning, market penetration, and networking of the former. They also show that the main driver of these impacts is the acquisition of the new technical competencies during the relationship between the scientists working in physics research and the engineers and managers of the firms.

The more general policy implication of this study is that public investment in research infrastructures can create beneficial spillover effects. Hence the scope of public procurement for innovation can be extended to science policy.

4 | TRACKING INNOVATIONS FROM RESEARCH INFRASTRUCTURES TO PATENTS

In most cases the innovative impact of research infrastructure is not immediately visible in the direct relations between scientists and firms, as the spillovers happen more downstream, along pathways that may not be easy to explore. Catalano, Lopez et al. test a new approach to study such effects by a detailed case study of the transition from science to patents. Their case study is the ALBA Synchrotron Light source facility located in Barcelona and in operation since 2012. The authors have collected around 400 questionnaires from direct and indirect users of the radiation beamlines at ALBA, a facility which is similar to an extremely powerful microscope with high resolution at the level of a single molecule. Applications are in such diverse fields as drugs, batteries, material science, computers, or heritage goods.

After having identified the scientific literature supported by experimental data at ALBA, the authors (both economists and physicists) search for patents citing such literature. The main interest of the paper is how they show the feasibility of a pathway analysis. While usually the managers of a research infrastructure are aware of the scientific output generated by its users, they are unaware of innovations originated by such new knowledge, but merging the information on publications with patent databases and citations it is possible to track the journey from science to innovation in a new way. In principle this study can be replicated for several waves of published literature and of patents respectively, and one may also study the cascade of mutual citations as a way to see unexpected interrelation arising from knowledge creation. The policy implications is here that research infrastructures indirectly support patents downstream and investing in them may be a long-term innovation strategy.

5 | HUMAN CAPITAL FORMATION AT "KNOWLEDGE FACTORIES"

Another important pathway of innovativeness links together research infrastructures and factor productivity: the creation of skills for early career researchers, such as PhD students and post-doc, who are then often employed outside science, including in industry, finance, government. Catalano, Giffoni and Morretta develop a case study about human capital creation at the Large Hadron Collider (LHC), the most powerful particle accelerator of the world, at CERN. The proxy for the measurable long term impact of such effect is the increase of life-long salary of former young researchers after they have completed their experience at the LHC in a variety of roles. The authors use three sources of data: firstly, data collected through a survey to CERN Alumni; secondly, a survey to professors ("team leaders") who supervised their students at CERN; thirdly, data on salary of skilled personnel in different fields. The authors find that skills developed at CERN are then transferred to other sectors, generate a "salary premium"—that is, a positive difference of earnings for those who enjoyed hands on training at the LHC compared to other students who did not have such training. The average lifelong salary premium is 8% (or between 5% and 11%), which is a notable impact in terms of the underlying value of productivity transferred from science to the economy. The policy implication is that governments and research infrastructure managers should expand experiential learning for students outside the traditional academic environment, taking advantage of the "knowledge factories" as a complement to universities.

6 | OPEN SCIENCE AS A PUBLIC GOOD

A founding principle of most research infrastructures, particularly in Europe, is an "Open Science" policy, and often by implication of "OpenData" approach, meaning that knowledge is widely disseminated, typically online, and with a limited lag of time since its creation. A good example of such policy is ELIXIR, a research infrastructure for life science data, with 21 Member countries, co-sponsored by the European Molecular Biology Laboratory. As it happens, research infrastructures do not need to be tangible objects, they can take the form of virtual architectures linking together databases and making them available to researchers in the whole planet, both for academia, governmental bodies, or private business. The question asked by the article from Martin et al. is how to identify the social value of such open science policy. The authors identify five main challenges to answer the question: analysis of the role of virtual and distributed research infrastructures in terms of relational capital; responding to stakeholders with evidence-based specific indicators, such as about human capital; responding to more general public value assessments through reference indicators as established by international organizations, such as OECD or ESFRI (the European Strategy Forum for Research Infrastructures); integrating quantitative and qualitative evidence of performance (case studies and narratives); building internal capacity on socio-economic impact analysis. Clearly, as a public good is created, the ways to measure its value cannot be based on market mechanisms and particularly on price of services, which is almost zero. This issue applies to any research infrastructure working on the principles of Open Science.

