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Science, technology and innovation studies at a crossroad: SPRU as case study

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ABSTRACT

The setting up of the Science Policy Research Unit (SPRU) at Sussex University 50 years ago represented a "transformative change" in the research on science policy and the understanding of the nature and origin of technological change and innovation studies. It influenced policymakers across the world in both the mature Organisation for Economic Co-operation and Development countries and the developing world. It made the topic of science, technology and innovation (STI) familiar to business studies scholars. Today though, the analysis of STI appears to be somewhat in crisis. On the one hand, there is growing evidence that the growth and welfare gains of new technologies and innovation are no longer forthcoming in an automatic "trickle-down" fashion. The knowledge and technology diffusion "machine" appears broken. On the other hand, there are growing environmental concerns about the negative externalities of unsustainable fossil-fuel-based growth as industrialization spreads across the globe. STI policy appears somehow stuck in an industrial efficiency and consumerism mode that is unable to address in a satisfactory way the impact of such negative externalities. Can the broader historical approach as popularized within the so-called Science and Technology Studies (STS) tradition provide additional, complementary insights? Yes, if STI and STS scholars are prepared to leave their respective conceptual comfort zones and address in complementary fashion some of the major societal policy challenges confronting science, technology and innovation policy today.

1. Introduction

Science, technology and innovation (STI) have emerged over the last 50 years as central concepts in economic policy. The setting up of the Science Policy Research Unit (SPRU) back in 1966 has directly contributed to the gradual policy recognition of the importance of these concepts in many countries: in the UK, the Organisation for Economic Co-operation and Development (OECD) countries and across the world. In the early days of SPRU's existence, and thanks to the close personal links between many SPRU scholars and the OECD's Directorate for Science, Technology and Industry (DSTI), the focus of much research was on the scientific and technological characteristics of new scientific and technological innovations. Historical in-depth descriptions of the emergence of new technologies as well as concerns about the overall societal impact of technological change were a characteristic feature of SPRU research. The new research unit set up at the then still very young red-brick University of Sussex could be said to have been created at exactly right moment:[1] the topic waiting, so to speak, to be explored and become relevant in policy terms;[2] and the unit, in a newly established University of Sussex tradition, being unique in bringing together scholars from very different disciplines: from natural sciences, engineering, social sciences and humanities.

In the 1970s and 1980s the policy relevance of research at SPRU[3] became increasingly recognized internationally – through, among other contributions, the critique on the Club of Rome report; advisory work for the OECD; close interaction with the (now defunct) US Office of Technology Assessment (and Forecasting) on patent indicators; and collaboration with various United Nations (UN) agencies dealing with energy, peace, appropriate technologies etc. In addition, and more broadly, these contributions included development issues, often in close interaction with the other well-known Sussex University based Institute of Development Studies, on the impacts of science, technology and innovation on growth, development, employment, skills and international competitiveness – themes that gradually became a dominant feature of

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[1] The coming to an end of the golden sixties, the so-called "trente glorieuses" to use Fourastié's term (1979), with many of the (West) European countries having caught up with US productivity levels and consumption patterns.

[2] One may refer here to Chris Freeman's devastating critique (Freeman, 1977) of the primarily Keynesian inspired McCracken report (McCracken et al., 1977).

[3] See for instance the (non-)complimentary report on SPRU in *Le Monde* in 1982 (Battle, 1982).

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SPRU's research.

In this paper I explore in Section 2 some of the trends in the primarily economically inspired analysis of "science policy and innovation studies", to use Ben Martin's (2003) description of the field, within SPRU and other STI institutes over the last 50 years.[4] In the third section I list some of the main challenges confronting STI studies today and discuss how Science and Technology Studies might provide additional complementary insights.

2. SPRU's analysis of STI

2.1. Positioning SPRU as a unique research institute

Following on from a long empirical tradition going back to Denison (1962), and probably best described as the search behind "the secret of economic growth",[5] SPRU had from an early stage established a strong reputation with its strong critique of the Club of Rome report.(see Cole et al., 1973; Freeman, 1973) highlighting the importance of science and technology for future growth and development. SPRU analyses did not, however, limit themselves, as did traditional growth studies, to the empirical observation, using a simplified production function framework, that science and technology would ultimately be the only factors contributing to long-term sustainable growth. The novelty of SPRU analyses was that science and technology would also bring about major structural changes in the economy and in society more broadly: changes in new, emerging and declining sectors; changes in incumbent firms and newcomers; changes in employment growth and displacement; changes in the skills needed or no longer needed; and many more.

Using the "framing" of innovation policy proposed by Schot and Steinmueller (2016), one might identify SPRU's economically inspired STI research over the first 25 years most closely with what they described as the first framing of innovation: "science and innovation for growth". The second framing of innovation policy suggested by Schot and Steinmueller, in which SPRU was again in its early years a major presence, can retrospectively be identified with endogenous growth models seeking to identify the various "endogenous" incentives in enhancing or restricting innovation and Schumpeterian processes of "creative destruction" within a country. It is the area that brought the notion of innovation to the attention of both business school communities and economic policymakers in developed and developing countries alike.

