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# Three frames for innovation policy: R&D, systems of innovation and transformative change

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ABSTRACT

Science, technology and innovation (STI) policy is shaped by persistent framings that arise from historical context. Two established frames are identified as co-existing and dominant in contemporary innovation policy discussions. The first frame is identified as beginning with a Post-World War II institutionalisation of government support for science and R&D with the presumption that this would contribute to growth and address market failure in private provision of new knowledge. The second frame emerged in the 1980s globalising world and its emphasis on competitiveness which is shaped by the national systems of innovation for knowledge creation and commercialisation. STI policy focuses on building links, clusters and networks, and on stimulating learning between elements in the systems, and enabling entrepreneurship. A third frame linked to contemporary social and environmental challenges such as the Sustainable Development Goals and calling for transformative change is identified and distinguished from the two earlier frames. Transformation refers to socio-technical system change as conceptualised in the sustainability transitions literature. The nature of this third framing is examined with the aim of identifying its key features and its potential for provoking a re-examination of the earlier two frames. One key feature is its focus on experimentation, and the argument that the Global South does not need to play catch-up to follow the transformation model of the Global North. It is argued that all three frames are relevant for policymaking, but exploring options for transformative innovation policy should be a priority.

## 1. 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 that create the foundations for policy analysis and action and shape expectations concerning potentials and opportunities (Goffman, 1974; Benford and Snow, 2000; Taylor, 2003). Framings evolve over time and change when they are 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. Some have argued that frame reflection might hamper action. Following Schön and Reid (1994) we believe the opposite; it is necessary to engage in frame reflection for designing and implementing effective policy solutions for complex policy problems.

Modern economic growth is generated by a collection of socio-technical systems based upon industrial mass production and individualized mass consumption that extensively employ fossil fuels, is resource and energy intensive and produces a massive amount of waste. Despite important improvements in life expectancy and material welfare in many countries, persistent problems of economic crises and rising inequality coincide with a growing realisation that current socio-technical systems for meeting our basic needs – whether in food, energy, mobility, materials, water or resources more generally – are unsustainable. While available framings of science and technology policy that evolved since World War II remain relevant, they offer little guidance for managing the substantial negative consequences of the socio-technical system of modern economic growth to which they have contributed and of which they are a part.

Our view is that it is time to articulate more forcefully and to experiment in practice with a framing for science, technology and innovation policy that emphasises socio-technical system change. Three framings related to science and technology policy can be delineated, two of which are available and are systematically employed in policy

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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, which addresses socio-technical system change, remains under-developed although it has existed in the background of policy discussions for many years; recently it has been acknowledged by the OECD (2015; see also (Steward, 2012; Weber and Rohracher, 2012 and Frenken, 2017).

The first framing focuses on innovation for growth, tapping the potential of science and technology for prosperity and nurturing socio-technical systems directed towards mass production and consumption. It arose as the emphasis on 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.

A third framing – transformative change - is in the making and its outlines have become clearer in recent years. The aspirations for transformative change were captured most recently in the UN Sustainable Development Goals published in 2015. These include ending poverty and reducing inequality in all its forms everywhere, promoting inclusive and sustainable consumption and production systems, and confronting climate change, 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 scientific debate, in relation 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 current science, technology and innovation policy, in short innovation policy, since for us innovation spans the entire process from scientific discovery to utilisation. Yet we do not argue that the first and second framing have become superfluous; they have their own rationale, which is still relevant today and might also be improved. Actual practice will reflect mixtures of frames. A deeper discussion and confrontation of frames and a process of critical frame reflection both by academics as well as policy makers is, however, important, and long overdue, since framings do have pervasive impacts on practice. This discussion paper aims to fuel and contribute to the critical reflection and eventually hopes to inspire new policy practices (Schön and Reid, 1994).[3]

## 2. Framing 1: innovation for growth

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 (Tindemans et al., 2009; Mowery and Rosenberg, 1989). 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 safeguard the peace and to bring industrial benefits. Defence research institutes pushed for the transfer of their research beyond military markets (Galison and Hevly, 1992).

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 flow into 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.

Attention to the issues of applied research and technological development and their treatment as an investment by firms suggested shortcomings moving beyond the pre-War 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 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.[4] The simplest definition of innovation in this context is commercialised invention.[5]

In the late 1950s the popular imagination favouring the economic

[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).

[2] http://www.un.org/sustainabledevelopment/sustainable-development-goals/ Accessed 28/11/17.