7 | SCIENTOMETRICS MEETS ECONOMETRICS

Ultimately, the mission of research infrastructures is to produce science that in the contemporary world take the form of publications. Many scientific bodies are both performing their own R&D but they are also funding external scientists. A particularly interesting case study is provided in the article by Vurchio and Giunta who consider the impact of the Italian Space Agency (ASI) on universities/research institutes. The authors performed a systematic search of papers in the scientific literature that acknowledge funding by ASI in the time period 1989–2017. The question asked by the authors is whether it is possible to measure the impact of grants received on the quality of research, proxied by the number of citations received by publications. Citations are a well known empirical measure of impact in a scientometric perspective, but the authors here contribute to the literature by testing such impact by performing parametric estimates with multiple levels of fixed effects (year, author and coauthors). With this empirical strategy the authors are able to show that articles mentioning ASI in the funding information are associated to a higher citation impact with respect to a control group of articles by the same authors, not financially supported by ASI. This is an encouraging result for donors of research funds, because—to say the least—it suggests that for teams reached by such grants the outcome in terms of impact is positive compared to research not supported by the grants. The policy implication here points to the positive role of grants administered by research infrastructures versus other funding schemes, probably because of the better selection of receivers when on the donor side there is the appropriate scientific background.

8 | EXTENDING THE RESEARCH INFRASTRUCTURE CONCEPT TO SOCIAL SCIENCES

Social scientists in general, and economists in particular, tend to be puzzled about the epistemological status of their disciplines. For example, is economics actually creating knowledge in the same sense as experiments at a particle accelerator? One way to answer the question is to look at proposals to create research infrastructures for social sciences, such as databases available online to a wide number of teams. An example is SHARE:[1]

> The Survey of Health, Ageing and Retirement in Europe (SHARE) is a research infrastructure for studying the effects of health, social, economic and environmental policies over the life-course of European citizens and beyond. From 2004 until today, 480,000 in-depth interviews with 140,000 people aged 50 or older from 28 European countries and Israel have been conducted. Thus, SHARE is the largest pan-European social science panel study providing internationally comparable longitudinal micro data which allow insights in the fields of public health and socio-economic living conditions of European individuals.

Another example is the proposal of the European Cohort Development Project (ECDP) or Euro-Cohort, aiming at the study of the feasibility of a European Research Infrastructure that would provide, over the next 25–30 years, comparative longitudinal survey data on child and young adult well-being. According to the project website:[2]

[1] http://www.share-project.org/home0.html

[2] https://cordis.europa.eu/project/id/777449/it

> This is achieved through the following three objectives: i. Building support from key political policy makers with a brief which covers child well-being as well as national funding agencies tasked with infrastructural spending on science and survey data collection ii. Develop a scientifically excellent research design iii. Establish a robust operational framework that will ensure the logistic integrity of EuroCohort.

In their article, Ecchia, O'Leary and Messori try to measure the social benefits to investment in such a platform available to social scientists and policy makers working on the well-being of children and young adults. Looking at the value of time saved by users of the platform, they are able to show that the probability that social benefits exceed investment and operation costs is high. In a methodological perspective their approach can be replicated elsewhere, when a full social cost–benefit analysis of research infrastructures is not feasible.

9 | CONCLUDING REMARKS

The traditional Big Science model, of the Manhattan Project (atomic bomb) fame has a top-down approach; it is typically linked to military and national ambitions and characterized by secrecy and restricted access to methods and data. In contrast, the new research infrastructure paradigm of science production, exemplified by the "Geneva model" of CERN, has a bottom-up approach; it involves an international coalition of funders, it is accessible by multiple users and adopts an open science approach. In Europe there are around three hundred major RIs supported by international coalitions and perhaps one thousand significant ones mostly funded by national governments and often with some support from the EU.[3]

In this evolving panorama, this special issue shows some empirical evidence and methods related to the socio-economic impact of public investment in science in such fields as biomedical research, life sciences, material sciences, particle physics, space exploration, and infrastructures for applied social sciences. In a methodological perspective the core question is the appropriate identification of proxies for social impact, such as the net social benefits of drug discovery, the transition from publication to patents, the concept of human capital and "salary premium", the combination of qualitative evidence, scientometric indicators combined with econometric methods, switching values of monetized benefits (in socio-economic terms, not in cash flow terms, see below).