SPRU had been leading in both areas thanks to the realization early on that both quantitative and qualitative evidence would be essential to bring the topic of STI to the attention of policymakers. One of the first projects at SPRU was the SAPPHO project, probably the first ever detailed survey carried out on both the success and failure factors behind innovation, defined as commercially successfully introduced new product or process inventions (see, e.g. Curnow and Moring, 1968; Rothwell et al., 1974). Following this almost unique survey, many other similar surveys in different countries were carried out. At the same time SPRU also became one of the first research institutes in the world using the newly computerized US patent data that had become available in the late 1970s. Its use opened many new avenues for empirical and econometric research (see, e.g. Pavitt and Soete, 1980; Pisano and Soete, 1982). Later on, the detailed classification of patents allowed Pavitt (1984) to provide a seminal contribution to the field on the nature and origin of technical change). It led to the blossoming of many micro-econometric studies on innovation.[6]

Despite the long tradition of detailed qualitative and quantitative empirical studies carried out at SPRU in the 1970s and 1980s, most of this research did ultimately not link up with the new economic insights on innovation as they emerged in the late 1980s under the term "endogenous" and Schumpeterian growth theory and associated with the names of Aghion, Howitt, Lucas or Romer. Similarly, few econometric studies on research and development (R&D), patents and innovation associated with the names of Griliches, Hall, Mairesse, Malerba, Mohnen and Pisano appear, at least at first sight, to have been influenced by the early SPRU quantitative studies. In short, most economic insights on innovation developed over the late 1980s and the 1990s within the framework of the Schumpeterian endogenous growth literature or the more econometric studies using STI indicators neither referred to nor cited the earlier SPRU work and developed policy concepts outside SPRU's influence,[7] with only a couple of exceptions such as Paul Geroski, who used extensively the SPRU innovation survey (see, for instance, Geroski, 1989).

2.2. On the need for a broad historical framework

From an economic perspective, the significance of research for innovation, economic growth and more broadly increased social welfare ultimately comes down to developing, applying and disseminating new technologies. However, these are, as illustrated in the long tradition of SPRU technological studies, particularly complex processes that rarely follow the same route and might be accompanied, as mentioned above, within the framework of the SAPPHO project, more by failure than by success. Contrary to traditional and new Schumpeterian endogenous growth theory, this complexity covers the core concepts used. Thus scientific fields can rarely be compared (a point that was most clearly and consistently made by Richard Nelson (see, e.g. Klevorick et al., 1995); there is sometimes linearity in the process of research and innovation with scientific breakthroughs leading to a new technology or innovation, but sometimes the exact opposite is taking place with technology leading to a new understanding of science (as argued most consistently by Keith Pavitt and Nathan Rosenberg; see, e.g. Kline and Rosenberg, 1986) or to scientific breakthroughs as in the use of new electronic instruments in science (see John Irvine and Ben Martin's various publications on this topic, such as one of the first influential studies on CERN – Irvine and Martin, 1984; Martin and Irvine, 1984). Given this intrinsic complexity, it was never a surprise that at SPRU, from the early years onwards, historical studies[8] would always be considered essential to understanding the emergence of particular

[4] Far from being complete, this overview represents a personalized review of the last 50 years based on discussions and debates at SPRU over the period 1975–86 when I attended SPRU first as a PhD student and later as a research fellow, and subsequently as an alumnus of SPRU starting a new economics research institute on STI in Maastricht, The Netherlands in close collaboration with some of my by then ex-SPRU colleagues such as Charles Cooper, Chris Freeman and Keith Pavitt.

[5] The "secret of economic growth" is probably the subject that has remained for *The Economist* magazine the most recurring theme for comment over the last 50 years. See e.g. a recent Root and branch contribution (Economist, 2018) on "Economists understand little about the causes of growth".

[6] As discussed below, at the broader macro-economic level that literature also became identified with the notion of national "systems" of innovation. Again, SPRU in the person of Chris Freeman is generally acknowledged to have been the first to use this term in his book on Japan's national system of innovation (Freeman, 1987). Overall though, I would claim that SPRU did not play a significant role in the further development of this particular concept in the further design and implementation of innovation policy in this "systemic" tradition. Other scholars such as Bengt-Åke Lundvall in Aalborg and later on at OECD took over (see Soete et al., 2010).

[7] Characteristically, the distinction between incremental, radical innovations and changes in the techno-economic paradigm introduced by Freeman and Perez in the mid-1980s became quite independently translated in endogenous growth models under the heading of "general purpose technologies" (Helpman and Trajtenberg, 1996).

[8] SPRU had the big advantage of being located in the same building as the History of Social Sciences Studies department. In the early 1980s it was debated whether it would be appropriate to integrate that department within SPRU, something that actually took place in 1983.

scientific breakthroughs and technological "trajectories". SPRU in the person of its founding father Chris Freeman was always keen to emphasize the importance of such historical studies and contributions. Following David Landes' "The Unbound Prometheus" (1969), for Freeman it was the Industrial Revolution that sparked off "the marriage between science and technology" with the chemicals industry as its precursor. Freeman (1963) was probably one of the first economists to emphasize with much detail the historical emergence of the separate R&D department within the chemicals industry, starting from the production of dyes and base chemicals, to fertilizers and new synthetic products such as PVC and polystyrene. His knowledge of German was instrumental in being able to go in greater depth into the emergence of R&D activities within the German chemical industry, and the history and restructuring of the major German chemical firms, world leaders in the 19th century.

Despite the "marriage between science and technology", it was, however, not until the mid-20th century that science and technology began to play a significant role within firms across a majority of industries (David Mowery (1983)) was one of the first scholars to study this phenomenon. Again the historical dimension was crucial in his approach.). It is notable that the actors one identifies today most with science and research – universities – only began to play a role in research and, in particular, applied research at a much later date. For the most part, they remained educational institutes. That situation changed after the Second World War. A subtle shift took place in the funding and location of research: whereas most research before the war took place in the private sector, with government laboratories or organizations carrying out publicly funded studies, after the war research gradually came to fall within the remit of universities, which until then had focused on education or on studies closely related to education (a point made most explicitly by Peter Tindemans, 2009).