[3] Together with others the authors have developed a new initiative entitled the Transformative Innovation Policy Consortium which aims at stimulating and facilitating policy experimentation – see www.transformative-innovation-policy.net.

[4] 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.

[5] 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).

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.

### 2.1. Rationale/justification for policy intervention

The explicit recognition that investment was required for science, combined with the empirical insight that 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).[6] 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.

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 secrecy, intellectual property, or simply by maintaining a competitive lead preventing rivals from imitating successful innovations.[7]

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 military 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. Maintaining domestic security by fighting poverty and urban violence and enabling urban renewal became another area for large scale investments in the 1960s (Light, 2003). The oil crisis of the 1970s led to the formulation of a new security mission set of policies to reduce reliance on the import of petroleum which contributed to the early development of renewable technologies. 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, allied with a promise of economic and social returns on public investment. A telling feature of the mission framing is physicist Robert Wilson's response to a question from US Senator John Pastore about the defence (mission) value of the new accelerator at Fermilab, at the time, the largest high energy physics research installation in the world -" … 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" (US Congress, 1969:113).

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, publication of works like *Silent Spring* (Carson, 1962) and the *Limits to Growth* report by the Club of Rome (Meadows 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 set pharmaceutical and food safety standards, began to regulate the effectiveness of pharmaceuticals after the worldwide thalidomide disaster.[8]

### 2.2. Framing 1: innovation model and actors

The model of innovation underlying Framing 1 is the commercialisation of scientific discovery with each of the processes that follow discovery driven by the economic logic of investment and financial return from the potential market for the innovation. This framing reflects a modernist confidence in the inevitability of progress and an economic rationale of the 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. This framing acknowledges that negative consequences do emerge, but these are attributed to shortcomings in scientific knowledge that can be remedied with further research. 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 risk and 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), an innovation that improved the safety and quality of refrigeration[9] eventually that was eventually recognised as a hazard to the ozone layer and its production was proscribed by international treaty (Montreal Protocol on

[6] 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.

[7] 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.

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

[9] CFCs replaced the refrigerants sulfur dioxide and methyl formate that were, in the case of leakage, directly hazardous to human health.

Substances that Deplete the Ozone Layer, 1987).[10] 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 80 s 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[11], to publish their work fully disclosing the methods and findings[12], 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, and eventually regulation. 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.

### 2.3. 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[13]) 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 promises about science's long run benefits.

The stress on the importance of science and technology led to the creation of many policy instruments aimed at stimulating complementary business R&D including favourable tax treatment, direct subsidies employed horizontally to specific industries and other favourable conditions for business investment on the premise that a share of this investment would flow to innovation activities. The recognition of the significance of new technology-based firms (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 (public and private) between countries became an important indicator of commitment and performance. More recently, the European Union has formalised 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 90 s was technology foresight (Martin and Irvine, 1989). Foresight activities are one means to bring societal considerations into the selection process, but in practice perceived technological opportunities often dominate.

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).

Finally, 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. Assuring the supply of researchers is seen as critically important to fostering science-based growth.

### 2.4. 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 invest in the level of R&D that was required. Sagasti (1980) argued that this was producing two civilisations, one that generates the knowledge and derives the principal benefits from it and the other (i.e. the developing world) 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 disadvantaging others as they required capabilities, infrastructures and a broader context which does not exist in the developing world (Stewart, 2008). These counter-framings 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 Prebisch (1950) and 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 their own innovation capacity and 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).[14] The success of these

[10] 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.

[11] 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)

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

[13] 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).

[14] In both areas, international pressures were important reasons for the

policies also contributed to the emergence of a second frame for science, technology and innovation policy with an emphasis on national systems of innovation.

Developments related to Schumacher (1974) and Stewart (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 (Kaplinsky, 2011). For the most part, innovations coming out of this movement addressed features of poverty (e.g. better ovens for using local fuels) rather than meeting expectations that they would provide significant additions to the income of developing country people. Nonetheless, ideas from this social movement have recently re-appeared in writings about frugal innovation (Radjou et al., 2012), innovation from the bottom of the pyramid (London and Hart, 2004), and inclusive innovation (Chataway et al., 2014). These ideas are becoming integrated in a third frame for science, technology and innovation policy aiming at enlarging participation in the innovation process.

