FRAMING INNOVATION POLICY FOR TRANSFORMATIVE CHANGE: INNOVATION POLICY 3.0

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Contents

Introduction

Public policies, including those directed at science and technology, arise from understandings of past experience with actions, reflections on contemporary challenges and perceptions of future potentials for action. The past, present and future are interpretively connected by policy scholars and practitioners as well as many others as a guide to analysis and action. These interpretive connections produce forceful framings – interpretations of experience, ordering of present circumstances and imaginations of future potentialities which provide the foundations for policy analysis and action and have a powerful influence on the imagination of potentials and opportunities (Goffman, 1974; Benford and Snow, 2000; Taylor, 2003). Framings evolve over time and they change as they become perceived as inadequate to current circumstances. Because they influence peoples' imaginations, they also extend beyond the public policy sphere to influence the mobilisation and activities of non-governmental organisations as well as the private enterprise sector and even families and individuals.

In the contemporary world, despite important improvements in life expectancy and material welfare in countries, persistent problems of economic crises and rising inequality coincide with a growing realisation that current models for meeting our basic needs – whether in food, energy, mobility, materials, water or resources more generally – are unsustainable. The available framings of science and technology policy that evolved quite recently in historical terms since World II remain relevant. However, they do not provide perspectives on how to manage the consequences of the socio-technical system of modern economic growth to which they contributed and of which they are a part. Modern economic growth is generated by a socio-technical systems complex based upon industrial mass production and individualized mass consumption which extensively employs fossil fuels, is resource and energy intensive and produces a massive amount of waste.

Our view is that three framings related to science and technology policy can be delineated, two of which are available and are systematically employed in policy discourse and action. Each of these framings involves a model of innovation which defines the roles of actors and describes actions that may be taken to address goals that are also part of the framings we examine. The third framing remains under-developed although it has existed in the background of policy discussions for many years.

The first framing focuses on innovation achieved through R&D, tapping the potential of science and technology for prosperity and extension of a socio-technical system based upon mass production and consumption and governed by regulation of any untoward effects of innovation. It arose as the socio-technical systems complex of modern economic growth emerged –two central features of which Kuznets (1973) identified as science-based industry and sustained improvement in factor productivity.[1] In terms of science, technology and innovation policy, however, this framing remained tacit or unarticulated until after the Second World War when it was extended to create a new vision for the role of the State in the writings of Vannevar Bush (1945) and others.

The second framing – national systems of innovation - emerged during the 1980s to address some of the consequences for individual nation states of the experience with modern economic growth – the intensification of international competition, globalization, the prospects of being left behind, and the promise of catching up. Similar to the first framing, some of the features of the second framing were present in an unarticulated form in earlier years with greater influence on the practice than on the rationale or theory of science, technology and innovation policy. This paper articulates both rationales more clearly and puts them into historical context.

[1] Kuznets (1973) identified six characteristics defining modern economic growth. The other four were rapid population growth, structural transformation (primarily urbanisation and the shift from agriculture to manufacturing and then to services), changes in ideology (e.g. secularisation), the increased global reach of developed countries (part of what is now referred to as globalisation), and the persistence of underdevelopment (at the time of Kuznets article, the persistence of non-modern growth experience among three quarters of the world's population).

A third framing – transformative change - is in the making and its outlines have become clearer in recent years. The historical background is captured most recently in the UN Sustainable Development Goals published in 2015. These include ending poverty and reducing inequality in all its forms everywhere, and promoting inclusive and sustainable consumption and production systems, full and productive employment and decent work for all, and many more.[2] This third framing involves a questioning of how to use science and technology policy for meeting social needs and addresses the issues of sustainable and inclusive societies at a more fundamental level than previous framings or their associated ideologies and practices.

The emergence of a new framing does not necessarily replace existing framings. However, framings compete with one another for the imagination of policymakers and, ultimately, citizens. The legitimacy of rationales and arguments for particular policies and the actions that follow from them is influenced by the prevalence and understanding of the framings. Our aim in this paper is to examine the historical development of all three framings, illustrating how each arises as a response to changing social and economic circumstances. Ultimately, we contend that research, experimentation, and reflection on the third framing should be a priority in any consideration of innovation policy. This paper is about the framing of science, technology and innovation policy at a high level of abstraction. We think it is important to articulate and assess these framings since they have pervasive impacts on practice, yet never fully shape what is happening on the ground; actual practice might reflect mixtures of all these frames.

Framing 1: R&D and Regulation

Concerns about the future of the industrially developed economies manifested themselves following World War II. The potential for the re-emergence of unemployment, inflation, and economic instability was feared and the roles of the state in mobilising and conducting the war effort legitimised state intervention that previously had been viewed sceptically, particularly in the British and American context. Substantial variation across countries in the state's support for research and development (R&D) prior to the war existed, but with a few exceptions, such as agricultural research in the US and Europe, these efforts were a direct consequence of the state's role in particular activities such as defence, telecommunications, medical research, geological surveys, and civil engineering works.[3] Following the war, and because of the ensuing Cold War, there was enthusiasm for an expanded state role in conducting scientific research which was expected to bring industrial benefits. There was also public enthusiasm and optimism that science would bring benefits notwithstanding the role of science in creating nuclear weapons.

A broad consensus emerged that the state could and should play an active role in financing scientific research on the premise that new scientific discoveries would tickle down to practice through applied R&D by the private sector. It was also recognised that science was making substantial contributions to the modernisation of industry – replacing craft practices and traditions with a continuation and intensification of scientific management as articulated in Taylorism and Fordism. Typically, during the 1950s, science and invention were viewed as distinct activities. As distinct activities, there were also a basis for a division of labour between the state and private enterprise. In social histories, both science and invention were discussed in terms of the 'heroic' or Promethean originator with familiar debates about the relative influence of individuals and groups.[4]

Attention to the issues of applied research and technological development and their treatment as an investment by firms suggested shortcomings in the focus on invention which emphasised discovery and discoverers. For these investments to be recouped, commercialisation of invention was required. Commercialisation would only happen if an invention were to be purchased by a significant number of customers. In effect, the framing describing the origins and nature of invention inherited from the past was

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[2] http://www.un.org/sustainabledevelopment/sustainable-development-goals/

[3] See Tindemans (2009) and Mowery and Rosenberg (1989)

[4] For example, contrast Bernal (1939) with the large number of encomiums for inventors such as Ford and Edison.

undergoing change. Initially, this involved a focus on R&D as an investment and led to questions about the rate of adoption (or path of diffusion) of new products. To capture these processes and to distinguish invention from the more complex processes of applied research, development and commercialisation, the word innovation began to be employed.[5] The simplest definition of innovation is commercialised invention.[6]

In the late 1950s the popular imagination favouring the economic benefits of science provoked a re-examination of the role of scientific and technological knowledge from both empirical and theoretical perspectives. Empirically, the relation between the factors of production and the growth of economic output was re-examined by Abramovitz (1956), Solow (1957) and others. Abramovitz and Solow demonstrated that the contribution of labour and capital growth fell far short of explaining growth in economic output, leaving a large residual which Solow attributed to technological change and which Abramovitz referred to as "some sort of measure of our ignorance about the causes of growth in the United States", (p.11). In terms of science and technology policy, this work seemed to confirm the benefits that science was providing to the economy. The findings were reinforced by the appearance of novel artefacts such as mass market televisions, passenger jet airlines, and, more darkly, intercontinental ballistic missiles. The significance of the residual provoked an increase in social scientist and policymaker interest in the processes of technological change. It also led to a re-examination of the rationale for public intervention in the research enterprise.