This also applied to economic research on STI. From the late 1970s onwards, with SPRU as probably the first and still today most distinctive example, a variety of different alliances began to crystallize in the social sciences and humanities including economics. National governments assigned planning offices or bureaux of economic analyses to focus on, among other things, the impact of technological change. Public research funding became recognized as playing a crucial role in economic process, with Richard Nelson's seminal (1959) paper one of the most important landmarks (see Ghosh and Soete, 2006). An important realization was that people, learning processes and networks were likely to play a vital role in creating value in different forms leading to spillovers and externalities of all sorts. Market failure as traditional justification for government intervention did not provide much guidance for government intervention, as market failure was more or less "ubiquitous" in the area of science and technology, as Freeman, Nelson, Pavitt and many other scholars and SPRU alumni were keen to argue in the many policy reports published over the last 50 years.[9]

A meta-survey of studies carried out by SPRU on the usefulness of publicly funded research, carried out 20 years ago but still relevant today (Martin et al., 1996; Salter and Martin, 2001), identified six positive "externality" effects: increasing the stock of useful knowledge; training skilled graduates; creating new scientific instrumentation and methodologies; forming networks and stimulating social interaction; increasing the capacity for scientific and technological problem-solving; and creating new firms.

2.3. Measuring science, technology and innovation

Despite the intrinsic conceptual difficulties in doing so, attempts at developing proxies for measuring STI and its impact became, as highlighted above, a second pole of expertise within SPRU.

Following the work of Chris Freeman for UNESCO and later for the OECD, leading to the Frascati Manual for research and development measurement, the 1980s saw an explosion of growth in SPRU publications analysing trends in R&D expenditures, patents, publications, citations, collaboration between researchers, research networks, innovation surveys, the anchoring of science in institutions, and so on. Ben Martin, John Irvine and Diana Hicks, all at SPRU in the 1980s, were instrumental in developing the empirical field of science policy, what has since become known as scientometrics. And as much research data became gradually electronically available at the level of countries, sectors and firms, many opportunities presented themselves to look further at the relationships between "official" science and technology investment data, patent statistics and other economic output data.

At the same time, innovation surveys in which SPRU had been instrumental through the SAPPHO project became an area in which a number of statistical offices, such as StatsCanada and later Eurostat with the so-called Community Survey, were gradually getting interested and then taking the lead under the auspices of the OECD. Many SPRU scholars were instrumental in developing and using such data.[10] In earlier years, the concept of innovation in the old Schumpeterian tradition had become closely associated with technology diffusion. At SPRU, again probably the first institute to collect data on innovation systematically, the discussion focused in the early years very much on the nature of such innovations: incremental versus radical (a feature central to the TEMPO project led by Charles Cooper and Chris Freeman in the early 1980s – see Cooper and Clark, 1982; Freeman et al., 1982; Freeman and Soete, 1987); the sectoral origin, use and measurement of innovation (in a Leverhulme Trust project led by Keith Pavitt), and of course the tremendous impetus following the Oslo Manual providing an international framework for national innovation surveys (see OECD, 2005).

The discussion on the need for innovation policy support policies followed a similar line, but was more controversial. For example, in 1986 at the Venice Conference on Innovation Diffusion[11] organized by Giovanni Dosi, Paul David made a passionate plea to Ken Arrow to acknowledge the importance of innovation and diffusion in designing research policy. The market failure argument did not have to limit itself to pure knowledge creation and research, he argued, but should be extended to include the many lags and difficulties new technologies would be confronted with in spreading across the economy. His plea was not met with much success. Arrow maintained that the dominant market failure paradigm justifying government support had to limit itself to the pure research component of research creation.

As the rapid catching up of European countries and Japan in the 1960s challenged this view, a new second angle emerged whereby innovation policy became viewed as an extension of industrial policy bringing about structural change in the economy: from picking winners to backing winners. Popular in Japan, Europe and later in the US with respect to particular industries considered of national importance (such as the US semiconductor industry), innovation became fully part of policies aimed at strengthening productivity growth and international competitive advantage (see also, e.g. Dosi et al., 1990).

Today this industrial policy view on innovation is still reflected in many contributions on emerging and developing countries, making an

[9] This is also the central tenet in the concluding chapter by Nelson and Soete in Dosi et al.'s (1988) "bible" on "Technical Change and Economic Theory".

[10] See, e.g. the early work of Giovanni Dosi, Keith Pavitt, Pari Patel and myself on patents and R&D by firm, sector and country (for an overview see Dosi, 1988). Unfortunately most subsequent econometric work on research and innovation developed outside SPRU, more in the tradition and footprints of Zvi Griliches' National Bureau of Economic Research with seminal contributions from, e.g. Bronwyn Hall, Jacques Mairesse and Pierre Mohnen.

[11] Conference on Innovation Diffusion, Venice, 17–21 March, 1986; the conference papers were supposed to be published in one or more books on "Frontiers in innovation diffusion" edited by Fabio Arcangeli, Paul David and Giovanni Dosi, which turned out to be a perpetual forthcoming series.

explicit case for the role of the state in creating industrial development trajectories (see, e.g. Cimoli et al., 2009). Adding the word "innovation" provided a "dynamic" economic growth feature to some of the old, well-known industrial development policy arguments.

In the area of quantitative studies, the dramatic growth in data availability and the continuous faster and more complex opportunities for "big data" analysis also offer opportunities in the area of STI (see Soete's contribution [2016] to the OECD Blue Sky Conference in Ghent in September 2016). Yet measuring the economic value of research appears to be put under pressure today by two opposing forces. On the one hand, the value of research is less and less a national affair – and this holds for the majority of countries in the world; on the other, and in some way as a corollary of the previous point, the value of research increasingly depends on the absorptive capacity of a national or local population. Being able to absorb scientific knowledge naturally also requires personal contact. In order to determine what the value of research is in any exact detail, then, what one really ought to be measuring is people, with a view to establishing the extent to which science has helped them acquire general knowledge and improved their ability to absorb and convey knowledge and use it to solve problems. We come back to this in the next section.

