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Public financing of innovation: new questions

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Abstract

Economic theory justifies policy when there are concrete market failures. The article shows how in the case of innovation, successful policies that have led to radical innovations have been more about market *shaping and creating* through direct and pervasive public financing, rather than market *fixing*. The paper reviews and discusses evidence for this in three key areas: (1) the presence of finance from public sources across the entire innovation chain; (2) the concept of ‘mission oriented’ policies that have created new technological and industrial landscapes; and (3) the entrepreneurial and lead investor role of public actors, willing and able to take on extreme risks, independent of the business cycle. We further illustrate these three characteristics for the case of clean technology, and discuss how a market-creating and shaping perspective may be useful for understanding the financing of transformative innovation needed for confronting contemporary societal challenges.

Keywords: financing innovation, innovation policy, market failure theory, renewable energy finance, direction of innovation

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1 Introduction

Schumpeter's focus on innovation and inter-firm competition made him place finance at the centre of his analysis. He called the banker the "ephor" of the exchange economy (Schumpeter 1912, p. 74). He did not, however, look at the problem of what kind of finance is the best to serve the purposes of innovation. The works of other prominent economists such as Veblen, Keynes and Minsky have focussed instead precisely on the problem of the quality of finance. Unlike the Modigliani-Miller theorem which assumes that financial structures are inconsequential to the workings of the real economy (Modigliani and Miller, 1958), they saw the quality of finance as central to understanding the workings of capitalism. Veblen (1904), for instance, distinguished between industrial and pecuniary motives, and emphasised how the pursuit of pecuniary gains by business managers and investment bankers is often in stark opposition to technological industrial advances (Wray, 2012). Keynes too, highlighted how 'speculative' finance is a threat to the workings of industrial enterprises, when "the capital development of a country becomes the by-product of the activities of a casino" (Keynes, 1936, pp. 142-3). Moreover, as Minsky succinctly put it, the "dichotomy between enterprise and speculation draws attention to the financial structure as an essential element in the capital development process" (Minsky, 1992, p. 11).

So what do we know about the relationship between finance and innovation? Financial institutions are indeed central to any system of innovation because they provide access to high-risk capital for firms interested in engaging with new technologies: from IT, to nanotech and the emerging green-tech industry. Innovation is highly uncertain, has long lead times, is collective and cumulative (Lazonick and Mazzucato, 2013). These four characteristics reveal much about the kind of finance that is needed. The uncertainty means that finance must be willing to bear high risks; the long-run nature of innovation and its cumulateness imply that the kind of finance must be patient; and the collective nature means that there is not only one type of finance that is involved — but rather different forms, from a variety of public and private sources. Thus, it can be expected that *the type of finance received will affect the nature of investments made* (O'Sullivan, 2004; Mazzucato, 2013b). In turn, the type of finance that is provided depends heavily on its source, whether it is the private or the public sector and the multitude of different types of public and private finance.

In this respect, recent literature has highlighted how private finance has increasingly retreated from financing productive activities (Turner, 2015) and the real economy itself has become increasingly financialised, with spending on areas such as share buybacks exceeding spending on long-run investments like human capital formation and R&D (Lazonick, 2013). Why is this happening? One of the reasons the private sector has been disinvesting in the difficult R side of R&D is its increasing short-termism. This has been caused both by corporate governance structures that prioritise

quarterly returns (Kay, 2012), as well as macroeconomic conditions, like low interest rates, that make share buybacks more profitable. The pressure to maximise shareholder value (Jensen and Meckling, 1976) differs across countries depending on their 'variety of capitalism' (for example, Japan vs. the US, see Hall and Soskice, 2001), and firms within sectors often respond differently to shareholder pressures depending on their corporate governance. In telecoms, for example, Huawei and Ericsson reinvest their profits back into production, while Cisco has become increasingly financialised (Lazonick, 2015). Davies et al. (2014) and Haldane (2016) provide firm-level evidence, showing that in recent decades capital markets have become excessively focused on short-term profits, with a negative impact on the investment rate of publicly-quoted firms. Other authors have concentrated on the problems associated with short-term finance in science-based industries, which are better served by long-term finance (Pisano, 2006; Mirowski, 2011). When companies receive long-term finance, they can learn more and dare to invest in areas that will require much trial and error (Janeway, 2012). For all these reasons, the type of finance that innovators receive *is not neutral* and can affect both the rate and the direction of innovation.

This debate about what sort of finance is relevant for innovation is particularly significant given the importance that policymakers are attributing to innovation policy as a way to address the so-called *grand societal challenges* such as climate change, natural resource scarcity, ageing and improved healthcare (European Commission, 2011). As these challenges require 'transformative' innovation (Mazzucato, 2016), it is crucial to understand source and type of finance that might be able to initiate and sustain such a transformation. Is there enough patient finance to fund long-term investments in the real economy and in particular for such high-risk societal challenges?

To answer this question we can learn from the lessons of previous technological revolutions (e.g. IT, biotech, nanotech), where different forms of public funds had been essential in providing the high-risk and early funding (Block and Keller, 2011; Mazzucato, 2013a). Most often, such investments had a 'mission-oriented' nature, actively creating new industrial landscapes that served a need (man on moon, or agricultural needs) that did not exist before (Mowery, 2010; Foray et al. 2012). The green technological revolution today is witnessing a similar dynamic whereby it is mission-oriented public funds that are investing in the most capital intensive and high risk areas (Mazzucato and Semieniuk, 2016). Such investment is provided not only for the supply side (research and development) but also for the demand side: deployment and diffusion (Climate Policy Initiative, 2013).

And yet the classic market failure perspective on public investment in innovation does not justify the breadth and depth of public investments that we observed across the entire innovation chain, from basic research to applied research, early-stage financing of companies, and demand-side procurement policies (Mazzucato, 2013a). At best it can justify investments where there are clear market failures, such as the presence of positive externalities (e.g. public goods like basic research requiring public investment in basic science) and negative externalities (e.g. pollution requiring carbon taxes). But as the history of innovation shows, the great extent of public commitment that is required entails more of a *market-making and market-shaping* approach than a simple market fixing one (Mazzucato, 2016).

Furthermore, the systems of innovation literature has also not adequately addressed the issue of the quantity and quality of public investment needed to address the market creating process.

In this paper we review evidence of market-shaping public financing of innovation, and discusses views of the state that are helpful for understanding it. Section 2 confronts market-failure arguments with the recent history of financing innovation, especially in the IT and pharmaceutical sectors in the US. It is argued that the quantity and quality of public finance for innovation cannot be explained through a standard market-fixing framework. Section 3 argues that better understanding the ‘mission-oriented’ role of the State, and the ‘Entrepreneurial State’ activities across the whole innovation chain, can provide key insights for understanding the type of finance needed for transformative innovation that addresses challenges like climate change. Here we focus on the need to understand the market-making and market-shaping, not only market fixing role of public finance. In Section 4 we substantiate this with evidence of ‘market making’ activity of public funds in the renewable energy sector. We conclude that without a market making agenda, climate change targets and the required technological revolution in energy will not take off. In Section 6 we discuss future research questions related to the use of a market making and shaping framework to guide innovation policy, and address caveats regarding the possibility also of ‘government failure’.