## 3. 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. The assumed global catching up as a result of technology transfer did not happen, except for the tigers in East-Asia. An explanation of this state of affairs, consistent with the first framing, was that the richer countries were protecting and thus holding back scientific or technological knowledge, thereby excluding other countries from utilising this knowledge to engage in a catching-up process. 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. 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 found to be social capabilities that stemmed not only from the level of education but also its qualities and the social capability of entrepreneurship.[15] 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 (path-disrupting), and cumulative innovations that reinforce and strengthen existing strengths and centres (path-reinforcing), often in ways that raise important barriers to new entrants.

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 et al. (1988) and Lundvall (1992) employed the term national systems of innovation to identify differing 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, contributing substantially to the explanation of the very uneven rates of productive and innovative performance throughout the world. In particular, Freeman et al. (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. Linsu Kim also made major contributions indicating that it is not just R&D investment but localised learning that generated development and allowed South Korea to catch-up (Kim, 1999). These insights complemented by 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).

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 across geographic spaces 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 (for an informed discussion of these varieties see Edquist (1997)).

### 3.1. 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. The explanation is that these countries had become competitive thanks to their national systems of innovations, which made it possible to participate in a positive way in the globalisation of trade and finance. The stress on competitiveness is aligned with neoliberal thinking, yet Frame 2 clearly departs from such thinking by emphasizing the ability of the state to shape a competitive nation.

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.[16] 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.

(*footnote continued*)
abandonment of the policies.

[15] 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.

[16] The neoliberal perspective is exemplified by Friedman (2005).

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 et al., 2014). From the perspective shared by Frames 1 and 2, growth of output and employment is also 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 firm production of traded goods. It also threatens the State's ability to distribute income from higher tax income. A central aim for science, technology and innovation policy is therefore 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.[17]

The national innovation system approach is thus 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 states need to assist in building up a national system of innovation either to preserve or to expand the competitive advantage of domestic firms. The rationale of the competitiveness agenda retains a Frame 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 in order to create a level playing field in international trade competition. Scholars have argued for (Graham, 1994) and against (Cohen and Noll, 1991) this extension of state action. A Frame 2 perspective would focus less on funding pre-competitive R&D and more on learning between the actors in the system. Recently Mazzucato (2013) focusses on the important role of the state as high-level risk-taker in developing new technologies, an activity that is both downstream and more purposeful than science investment. More generally, she draws attention to the important role of finance plays in national systems of innovation, a role which has been ignored in many national system of innovation policies and approaches. She argues that long term patient finance is needed, provided by the state, to make commercialisation and diffusion happen.

In terms of the governance of policy interventions, Frame 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. Other system failures are 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 dealt with by 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.[18]

### 3.2. 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 technology push 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 is limited to providing input into the knowledge production process by firms and other knowledge providers such as universities.

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 et al., 1994). This work distinguished five features of Mode 2 knowledge production: 1) knowledge is increasingly produced in the context of application,[19] 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 knowledge production, 4) social accountability and reflexivity, involving a wider range of experts in the research process to accommodate ethical and environmental concerns[20], 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 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 intertwined nature of government, industry, and university research efforts. Similar to Gibbons 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

[17] 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 more recent history to periodic episodes of tariff increases and breakdowns in international trade.

[18] For example, in 1999, the US repealed the Glass Steagall Act (1933) which had regulated concentration of banks due to the perceived competitive threat of large foreign banks.

[19] According to Gibbons 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.

[20] This foreshadows our discussion of these issues in Framing 3. The discussion of this in Gibbons 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

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), further developing the 'stickiness' of knowledge.

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.

### 3.3. 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 (Steinmueller, 2010). Central governments have undertaken substantial efforts to build technopoles (e.g. Sophia Antipolis in France (Longhi, 1999)) and 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. the Research Triangle in the US state of North Carolina (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 proposed and enacted in order to encourage research network formation (Jorde and Teece, 1990). 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)[21] 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) provide the majority of employment in most economies. In many contexts, this is more of a problem than an advantage (compared with their larger rivals, SMEs generally do not have the resources or market presence to engage in R&D or the large-scale promotion of new technologies, often have lower levels of productivity and experience higher rates of bankruptcy). The identifying feature of NTBFs, however, 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 many 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.[22]

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.[23] In developing economies, the appropriate direction of educational and skills training policies often involves the achievement of particular instrumental skills in science and technology. 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 (Machin and Vignoles, 2015).

### 3.4. 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

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

[22] 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.