2.4. National systemic interactions

The final distinguishing angle for much of SPRU's STI research focuses on the nature and specifics of countries' particular national institutional set-up, as it became identified with the "national system of innovation" (NSI) launched in the 1980s from different perspectives by, among others, Chris Freeman (1987) to explain the particular success of Japan's rapid catching up strategy, Bengt-Ake Lundvall (1992) to explain the different country and industry user–producer relationships, and Richard Nelson (1993) to explain the differences between countries in the setting up of research and education institutions. Very quickly, the concept of NSI became particular influential in national policy circles and international organizations such as the OECD in the 1990s and later at a more global level[12] also at different UN agencies such as ECLAC (Economic Commission for Latin America and the Caribbean) (Primi, 2011).

Linking the discussion on NSI to the previous discussion of indicators, four factors appear at the outset essential for a well-functioning "national" system of innovation.

First, the investment of the country in social and human capital; the cement, one could argue, that keeps the knowledge and innovation system together. It is incorporated in knowledge-generating institutions in the public as well as the private sector, both of which include universities, polytechnics and other skills' training schools. Higher education will be crucial for the continuous feeding of fundamental and applied research. With the development of "new growth" models in the economics literature, the role of education and learning in continuously generating, replacing and feeding new technology and innovation has received more emphasis recently. An initial stock of human capital in a previous period is likely to generate innovation growth and productivity effects, downstream as well as upstream, with many spillovers and positive externalities, affecting other firms, regions and countries.

The second central node of any system of innovation is the research capacity of a country (or region) and the way it is closely intertwined with the country's higher education system. From a typical "national" innovation system perspective, such close interaction appears important; from an international perspective the links could be much looser, with universities and research institutions seeking to attract talent worldwide. In many technology growth models, these two first supply-based nodes could be viewed as forming the essential "dynamo effects" (Dosi, 1988) or "yeast" and "mushroom" effects (Harberger, 1998) implicit in the notion of technological change. Knowledge and human capital would act like yeast to increase productivity relatively evenly across the economy, while other factors such as a technological breakthrough or discovery would suddenly mushroom to increase productivity more dramatically in some sectors than others.

The third "node" holding knowledge together within the framework of a national system of innovation is geographical proximity. The regional clustering of industrial activities based on the close interactions between suppliers and users, involving learning networks of various sorts between firms and between public and private players, often represents a more flexible and dynamic organizational set-up than the organization of such learning activities confined within the contours of individual firms. Regional or local learning networks allow for much more intensive information flows, mutual learning and economies of scale among firms, private and public knowledge institutions, education establishments etc.

In addition to human capital, research and the related phenomenon of local networks, the fourth and last notion essential to any innovation system approach is the "absorptive capacity" (see Cohen and Levinthal, 1990) of agents (firms, clients, consumers, government services) in a specific region or country. The ability of companies to learn will of course in the first instance depend on their internal capabilities represented by the number and level of scientifically and technologically qualified staff. Firms must do enough R&D to be economically dynamic and to have the "absorptive capacity" to conduct a professional dialogue with the public research sector and other external sources of knowledge. At the same time, consumers, clients and citizens might be either very open to new designs, products, even ideas, enabling rapid diffusion of such new products created by R&D in knowledge-intensive sectors, or very conservative, resistant to change and suspicious of novelty. The absorptive capacity of countries, regions and even suburbs varies dramatically.

As an aside, following this framework, it will be clear that the European policy challenge to STI is that the governance mode for each of these four key nodes has historically grown in rather different directions. Higher education, the first node, has remained first and foremost a nationally organized and funded activity even though curricula, evaluation and accreditation of an increasing number of study fields have become increasingly internationally organized. Public research funding, part of the second node in the NIS approach, is by contrast governed, as defined in the Lisbon Treaty, in a "shared" way: at individual member states level and at European level. Applied research, technology transfer, the use and reuse of "foreign" technology as well as innovation and entrepreneurship, the third node identified above, all have a strong regional and local focus. Finally, the fourth node brings to the forefront some of the intrinsic differences in absorptive capacity between individual European countries.

As mentioned before, this is a personal overview of what SPRU's economically inspired STI research has contributed to the understanding of STI over the last 50 years, and in particular during its first 25 years: a particularly impressive set of contributions that have unfortunately not been sufficiently recognized in the economics of research and innovation literature. Let me now turn to the future: the future of SPRU and of the STI research field.

3. Challenges to the science policy and innovation studies research community

3.1. How to enrich STI with STS insights

Both "science policy" and "innovation studies", to stick to Ben Martin's terminology, are, I would argue, today in a fundamental, even existential crisis; as if the economic-inspired policy approaches to science, technology and more broadly innovation, have reached their intrinsic limits.

This holds for the "measurement" of STI where national measures

[12] For an overview of the NSI literature see Soete et al., 2010.

seem increasingly of less relevance to concepts that are today primarily dependent on internationally networked science communities and private innovation actors acting within global value chains. How do, and why would, national investments in science and research result in primarily national productivity gains? The standard answer is that knowledge does not travel well. In the current context of immediate, international access to science and more broadly codified knowledge, such answers are no longer convincing. The focus has shifted and now emphasizes the local "knowledge-absorbing capacity" of such national investments in science and research. The latter should be governed by excellence to be able to participate on equal footing internationally in research and by impact to reap the local advantages of such investments.