2 Beyond fixing markets

The idea that the State is at best a fixer of markets has its roots in neoclassical economic theory, which sees competitive markets as bringing about optimal outcomes if left to themselves. This theory justifies government ‘intervention’ in the economy only if there are explicit *market failures*, which might arise from the presence of positive externalities (e.g. public goods like basic research, which require public sector spending on science), negative externalities (e.g. pollution, which require public sector taxation) and incomplete information (where the public sector may provide incubators or loan guarantees).¹ Thus, apart from financing R&D, there is little active role for public financing of innovation. On top of this the literature on systems of innovation, have also highlighted the presence of system failures—for example the lack of linkages between science and industry—requiring the creation of new institutions enabling those linkages (Lundvall, 1992).

And yet the recent history of capitalism depicts a different story – one in which it is the State that has often been responsible for actively shaping and creating markets and systems, not just fixing them; and for creating wealth, not just redistributing it. Indeed, markets themselves are outcomes of the interactions between both public and private actors, as well as actors from the third sector and from civil society. More thinking is required to understand the role of the public sector in the market

¹ Excellent reviews of the impact of positive externalities and incomplete information on innovation financing is provided in Hall (2002), Hall and Lerner (2009) and more recent evidence is reviewed in Kerr and Nanda (2014). The role for government in the face of negative externalities (climate change) is laid out in Jaffe et al. (2005).

creation process itself. This is what the work on mission oriented innovation has argued (Mowery, 2010), but only indirectly. Missions are about the creation of new markets, not the fixing new ones—and yet this framework has not debunked the market fixing policy framework. Indeed, even the systems of innovation literature (Lundvall, 1992) has not fully divorced itself from a ‘fixing’ perspective, as the way it is often interpreted is in terms of fixing system failures (e.g. formulating the missing links between science and industry) . In her book *The Entrepreneurial State* (2013a), Mazzucato has attempted to use this work to consider the lead investment role of public agencies, taking on extreme risk in the face of uncertainty, which then generates animal spirits and investment in the private sector.

Before considering what a new framework for thinking about financing innovation might look like, we first consider key evidence to show the degree to which the market failure framework is limited in its ability to justify the depth and breadth of public activity. We focus on three key areas: (1) public investments spread across the entire innovation chain, not only key areas where positive externalities or incomplete information are present; (2) the mission oriented, hence market-making, nature of the organisations involved in the investing activity; (3) the high level of risk taking and portfolio management that an entrepreneurial State perspective entails that entails a counter- and pro-cyclical nature of public investments.

2.1 Investment along the entire innovation chain

Market failure theory justifies intervention when there are clear market failures, such as when there are positive externalities generated from ‘public goods’ like basic research. Yet while technological revolutions have always required publicly funded science, what is often ignored by the market-failure framework are the complementary public funds that were spent by a network of different institutions further on in the innovation process as well. In other words, the public sector has been crucial for basic research as well as for applied research, and for providing early-stage high-risk finance to innovative companies willing to invest. It was also important for the direct creation of markets through procurement policy (Edler and Georghiou, 2007) and bold demand policies that have allowed new technologies to diffuse (Perez, 2013). Thus, Perez argues that without the policies for suburbanisation, mass production would not have had the effect it did across the economy.

Figure 1 indicates (at its bottom) some of the key public agencies in the US innovation landscape, including National Institutes of Health (NIH), NASA, DARPA, Small Business Innovation Research Program, National Science Foundation (NSF) etc. that were active across the entire innovation chain. Such organisations have been ‘mission driven’, that is, have directed their actions based on the need to solve big problems and in the process actively created new technological landscapes, rather than just fix existing ones (Foray et al. 2012). Downstream investments included the use of procurement policy to help create markets for small companies, through the public Small Business Innovation Research (SBIR) scheme, which historically has provided more early stage high-risk finance to small and medium sized companies than private venture capital (Keller and Block, 2012), as Figure 3 shows.

And guaranteed government loans are regularly used to pump prime companies, such as the \$465 million guaranteed government (DoE) loan received by Tesla to produce the ‘Tesla S’ car.

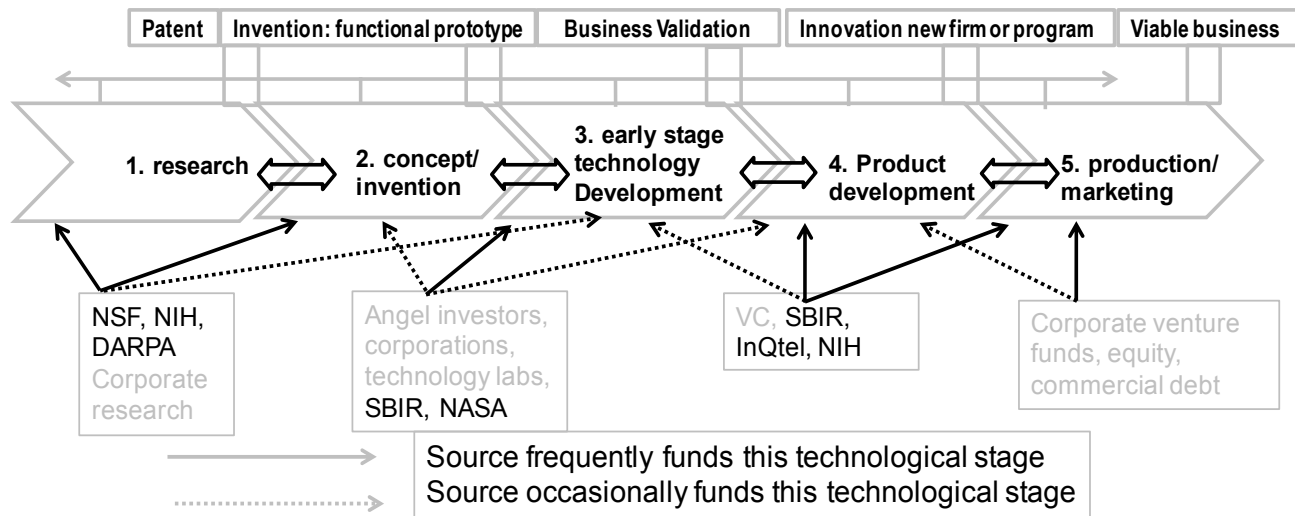


Figure 1. Mission Oriented Finance along entire innovation chain. *Source:* Mazzucato (2013a) addition to Auerswald/Branscomb (2003).

Likewise, Compaq and Intel benefited from early-stage funding to set up the companies, not from venture capital but from the SBIR programme. While it is a common perception that it is private venture capital that funds start-ups, evidence shows that most high-growth innovative companies receive their early stage high-risk finance from public sources, such as Yozma in Israel (Breznitz and Ornston, 2013); venture funds in public banks (Mazzucato and Penna, 2016); and the SBIR programme funds in the US (Keller and Block, 2012). Venture capital entered the biotech industry mainly in the late 1980s and early 1990s, meanwhile the State had already made most large-scale investments in the 1950s and 1960s (Lazonick and Tulum, 2011; Vallas et al., 2011). In all these cases, government intervention was far from ‘neutral’, as the market failure framework would recommend. Instead, it deliberately targeted industries and even enterprises with a massive amount of public venture capital assistance.