[23] 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.

framing continues the technocratic politics of the innovation for growth framing (Framing 1). Both framings, as commonly employed in policy discussion, share an understanding that investment in R&D and innovation is positive. This investment might be criticised and thus stopped for ethical or environmental constraints, but there is not a multiplicity of pathways or alternatives which need to be discussed by all stakeholders including users and the wider public. The alternative or counter framing is one that explicitly introduces participatory and inclusive processes that are empowered to identify alternatives and to influence or take decisions regarding all possible options. This is not a process which should be left entirely to the scientific community.

This alternative framing suggests thus the need to open up process of choice to all stakeholders including 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 et al. (2009) and others who draw on a national system of innovation approach. They 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 has been present in criticisms and debates in Europe and the US since the 1970s. It has often led to one-way public understanding of science type of initiatives which aim at making the public understand why investment in science deserves support (Miller, 2001). However, it also led to suggestion for more radical new policy practices 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 et al., 1995; Irwin, 2006).

### *3.5. 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 markets over 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 important innovations, a perspective that is consistent with the first and second framing.

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. It is unclear whether more investment in R&D and building national systems of innovation will lead to development and catching up. Questions are also asked whether these investments will reduce inequality and help solve social problems. They may even deepen these, because only a small segment of the population will receive the primary benefits from these investments. 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 pursued within the first and second framing have suggested that the regulatory model bolted on to the basic innovation model is unable to address these externalities. What is needed to address social (inequality, poverty) and environmental problems is a focus on the directionality of socio-technical systems, and a more participatory and inclusive approach. These features are not easily encompassed in the first and second framings.

## 4. Framing 3: transformative change

For a decade now governments have recognized they may need to align social and environmental challenges better with innovation objectives. Climate change, reduction of equality, poverty and pollution have been transformed into challenges and opportunities for science, technology and innovation policy. Through initiatives such as Horizon 2020, the EU expects innovation to address a number of well-chosen societal challenges and for example contribute to a transition to low-carbon and inclusive economy.[24] 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. [25] 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.

Can we expect innovation to deliver on these challenges? Science, technology and innovation policies are based on the assumption that innovation is a force for creating a better world.[26] The idea is that developing new technologies will lead to higher labour productivity and economic growth, and a better competitive position. It is expected that remaining externalities can be managed through regulation. Innovation policy focuses subsequently on stimulating R&D and building national systems of innovation. The assumption is that such a policy can lead to green growth in which governments are able to invest in clean technology missions, reducing pollution and cleaning up the environment. It is also assumed that inequality will be reduced through new job opportunities generated from growth and income redistribution. However, this is of course only so when we assume nation-states, despite globalisation, have the ability to invest in clean technologies in a persistent way for a longer time period, are in the position to organize the distribution function in an adequate way, confront tax avoidance, and are not captured and/or corrupted by other interests which favour investment and distribution in other directions. A main challenge is whether the State is indeed in the position to deliver on this.

The potential erosion of the power of nation-states, however, is not the main challenge. A more fundamental challenge is whether the externalities that are generated by growth such as such as climate change can indeed be managed ex-post through clean technology and distributional measures, even with a strong state in place. Our core

[24] European Commission, KI-31-12-921-EN-C

[25] https://www.ukro.ac.uk/authoring/researcher/Documents/151215_lund_declaration.pdf

[26] Exceptions include military security where the operative goal is better stated as avoiding worse states of the world.

proposition is that the existing R&D and national systems of innovation frames for science, technology and innovation policy are unfit for addressing the environmental and social challenges. An important reason is that both Frames 1 and 2 assume that stimulating innovation is positive, there is no deep engagement with the fact that innovation always represents a certain directionality. Of course, both framings recognize that technology development might lead to some bad outcomes in the short term, but it is claimed that the overall benefit compensates for this. For example, innovation may lead to unemployment in sectors experiencing rapid technical change; however, 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. We think it is time to recognize in our framings for innovation policy that many technologies are deeply implicated in persistent environmental and social problems. Innovation contributes massively to the current resource-intensive, wasteful and fossil fuel-based paradigm of mass production and mass consumption (Meadows et al., 2004; Bardi, 2011; Steffen et al., 2015). It also contributes directly to inequality because current innovation trajectories favour high tech solutions which assume high quality and pervasive infrastructure, and produces mass-produced products aimed mainly for consumers with substantial purchasing power (Kaplinsky, 2011). Innovation policies in their current formats may lead to economic growth but often exacerbate inequalities. Even fast growth, such as China's, is accompanied by growing inequality (Dutrénit and Sutz, 2014). The starting point of a new third frame for science, technology and innovation policy should be that innovation cannot be equated with social progress, even when corrective social policies are in place. After all, innovation itself may be causing a growing set of externalities. How then can science, technology and innovation policy address the double social and environmental challenge?