While there is clear progress in this area, and this special issue contributes to it, further research is needed on several topics. I list three of them here, that in my opinion have the highest priority because of their policy implications:

1. *Open science as a public good, versus knowledge-based oligopolies and social inequality*. The paradox of the Open Science model adopted by the contemporary research infrastructures is the following one: on one side, knowledge is created as a public good with the support of taxpayers, but on the other side, oligopolistic private companies, such as the Tech Giants or Big Pharma, privatize such knowledge. This happens because patents and other mechanisms protecting intellectual property rights were designed as incentives for the individual inventor, while knowledge creation in our times is increasingly a cumulative and collective e venture. The imbalance between the donation to everybody of the World Wide Web by the CERN (exactly 30 years ago, 1991) and the fortunes of the owners of Facebook, Google, Amazon and

[3] https://www.riportal.eu

other web-based companies is striking. We need to study in depth such transition and find ways to protect the public interest when such a large share of downstream innovation has its origin in public investment, public money and public sector employees.

2. *Social cost–benefit analysis of RI and other quantitative methods of impact assessment*. For traditional infrastructures, such as for transport, energy and telecoms, economists were able to provide—at least in principle—rigorous quantitative methods in the form of social cost–benefit analysis (CBA). Public investment cannot be valued by book-keeping concepts such a return on equity. This is why CBA was invented in France in the 19th century for the assessment of transport infrastructure. The same intellectual challenge should be seen now for public investment in science. With my colleagues at the University of Milan and at the Centre for Industrial Studies we have shown that this was possible for the LHC at CERN but also for the National Centre for Hadrontherapy (CNAO) in Pavia (Italy), a synchrotron for treatment of some radio-resistant tumors (Florio, 2019). We are also currently working with these methods for the Italian Space Agency and for other research infrastructures in Europe. It is unfortunate that there is still misunderstanding in the literature on public investment of what social CBA can achieve, a misunderstanding arising perhaps from a confusion between the economic theory of social welfare on which CBA should be based, and the business economics framework that supports investment appraisal in a "value for money" perspective. The confusion probably arises because of the association of CBA with the neoclassical paradigm (Mazzucato, 2021), although a social CBA does not need to proceed that way (Florio, 2014).

I would welcome further applied economic research that patiently, with serious empirical methods, shows how to measure the social benefits of public investment in science, including the public good value of knowledge as perceived by citizens.

3. *Science and technology missions for public enterprises*. A third topic has been identified in the recently published Handbook of State-Owned Enterprises (Bernier et al., 2020): the actual and potential role of SOEs as patient investors to promote R&D in some fields. It is now well known that in several sectors, for example in electricity or telecom, privatization of the former SOEs was correlated with declining R&D expenditures (Jamasb & Pollitt, 2008). Less known, though it should have been expected, is that this decline is also correlated with fewer patents filed by privatized enterprises than by companies still controlled or participated by governments in some countries (Clò et al., 2020). The research question here is how to reinvent SOEs as knowledge-based organizations with clear public missions. An example is the need to support public policies to counteract global warming and climate change. To do so, governments and the EU institutions tend to rely on incentives and taxes targeted to private firms, for example through "carbon price", a form of tax on emissions, or they offer subsidies to firms adopting certain carbon-free technologies (such as photovoltaic panels for electricity generation). However, one would like to see that SOEs in the energy industry do not mimic their private counterparts and instead invest in disruptive technologies for a carbon-free world.

To sum up my view, governments need to invest more in science. In a recent book Gruber and Johnson (2019), two MIT professors, have suggested reversing the decline of public spending in R&D in the USA. They have proposed an increase in federal spending on R&D of 0.5% of GDP. This would amount to an increase of around $100 billion per year. In their proposal there should be a combination of basic research, development (including the manufacturing of new drugs), partnership with the private sector, and infrastructure investment, including in education, research infrastructures, business parks. The Biden administration seems to be listening, and the Senate is going to pass a major bipartisan bill on industrial policy, not least because the US is currently lagging behind China in government spending as a share of GDP (0.65% for the former and 1.30% for the latter; Leonhardt, 2021).

From the European perspective, France and UK governments are spending even less than the US percentage, with only Germany above it (with 0.93% of GDP). There is much scope for a new frontier of public investment, and economists and social scientists in general should pay attention to some of the crucial research questions to be asked in a changing public policy panorama.

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