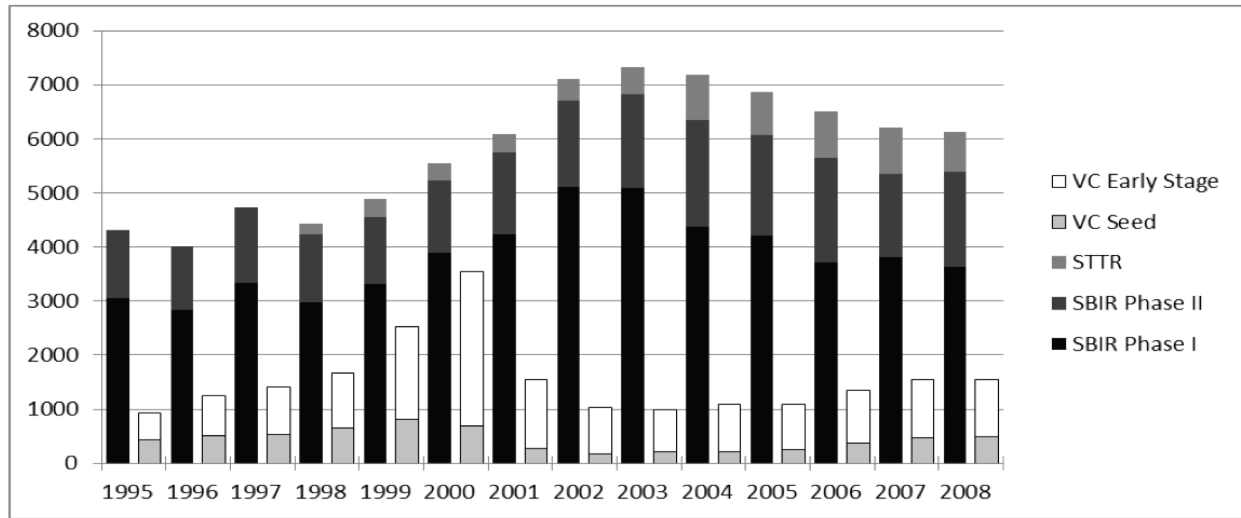


Figure 2. Number of SBIR and STTR grants compared to private venture capital. *Source:* Keller and Block (2012).

2.2 Decentralised *mission-oriented* agencies

Crucial to this public funding was the nature of the organisations themselves: a decentralised network of strategic *mission-oriented agencies* (Mazzucato, 2016). The vision behind these agencies is something that is not foreseen in the market failure perspective: they do not see their job as fixing markets but as actively creating them. Mission statements can help direct public funds in ways that are more targeted than, say, simply helping all SMEs. Examples of mission statements are below:

- **NASA's** mission is to “*Drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.*” (NASA 2014 Strategic Plan);
- “*Creating breakthrough technologies for national security is the mission of the Defense Advanced Research Projects Agency (DARPA)*”;
- “**NIH's** mission is to seek fundamental knowledge about the nature and behavior of living systems and the *application* of that knowledge to enhance health, lengthen life, and reduce illness and disability”.

In the case of IT, as Figure 3 illustrates, all of the technologies that have made Apple's i-products (iPhone, iPad, etc.) ‘smart’ were initially funded by different mission oriented public-sector institutions: the Internet by the Defense Activated Research Projects Agency (DARPA); global positioning system (GPS) by the US Navy; touchscreen display by the Central Intelligence Agency (CIA); and the voice-activated personal assistant Siri by DARPA again (Mazzucato, 2013a). These ‘mission-oriented’ institutions (Mowery, 2010; Foray et al., 2012) actively created new industrial and technological landscapes. Missions are problem specific, using innovations in *multiple* sectors

to achieve concrete problems—whether for military purposes, or for achieving targets in areas like energy (e.g. zero carbon emission) or health (e.g. eradicating cancer).

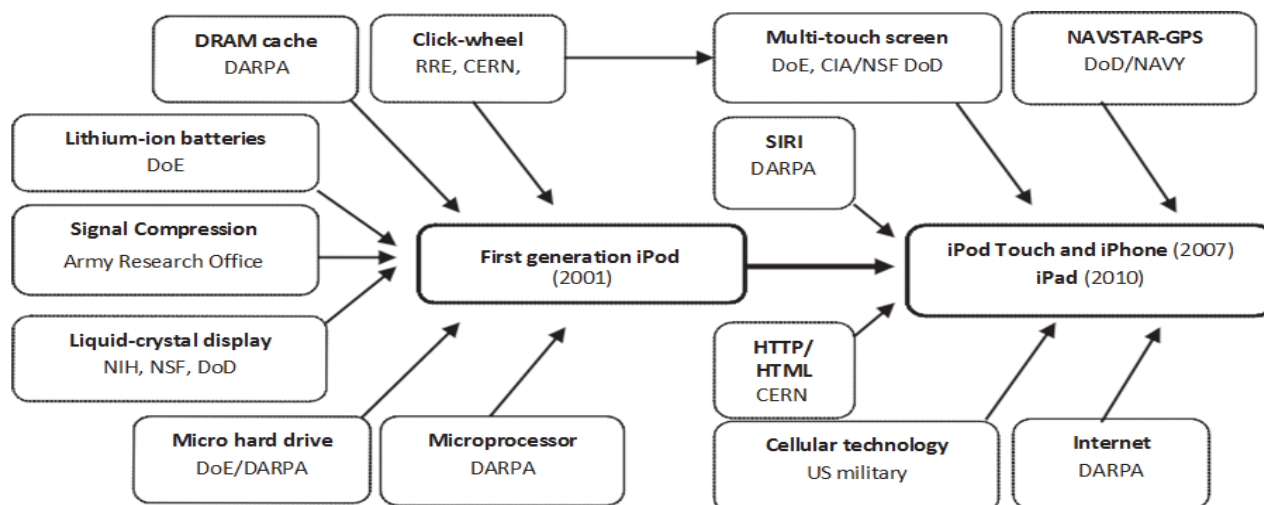


Figure 3. Publicly funded technology in ‘smart’ phones. *Source:* Mazzucato (2013a), p.109, Fig. 13.

Mission-oriented agencies are potentially better able to attract top talent as it is an ‘honour’ to work for them. By actively creating new areas of growth, they are also potentially able to ‘crowd in’ business investment by increasing business expectations about where future growth opportunities might lie (Mazzucato and Penna, 2015).

2.3 Risk taking across the business cycle

Market failure theory foresees the need to also fix ‘coordination failures’ such as pro-cyclical spending in the business sector. Yet evidence shows that the mission oriented agencies have been critical across the business cycle, not only to stimulate investment during recessions. Among those agencies mentioned above, the National Institutes of Health (NIH) have spent billions on health R&D, stimulating what later became the biotechnology revolution in both periods of boom and bust. Their budget has been increased during periods of sustained economic expansion (i.e. from the mid-80s and throughout the 90s).