We argue that to meet the ambitious challenges expressed for example in the SDGs, we need a new framing for innovation policy. This is what we call Framing 3 aimed at transformative change. This raises the question – what needs to be transformed? Based on the research in sustainability transitions studies we argue that transformation of socio-technical systems is needed in energy, mobility, food, water, healthcare, communication, backbone systems of modern societies (Grin et al., 2010; Markard et al., 2012; Steward, 2012; OECD, 2015). Socio-technical system transformation is very different from just developing new radical technological solutions. For example, science, technology and innovation policy can focus on the introduction of electric vehicles and its weak spot: overcoming the limited range through battery development. However, if the electric vehicle only is a substitute for the current car and we continue with a car dominated mobility system, the low carbon and inclusive economy will still be far away. Industry structures may be transformed but ambitious SDGs are not met. Therefore, we argue, it would be better to focus innovation policies supporting the emergence of new mobility systems in which for example private car ownership is less important, other mobility modalities such as small taxi vans, public transportation, walking and bicycling are more used in combination with for example electric vehicles provided by types of companies dedicated to the provision of mobility services using ICT capabilities. In this new system, mobility planning and thus also reduction of mobility has become an objective of all actors, and even a symbol of modern behaviour. This is what we call a socio-technical system transition, it implicates co-production of social, behavioural and technological change in an interrelated way. Socio-technical system transformation (or transition) is about changing skills, infrastructures, industry structures, products, regulations, user preferences and cultural predilections. It is about radical change in all elements of the configuration. This also makes system transitions difficult, because elements tend to be aligned and reinforce each other. It involves social innovation, since the focus is on many social elements and their relations with technological opportunities. It can include high tech solutions as well as innovation in old technologies (bicycles in the example above). System innovation always involves multiple actors, including civil society and users who can play a crucial innovative role – not just one of articulating a demand to be supplied by firm innovation (Oudshoorn and Pinch, 2003; Schot et al., 2016).

### 4.1. Rationale/justification for policy intervention

Weber and Rohracher (2012) have explored various rationales which legitimize science, technology and innovation policy. They argue that the market failure and system failure rationales that underpin current innovation policies should be complemented by policies aimed at transformation. We agree that the framing of transformative needs a strong narrative and analysing the characteristics of failures could be a good starting point. Weber and Rohracher propose that policies for transformative change begin with the recognition of four type of failures: directionality, policy coordination, demand-articulation and reflexivity. This is a very useful framework we would like to draw upon and add to.

Directionality failure refers to the lack of means for making social choices over alternative pathways of development. The transformative change frame takes the question of direction as a starting point and requires a process for setting collective priorities. It assumes deliberation, a diversity of opinions and thus conflict. Eventually it aims to establish what Weber and Rohracher call corridors of acceptable development pathways.[27] Stirling (2008; 2009) argues convincingly that working with a greater diversity of options without turning too easily and quickly to "for" or "against" arguments regarding specific ones is crucially important. Addressing directionality failures requires taking into account options beyond the narrow boundaries set by incumbents. It nurtures opportunities for various groups to challenge dominant views embedded in the current socio-technical systems.[28] Yet at some point in the process, there will be a need to close down exploration and focus on certain options. This is not only because solutions need concentration of resources and build-up of capabilities, but also to prevent continuing investment in less promising options (from a transformational point of view) which will block the upscaling of sustainable trajectories. Addressing directionality failure is thus not only about the lack of consideration for a large set of diverse options, but also refers to the lack of attention to the connections between options and SDGs or other social challenges. Transformative innovation policy therefore faces difficult ex-ante and continuing trade-offs among the interests and visions of different groups. The governance of transformative innovation should be recognized for what it is: a political process which should provide room for appraising and negotiating the development of a diverse set of pathways as well as making choices for specific ones. In this negotiation process, visions of various groups do not have to be fully congruent, stakeholders need to recognize sufficient commonly attractive elements they can relate to in order to move forward (Grin et al., 2010: 335).

Policy coordination failure refers to lack of ability to coordinate horizontally policies from various domains. This is different from Frame 2 coordination failure which refers to coordination among the actors in the science, technology and innovation domain. The coordination failure addressed by innovation policy for transformative change is about coordination with specific sectoral policies for healthcare, transport, energy, food and agriculture, which are obviously crucially

[27] This definition of directionality is broader than the one advanced by Stirling (2008; 2009). Who focuses more on one end of the process; the need for innovation policies which open up a variety of different pathways.