Rationale/Justification for policy intervention

The explicit recognition that investment was required for innovation, combined with the empirical insight that innovation or technological change was the single largest factor in economic growth, presented a theoretical question for economists. It was in this context that Nelson (1959) and Arrow (1962) asked the question – Are the incentives of market actors adequate to produce the socially desired level of scientific knowledge? Their negative answer reflected the nature of scientific knowledge (the challenges of 'appropriating' or owning it) and the logic of the market (a firm expending costs that will equally benefit rivals is not making a rational economic decision since the rivals can free ride and obtain a cost advantage from not making the research expenditure).[7] Thus, economic theory provided a robust rationale for the public support of only *a component* of innovation (discovery or invention). In economics language, discovery and invention were said to have the features of a public good, akin to roads or sewers and it was reasonably well-accepted that public goods suffer from 'market failure' – the inadequacy of market incentives to produce them at the desired level or quality.[8]

The question of whether a similar market failure might apply to the latter stages of the innovation process – applied research and commercialisation – was not addressed because it was assumed that these in these later stages, the knowledge would be *appropriable* – appropriation of benefits could be protected by trade

[5] For economists, who were developing the theory of production to reflect the contributions of technology, the broader terms technical or technological change were employed in parallel since it allowed discussion of both innovations representing new products and improvements in processes for producing products. Later, the terms process and product innovations began to be used as types of technological change.

[6] This was a particular concern of Chris Freeman due to his interest in the social functions of science (Bernal, 1939) and the need to distinguish between invention and commercialisation of invention. While Freeman was not the first to make this distinction, he was influential in getting this established due to the success of Freeman (1974).

[7] Both of these assumptions were later questioned. Most dramatically, the public good nature of science was questioned by Collins (1974) and later by Callon (1994). Rosenberg (1990) observed that firms did invest in 'non-appropriable' science with their own money, perhaps because this was a necessary condition for employing scientists or integrating their scientists within scientific communities and networks.

[8] Substantial debates continued in political economy concerning which goods were necessarily public goods with those of libertarian or neoliberal views contesting virtually every candidate, including science, see e.g. Kealey (1998)

secrecy, intellectual property, or simply by maintaining a competitive lead preventing rivals from quickly imitating successful innovations.[9]

Policymakers contributed an additional feature to the first framing by sponsoring mission oriented research, a continuation and, in some cases, an extension of the previous role of government research funding for government activities. Technologies were developed to wage war – atomic weapons, radar, jet aircraft, ballistic missiles, and computers were further developed for 'defence' and adapted to civilian application. The most improbable of these adaptations, the civilian use of ballistic missiles, was transformed into a space programme and a space race paralleling the Post-War arms race in nuclear weapons. Policymaker definition and pursuit of missions was motivated by national prestige and ideological competition between the state socialism of the then Soviet Union and China and the capitalism of the West, rather than by economic returns on public investment. Scientists also benefitted from their perceived contribution to war efforts. The physicist Robert Wilson responded to a question from a US Senator concerning the defence (mission) value of the proposed new accelerator at Fermilab, at the time, the largest high energy physics research installation in the world - "In that sense, this new knowledge has all to do with honour and country but it has nothing to do directly with defending our country except to help make it worth defending" (Wilson, 1969).

Economists and policy makers were not the only contributors to the first framing of science and technology policy. Awareness of the potentially negative consequences of scientific development was, in the 1950s, limited to a few areas such as the risks of nuclear war and radiation exemplified by the 'Doomsday Clock' regularly updated on the cover of the Bulletin of Atomic Scientists. However, the publication of, for example, *Silent Spring* (Carson, 1962), and the *Limits to Growth* report by the Club of Rome (Meadows, Meadows, Randers et al., 1972) opened a much wider agenda of social concern about the potentially negative consequences of the new products of science. During the 1960s, considerable anxiety about and protest against the possible consequences of science for public health and safety and, ultimately, environmental quality, emerged. Policy makers responded to these developments, often reluctantly, by developing new regulatory agencies or making important changes in those agencies that had been established in an earlier era. For example, the US Food and Drug Administration (FDA), which had been established in 1906 to license pharmaceutical products and set standards for food standards, began to regulate the effectiveness and safety of pharmaceuticals after the worldwide thalidomide disaster.[10]

Framing 1: Innovation Model and Actors

The model of innovation underlying Framing 1 is the commercialisation of scientific discovery with each of the processes following discovery driven by the economic logic of investment and financial return in the potential market for the innovation. This framing reflects a modernist confidence in the inevitability of progress and an economic rationale for the social welfare benefits of choice across a range of competitively mass produced (and hence relatively inexpensive) goods. It is expected that this science-led process will contribute substantially to long term economic growth and provide numerous business opportunities. Somewhat reluctantly, this framing allows for mistakes which are themselves attributed to shortcomings in scientific knowledge that can be remedied with further research. In general, regulation of these potential mistakes – their anticipation and correction – is outside the main model of innovation. Regulation is, for the most part, applied after the research process is completed and at the point when problems are experienced in the adoption and use of the innovation. To identify these problems, governments use technology assessment exercises and create specific agencies which inform Parliaments (Vig. and Paschen, 2000). Yet these technology assessment activities are not seen as a core part of a science, technology and innovation policy, but as a useful add-on at best. An example of ex-post problem solving is CFC (chlorofluorocarbons)

[9] Exceptions to this rule included defence where planning most often dominated market competition, medical research which was seen as inherently public, and agriculture where a considerable share of advance was thought to stem from more widespread adoption of best practice.

[10] This was done with Kefauver Harris Amendment or Drug Efficacy Amendment, a 1962 amendment to the Federal Food, Drug, and Cosmetic Act.

where an innovation that improved the quality of refrigeration[11] eventually were recognised as a hazard to the ozone layer and production was proscribed by international treaty (Montreal Protocol on Substances that Deplete the Ozone Layer, 1987).[12] Concerns about the broader implications for the environment or human health and welfare of the path of scientific advance were viewed somewhat fatalistically as the cost of progress. They were mostly marginalised until the late 1970s and 80s when incidents such as ozone depletion resulting from CFCs and the Three Mile Island (1979) and Chernobyl (1986) nuclear accidents occurred.

The actors in this innovation model have a clear division of labour and responsibility. Scientists are expected to pursue the advance of scientific understanding with only incidental attention to the potential commercial value of their discoveries[13], to publish their work fully disclosing the methods and findings[14], and to assume that those taking up their discoveries will use them in a socially responsible manner. The public sector is expected to fund scientific research generously and to regulate science to assure its openness and to encourage self-regulation of scientific misconduct (e.g. falsifying results or making unjustified claims) by the scientific community. The public sector is also expected to offer a means for identifying problems arising from the application of science and to refer these to experts in the scientific community for evaluation and solutions. The role of the private sector is to transform scientific discoveries into innovations which will support sustained long term economic growth. In the 1960s, it was assumed that the competence to do this would exist primarily in large incumbent corporations who would be able to build the industrial research capacities to perform the applied research and development efforts necessary to commercialise scientific discovery. Towards the ends of the period it became clear that a new group of actors, new technology based firms (NTBFs) had emerged and with them an increasing interest in the nature of entrepreneurship and entrepreneurs that Schumpeter had written about earlier in the century.

Framing 1: Policy Practices

The first framing encouraged an expansive view of the benefits of research but, nonetheless, policy practitioners had to negotiate the political process through which research funds are allocated. The policymaker definition of missions and mission led research programmes discussed above were most apparent in the US where several large governmental Departments (defense, energy, and health[15]) have continued to sponsor basic and applied research and in France where atomic energy and medical research epitomised a dirigiste approach to scientific advance. The political advantage of mission-led research is that the funding of basic scientific research can be justified in terms of its contribution to specific objectives rather than relying solely on the somewhat vaguer promise that science ultimately (in the long run) brings prestige or cultural benefits.

Similarly, although the underlying market failure model only justifies public investment for scientific and technological knowledge that is a public good, the framing that research is the source of long term economic growth led policymakers to respond favourably to the support of all types of research. This lead to the

[11] CFCs also replaced the refrigerants sulfur dioxide and methyl formate that would, in the case of leakage, be directly hazardous to human health.