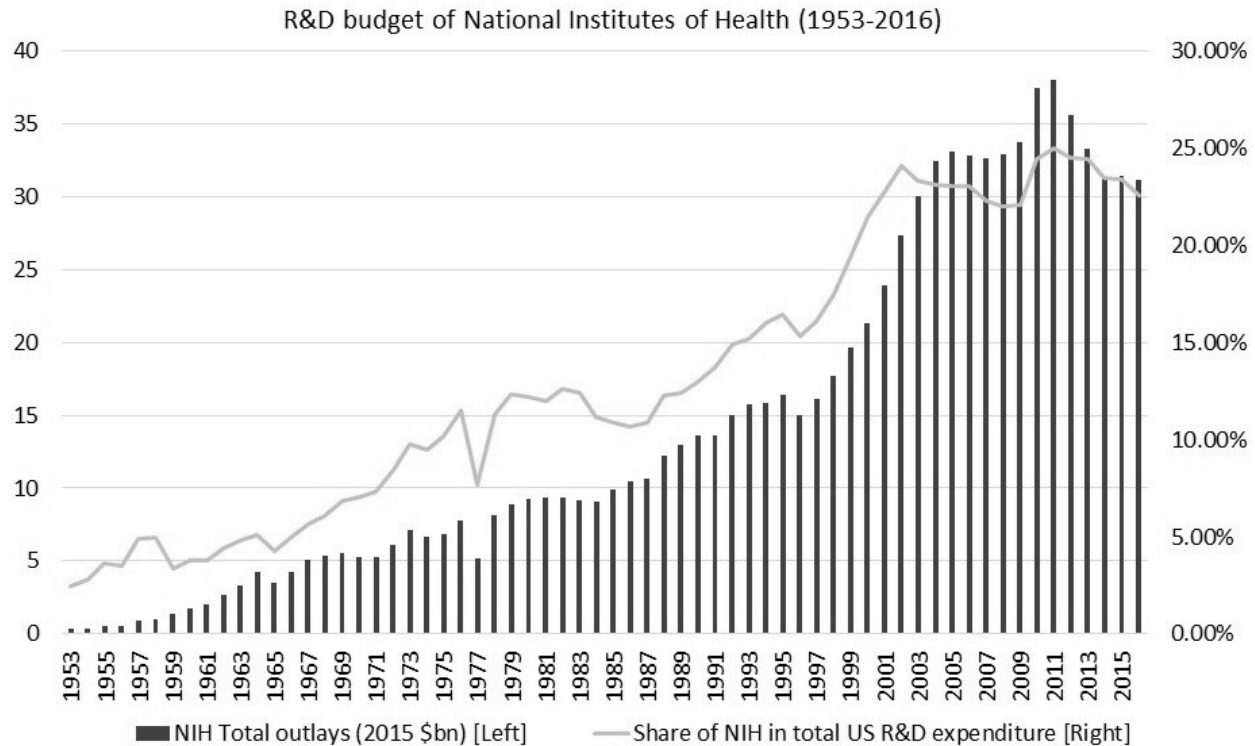


Figure 4. R&D budget of National Institutes of Health (1953-2016, in 2015 dollars). *Source:* http://officeofbudget.od.nih.gov/approp_hist.html

From 1936 to 2016, cumulative R&D expenditure by NIH has amounted to more than \$900 billion (in 2015 dollars), and was annually above \$30bn since 2004 (Figure 4). Concomitantly, research shows that around 75 percent of the most innovative drugs on the market today (the so-called ‘new molecular’ entities with priority rating) owe much of their funding to the NIH (Angell, 2004). Moreover, the share of R&D expenditure of NIH in total US federal outlays in R&D have constantly increased over the past 40 to 50 years. This suggests that the surge in absolute NIH-related R&D expenditure cannot simply be conceived as resulting from a generalised and proportional increase in total R&D expenditure by the government during downturns, or to simply level the playing field. Instead, it appears as a deliberate and targeted choice on where to direct public R&D funding.

Innovation is highly uncertain: for every success (e.g. the Internet) there are many failures. High failure rates are just as common upstream (in R&D projects) as downstream in public financing of firms. It is thus essential to better understand how portfolios are managed in mission oriented agencies is important —such as Yozma in Israel, Sitra in Finland, or SBIR in the USA. This requires a lead investor understanding of public funds, that goes beyond the need to correct for asymmetric information. It is not a matter of lacking information, but rather the willingness to engage in big thinking, and its underlying uncertainty.

In other words, public investments in innovation have been critical for sustaining high levels of risk taking and innovation across different stages of the business cycle. More generally, this section has supplied evidence for continual, wide-spread and directed public financing of innovation—across the entire innovation chain— that a market failure framework has difficulty justifying. The market itself—in different sectors—has been an outcome of this investment (Polanyi, 1944; Evans, 1995; Mazzucato, 2016). Hence rather than accusing public actors of *crowding out* market actors, more research needs to be applied to building an alternative theory that acknowledges the large influence of public actors, and shines a better light on *how* public finance of innovation impacts the evolution of markets.

3 An alternative theoretical framework for financing innovation

Given the historical evidence above, it is important to build a framework that can both describe past public investments that transcended fixing markets, as well as justify and evaluate future investments. Such a framework can benefit from insights from the work of Karl Polanyi, who in his seminal work, *The Great Transformation* (1944), describes the role of the State in forcing the so-called free market into existence: ‘the road to the free market was opened and kept open by an enormous increase in continuous, centrally organized and controlled interventionism’ (p. 144). Polanyi’s perspective debunks the notion of State actions as ‘interventions’. It is rather one in which markets are deeply embedded in social and political institutions (Evans, 1995), and where markets themselves are outcomes of social and political processes. Indeed, even Adam Smith’s notion of the free market is amenable to this interpretation. His free market was not a naturally occurring state of nature, ‘free’ from government interference. For Smith the ‘free market’ meant a market ‘free from rent’, which requires much policymaking (Smith, 1776).

Polanyi analyses not only how markets form over the course of economic development. His thinking can also be applied to understanding the most modern forms of markets, and in particular those driven by innovation. As discussed above, market-failure theory provides little guidance for the more ambitious role that the State has historically played in shaping and creating markets, and not just fixing them. This requires what Schumpeter (2002 [1912], p. 97) calls *dynamic not static economics*. A dynamic economic framework that could be useful for justifying public policies must account for the role of the State in directing investments, creating markets and taking on risks and uncertainties as investor of first resort, not only lender of last resort.

To develop a transformational market-creating/-shaping policy approach, it is necessary to rethink the role of the State in fostering innovation-led growth. Two useful frameworks are here presented: the ‘mission-oriented’ innovation policy framework (Mowery, 2010; Foray et al. 2013) policies and the work of Mazzucato (2013a) on the ‘Entrepreneurial State’ in its leading risk-taking role.

3.1 Mission-Oriented Innovation Policy

The history of innovation policy, studied through Freeman's systems of innovation (1995), provides key insights into the limits of market-failure theory in justifying the depth and breadth of investments necessary for radical technological change to emerge. This approach emphasises system - rather than market - failures and the need to build horizontal institutions that allow new knowledge to diffuse across the entire economy (Lundvall, 1992). Innovation policy, in this historical framework, takes the shape of measures that support basic research; aim to develop and diffuse general-purpose technologies; expand certain economic sectors that are crucial for innovation; and promote infrastructural development (Freeman and Soete, 1997).

This type of broad-based innovation policy has been called 'mission-oriented' for its aim to achieve specific objectives (Ergas, 1987; Freeman, 1996). It does not merely facilitate innovation through playing field-levelling horizontal policies that prescribe no direction. On the contrary, such policies by definition give explicit technological and sectoral directions to achieve the 'mission'.

Examples of such direction-setting policies abound, including different technology policy initiatives in the US (Chiang, 1991; Mowery *et al.*, 2010), France (Foray, 2003), the UK (Mowery *et al.*, 2010) and Germany (Cantner and Pyka, 2001). These policies were implemented by mission-oriented agencies and policy programmes: military R&D programmes (Mowery, 2010); the National Institutes of Health (NIH) (Sampat, 2012); grand missions of agricultural innovation (Wright, 2012); and energy (Anadón, 2012). In such cases, it was the organisation that had to make choices on what to fund: tilting the playing field rather than 'leveling it' (Mazzucato and Perez, 2015). Thus the 'picking winner' problem, which continues to dominate the industrial policy debate, is a static one that creates a false dichotomy: what is crucial is not whether choices must be made, but how 'intelligent' can the picking of 'directions' be performed.