[28] Stirling et al developed a very useful multi-criteria mapping tool to support this process, see http://www.sussex.ac.uk/mcm

important when socio-technical system change in these areas is at stake. However, since transformative change is about transforming many systems, and in the end also the structure of the economy and society, coordination with other cross-cutting policies, including tax policy, economic policy, social policy, is vital. Finally, there are multi-level policy coordination failures to overcome between local, regional, national and international policy. Transformative change thus needs a whole of government approach; yet such an approach is prone to red tape issues, huge transaction costs and capture by incumbents who are thriving on the dominant socio-technical systems. Therefore, it is questionable whether the usual approach of creating committees tasked with coordination, and other coordination structures such as national research and innovation councils will overcome this policy failure.

We argue that transformative change requires addressing coordination failure by integrating coordination improvements *during the construction* of transformative change pathways. The focus should be on emerging and open-ended coordination in a process of working together towards transformative change. The notion of tentative governance advanced by Kuhlmann and Rip (2014) captures this spirit. It is defined as an approach which is provisional, revisable, dynamic and open and includes experimentation, learning, reflexivity, and reversibility. Experimentation is promoted in the sustainability transitions literature, for example through the concept of Strategic Niche Management (Kemp et al., 1998; Schot and Geels, 2008), one means of implementing coordination within innovation policy. Here experiments are seen as temporary spaces for actors working together on a variety of concrete pathways, including policy actors as well as other business, civil society, users and private funders. Strategic niche management should be seen as a novel form of policy and action and even a new form of transformative governance, not just a means of piloting or demonstrating novel solutions (Turnheim et al., 2018). It is often very difficult to assure that such spaces go beyond classical technically-oriented demonstration and pilot projects. Experiments demand that actors embrace uncertainty and accept failure as part of the learning process, focus on articulation of new shared expectations and visions, the building of new networks, and the shaping of new markets (called niches) which eventually will challenge dominant practices in mainstream markets and institutions.

Finally, reflexivity failure must be addressed. For Weber and Rohracher this is about the capacity to monitor, anticipate and involve all actors in the self-governance process of transformative change. This is indeed important, but in terms of failure we would like to stress a particular form of reflexivity which is connected to deep learning (or second-order learning) which happens when actors question their underlying assumptions for example about mobility and energy consumption (Schot and Geels, 2008). In policy-making, technology options are often tested against assumed stable preference such as the need for mobility and provision of long trips by cars as in the electric vehicle example above. Hence the emphasis on batteries and not on new mobility services because the electric vehicles is seen as a substitute for the current gasoline car not as a stepping stone towards a new mobility system. Deep learning assumes that actors critically assess their own preferences and experiment with alternatives. This is what addressing the reflexivity failure should be about: stimulating the ability to look from a distance (this could be an imagined future; or a set of social and environmental challenges) at one's own deeply embedded routines which drive collective behaviours and socio-technical change towards optimisation instead of transformative change.

### 4.2. Framing 3: innovation model and actors

In the innovation model underlying Frame 3, there is no single best pathway to sustainability, equality or any other socially desirable goal. Instead the process of system innovation (embodying invention, innovation and diffusion) involves multiple actors in negotiating alternative pathways that have the potential to achieve system change. 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 challenges or feasible in large scale application. It is only through the accumulation of experience by a variety of actors with different motivations and priorities that an acceptable pathway or pathways can be discovered and pursued. The aim of experimentation is systemic and disruptive change informed by scepticism that marginal changes in existing systems are likely to be ineffective. Yet it is true that it is, as yet, unclear how experimentation can generate transformative change, beyond the pilot and/or the niche development which may follow from it. The question of anchoring and scaling up of experiments is not sufficiently addressed in the literature or in practice (Kivimaa et al., 2017).

The sustainability transitions literature does suggest that although having policies in place for experiments building alternative niches is crucially important, it is not sufficient. The policy mix should also contribute to a process of destabilisation of existing locked-in socio-technical systems (Turnheim and Geels, 2012; Kivimaa and Kern, 2016; Rogge and Reichardt, 2016; Kern et al., 2017). The resistance to change from incumbent networks benefitting from the current systems can be very strong. Such networks often include industries, parts of the governments as well as users and civil society. These actors do not perceive a need to change their behaviour and also believe that they can cope with challenges ahead within existing frameworks. Incumbency is not only about vested interests and organisational commitments but also about cognitive lock-in and values, and thus in the end about prevailing regulatory, cognitive and normative collective rules embedded in prevailing socio-technical systems. Obviously, any new policy attempt must navigate pre-existing policies and find ways to create a productive layering of existing and new policies.