[12] The Montreal Protocol is an example of incomplete regulation since it did not provide measures for sequestering and destroying existing stocks of CFCs. So one line of investigation in Framing 1 is regulatory effectiveness from which ideas about the 'precautionary principle' follow.

[13] An interesting revision of this part of the model was suggested by Stokes (1997) who suggested it might be possible to distinguish between lines of scientific research which might be 'use-inspired' (e.g. Pasteur's investigations into the mechanisms of fermentation) from those that are 'pure' (e.g. Bohr's investigation of energy states in atoms)

[14] See Dasgupta and David (1994) for an interpretation of scientific disclosure as an alternative system to appropriability for generating social welfare.

[15] The unusual structure of the US government (compared to centralised parliamentary democracies) severs the usual relationship between higher education and science policy. In the US, the majority of universities are established and financed by individual states of the union. The very substantial increase in Federal funding for research greatly benefitted several of these (e.g. University of California and the universities established by the Morrill Act of 1862, which provided a one-off grant of substantial land from the Federal government) as well as several leading private universities (MIT, Stanford, Harvard, Chicago and Columbia). See Geiger (1993)

creation of many policy instruments aimed at stimulating R&D including favourable tax treatment and direct subsidies employed horizontally to specific industries to encourage competition. In addition, nations have attempted to create favourable business climates for business investment on the premise that a share of this investment would flow to innovation activities. The recognition of the significance of NTBFs in fostering innovation led to the idea that taxation on capital gains from the elevation of equity values should also receive favourable tax treatment to encourage further investment in these firms. Comparison of the levels of R&D investment between countries became an important indicator guiding government policy which later became an explicit policy in the European Union with the aspiration of achieving a 3% of GDP average research intensity across the EU (European Commission, 2010).

Yet while governments are positive about public funding, almost no country can afford to do everything in science and technology. Choices are necessary. This led to the development of mechanisms for making choices between competing alternatives. A prominent mechanism which developed during the 1980s and 90s was technology foresight (Martin and Irvine, 1989). These activities made it possible to bring societal considerations into the selection process, but in practice supply factors (perceived technological opportunities) often dominated. Foresight offers a process approach to the selection of priorities which then allows governments to leave the responsibility for selection to the companies involved which fits the rationale of a Framing 1 approach.

To ensure that the division of labour between scientific research as a public good and the private appropriability of applied research, development and commercialisation, policy actions to strengthen and extend intellectual property protection were undertaken. The US has been particularly aggressive in this area with the establishment of the Court of Appeals for the Federal Circuit (1982) with a principal remit to review patent litigation, extensions to the patent life for pharmaceutical products (1984), and taking a leading role in the Trade Related Aspect of Intellectual Property (TRIPS) agreement incorporated in the 1994 Uruguay Round of the General Agreement on Tariffs and Trade (GATT). Providing the inputs for science and innovation through education is another role of government. Education for research careers was a common policy aim throughout the first framing period and has continued more recently with an emphasis on STEM (science, technology, engineering and mathematics) subjects and a corresponding re-alignment of education funding in several countries (e.g. the UK) to reflect this priority.

Learning from policy practice was particularly important between 1960 and 1990. The petroleum crisis of the 1970s highlighted the reliance of virtually all countries' dependence on the import of petroleum to operate the mass production and distribution technologies that arose from the first framing. It gave rise to a new mission oriented policy in the US and other countries seeking to reduce energy dependence and this contributed to the early development of renewable technologies.

Framing 1: Alternative or Counter Framings

The first framing's depiction of large scale scientific enterprise joined with large enterprise or complex eco-systems of NTBFs was very dominant in the US and Europe, but it posed a major challenge for less developed countries which lacked the resources to construct the socio-technical system that was required. Sagasti (1980) argued that this was producing two civilisations, one that generates the knowledge and derives principal benefits from it and the other (i.e. the developing world) seemingly passively receiving a part of this knowledge and thereby a diminished capacity for sovereignty and self-determination. In addition, the technologies developed by this 'first civilisation' were themselves seen as disadvantageous (Stewart, 2008). These counter-framing of the beneficial nature of scientific progress and innovation in the developed country context led to responses by scholars and policymakers in the less developed countries. Following the earlier work of Raul Prebisch (1950) and Hans Singer (1950), a doctrine of import substitution led a number of countries, particularly in Latin America, to withdraw from the general trend toward more liberal international trade tariffs in order to build infant industries. The same types of policies were employed in East Asia, perhaps with a greater degree of targeting of specific industries and with a clear intent to build export capacity rather than import substitution. Although largely abandoned by the 1990s, many concluded that these policies had positive effects in the East Asian context and some argued that these policies had positive impacts in the Latin American context, e.g. Colistete (2010).[16] Developments related to Schumacher (1974) and Stewart's (1973) argument calling for an appropriate technology movement attempted to harness research processes to produce technologies that would be more suitable in the developing country context.[17] For the most part, innovations coming out of this movement were very rudimentary (e.g. better ovens for using local fuels) and generally fell short of the expectation that they would provide significant additions to the income of developing country people. Nonetheless, ideas from this social movement re-appear in writings about frugal innovation (Radjou, Prabhu and Ahuja, 2012), innovation from the bottom of the pyramid (London and Hart, 2004), and inclusive innovation (Chataway, Hanlin and Kaplinksy, 2014).

Framing 2 – National Systems of Innovation

The emergence of Framing 2 was a response to the perceived incompleteness of the first framing and to the some of the consequences of pursuing this model. The post-World War II growth experience that continued with relatively minor interruptions until the oil shocks of the 1970s and the serious recession of 1981 (often referred to in Europe as an economic crisis) intensified competition between countries and highlighted differences in national industry innovative and productive performance. It also became more apparent during the 1980s that the convergence between higher and lower income countries was occurring at a much slower rate than could be explained using the first frame's premise that scientific and technological knowledge was a global public good – in principle, available to everyone in the world. An explanation of this state of affairs, consistent with the first framing, was that the richer countries were holding back scientific or technological knowledge, thereby excluding other countries from utilising this knowledge to engage in a catching-up process.[18] This idea was contested by Soete (1985) who observed that the industrial structure of technology based companies often contained smaller or medium sized firms that were able and willing to sell technologies (e.g. license patents, sell advanced capital goods, or be acquired at prices lower than the implicit costs of reproducing their technologies).

These conundrums in the application of Framing 1 led scholars to re-examine the linear model of innovation that underlay this framing. Four important modifications were indicated. First, rather than a global public good, it was recognised that scientific and technological knowledge often contained important tacit elements. The knowledge did not freely travel over geographical and cultural distances, but instead was sticky (Von Hippel, 1994). Second, the ability to absorb knowledge from the worldwide network of research and researchers depends on absorptive capabilities (Cohen and Levinthal, 1989) which require prior experience in related research and application. Third, 'absorptive capacities' were one of a range of social capabilities that stemmed not only from the level of education but also its qualities and the social capability of entrepreneurship.[19] Fourth, the character of technological change was recognised as being cumulative and path-dependent (David, 1975; Arthur, 1983). A balance existed between major disruptive innovations that alter the trajectories of search and improvement, and cumulative innovations that reinforce and strengthen existing methods, often in ways that raise important barriers to new technologies that might be more, or more rapidly, disruptive than without these cumulative improvements. These modifications were seen as complementary to the growing empirical recognition that innovation is often initiated by users (von Hippel, 1988) or through feedbacks among applied research, development and commercialisation activities in what Kline and Rosenberg termed a chain link model of innovation (Kline and Rosenberg, 1986).

[16] In both areas, international pressures were important reasons for the abandonment of the policies.

[17] See also Kaplinsky (2011).

[18] Gerschenkron (1962) had highlighted the advantages of economic backwardness for rapid economic growth by noting the potential for large increments to productivity and output by adopting techniques well known in wealthier economies. During the 1960s and 1970s there had been considerable optimism concerning the prospects for 'technology transfer' as a key component of development strategy.