However, the literature has not integrated empirical insights to provide a full-fledged theory. Consequently, studies have resulted in ad-hoc theoretical understandings and policy advice on how to manage mission-oriented initiatives, without tackling the key justifications for mission-oriented finance that contrast those of market failure. In a market failure framework, ex-ante analysis aims to estimate benefits and costs (including those associated with government failures) while ex-post analysis seeks to verify whether the estimates were correct and the market failure successfully addressed. Instead, a mission-oriented framework requires continuous and dynamic monitoring and evaluation throughout the innovation policy process. In its most general form, the mission-oriented framework differentiates between public policies that target the development of specific technologies in line with State-defined goals ('missions') and those that aim at the institutional development of a system of innovation (Ergas, 1987; Cantner and Pyka, 2001). The State must therefore be able to learn from past experiences in mission-oriented innovation policy.

Systemic mission-oriented policies must be based on a sound and clear diagnosis and prognosis (foresight). This not only requires the identification of missing links, failures and bottlenecks – the weaknesses or challenges of a national system of innovation – but also the recognition of the system’s strengths. Foresight is necessary in order to scrutinise future opportunities and also identify how strengths may be used to overcome weaknesses. This diagnosis should be used in devising concrete strategies, new institutions and new linkages in the innovation system (Mazzucato, 2016). It may also be necessary to ‘tilt’ the playing field in the direction of the mission being pursued rather than ‘leveling’ it through such means as technologically neutral policies (Mazzucato and Perez, 2015).

Mission-oriented policies can therefore be defined as systemic public policies that draw on frontier knowledge to attain specific goals or “big science deployed to meet big problems” (Ergas, 1987, p. 53). The archetypical historical mission is NASA’s putting man on the moon. Contemporary missions aim to address broader challenges that require long-term commitment to the development of many technological solutions (Foray et al. 2012) and “a continuing high rate of technical change and a set of institutional changes” (Freeman, 1996, p. 34). The current active role of the public sector in tackling renewable energy investments can be seen as a new mission in relation to the green economy (Mazzucato and Penna, 2015b). Other new missions include addressing such ‘grand societal challenges’ as the ageing/demographic crisis, inequality, and youth unemployment (European Commission, 2011). In fact, these challenges – which can be environmental, demographic, economic or social – have entered innovation policy agendas as key justifications for action, providing strategic direction for funding policies and innovation efforts.

3.2 The Entrepreneurial State: The State as Lead Risk-Taker and Investor in the Economy

Alternative approaches to innovation policy, such as those described above, have questioned particular aspects of the economic dynamics embodied in neoclassical theory. However, they have not disputed the underlying assumption of business being the only risk-taker. The Entrepreneurial State agenda has sought to challenge the notion of the entrepreneur being embodied in private business, and policy-making being an activity outside of the entrepreneurial process (Mazzucato, 2013a). This perspective builds on studies in industry dynamics that have documented a weak relationship between entry of new firms into industries and the current levels of profits in those industries (Vivarelli, 2013). Firm entry appears to be driven by expectations about future growth opportunities, even when such expectations are overly optimistic (Dosi and Lovallo, 1998). Business tends to enter new sectors only after the high risk and uncertainty has been absorbed by the public sector, especially in areas of high capital intensity. As described in the previous section, this has been the case with the IT revolution (Block and Keller, 2011), the biotechnology industry (Lazonick and Tulum, 2011), nanotechnology (Motoyama et al., 2011), and for the emerging clean-tech sector (Mazzucato and Penna, 2014). Moreover, private venture capital funds have focused on financing firms mid-stage, which had previously received early-stage financing by public programmes, like the SBIR programmes (Keller and Block, 2012). While the literature has described such dynamics simply in

terms of 'crowding in,' this ignores the direct risk-taking that such public activity entails, and hence the occasional failures that will inevitably result. In innovation policy the State not only 'crowds in' business investment but also 'dynamises it in', creating the vision, the mission and the plan.

An Entrepreneurial State does not only 'de-risk', but envisages the risk space and operates boldly and effectively within it (Mazzucato, 2013a). Unlike in theory of technology adoption of 'developing economy, where the technology already exists elsewhere, an Entrepreneurial State does not foresee what the details of the innovation are, but it knows a general area that is ripe for development, or where pushing the boundaries of knowledge are desirable. The State welcomes and engages with Knightian uncertainty for the exploration and production of new products which lead to economic growth. The State has been 'entrepreneurial' when it has taken the lead by formulating a vision of a new area (for example the Internet or the genetic sequence). Then public financing of innovation comprises investing in the earliest-stage research and development; creating and funding networks that bring together business, academia and finance; funding high-risk ventures; and investing in high risk demonstration and deployment.

In sum, a theoretical framework of public financing of innovation starting from these preconceptions would emphasise the influence that public institutions take on the course of transformative innovation and their risky active involvement in financing of that innovation along the innovation chain. We next illustrate this with reference to a current societal challenge.

4 The Green Challenge

The insights about the market-shaping and creating role of public actors take on a new importance for meeting today's societal challenges (European Commission, 2011). We consider the climate change challenge which is widely seen as requiring not only a transformation of the energy system but also such transformation on a short time scale, and on which leading climate scientists and economists are currently reaffirming that not enough is done and not fast enough (Guardian 2016a, Guardian 2016b). Not enough progress is made in replacing the greenhouse gas emitting fossil fuels with a renewable power supply instead, and one bottleneck is the finance for renewable energy innovation.

Innovation in renewable energy has been especially difficult to finance for private actors because of the competition from incumbent fossil fuels. Profits have been dependent on public subsidies that ensure temporary competitiveness. With those subsidies in the form of feed-in tariffs, tax breaks and power purchase agreements, investment in the renewable energy sector, along the innovation chain from R&D over piloting and demonstration to deployment, stood at USD 285 billion in 2015 and has been rising by less than a percent annually since 2011 (UNEP & Bloomberg 2016, p.12). In contrast with this slow growth, the International Renewable Energy Agency (IRENA) estimates that a 9%

compound annual growth rate in investment over the next 15 years is required to keep global warming to two degree Celsius temperature rise (IRENA, 2016, p.121).²

IRENA, like others, does not specify the sources of the historical or future finance for the renewable energy sector. However, the report suggests that policymakers should play an `enabling' role and `correct for market distortions to create a level playing field' (IRENA, 2016, p.20), which reflects the report's market failure lens. In fact, from the market failure perspective, the damages from climate change are an externality of energy production, hence require a correction of the externality, while innovation requires correcting the positive externality of knowledge-spillovers. Hence, carbon taxes and R&D spending are recommended (Newell, 2010, Fisher et al., 2013). But existing public sector policies fail to tax carbon, not least due to the difficulty of agreeing on one internationally, and subsidies have been employed instead. Hence, the main conclusion that a market failure perspective can draw is that existing policies – besides R&D support – are inefficient, and should instead focus on a carbon tax and small interventions to start the “private innovation machine” (Veugelers, 2012).