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 on the system level, 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 them in order 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 in all its dimensions. Since socio-technical systems will be defended by policy-makers, users, industry and civil society groups who benefit from their current shape and hold worldviews and values which would not require systematic change, transformative innovation policy necessitate engagement in science and technology *politics* not just policy. The type of politics promoted is one which opens up spaces for experimentation, societal learning, public debate, deliberation and negotiation, as advanced in the earlier concept of constructive technology assessment (Rip, T.J. Misa and Schot, 1995; Schot et al., 2003).

Framing 3 departs from the innovation model of Framing 1 which focuses 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 on 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 with the aim of producing technological change, and facilitating entrepreneurship in the service of the goals of growth, employment and international competitiveness. The innovation model of both Framings 1 and 2 views 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. It is built on the belief that inclusive deliberation processes give rise to more 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 does not assume consensus, instead the underlying innovation thrives on the need to identify and work with diversity, dissension and conflicting worldviews, recognizing the contributions which can be made by a large variety of actors, and bringing out into the open the politics involved in any innovation process.

The development and implementation of transformative innovation policy requires a new knowledge base. Not one dominated by economics and innovation studies, but a more interdisciplinary one in which sustainability transitions studies, STS and more broadly governance studies, history of technology, and other fields contribute. Since transformation is a global process, it also requires a deep involvement of development studies. There are signs interactions between these fields is emerging, but overviews of innovation policies are often still far too limited in their scope (Smits et al., 2010; Fagerberg et al., 2013; Fagerberg, 2016). There is still a long way to go.

### 4.3. Framing 3: policy practices

The policy actions needed for transformative can be translated in new public missions, yet this will not be sufficient and if done in the wrong way may lead to problematic outcomes. Public investment on its own will not bring about the necessary system transformation (Kuhlmann and Rip, 2014; Foray et al., 2012). Mission oriented policies could be productive if the missions are formulated in an open-ended way that encourages experimentation and diversity. New forms of engagement and networks are required between public, private and third sector actors.

Transformative change requires change of life-style, and thus daily mobility, water, energy, food and other resource use practices, not only of individual users (or consumers) but also of industrial and professional users. In the end, change is not only about the construction of new production structures, but also of user environments and markets in which new type of demands and use preferences will be dominant (Ornetzeder and Rohracher, 2006). Mazzucato (2015; 2016) stresses the need for actively shaping and creating. Such a process cannot be left to the producers, it needs to involve the users in a wide range of capacities: as user-producers (users-entrepreneurs) actively coming up with new solutions, users-legitimators providing new visions and expectations which help shape investment decisions and policy changes, user intermediaries who broker contacts between producers and larger groups of users, user-citizens who lobby for wider system reform and user-consumers who develop new life-styles, preferences and practices (Ornetzeder and Rohracher, 2006; Schot et al., 2016). This involvement of users goes far beyond raising awareness and/or measures to articulate existing demand. Instead transformative innovation policy practices should seek active contributions and find ways to assist users in constructing new demands, user environments and markets.

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 Frame 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 and use of new physical artefacts or information processes. 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? Here we come back to our argument that 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 experimentation 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. As argued above, this entails political struggles around the new goal of sustainability and it requires incumbent networks including firms to go through process of strategic reorientation (Geels and Penna, 2015). In this process 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 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. Such bridging skills can be developed through the emerging practice of responsible research and innovation (Stilgoe et al., 2013; Rip, 2014). 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 also 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.

## 5. Final discussion

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 are seen as largely external to innovation policy in Framings 1 and 2. This makes these framings partly incompatible. Yet our articulation of Framing 3 does not imply we believe governments should completely abandon Framings 1 and 2. Investment in knowledge infrastructure and R&D is an important component of any science, technology and innovation policy as well as building up of a set of linkages between main actors and the encouragement of productive interactions and learning processes among them in the context of national, sectoral, regional and in fact transnational systems of innovation. Real world policy contexts will also always involve a wide range of policy instruments drawing on several rationales. The policy evolution may take three forms: adding new goals and instruments (layering), added new rationales and goals without changing instruments (drift), and adding instruments without altering rationales (conversion) (see Kivimaa and Kern, 2016). What we have seen in our work with the Transformative Innovation Policy Consortium is mainly forms of drift and conversion, less so a process of layering (Chataway et al., 2017). Layering can also lead to inconsistencies, and that is where our thinking about combining three frames should begin: what would be productive forms of layering?