[19] The promotion of entrepreneurship is often a stand in for pro-business and anti-government political sentiments (i.e. the favouring of private rather than public collective action). However, it also reflects social norms regarding taking initiative and departing from existing practices often involving the building of new businesses.

These modifications of the underlying model of innovation suggested that important international differences might exist in the capacity to innovate and focussed attention on the processes of learning and the relation between different organisations in a society. Freeman (1988) and Lundvall (1992) employed the term national systems of innovation. The national systems of innovation approach directed attention to the various configurations of organisations concerned with the generation and utilisation of scientific and technological knowledge. Central to this idea was that some configurations might be much more effective than others. Thus, these might contribute substantially to the explanation of why very uneven rates of productive and innovative performance were observable throughout the world. In particular, Freeman (1988) suggested that Japan had made important organisational innovations in the generation and utilisation of technological knowledge which explained its ability to catch up and overtake companies in advanced manufacturing sectors such as automobiles and televisions.

In the version of national systems of innovation offered by Freeman (1987, 1988), these systems had a national character, reflecting differences in institutions and policies. In Lundvall (1985, 1988), the centrality of capabilities for learning was additionally emphasised as a national characteristic that applied to country-based organisations. The justification for a geographic-political bounding of these systems was twofold: institutions and policies are largely established at a national level and knowledge does not travel easily outside the socio-cultural milieu in which it is created. Further differentiation of systems of innovation thinking involved an emphasis on the 'stickiness' of knowledge suggesting regional systems of innovation or, alternatively, cognitive alignment created by common participation in an industry and its technological problems regardless of nationality, leading to sectoral systems of innovation.[20]

Rationale/Justification for policy intervention

The socio-historical context of the systems of innovation literature is important. It arose in an attempt to explain the insurgence of East Asian economies, first Japan, then the four 'tigers' (Taiwan, Korea, Singapore, and Hong Kong) and, most recently, China. One way of thinking about this historical context is to focus on the further development of the internationalisation of trade and finance that was occurring in the latter two decades of the 20th century – the beginnings of processes which are now collectively referred to as globalisation. [21]

From a neoliberal economic perspective, globalisation is seen as the spread of an international system of liberal trade and investment creating the basis for international competition and, hence, efficiency in production and distribution.[22] However, there are important qualifications to the positive interpretations of this perspective – the processes of globalisation simultaneously have allowed millions of people to improve their material wellbeing and impoverished millions of others. While many of the less developed economies have made major strides in total national income, the distribution of this income within countries has, in many cases worsened, and the gap between the income of the richer nations and the poorest nations has widened (Keeley, 2015; van Zanden, Baten, d'Ercole et al., 2014). From the perspective shared by Framing 1 and 2, growth of output and employment is of central importance in the future economic welfare of countries and their citizens. Falling behind in growth raises the spectre of decline and a downward spiral in which a country becomes less able to compete in international markets and, because of increasing imports, to maintain domestic markets in traded goods. A central rationale for government intervention is the maintenance of competitiveness – a goal often stated in mercantilist terms as becoming ever more competitive in order to stimulate continuous growth through exports while preserving a dominant share in domestic production for domestic consumption.[23] In many countries, the displacements stemming from

[20] The varieties of systems ideas is examined in Edquist (1997).
[21] Among the many developments accompanying globalisation is the increase in the international movement of goods. A measure of the intensification of globalisation is the growth of containerised shipping over the last 20 years which has grown from 40 million to 180 million TEU (twenty foot equivalent unit) (UNCTAD, 2015:19)
[22] The liberal perspective is exemplified by Friedman (2005)
[23] Of course, this raises the same problems with economic sustainability that Smith (1960 [1776]) observed with regard to earlier mercantilist practices and that led then and in the following 150 years to periodic episodes of tariff increases and breakdowns in international trade.

globalisation have produced a political competitiveness agenda the economic logic of which is, at best, questionable (Krugman, 1994).

The national innovation system approach is complementary to a competitiveness agenda, based upon trade advantage rather than national prestige or military power. Advocates of this agenda (which remains influential today) argue that innovation broadly requires government intervention either to preserve or to expand the competitive advantage of domestic firms. The rationale of the competitiveness agenda retains a Framing 1 perspective to the extent that interventions are limited to pre-competitive research, i.e. the creation of knowledge upstream of product design. This limitation is largely due to concerns about state support or quasi-mercantilist policies which were proscribed to create a level playing field in international trade competition. A number of scholars have argued for (Graham, 1994) and against (Cohen and Noll, 1991) this extension of state actors. Mazzucato (2015) has advocated an Entrepreneurial State which should not stimulate investment because of market failures, but instead be an actor that shapes markets, bringing companies along into new markets by leading in the discovery and testing of new technologies. She also argues that the state should also not be satisfied with the returns it receives from such investments (due to taxation) and should more directly benefit from its investments in science and technology (Mazzucato, 2016). This is consistent with a mission led and innovation systems based approach and therefore with a hybrid between Framings 1 and 2.

In terms of the governance of policy interventions, Framing 2 suggests the desirability of alliances and coordination among the actors within the innovation system to avoid system failure – the lack of cooperation and coordination. A variety of other system failures is possible including capture by vested interests of government policies aimed at facilitating research and innovation and the creation of cartels under the banner of improved research cooperation and coordination. In this framing, these should be relegated to the, often separate, regulatory ministries or agencies of national governments which, due to the competitiveness agenda often have been unwilling to act against domestic concentrations of economic power due to fears of loss of competitiveness in relation to other large multinational companies.[24]

Framing 2: Innovation Model and Actors

Despite its inclusion of a wide range of actors who are seen as having agency to improve innovation systems, Framing 2 sustains the government and producer-centric perspective of Framing 1. Although users are specifically identified as a possible source of innovation in the model of innovation underlying Framing 2, and user-producer relations are seen as key, the agency of users to affect the direction or nature of innovation generally has not been considered as a matter for policy, and users are not mobilised or perceived as innovative actors.

The underlying model of innovation in Framing 2, however, was fundamentally revised with important implications for policy practice. It moved away from a linear understanding of innovation towards a more interactive model as is exemplified by the chain-linked model. A key relevant work distinguished a Mode 1 and Mode 2 structure of knowledge production similar to our two framings (Gibbons, Limoges, Nowotny et al., 1994). This work distinguished five features of Mode 2 knowledge production: 1) knowledge is increasingly produced in the context of application,[25] 2) transdisciplinarity, the merging or 'inter-penetration' of disciplinary frameworks to produce new common frameworks for research in the context of application (p.29), 3) heterogeneity and organisational diversity, reflecting the increasing diversity of actors involved in

[24] For example, in 1999, the US repealed the Glass Steagall Act (1933) which had regulated concentration of banks due to the existence of large foreign banks. Some have argued that this contributed to the subsequent problems in dealing with the US-initiated banking crisis and global recession of 2008 although this remains controversial.

[25] According to Gibbons, Limoges, Nowotny et al. (1994) knowledge production was becoming more 'socially distributed' and had 'transcended the market' (p.4) although their work continues to focus on distinctions between university and industry producers of knowledge with only an oblique reference (p.37) to von Hippel (1976, 1988) that 'the presence of potential buyers and users directly in the contexts of development influence the direction that innovative lines of research will take.' In fact, von Hippel documents in these two works that it was users who were directly responsible for many major innovations in the scientific instrument and other fields.

knowledge production, 4) social accountability and reflexivity, involving a wider range of experts in the research process to accommodate ethical and environmental concerns[26], and 5) quality control, the observation that traditional disciplinary peer review of what constitutes good science becomes more complex as knowledge is produced in the context of application rather than within established disciplines and their self-referential norms. Gibbons, Limoges, Nowotny et al. (1994) suggested the need for institutional reform with particular attention to the relationships between direct government research efforts (e.g. in public research laboratories), industrial research and university research to stimulate the creation of networks to facilitate coordination and cooperation. This focus on institutional links and interactions resonates very well with Framing 2, the national system of innovation approach.