This approach, however, overlooks what the public sector in fact does, besides giving subsidies in the market for electricity producers. The public sector is much more active in directly financing renewable energy innovation, creating markets and, in the process, taking on high risks. We go through the same set of three areas of public activity as in section 3, and highlight how in each of these, some public actors' behavior is characteristic of a market-shaping role of the public sector.

4.1 Entire Innovation Chain

First of all, public actors in renewable energy innovation are active along the innovation chain. Government agencies are involved in R&D with around fifty percent of renewable energy sector R&D spending originating in the public sector according to the Bloomberg New Energy Finance (BNEF) estimates (UNEP, 2016), including such institutions as the recently created 32 Energy Frontier Research Centers (EFRCs) in the US that are charged to deliver `use-inspired' basic research for renewable energy (DoE, 2016, see also Anadon, 2012). But public actors are distributed and highly active further along the chain: more applied research and development takes place in such diverse settings as the German Fraunhofer Institutes (e.g. on Solar Energy Systems), or the State-owned company development funded by the Chinese Ministry of Science and Technology's `863' program (Kempener et al., 2010, p.37). Moreover, several publicly-owned agencies are engaged in financing the commercialisation of technologies through providing venture capital: the Sustainable Development Technology Canada alone spent USD 100 million (at current exchange rates) in venture funding (SDTC, 2016), which represents some 7% of global private venture capital funding in 2015 (which stood at 1.3 billion). In 2014, the US Advanced Research Project Agency-Energy (ARPA-E) single-handedly funded commercialization-oriented projects to the tune of USD 188 million, or almost 20 percent of that year's private venture capital spending (ARPA-E, 2015). The Chinese State Council's Innovation fund supported one thousand energy efficiency and renewable energy ventures with RMB 1 billion already between 1999 and 2002 (Cherni, 2007, p.3619) and the Global Energy Efficiency and

² IRENA's and UNEP's numbers are slightly different as the former includes investment in large hydro (dams above 50MW capacity) and industry and building efficiency, which the latter excludes.

Renewable Energy Fund (GEEREF) is a publicly-run fund-of-funds with EUR 112 million in Norwegian and German government funds, and advised by the European Investment Bank, that leverages additional private funds and invests in renewable energy private equity (GEREEF 2016). Government activity is also wide-spread at the demonstration level of new technologies; a recent study of demonstration projects (first of a kind) in concentrating solar power, wind power and biofuels find that the median public share of funds financing those projects is above 50 percent (Nemet et al., 2016).

At the subsequent market-creation and deployment stage, another variety of public actors are active, ranging from government agencies and investment funds, through tremendous amounts invested by State banks, to State-owned utilities, which have both pioneered European offshore wind farm deployment (Mazzucato and Semieniuk, 2016). State-owned utilities are also behind China's rise to by far the biggest capacity of wind energy installed, as much as the whole of Europe at the end of 2015 (GWEC, 2016). In fact, at the deployment stage, publicly controlled organisations (where the public has at least a 51% share for stock-market listed organization), are now responsible for almost half of global asset finance for utility scale power plants (Mazzucato and Semieniuk, 2016). For smaller capacity, public actors provide important demand side finance such as subsidies for rooftop photovoltaic cells and individual wind turbines in Germany by the German development bank, KfW (KfW, 2015), and also large-scale solar and hydro power plants in China by its Ministry of Finance (Lo, 2014).

Finally, this public support along the chain is completed with finance from the world's export credit agencies, which 31 countries maintain (OECD, 2016), that guarantee paybacks for national champions, when they invest abroad in risky renewable energy projects. For instance, the Danish export credit agency has sponsored wind farm development to the tune of circa USD 1.5 billion in each of 2013-2016, which insures national developers against risk by guaranteeing their repayment, which in the Danish case is, among others, the national champion Vestas, one of the world's largest wind turbine manufacturer (EKF, 2016). Figure 5.1 summarizes the discussion, by replacing the public actors from other sectors, showed above in Figure 2, with those specific to renewable energy innovation finance.

The data also show that this variety of public actors is not neutral but gives directions to innovation. Public actors invest in portfolios that favor one or another technology. Figure 6 shows the portfolios of asset finance for deployment invested by four different types of public actors, aggregated over individual organisations within each type.³ The portfolios are constructed by finding the share of each actor type's total renewable energy finance that it invests in a particular technology. The shares are taken over two periods: 2004-2008, and 2009-2014. Clearly, the different types of actors held widely differing portfolios. In the aggregate, government agencies invested in a relatively balanced portfolio

³ The data are based on our research in a companion piece (Mazzucato and Semieniuk, 2016), where we merge a deal-by-deal asset finance dataset from BNEF for the period 2004-2014 with organization indicators to identify which organisations invest in which deals. For corporations, we labeled those as public where the public sector owned at least a 51% of the shares. Based on the organization identifiers, we distinguished whether the public organisation is a government agency or research institute, a public financial institution, a publicly owned utility, or another state-owned company.

across technologies – governments have not picked one winner technology, but supported innovation across a suite of alternatives within renewable energy.⁴ State banks, on the other hand, concentrated more than half of their investments in only two technologies in both periods. However, State banks are in turn more diversified than publicly owned utilities, which, outside China, targeted the financing of wind energy, and especially offshore wind investments after 2008. This distinguishes them not only from other public actors but also from privately owned utilities whose share of investments in offshore is lower than that for State banks (they invest heavily in less risky onshore wind). We have separated out Chinese State-owned utilities, which are the main vehicle for Chinese renewable energy expansion and are the main driver behind China’s rise to the number one in terms of installed wind capacity. While the review of organizations was selective, it emerges that in countries with a strong renewable energy, public organisations were active along the innovation chain, which is typical of the market-shaping behaviour of the public actors we discussed above.

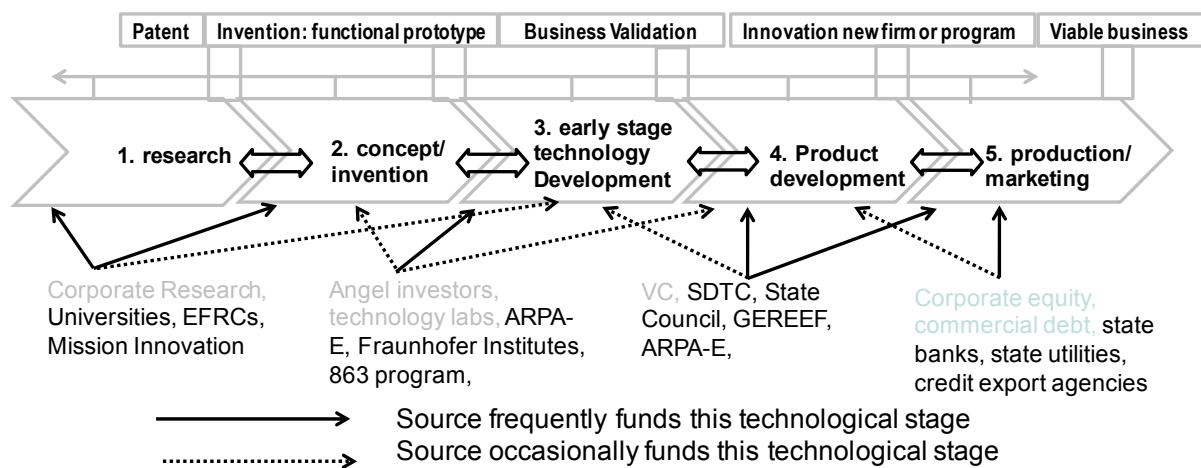


Figure 5 Mission-Oriented Finance along entire innovation chain in the renewable energy sector

⁴ Of course, government agencies also heavily fund nuclear power and the US Department of Energy was funding and carrying out the innovations leading to the shale-gas technology (Trembath et al., 2012).