At the innovation level, similar questions are raised following the increasing lack of evidence on the "trickling down" of productivity gains from innovating firms and sectors to the rest of the economy (European Commission, 2017); concerns that even question the current nature of technological change. For some authors such as Robert Gordon (2016), the lack of evidence on productivity gains is illustrative of the current lack of radical technological breakthroughs, compared to those of the 20th century. In this sense it is not really surprising that in the STI field evidence-based policy making appears no longer to be in a position to convince policymakers about the further need for public support for science, compared to other policy priorities.

At the same time, innovation appears today as mysterious as ever. Disruptive: involving creative destruction but now and then also destructive creation; sometimes without involving any research but primarily dependent on design and marketing; and spreading to new areas such as social innovation. These are areas in which the over-reliance on a purely economics approach appears no longer convincing. In short, today, from a policy perspective neither research nor innovation seem to provide any longer, at least in mature economies, any guarantee for future productivity or welfare gains.

It might, therefore, be time to broaden the traditional economic approach to STI to other approaches, relying less on standard economic arguments. The one considered here, and in line with the Schot and Steinmueller (2016) framing trilogy, is the more social science and technology studies (STS) approach, which makes a central point that technological developments often involve making choices: some visible, such as users' choices, but many others invisible such as scientific and technological choices. Scientific evidence is from this perspective more the result of the choices made in the past with respect to certain scientific directions or technological trajectories. In some cases, such choices might have resulted in a "locking-in" to a particular research direction. In this view, it is important to keep options open and to exploit fully the increased research and technology participation that has received a major boost thanks to global information and communication and social media access.

The STS approach has some connection with evolutionary economics in the description of phenomena such as historical locking-in, and the emergence of particular technological paradigms that drive technical change in directions that, from a society's perspective, are possibly non-optimal. But for STS these non-optimal directions are to some extent "given". They require transformative change at the level of socio-technical systems. As Schot and Steinmueller (2016) put it:

> Both Framings 1 and 2 view social and environmental goals as being achieved through economic growth and the possibility of re-distribution of surpluses generated by productivity improvements and by a capacity for technocratic elites to regulate externalities in the service of social and environmental goals. By contrast Framing 3 involves deliberating and exploring these social and environmental goals and underlying values and embedding them in processes of systemic change. Deliberation processes give rise to common commitments to a search for effective solutions to social and environmental challenges and to recognition that these solutions necessitate experimentation and learning about underlying assumptions and values. Framing 3 gives recognition to the fact that assumptions and values are co-produced in these processes, they are emergent in character and are further shaped and consolidated in the process of systemic change. (p. 21)

STS as an intellectual community has grown rapidly in academic importance within History of Science and Technology departments developing its own set of terminologies. I am not an STS scholar but it seems to me that to further progress, it is time for STS, if it wants to complement economic analyses in the field of STI, to come out of its own disciplinary comfort zone describing concepts, taxonomies and theoretical frameworks and pragmatically describe how particular challenges of sustainability and social inclusion – the two main areas of need for transformative change – would be addressed within the current open international competitive environment in which mature and developing countries operate today.

Both approaches have their value. As highlighted in the previous section, STI analyses responded to both the growing need for a clear statistical measurement framework and the growing interest from national and international policymakers for macro and micro "evidence-based" studies on the impact of STI. While STS with their detailed anthropological descriptions appear to offer interesting academic historical insights on how particular developments have taken shape and evolved, they are often considered of less immediate policy relevance as they lack a clear normative framework, which economics, even evolutionary economics, offer in describing possible frameworks for policy experimentation.

From this perspective the time seems ripe to try to pull together again STS and economic approaches to STI.[13] One approach would be to jointly address a number of specific policy problems from an STS and economics approach with the intention of highlighting the different insights each approach might offer. To start the debate, and without pretending to be able to offer any valuable STS insights, let me consider several specific STI policy issues with which policymakers are currently confronted, using again some old SPRU examples.

3.2. The link between science, technology and innovation

As highlighted in the first section of this paper, the relationship between science, technology and innovation has always been particularly complex. As Keith Pavitt highlighted in his inaugural lecture at SPRU some 30 years ago:

> With the growth of industrial R&D departments in the 20th Century, and the large-scale recruitment of university trained scientists by them, the debate has become more complicated. When scientists working in US General Electric, in Dupont, in the Bell laboratories or in EMI, win Nobel Prizes, is the distinction between science and technology useful anymore? This may help explain why some social scientists have recently questioned the analytical usefulness of distinguishing between the content of science and of technology. Thus, it has been suggested that the analytical tools of the sociology of science can readily be transferred to technology (Pinch and Bijker, 1984, 1986). And two distinguished economists, Partha Dasgupta and Paul David (1994) have argued that the essential difference between science and technology is that the former produces public and published knowledge, whilst the latter produces private and often unpublished knowledge. (Pavitt, 1987)

Thirty years later, and following the onslaught of digital instrumentation technologies in practically all scientific fields, it would be interesting to reassess the evidence underlying some of Pavitt's old

[13] As noted earlier, such a merger occurred at SPRU in the 1980s when the History of Social Sciences Study group was integrated within SPRU.

arguments. Some of those arguments were reformulated by Gibbons et al. (1994) as the "mode 2" of STI nearly 25 years ago, in the pre-internet age. It would be useful to reassess Pavitt's arguments within the current context of the rapid digitalization of our economies including research and innovation.