A related line of research and policy advocacy within Framing 2 has been presented using the term Triple Helix (Etzkowitz and Leydesdorff, 1997; Etzkowitz, 1998, 2008) – the label refers to the increasingly inter-twined nature of government, industry, and university research efforts. Similar to Gibbons, Limoges, Nowotny et al. (1994), scholars participating in triple-helix studies have sought to map and analyse the new forms of cooperation emerging between institutions, to consider processes of governance that align the interests of these different institutions and to provide guidance to each type of institution as to how they might enact reforms that would make national systems of innovation function more effectively. An important element of triple-helix research has been the premise that universities should become more entrepreneurial, fostering new company formation through spin-offs and licensing technology produced through university research.

The difficulties in transferring knowledge between locations provoked a re-examination of geographical localisation effects (Gertler, 2001). Initial studies highlighted the existence of industrial clusters (Castells and Hall, 1994) suggesting policies aiming to concentrate activities of a particular type, e.g. the Malaysian multimedia corridor (Bunnell, 2002). However, later studies found that governance issues were of critical importance and difficult to reproduce (Cooke, 2001) and that proximity in several different senses had the potential for detrimental as well as positive effects (Boschma, 2005).

A parallel line of investigation focussed on the effects of cognitive proximity and alignment and particularly on the significance of the cumulative nature of technological change. From this perspective, knowledge is acquired through situated learning rather than from the transmission and receipt of information. An influential contribution in this area suggested that organisational and societal arrangements for improving learning through experience and interaction are central in generating and utilising knowledge (Lundvall, 1985, 1988, 1992). In the Korean context, Lin Su Kim also made major contributions indicating how learning could be used effectively in a catching up context (Kim, 1999).

In terms of actors and innovation, Framing 2 reflects perceived changes in the processes by which applicable knowledge is generated and exchanged. Rather than being a linear flow from science to applied R&D to commercialisation, knowledge is generated through interaction among the (more diverse) actors in national, sectoral and regional information systems. These interactions involve a process of interactive learning and the building of capabilities to absorb and adapt knowledge, often influenced by physical and cognitive proximity. For these processes to be effective, alignment of these actors' objectives and capacities for interaction is necessary. Within this model, considerable attention is paid to exemplars such as Silicon Valley (Kenney, 2000) or Route 128 (Saxenian, 1996) in the US or the Cambridgeshire area of England (Garnsey and Heffernan, 2005). There is, however, little consensus as to how this model might be influenced by policy.

Framing 2: Policy Practices

The lack of academic consensus regarding the relative effectiveness of different types of interventions based on a Framing 2 perspective has led to considerable variety in actual policy practices. Central governments have undertaken substantial efforts to build technopoles (e.g. Sophia Antipolis in France (Longhi, 1999)) and

[26] This foreshadows our discussion of these issues in Framing 3. The discussion of this in Gibbons, Limoges, Nowotny et al., (1994) (pp. 7-8 and in brief reference throughout the work) suggests that mechanisms of accountability and institutions for reflexivity were already in place. However, almost no evidence is offered for this conclusion

science hubs (e.g. Tsukubu science city in Japan (Tatsuno, 1986). Regional authorities have attempted to re-vitalise areas by making investments in new technology based firms, e.g. Research Triangle in North Carolina, US (Link and Scott, 2003). These efforts have had mixed success and the time horizon for successful national or regional development appears to be very long relative to the tenure of political decision makers who initiate such plans.

Policies that aim to improve the coordination and alignment among different actors in innovation systems have been undertaken in many countries. These often involve funding conditionality, e.g. research funding on the condition of participation with other organisations in a network. Such conditional funding has been applied to university, corporate, and public research laboratory funding. Exemptions from competition policy guidelines limiting meetings and collaborations among firms in specific industries have also been enacted in order to encourage research network formation. Foresight has also been used and advocated as a tool for better communication, more effective coordination, development of consensus and generation of commitment (Martin and Johnston, 1999).

One of the distinguishing features of Framing 2 is the greater role ascribed to agency as compared to Framing 1 and, accompanying, this is a greater interest in entrepreneurship. The nature of the entrepreneur was a central issue in the writings of Schumpeter (Schumpeter, 1947, 1949). However, it was not until the 1980s that a specific focus on policies cultivating entrepreneurship involving the formation and growth of new firms, particularly those involving the use of new technologies started to be a central concern of policy. Promotion of new technology based firms (NTBFs)[27] sits uneasily with neoliberal views of the efficacy of markets and which suggests firm size is irrelevant to the degree or nature of innovativeness (Kulicke and Krupp, 1987). However, when issues of agency are considered explicitly, the focus and drive of such firms, along with the personalities of their entrepreneurial founders, suggests a reason for special consideration of these types of firms in government promotion policies. Such policies also reflect the growing concern for employment and the associated observation that small and medium sized firms (SMEs) comprise the majority of employment in most economies. Although in many contexts, this is more of a problem than an advantage (SMEs generally do not have the resources or market presence to engage in R&D or the large scale promotion of new technologies and often have lower levels of productivity than their larger rivals), the identifying feature of NTBFs is their pioneering of new technologies, some of which produce rapid growth in employment and output. NTBFs also contribute to the larger national system of innovation by creating a greater degree of diversification and specialisation, enabling larger firms to select from a population of firms with many more new ideas than might be produced solely through internal R&D processes.

Framing 2 also suggests a renewed policy focus on the issues of technological diffusion or take up. The systems approach emphasises the connection between supply and demand which is taken to be mediated by non-market as well as market processes. Many modern technologies involve coordination between firms in sectors such as aerospace, electronics, COPS (complex products and systems, such as flight simulators) and zero net carbon emission buildings involving not only substantial scientific and technological knowledge; but knowledge that is distributed across a wide range of specialised firms. In order for these sectors to develop and flourish the relationship with their customers need to be sufficiently stable to support investment while the networks of firms comprising these sectors need to be adequately coordinated. Issues of demand and coordination were often addressed historically through government procurement. While government procurement remains important, private sector demand for the products and services of these sectors has increased dramatically (in part due to the privatisation of previous government enterprises in telecommunications and transport). Privatisation not only introduces markets, it also restructures the non-market relations within these sectors. Governments have a choice whether these restructurings are conducted in a laissez faire fashion or involve a role for government regulation, promotion, and interventions.[28]

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[27] As a descriptive category, NTBFs already existed in reviews of industrial performance.

[28] A pure laissez faire approach is rare since governments typically remain involved in issues such as standardisation and regulation as well as being major customers in the restructured sectors.

Government policy practices in the Framing 2 involve education and training of the workforce with the aim of supporting the absorptive capacities of firms and other organisations. Absorptive capacity is one of several types of non-market capabilities that become visible when the analysis of knowledge generation and distribution is deepened beyond the linear model embodied in Framing 1.[29] In developing economies, the appropriate direction of educational and skills training policies often involves the achievement of particular instrumental skills in science and technology and an engagement with post-colonial or traditional heritages the are difficult to reconcile with aspirations for development and identity in a contemporary world (Freire, 1970). In the industrialised economies, there is a continuing tension between laissez faire education policies and skills and labour force development policies that provide greater resources for particular types of education (e.g. US policies under the National Defense Education Act (1958) or various reforms of the UK education system aimed at productivity and skills attainment (Machin and Vignoles, 2015)).

Framing 2: Alternative or Counter Framings

The national systems of innovation and related (sectoral and regional) frameworks are structured around knowledge sharing and collaboration among organisations employing professional researchers. A consequence of this is that the broader societal discussion of technological options and directions is not integrated into the operation of networks, even when these networks are established as the result of government intervention. In effect, the national system of innovation framing continues the technocratic politics of the R&D and regulation framing (Framing 1). Both framings, as commonly employed in policy discussion, share an implicit understanding that there is a single best path for scientific and technological development. This path might be inflected by ethical or environmental constraints, but there is not a multiplicity of paths or criteria by which to evaluation scientific and technological developments. The alternative or counter framing, an element of Framing 3, is therefore one that explicitly introduces participatory and democratic processes that are empowered to identify alternatives and to influence or take decisions regarding these alternatives.