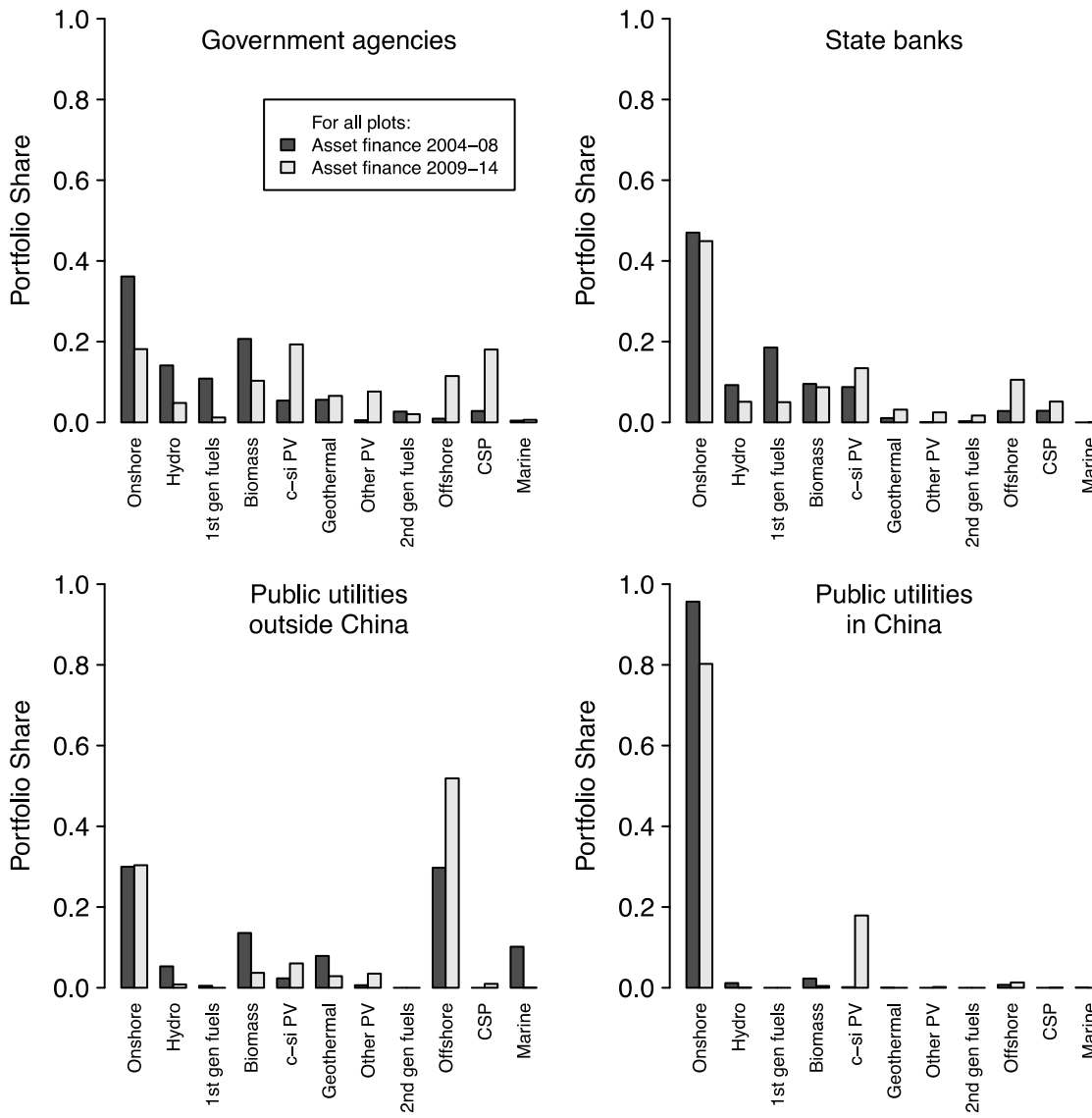


Figure 6 Portfolios of four types of public actor. The share of the portfolio invested in each of 11 technologies is on the y-axis. The dark bars show the share of investment in the period 2004-2008, the light bars the share of investment in the period 2009-2014 that go to a particular technology. CSP stands for ‘concentrating solar power’, PV stands for photovoltaics. Marine refers to energy gained from the ocean, whether through wave or tidal energy. Data sources are explained in Mazzucato and Semieniuk (2016).

4.2 Decentralised network of mission-oriented agencies

Many of the reviewed public actors are also mission oriented. Innovation in the energy sector has historically been driven by missions. In the 1970s, the mission was to boost national security by reducing dependence on the then expensive crude oil from OPEC countries. Contemporary innovation is justified by multiple missions (Anadon, 2012), but the most visible issue is that of climate change,

with the mission being to limit global warming to two or preferably 1.5 degree Celsius (United Nations 2015, p. 2). Befittingly, at the Paris Conference of the Parties on climate change in 2015, twenty governments unveiled 'Mission Innovation', and set themselves the goal to double their national R&D spending on clean energy over the next five years. As with previous missions, these investments are not justified by correcting a market failure but by achieving a target. In this specific case: the halting of global warming. As with previous missions also, the public sector here also seeks to draw in private sector investments, and a simultaneously launched 'Breakthrough Coalition' has 28 investor members that represent private sector leadership in key economic sectors (Mission Innovation, 2016).

But crucially, the mission orientation goes beyond R&D agencies. Thus the ARPA-E mission is to *catalyse* the development of transformational, high-impact energy technologies. The mission of the German KfW Group is to support change and encourage *forward-looking ideas* – in Germany, Europe and throughout the world. And the German Fraunhofer Institutes put it succinctly: "We are creative. We shape technology. We design products. We improve methods and techniques. We open up new vistas. In short, we forge the future" (Fraunhofer Institutes, 2016). In Germany, moreover, the 'Energiewende', the project to base the German energy supply largely on renewable energy sources, has seen the government introducing legislation favoring the mission of an energy transformation since 1990s (Hake et al., 2016). The Renewable Energy Law (EEG) states in its 2017 version that its aim is to develop a sustainable energy supply to protect climate and environment, and stipulates an 80% share of electricity from renewable energy by 2050, and 40-45 percent in 2025 (EEG, 2016, §1). Clearly, the organisations setting out these missions are active beyond the R&D ambit.

Agencies in the energy sector have also been able to attract top talent. The US Department of Energy was led by Nobel Prize winning physicist, Stephen Chu (2009-2013), now replaced by another MIT physicist, Ernest Moniz, and ARPA-E founding director, Arun Majumdar (2009-2012) is a leading engineer in thermoelectric materials. In sum, a slate of the most influential public institutions funding renewable energy research do not understand themselves as fixing market or system failures – they see themselves as pushing new and exciting horizons.