There is, of course, the information and communication technology (ICT) sector itself, which has gone through a major transformation with the emergence of a few "superstar" digital platform firms fully exploiting network advantages at global level and investing heavily in what appear to be global monopoly rents in research, leading to a growing concentration of research investments in ICT, artificial intelligence and machine learning with significant implications for international competition policy. At the same time, those global platforms offer major opportunities for innovation through local applications, for new business models and disruptive innovation in many other sectors, in particular in services. We seem to be witnessing a new separation between science, technology and innovation, with, depending on the particular sector, only a couple of high-tech global firms[14] involved in research and most other firms focusing only on technological development and innovation. It is as if with the further increased commodification of technological knowledge there are now many more opportunities for firms to "buy" or simply obtain access to technological knowledge, which undermines the need to invest and take the risks of research investment themselves. In short, private research investment is primarily the expression of those few companies capable of maintaining innovation-based monopoly rents.[15]

3.3. STI and (inter)national competiveness

A second topic deserving renewed attention, again based on some of the early SPRU work on the competitiveness of particular British industries in the tradition of Chris Freeman's pioneering empirical research on the plastics (1963) and electronic capital goods (1965) industries, is the empirical research on the close link between national technological performance indicators and competitiveness. Again let me turn to Pavitt's inaugural lecture, summarizing a tradition of empirical research in which he led many scholars from Giovanni Dosi, Pari Patel to myself:

> I shall address an issue which is central to most of these debates: namely, the development and diffusion of often rather prosaic technologies in industry, agriculture and services; technologies associated with economic and social change, with international competition, and with increases in measured Gross National Product per head. Such a focus inevitably reflects my values which, for what it is worth, are that continuous improvements in the quality of life depend – amongst other things on keeping up, or getting closer to, world best practice in these technologies; and that the experience of this country over the past 25 years is an ample justification for this position. (Pavitt, 1987)

The many ensuing articles and books, and the international recognition of this particular research trajectory across the globe in emerging and developing countries, have been closely identified with SPRU scholars and alumni.

Again, to what extent is evidence based on "national" technological performance and industrial competitiveness still the appropriate focus for STI policy? Or should national STI policy address, as a matter of priority, global challenges such as sustainability and inequality as emphasized by STS scholars and in particular picked up in Schot and Steinmueller's (2018) third framing of innovation policy? The assumption that STI policy does not pay much attention to the unsustainable nature of fossil-fuel-based growth is only partially valid. Even in the late 1980s and early 1990s Freeman, Kemp and Soete had written about the particular regulatory and public policy challenges linked to the diffusion of "green technologies" (Kemp and Soete, 1990, 1992). To quote Freeman (1994), "The largely separate debate among economists and sociologists about 'trajectories' and 'paradigms', which is well described in the papers by Kemp and Schot et al. led also to increasing emphasis on the systemic aspects of innovation, as did the work of historians of technology, such as Hughes, Gille and Rosenberg" (p.1020). In 1993, a Maastricht Memorandum (Soete and Arundel, 1993) was written at the request of the European Commission in which Freeman and David wrote the chapter on the new challenges for "mission-oriented" STI policy in the area of sustainability and green technologies. Many of these early STI analyses provided policymakers with a clear normative framework for policies enhancing the diffusion of particular new green technologies. So, many STI scholars did pay a great deal of attention to the sustainability challenge. However, viewed in retrospect it could be argued that they remained within the existing constructed "social order" as it had evolved over the last decades and focused rather narrowly on particular objectives such as greenhouse gas emissions and possible technological "fixes".

Green technologies and sustainability are not synonyms. Today there is a much clearer acknowledgement that the scale of socio-technical change required to address sustainability requires a much more overarching transformative change, going way beyond green technology solutions and along the lines of Schot and Steinmueller's Frame 1 and 2 approaches to STI. It covers a wider set of issues including behavioural change that takes into account the endogeneity of preferences, perceptions about the environment as a commons for which one is both individually and jointly responsible, and the acknowledgement that market-based solutions will also create negative externalities, for example, unintended effects such as the intensification of natural resource utilization or the displacement of workers that will create a social burden.

STS, by contrast, while more critical about "the constituted social order" behind the chosen industrial growth path of nations competing with each other in total ignorance of environmental negative externalities, would need to take into account more explicitly the degrees of freedom within which such social orders operate. To just describe the limits of such freedoms, the likelihood of war or other major disturbances is insufficient. Normative ways in which such transformative changes can be achieved while taking into account the constituted social order is also what is expected from STS. In doing so, STS could bring to the forefront in a much more critical way understanding of the social formation and perpetuation of institutions that appear incapable of addressing the various global challenges that confront most nations in the world today, such as climate change, the financial crisis of 2007–2008, migration and the rapid rise in inequality within countries.

3.4. Global science funding

A third topic relates to the growing concern about the public funding of research, in particular frontier research. In most developed, high-income countries, with only a few exceptions such as South Korea and Germany, the public funding of frontier research has been under significant budgetary pressures. New priorities linked to ageing (pensions, health), security and migration are starting to dominate priorities in public funding. Combined with a lack of empirical evidence on the impact of basic research on innovation and productivity, this brings back to the forefront the debate on the opportunities for countries to "free ride" on global frontier research. After all, the total amount of research spent at the global level, both in absolute and relative terms (as a percentage of gross domestic product), has never been higher; and the number of scientists and engineers is double what it was just 12 years ago. To quote Keith Pavitt back in 1987 again:

[14] While business R&D increased in the US by 67% between 2003 and 2014, it increased by 92% for the hundred companies with the largest R&D budgets.

[15] The challenges this poses more broadly for income inequality have been highlighted recently by the OECD (see Guellec and Paunov, 2017).