This alternative framing suggests the need to open up process of choice to marginalised actors to provide them a voice and influence over what paths are followed in research and its funding. This issue has been taken up more recently by Dutrénit and Sutz (2014), Lundvall, Joseph, Chaminade et al. (2009) and others who draw on a national system of innovation approach, but ask why this approach gives little attention to the problems of developing countries. Their central concern is that the national system of innovation approach is leading to social exclusion, and they stress, the need for participatory approaches so as to democratise knowledge production (Dutrénit and Sutz, 2014). The call for more and wider participation is also present in criticisms and debates in Europe and the US. It has led to suggestions for policy practice such as Constructive Technology Assessment, Interactive Technology Assessment and Participatory Technology Design to help in the identification of options and consequences to existing trajectories of development and change (Rip, T..J. Misa and Schot, 1995)

Summary

As noted earlier, frames are persistent. The first framing of science and technology policy, based on the premises that science is the basis for long term economic growth, and that innovation largely involves the commercialisation of scientific discovery, is present in contemporary discussions. Many of the policy practices developed within this framing of the issues are still practiced although some have been subject to modification as competing framings of economic policy such as neoliberalism have sought to limit state aid and to favour market over collective action in government policies more generally, including innovation policy. Representatives of the scientific community commonly argue that the independence of members of this community to pursue curiosity driven research is a prime value and is responsible for profoundly

[29] Capabilities for networking including supplier and value chain management, market development and knowledge management are other examples of such non-market capabilities. Although some parts of these capabilities can be acquired through market transactions, the choices involved in these transactions themselves require capabilities within the firm or organisation.

important innovations, a perspective that is consistent with the first framing. Among those NTBFs established in the middle of the 1970s and 1980s that have survived, some have grown into major multinational corporations although many of these are located in the information and communication technology (ICT) sector. While the ICT sector has contributed considerably to economic growth it does not, itself, employ people in proportion to its turnover.[30]

Scientific discoveries clearly remain important in opening new opportunities for economic growth although contemporary understanding of the research process suggests that, in addition to the heroic entrepreneur, many research efforts involve large teams and inter-organisational coordination, features that are largely outside the first framing which is not much concerned with the organisational structure of research processes. Important exceptions to this include Langrish, Gibbons, Evans et al.,(1972) and SPRU's Project Sappho (Curnow and Moring, 1968). These reflections on policy practice stemming from the first framing have led to questions about the focus on R&D. It was argued that it is important to look at how the results of research efforts are used and absorbed in the economy. The second framing emerged aimed at boosting the absorptive capacity by entrepreneurs and through institutional linkages.

Over time it has become clear that the processes of technological change are uneven in both time and space. Clusters of innovations that restructure particular sectors have been characterised as disruptive or major innovations because of their effects on incumbent firms and jobs. Although the general optimism suggested by the first and second framings regarding the social welfare impacts of these changes prevailed throughout the 20th century, the extent of income inequality in high income countries has increased. A number of middle income countries appear to be trapped into reliance on natural resource based growth and trade, and although the BRIC group (Brazil, Russia, India and China) is a partial exception, many lower income countries have made little progress in catching up. All of these developments suggest that the first and second framings are unsatisfactory for a variety of actors and are particularly focussed on a relatively limited period of historical development (the latter half of the 20th century). During this, period particular countries emerged as leaders in science-based growth, even though within these countries income disparities often remained large. In addition, the climate change effects of greenhouse gas emissions, the environmental effects of the volume of household and industrial waste, and other externalities produced by the pattern of growth envisaged in the first framing have suggested that the regulatory model bolted on to the basic innovation model is unable to address these externalities. It is not only the rate of technological change, but its direction which is energy and material intensive, and not inclusive enough. These features are not easily encompassed in the first and second framings.

Framing 3: Transformative Change

Over the last decades, science and technology have come to be framed as strategic resources for industry and government. Investing in them would boost economic growth, even green economic growth, and help to reduce inequality. The benefits of this growth are to be re-invested in science and technology. Whether these positive benefits happen depends on state intervention since governments have to ensure that clean technologies receive a high priority and fairer income distribution measures need to be taken. Stimulating R&D and building national systems of innovation might be a means of gaining competitive advantage in the short term and in the long run if governments continue to invest in the right direction. However, this is only so when we assume nation-states, despite globalisation, have the power to direct science and technology, are in the position to organize the distribution function in an adequate way, and are not captured and/or corrupted by other interests. The potential erosion of the power of nation-states, however, is not the main challenge. A more fundamental challenge is the nature of the innovation process itself.

[30] The ICT sector clearly stimulates both job creation and destruction in other sectors. For example, direct dial telephones have largely eliminated the job of being a telephone operator while this and related technologies have led to the creation of 'call centres' which employ very substantial numbers of 'operators.'

Science, technology and innovation policies are often based on the assumption that innovation is a force for creating a better world.[31] The idea is that developing new technologies will lead to positive outcomes and that remaining externalities can be managed through regulation. It is recognized that technology development might lead to some bad outcomes in the short term, such as unemployment in sectors experiencing rapid technical change, but in the long term everyone will benefit since new high quality jobs will be generated. It was for this reason that Schumpeter regarded technical change as a process of creative destruction. As Soete (2013), however, reminds us, innovation may also lead to destructive creation, benefiting the few at the expense of the many, leading to low quality jobs, and creating more problems than it solves. Many technologies are deeply implicated in a set of persistent environmental problems. They contribute to the current resource-intensive, wasteful and fossil fuel based paradigm of mass production and mass consumption (Meadows, Randers and Meadows, 2004; Bardi, 2011; Steffen and et al, 2015).

The double social and environmental challenge for science, technology and innovation policy is now being recognized by many governments and other actors. Through initiatives such as Horizon 2020, the EU expects innovation to address a number of well-chosen societal challenges and it has also embraced the notion of Responsible Research and Innovation (RRI).[32] The 2015 Lund Declaration explicitly prioritises training a new generation of researchers who will have the skills to address grand societal challenges underpinned by an excellent research base. [33] Also the newly signed universal Paris climate change agreement has set the ambitious goal to reach zero net carbon emissions in the second half of the century, and the United Nations (2015) has formulated 17 Sustainable Development Goals (SDGs), calling for greener production, increased social justice, a fairer distribution of welfare, sustainable consumption patterns and new ways of producing economic growth.

Notwithstanding this shift in emphasis, many science, technology and innovation policies are still based on the 20th century supply-driven innovation model which takes competition between nations and support for R&D and national systems of innovation (Framings 1 and 2) as the main entry points for policy making. Thinking creatively about how innovation could directly address environmental challenges as well as the additional issue of social challenges is rarely present. Even if policies start to be aimed at addressing these challenges, as many governments are presently doing, it is unclear how to implement such policies (see Kuhlmann and Rip, 2014).

It is clear that delivering on the economic, environmental and social challenges, the three pillars of sustainable development, will need a fundamental change in the socio-technical systems for food, energy, material, mobility, healthcare, and communication provision. Innovation policy for transformative change needs therefore to focus much less on products, processes, firms, and R&D, but on the achievement of systems wide transformations, since optimization of existing systems will not be a sufficient answer (OECD, 2015). The required systems wide transformation might be called a Second Deep Transition (Schot, 2016; Schot and Kanger, 2016). The transition is deep because it involves changing a set of deeply embedded directions shared among several socio-technical systems. These directions have led to high levels of wealth and welfare in a number of countries, but also have left many people in the developing world behind and currently are contributing towards increased inequality within the rich and highly innovative countries as well. They also lead to increasing resource intensity, carbon lock-in, and severe ecological degradation. These directions were created during the First Deep Transition to industrial modernity. The magnitude of social and technical changes required for a Second Deep Transition implies entering a new phase in the history of industrialization, industrial capitalism and perhaps even modernity if this third framing is to take hold. .