We would argue the inconsistencies between Framings and instruments can be prevented by thinking about the layering through the lens of one particular frame. If we were to look at Framings 1 and 2 from the point of view of Framing 3, we would see that R&D investments promoted in Framing 1 need to become aligned with ongoing process of anticipation and experimentation and the process of establishing sustainable pathways. Assessing whether regulation delivers barriers for socio-technical systems change as well as how it could be used to contribute to the transformative process, for example through a process technology forcing standard setting, is also necessary. Framing 2 processes of building up systems of innovation and promoting entrepreneurship need to be opened up too. Questions need to be asked whether the current systems and entrepreneurial activity only lead to related variety, reinforcing unsustainable pathways, or whether there is scope for unrelated variety, too, which would allow a diversification process in new, more sustainable directions (Frenken, 2017). In addition, it is not just learning by using, production and interacting which would be encouraged in Framing 2 (these are all examples for first order learning), but deep learning too, and this can only happen when the systems of innovation accept conflict, diversity and dissension. In the long term, Frame 3 initiatives should be allowed to shape the composition and directionality of systems of innovation and of R&D investments.

However, even when policy actors would be able to coordinate across the framings and thus achieve productive layering from a Frame 3 perspective, there remains an incompatibility between the framings which policy actors will have to navigate. This is because Framing 3 encourages a deeper set of questions concerning the fit of current socio-technical systems of provision with societal goals and, ultimately, about the governance of innovation processes. It argues that eventually we will need transformative change in many socio-technical systems for sustainable food, energy, mobility, healthcare, water, and communication provision. Such systems change is not only about change of production, but also of distribution and consumption, so it involves all actors in the economy and society, and is thus pervasive across the entire economy and wider society. The required systems-wide transformation might be called a Second Deep Transition (Schot, 2016; Schot and Kanger, 2018; Kanger and Schot, 2018). The transition is deep because it involves changing a set of deeply embedded directions such as mass production, individualised mass consumption, productivity, resource-intensity, carbon-intensity, and global production, 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. The 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, new networks between the state, business, civil society, and new supranational structures ensuring global coordination.

Eventually these new relationships will delegitimize the market failure argument on which Frame 1 is premised. They will question the contribution of R&D investment to social goals and purposes, and argue for government involvement and investment in situations where this contribution is lacking. It may lead to a much more intensive partnership with investments of governments interfering in what is considered a free market and thus be viewed as anathema to Frame 1 thinking. Framing 3 may also well lead to a complete rethinking of the relevance of the notion of systems of innovation and who is involved and can speak on whose behalf. Instead of the recommendation to build systems of innovation of various kinds, it may lead to the conclusion that the role of the government is precisely the opposite: to experiment and transform the existing set of relationships, and for example focus on local and transnational instead of national linkages.

Framings 1 and 2 emerged and were developed mainly in the US and Europe, and they have been criticised from a development perspective. Both frames assume that developing countries need to catch-up, build their own systems of innovation process in order to absorb what comes from the developed world and build their own capability. 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 are in a position to experiment with and contribute to transformative change and that mutual deep learning can be beneficial. In this framing, diverse pathways are promoted and local generation, experimentation and adaptation within a complex process of system transformation should be embraced.

A final question is whether transformative change is an over-ambitious goal for the scholarly and practitioner community presently engaged with science, technology and innovation policy[29]. On the one hand, the answer is clearly yes: such a change cannot be achieved solely by STI policies; other policies need to contribute too. One should even go further and recognize that transformative change will not come about because of new policies; it is a much broader historical process, in which many actors actively participate already. Transformative innovation policy should thus be seen as a response to what is happening in and to the contemporary world in transition. We would like to add that the challenges as defined and expressed in the SDGs are very real. If inequalities become more severe, consequences of climate change and pollution begin to hit harder, leading for example to more migration and perhaps even contribute to more conflicts, popular unrest and threat of armed conflict will ultimately force governments and other actors to respond. Science, technology and innovation will have to be part of this response, since they are hugely implicated in the generation of all these so-called externalities. Therefore, it is urgent and timely for policy-makers and researchers in this area not to wait, but to develop not only a new framing but also begin to experiment with new policy practices. These should address the double social and environmental challenges head on and contribute to peaceful and low-cost transitions to new socio-technical systems.

[29] The scale of challenge to this community has been outlined in Nelson (2013).

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