> the arguments that Britain could usefully carry a smaller "burden" of the world's freely available scientific knowledge begins to look as threadbare and wrongheaded as those earlier arguments about the white man's imperial burden, that Britain was sometimes said to be carrying for the benefit of the world. As we have seen, the world's basic research cannot be applied by users without costs to them, comprising the costs to firms of employing graduate scientists and engineers, and the costs to governments of providing the academic infrastructure, including post-graduate training and research. If a government decides to run down the infrastructure, industrial firms will have to provide themselves or, as hinted by the recently retired chairman of ICI they will move their core activities to places where an adequate infrastructure is provided. (Pavitt, 1987)

This undoubtedly sounds rather timely 30 years later following the Brexit referendum, but it does not sound that convincing any more with treasury or finance ministers. And it is at odds with many countries in the world shifting the focus of R&D policies towards more immediate impact outcomes including commercial applications. In many research areas, the complexity of the challenges confronting humanity, the so-called wicked problems requiring scientific contributions from a range of different scientific fields from life sciences to nano-electronics, is such that collaborative efforts in science will be essential. There is today an urgent search going on for alternative funding opportunities for frontier research.[16]

3.5. Innovation and regulation

A fourth topic relates to regulation and innovation. While this too has been a topic with a long historical past both within the STS community and among economists of STI, let me jump to the current debate in Europe on the European Risk Forum's Innovation Principle: the idea that, when confronted with new technologies or innovation opportunities, rather than basing regulation on a precautionary principle, one should start from the opposite Innovation Principle, encouraging innovation and adjusting or adapting in an experimental fashion existing regulation along the lines of the so-called innovation deals. The objective of innovation deals is to bring together innovators and regulators, so that they can reach a common understanding of how a specific innovation can be introduced within existing regulatory frameworks. This approach builds on the Dutch green deals, but will apply to European Union (EU) level regulations. A first call for experiments with the new instrument in the field of circular economy, a field where regulation plays a major role as a factor impinging on innovation, was introduced in 2017 (European Commission, 2017).

The way this debate is taking place in Europe, confronted with conflicts between existing regulation frameworks and new organizational innovations of the "sharing economy" type, reminds me of Nelson's (2003) article, on the complexities and limits of market organization. In many ways the new types of organizational innovations undermine existing regulatory rules governing particular service markets and raise new regulatory challenges.

In the Jahoda memorial lecture that I gave in 2011 (Soete, 2012), I reminded the audience that "Innovation is good for you" appeared to be a common feature of most STI studies over the last decades. Hence the simple question that was central in my lecture: could it be that innovation is not always good for you? That at a societal level, innovation, rather than representing a Schumpeterian process of "creative destruction" (renewing society's dynamics and hence leading to higher levels of economic development and welfare – destroying a few incumbents to the benefit of many newcomers), sometimes presented the exact opposite pattern: a process of "destructive creation" – innovation benefiting a few at the expense of many. A common feature of "destructive creation" innovation is its short-termism: its easy, free rider nature; and its dependency on networks whereby the regulatory framework governing the network provides the major source for innovation. The reason, I argued, was simple: the advent of ICT had allowed a dramatic growth in opportunities for fragmentation of service delivery. Picking out the cherries of service delivery is, however, also accompanied by negative societal externalities. In network services it has increasingly become expensive to be poor. Our community, so I claimed, seemed to have not been sufficiently forthcoming in highlighting the limits of innovation in sectors where forms of destructive creation appeared much more common than usual forms of creative destruction.

3.6. STI and the future of work

A fifth topic, and one in which SPRU had again been instrumental in already raising the issue in the late 1970s, is the vexed question about the impact of STI on employment and skills. Forty years later it is interesting to note how this debate is being recast now within the context of the many new opportunities for artificial intelligence, data analysis and cybernetics. I must admit that it is somewhat difficult to take an independent position here. Indeed for somebody who has written many papers and books on the subject with Chris Freeman, John Clark and Charles Cooper in the late 1970s and 1980s little seems to have changed. The recent discussions on robotics (see, e.g. Brynjolfsson and McAfee, 2014; Michaels and Graetz, 2015) as the new challenge for employment, raising the spectre of mass unemployment, sound rather traditional and old. I think that again the speed of the impact of robotics and, more broadly, artificial intelligence is likely to be strongly overestimated. And historically the evidence of disappearing skills as a result of new technologies has not really been at the core of the emergence of mass unemployment.

Rather, the discussion would need to start to focus on alternative income systems disconnected from employment, such as "basic income". Following Jahoda et al.'s (1933) study of unemployment in Mariënthal, employment could still be considered today to represent one of the most important factors for social integration and personal recognition. At the same time, given the tremendously increased opportunities for social contact outside the sphere of employment over the last 20 years, it is also reasonable to assume that an unconditional "basic income" might well lead to a substantial shift in labour market participation to the benefit of individuals, even their health and happiness, and to the benefit of society. It might do so, though, only under the condition, and using the detailed micro insights from Jahoda et al. (1933), that serious efforts are made at new forms of social integration resulting from such income without work: in particular the absence of a workplace, workmates and work structure. Such social integration could form the basis of a new social welfare model in which the caring economy would take its full and crucial place in our economies: not as a cost factor but as an investment. While basic income is likely to be a great advantage for creative people, enabling them to earn a living from their art and more broadly creativity, one should avoid a new duality emerging with those lacking intrinsic motivation to become active in their home, family or local society once receiving a basic income.

Ultimately, one could view "basic income" as the monetized STI "manna from heaven", a simple way to redistribute gains from technical change to all.