The actions needed for system wide transformation can be translated into new public missions, yet this will not be sufficient. This is because public investment on its own will not bring about the necessary system transformation (Kuhlmann and Rip, 2014; Foray, Mowery and Nelson, 2012). Mission oriented policies may

[31] Exceptions include military security where the operative goal is better stated as avoiding worse states of the world.
[32] European Commission, KI-31-12-921-EN-C
[33] https://www.ukro.ac.uk/authoring/researcher/Documents/151215_lund_declaration.pdf

even be counter-productive if the missions are not formulated in an open-ended way that encourages creativity and diversity. Systems transformation requires a broad change process which gives the development of these systems new directions aimed at addressing social and environmental challenges. In this framing, it is important to consider how to combine technology push and demand pull instruments and to consider policy mixes rather than single policy instruments so as to achieve policy coordination across government (Kivimaa and Kern, 2016; Rogge and Reichardt, 2016).

Providing new directions for socio-technical systems change involves processes of opening up a wide range of choices before eventually closing down the options to be pursued. Transformative innovation policy must involve adaptability, reversibility, learning, and anticipating a greater diversity of options without turning too easily and quickly to "for" or "against" arguments regarding specific options. This approach to policy should enable experimentation with options beyond the narrow boundaries set by incumbents. It should be based on scientific advice from a broad range of perspectives and it should nurture opportunities for stakeholders to challenge dominant views. Since innovation policy necessarily involves tensions and disagreements and faces difficult trade-offs among the interests of different groups, the governance of transformative innovation needs to involve policy processes that provide a means of negotiating these difficulties without losing sight of democratic ideals for social transformation (Stirling, 2008, 2009)

Rationale/Justification for policy intervention

While in Framing 1 and 2 it is assumed that, with the exception of negative externalities, the process of innovation is compatible with social welfare and progress, Framing 3 raises questions about the shortcomings of science, technology and innovation in addressing issues of sustainability and poverty or inequitable income distribution. These shortcomings may be seen as large externalities that are subject to regulation as in Framings 1 and 2. However, Framing 3 encourages a deeper set of questions to be asked concerning the compatibility of current socio-technical systems of provision with societal goals and, ultimately, about the governance of innovation processes.

This rationale for this type of innovation policy which is centred on socio-technical system change draws upon Science and Technology Studies (STS) insights into the contingent nature of technologies. Some scholars observe that technologies are constructed by powerful actors in their worldview and/or interests (Winner, 1977; Noble, 1984; Mirowski, 2002), and that alternative innovations offering greater potential for social inclusion or more equitable patterns of income distribution often lack sponsorship or agency. STS scholars, in particular, are generally sceptical that science and technology investments are consistent with social and environmental values and of the ability to achieve these values through market regulation or price controls. For these scholars, as well as many others, achieving these alternatives requires a science and technology politics that opens up space for societal learning, public debate, deliberation and negotiation (Rip, T..J. Misa and Schot, 1995; Schot, 2003). An early expression of this rationale notes that our socio-technical system is fundamentally toxic to the natural environment and human prospects (Mumford, 1934; 1964) and that this is largely due to the concentration of power in actors who are themselves disconnected from the natural world and ordinary social relations. This means that a fundamental transformative change is required, one that involves the democratising of control over innovation production and diffusion and the creation of negotiation spaces or market niches for alternative technologies to become established, capture imaginations and win constituencies among actors that would otherwise be excluded.

The central focus of the third framing is the achievement of fundamental systemic change in the interests of social, economic and environmental sustainability. There is a range of types of policies that can contribute to this systematic change. The emerging field of socio-technical transition research building upon evolutionary economics and STS focuses on how to achieve transformative change (Grin et al., 2010; Markard, Raven and Truffer, 2012). In this field it is argued that substantial progress may be made by protecting and enlarging the spaces in which social and technological experimentation is conducted enabling the emergence of alternatives which, in turn, garner constituencies and advocates for their broader implementation and, ultimately, for system change. It may also be necessary to devise means of directly disrupting incumbent systems due to their monopolisation of resources and domination of visions of what is possible and desirable, and their active resistance to system change (Geels, 2014).

Framing 3: Innovation Model and Actors

Framing 3 aims to change systems that are socio-technical configurations. Several elements, including skills, infrastructures, industry structures, products, regulations and policies, user preferences, and cultural factors are understood to co-evolve together in a socio-technical system. The components of the systems tend to aligned and reinforce each other, making them difficult to change. System Innovation refers to radical change in all the elements of the configuration, and to the process of developing the new configuration and embedding it in the broader economy and society (for an overview see Rip and Kemp, 1998; Grin et al., 2010). System innovation also involves social innovation, since the focus is not only on the technological components, but on all the components including user preferences, policies and the perception of the value and culture by actors within the system. System innovation, in this context, involves new technologies, but it also might involve the re-use and remaking of old technologies as well as low-tech options. System innovation involves multiple actors, including innovative civil society actors, who play a crucial role in co-construction of new systems (Oudshoorn and Pinch, 2003; Schot, 2016). System innovation practices have been pursued throughout the history of Framing 1 and 2 policies, but many of the actors and system components have always been beyond the scope of the innovation model (primarily centred on economic justifications) underlying these framings (Steinmueller, 2010).

In the innovation model underlying Framing 3, there is no single best pathway to sustainability, income equity and other socially desirable goals awaiting discovery. Instead, the process of system innovation (embodying technological change and diffusion or take up) involves actors in negotiating alternative pathways, each with the potential for setting a trajectory for system change (Stirling, 2009). In this framing the model of innovation must be experimental because, at the outset, no pathway is known to be fit for purpose in meeting social goals or feasible in large scale application (Schot and Geels, 2008). It is only through the accumulation of experience by variety of actors with differing motivations and priorities that a pathway which is fit for purpose can be identified. The aim of experimentation is systemic change informed by scepticism that marginal changes in existing systems is likely to be effective in meeting social goals.

It is important to stress that Framing 3 is not principally a model of science and technology regulation. Instead, it focuses on innovation as a search process, guided by social and environmental objectives, informed by experience and the learning that accompanies that experience, and a willingness to revisit existing arrangements to de-routinize existing them so as to address societal challenges. A claim underlying Framing 3 is that the innovation process is likely to be effective in achieving these goals if it is inclusive, experimental and aimed at changing the direction of socio-technical systems. This departs from the focus of Framing 1 on R&D investment, and the enlargement of flows of useful knowledge in which interactions between government and the scientific community are central, with some additional attention to issues of diffusion. It also departs from the Framing 2 system focus which is directed at boosting the absorptive and learning capacity of the system of innovation by building networks of knowledge among producer and user organisations, stimulating the alignment and coordination of these organisations in an effort to produce technological change, and facilitating entrepreneurship, but in the service of the goals of growth, employment and international competitiveness.

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 system change.

Framing 3: Policy Practices

Because of the importance of search, experimentation and learning, policy practices in Framing 3 involve finding means to facilitate and empower those engaged in these processes. Technological change has always involved a process of search. However, in this framing it is essential to reflect on social and environmental needs and the search process has to be guided by improvements in *anticipation* of collateral effects and consequences. Developing processes through which anticipation might be feasible is a priority for bringing Framing 3 into practice. Some guidance on the processes that facilitate anticipation is available in the practices developed in connection with Foresight activities and those of technology assessment groups. The focus of their efforts is often directed at large scale commercial application aimed at catching the next wave of technological opportunity which may open new possibilities, as in technology assessment of nanotechnology or biotechnology. In Framing 3, the aim of anticipation is to identify areas for experimentation and, in doing so, to examine the consequences that may follow in terms of energy and materials use, the jobs likely to be created, and the effects on the environment of the introduction of new physical artefacts or information processes that may be produced. Anticipatory deliberation aims not at producing blueprints, but at generating multiple possibilities and diverse pathways. It aims to sustain a process of collective search and learning rather than a short term assessment based on narrow criteria and yes/no type decision making.

Anticipation is by nature speculative. While it can provide broad outlines of possibilities it cannot foresee the details that come to light only through experimentation and learning. Thus, while essential, anticipation must be joined with experimentation within a range of possibilities suggested by anticipation exercises. Is it better to recycle than to repair and upgrade? What agricultural practices will prove viable as alternatives to current reliance of fossil fuels for energy, fertilisers, transport and processing? What practices will be most effective in achieving carbon neutral buildings and infrastructures? These questions can only be answered through experimentation at a scale well beyond that of the R&D laboratory. It calls for societal experimentation. It is only through actual practice that experience and deep learning are generated and that the advantages and disadvantages of a particular innovation pathway can be identified and remedied by revision or by choosing a different development pathway. Deep learning occurs collectively and enables changes in cognitive frames and assumptions and is akin to second-order learning (Schot and Geels, 2008). Societal experimentation must include grassroots innovation with communities and civil society (Smith and Seyfang, 2013). Framing 3 envisages that it grows and nurtures new pathways and, in the process, challenges incumbent firms and government agencies that are aligned with them (regime actors) in preserving the existing trajectory. It entails political struggles around the new goal of sustainability and it requires incumbent firms to go through process of strategic reorientation (Geels and Penna, 2015). The role of intermediary actors in advocating competitive niches, new visions and policies is crucial (Kivimaa, 2014), as is the construction of networks embracing both niche and dominant regime actors (Diaz, Darnhofer, Darrot et al., 2013)

The need for anticipation, experimentation, learning, and the formation of bridging networks and alliances suggests new institutional arrangements and governance structures that cut across governments, markets, and civil society. It also suggests involving public and private finance and new ways to share and appropriate the gains in knowledge from these activities. In addition to these new institutional arrangements, ways to better connect existing institutions to achieve coordination and to record and learn from processes of anticipation and learning are needed. This will require new sets of skills for bridging the social sciences and the science, technology engineering and mathematic (STEM) fields which have recently been a priority in many countries seeking to respond to the imperatives of international competition and economic growth through productivity increase. When the goals set for of socio-technical systems reflect a range of social and environmental needs and more inclusive ideas about social welfare, bridging between what is possible and what is desirable will require individuals with capabilities for bridging social and scientific and technological domains. This implies a re-orientation of education policy and, ultimately, a pedagogy that is consistent with the desired transition to more sustainable outcomes.

Framing 3: Alternative or Counter Framings

A primary alternative or counter framing to Framing 3 is that it is possible to address the social and environmental challenges through the implementation of capital-intensive solutions (e.g. centralized energy production with big wind and solar farms, the expanded use of nuclear energy and further development of a global value chain of waste products; geo-engineering) and technologies that aim to mitigate ex-post the impacts of carbon-intensive development (e.g. carbon capture and storage). In this alternative, actors focus on the economic growth agenda, while distributional consequences (social and ecological costs) are of secondary importance. Along this path there is the danger that it social, political, and ecological lead to economic stagnation, increases in social equality, war for resources, increases in the occurrence of natural disasters and more forced migration. For this counter framing to achieve its aims, powerful forces would need to be in place to prevent and mitigate disasters and conflicts, compensate for social excesses, and underwrite the legitimacy of the system in order to avoid potentially catastrophic outcomes. Given the high ecological and social costs that would need to be absorbed, this framing implies constructing a new relationship between the state, the market, and civil society, and most likely, new forms of pro-active and entrepreneurial state action on national and as well as city levels, strong relationships between the state and business, and new technocratic supranational structures ensuring global coordination. These seem unlikely in view of the difficult to achieve such changes in response to recent social and economic challenges.

Conclusion

Rethinking innovation policy is timely. Many research councils, governments and international organizations worldwide want innovation to address societal or grand challenges. The growing impact of Responsible Research and Innovation (RRI) is a sign that these challenges are being taken seriously. Yet how to design, implement and govern challenge-led innovation policies is far from clear. Most innovation policies are based on the 20th century supply-driven innovation model which takes competition between nations and support for R&D as the main entry point for policy making without thinking creatively about the broader suite of innovation policies that could be put in place. In the post-World War II period, two main innovation policy framings have developed.

The first framing portrayed innovation policy as providing incentives for the market to produce socially and economically desired levels of science knowledge (R&D). This is mainly implemented by subsidies and measures to enhance the appropriability of innovation through intellectual property protection. Foresight was developed to identify areas in need of support and various forms of technology assessment have been established to examine negative externalities and to protect society when the impacts become a problem. Regulation is then an option that can be put in place. This framing identifies the most important element of innovation as the discovery process (invention) and the linear model in which technology is regarded as the application of scientific knowledge is privileged. The linear model privileges discovery over application partly because the rewards of application are assumed to be captured through an adequately functioning market system. Only in the case of market failure, is government action required.

The second framing aims to make better use of knowledge production, support commercialisation and bridge the gap between discovery and application. This framing makes central various forms of learning, including learning by using, producing and interacting, linkages between various actors, absorptive capacity and firm capability formation, and entrepreneurship. The rationale for policy intervention is system failure: the inability to make the most out of what is available due to missing or malfunctioning links in the innovation system. Innovation policy focuses, for example, on technology transfer, building technology platforms and technology clusters to stimulate interaction, and human capital formation. In this model foresight, technology assessment and regulation are add-ons to the core activity of promoting innovation on the assumption that any innovation is to be encouraged since innovation is seen as the motor for producing economic growth and competiveness.

A third frame for innovation policy, transformative change, takes as its starting point that the negative impacts or externalities of innovation can be greater than the positive contributions. This frame focuses on mobilising the innovation process to address a wide range of societal challenges including inequality, unemployment and climate change. It emphasizes policies for directing socio-technical systems in socially desirable directions and embedding processes of change in society. It entails the exploration of socio-technical system change involving a structural transformation in governance arrangements among the state, the market, civil society and science, together with experimentation and societal learning, responsible research and innovation, and a constructive role for foresight aimed at early shaping of the innovation processes and on a continuing basis. Innovation policy for transformative change aims to:

- *Broaden the concept of innovation* beyond its traditional focus on invention to include innovation and the impacts arising from embedding innovation in society - thinking far beyond support for R&D and the prioritisation of specific research avenues. Innovation policy should support constant 'tinkering' and the re-making of socio-technical systems as well as the development of new services and organisational models to meet social and economic challenges. Policy formation and implementation necessarily involve a wide range of actors from firms and other knowledge producing institutions to users, NGOs and governments.
- *Provide direction to innovation.* In Framing 3 innovation policy is not about setting priorities, but about improving the process of opening up to a wide range of choices and giving greater attention to the rationale for closing down options. Innovation policy should allow for deep learning, challenges to dominant views, and nurturing a greater diversity of options. It should enable experimentation with options beyond those emerging within the narrow boundaries set by incumbent institutions – public and private. It should draw upon scientific advice from a broad range of perspectives which necessarily involves conflict and political struggles since it involves the assessment of trade-offs among the options favoured by different groups. It involves ensuring that governance arrangements are made compatible with these aims.

One last note -- Framings 1 and 2 emerged and were developed mainly in the US and Europe, and have been criticised from a development perspective. Both frames assume that developing countries need to catch-up and that science, technology and innovation policy is a tool for this process. Frame 3 does not assume that innovations and socio-technical system change will necessarily come from the Global North or that other countries need to play catch-up with those innovations. On the contrary, the assumption is that both the Global North and Global South must be in a position to contribute to transformative change and that mutual learning can be beneficial. In this framing, it is clear that diverse pathways are possible and that local generation and adaptation within a complex process of system transformation should be embraced.

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