I could continue listing many other fields, including those dealing with the selection and allocation of resources to research within universities; the management of innovation and in particular disruptive

[16] At the 2016 OECD Blue Sky Indicators conference, I proposed an alternative funding mechanism for applied research using blockchain technology (Soete, 2016). For frontier research, the policy challenge seems much more fundamental given the systemic complexity and hence the substantial costs of some of the lines of research being pursued – e.g. in biology the range of knowledge required to properly engineer new forms of life or in physics the scale of instruments needed to understand sub-atomic particles/fields.

innovation; or generic versus specific research policy. In each of those areas it might be good, in order to enhance mutual understanding between the two communities of STI and STS, to get some feedback on how to address the major policy challenges.

4. Conclusions

The setting up of the Science Policy Research Unit 50 years ago at Sussex University represented in many ways in STS terms a "transformative change" and in STI terms a radical innovation in the field of science policy and innovation studies. It influenced policymakers across the world in developed and developing countries alike. It made the topic of innovation familiar to business studies scholars, and as a sort of "general purpose" concept invaded many new areas far from its origins within science-based industries and "the marriage between science and technology".

Today, the analysis of STI, as I have argued here, appears in something of a crisis. On the one hand, there is growing evidence that the growth and welfare gains of new technologies and innovation are not forthcoming. The fact that productivity growth is actually slowing in most mature developed countries, for example, remains a puzzling feature in any debate on the current phase of the digital transformation of our societies. In a period when not only are many new technologies being introduced, but also more firms and countries are integrated into global value chains and workers are more highly educated than ever, it remains surprising, to say the least, that productivity growth is not rising in a much more significant way. As reported in many recent micro-econometric studies, it is the gap in productivity growth between global frontier firms and more domestically oriented firms that raises questions about the ability of the most advanced firms nationally to adopt new technologies and knowledge developed by such global leaders, and for the firms trailing them at national level to catch up. Today, the knowledge and technology diffusion "machine" appears broken, with many large firms hesitating to make larger capital investments and preferring to await signals for new market creation from other parties.

On the other hand, there is the environmental challenge, with the rapidly growing negative externalities of unsustainable fossil-fuel-based growth as industrialization spreads across the globe. Those negative externalities cover the full spectrum of society and the globe: from climate change to the dangers of local flooding, from the local depletion of fishing stocks to global pressures on migration, from water access to famine and wars, etc. STI policy appears somehow stuck in an industrial efficiency and consumerism mode unable to address in a satisfactory way those negative externalities. Traditional economic measures such as the pricing of such externalities appear ineffective within an open international framework of global competition between nations. The Paris Agreement of 2016 does, however, allow for sub-national groups to make pledges through the United Nation's Non-State Actor Zone for Climate Action (NAZCA) portal, even though such pledges do not have the legally binding nature of countries' pledges. Within this context, local states and cities might be more inclined to take appropriate measures, as they might become more directly confronted with some of the negative externalities associated with unsustainable growth. Large cities, for example, are likely to be confronted with what is called the "urban heat island" effect. Such effect occurs when natural surfaces, such as vegetation and water, are replaced by heat-trapping concrete and asphalt, further exacerbated by heat from cars, air conditioners and the like. There are different local STI-based solutions available at relatively low costs for combating this urban heat island effect, in particular cool pavements – reflecting more sunlight and absorbing less heat – and cool and green roofs.[17]

Global challenges such as climate change illustrate how local and global impacts are intertwined. Local issues, such as failed and failing states or disputes over trans-boundary resources, can turn into global threats. Global problems, such as climate change, environmental degradation, water shortages, energy and food insecurities and population changes, can translate into local conflicts.

Where both STI and STS approaches should agree is that science, technology and innovation are ultimately the vital "tools" of soft power in the search for mutually acceptable solutions to those global common challenges. The interplay of STI with policy making, decision making, foreign policy and international politics has, however, played a much more central role than STS in the formulation of international agreements such as the Paris Agreement. At the same time there is also significant debate about the future chances of success of such international agreements.

As argued in the RISE report on "Europe's Future" (European Commission, 2017), and focusing only on the role of Europe in using STI as soft power tool, while there is still scope in this area for science diplomacy, it is time for the EU to take a more active world-leading role in designing a new set of "mission-oriented" research and innovation policies in those areas of global challenges:

> With the high concentration of researchers and research facilities in Europe, the EU owes it to itself and the rest of the world to remain a central player in addressing the big, societal challenges of our times. But here too the knowledge-innovation axis appears more complex than generally assumed and can be said to function poorly today. Traditionally, addressing societal challenges has been a primarily "supply-pushed" concern with the research community playing a central role and becoming even a stakeholder in the way to address such "big challenges", relying in its financial sustainability increasingly on EU-funded research projects addressing those societal challenges. Implementation in terms of innovation has, however, often been disappointing. Typically, users and more broadly the demand side, has been insufficiently involved in the design and development of innovative ways to address those societal, global challenges… [W]hereas there are numerous opportunities for the science community to become the engine of international collaboration in signalling the global challenges ahead and planning ways to overcome them, with a potential significant role for science diplomacy, achieving the Sustainable Development Goals will ultimately depend on success achieved in CO^2 reduction in production, distribution and consumption; in having redirected demand towards more sustainable consumption paths, in developing and designing new circular economy market principles, etc. In short, it will be crucial to break open the current supply-side research dominance in addressing societal challenges, which has sometimes cornered the discussion and debates to technical debates about measurement, evidence and methodologies. (European Commission, 2017)

It is here that, in my view, STS approaches can be of particular value and helpful in bringing about real transformative change.

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[17] As Richard Tol noted (Estrada et al., 2017): "city-level adaptation strategies to limit local warming have important economic net benefits for almost all cities around the world. It is clear that we have until now underestimated the

(*footnote continued*)
dramatic impact that local policies could make in reducing urban warming."

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