4.3 Risk taking and portfolio management

Lastly, there is also evidence in the renewable energy sector and clean tech more general, for public actors leading in risk taking across the business cycle. The technologies listed in Figure 6 above are ordered according to an increasing degree of riskiness from left to right. Thus, publicly owned utilities take on considerable risk by investing a large share of their portfolio in offshore wind. In a companion piece (Mazzucato and Semieniuk 2016), we have not only justified this risk ordering, which is ordinal and suggests that onshore wind is no more risky than any other technology investment on average but does not attempt to quantify the amount of risk taken. We have also shown that with this measure public actors hold on average a much riskier portfolio than private actors in asset finance, at least when excluding the Chinese utilities charged with onshore wind diffusion. Here, we push this

research one step further and analyse how high-taking by private actors is correlated with co-investment by public actors. We single out investments into high-risk areas only.⁵

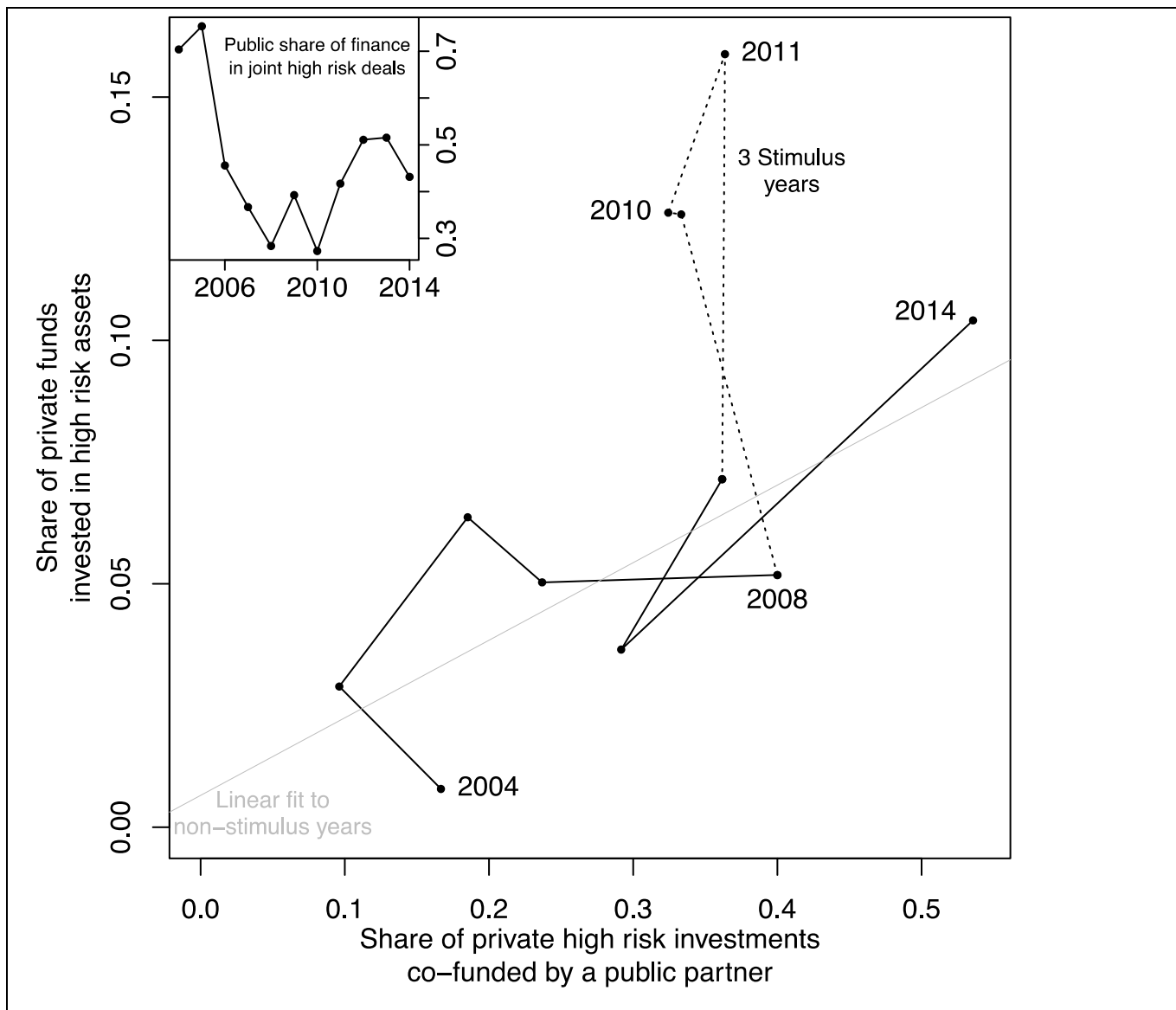


Figure 7. Scatter of annual share of high-risk private renewable energy investments involving a public financing partner (x axis) vs the annual share of private funds invested into high risk assets. Edges connect subsequent years. The dotted lines indicate years with significant grant and loan guarantee support as part of post-crisis government stimuli, that imply indirect public support to high risk deals carried out exclusively with private funds.

⁵ High risk technologies are marine energy investments, concentrating solar power, offshore wind, concentrator PV, 2nd generation biofuels, thin film PV before 2011, and c-si PV before 2008. Financing of all other technologies shown on the x-axis of Figure 6 is excluded.

Figure 7 correlates the private investment into high risk assets with the participation of public actors in private high-risk finance. It plots the share of total private funds invested in high-risk assets in any single year against the share of these high-risk funds that are invested into an asset in which at least one public actor is also investing. In 2004, only about 1 percent of public funds went into high-risk projects, and of these, only 18 percent had a public co-investor. Both shares increased over time, so much so that a decade later in 2014, the share of high-risk projects co-funded by a public organisation stood at above 50 percent, while around 10 percent of private funds went towards high-risk investments. The correlation is high (indicated by the grey linear fit), when one excludes three exceptional years – 2009 through 2011 – during which massive Keynesian stabilisation programmes kicked in, inundating markets with grants and loan guarantees. That coincided with private actors financing more risky projects with private funds only (but backed by public guarantees). From this time hails, for instance, the largest concentrating solar power plant in the Ivanpah powerplant in the US, was financed by private investors, but backed by a USD 1.6 billion loan guarantee from the US Department of Energy. The inset shows moreover, that when public actors have participated in high risk deals, they have tended to finance on average between 30 and 50 percent of the deal's volume. These statistics show that as more public actors were stepping forward finance assets, the private side became more willing to invest in the higher-risk deployment. While causality cannot be attributed, the strong positive correlation between public participation and private risk-appetite suggests that the public sector's appetite for high-risk investments was important for a significant share of deployment of those technologies that have farthest to go in terms of innovation through learning by doing.

The exceptional measures taken in 2009-2011 by governments indicate that in the energy sector, over the last business cycle, public financing was significantly driven by a coordination failure logic. Figure 8 shows clearly how the grants for renewable energy research, development and demonstration given out by the US Department of Energy (DoE) and all other grant-giving organisations spiked in those three years and dropped back almost to pre-crisis levels. A similar, albeit less pronounced pattern can be detected in investment behaviour of the big development banks – China Development Bank, KfW, and European Investment Bank. However, while declining, these banks have kept their investment at a much higher level than pre-financial crisis. Similarly, while US institution such as the EFRCs and ARPA-E were initially funded with stimulus money (Anadon, 2012), their annual funds have to date been maintained and the EFRCs even expanded in their numbers. At the same time, of course, the world economy is widely seen to remain in 'secular stagnation' (Summers, 2016). It remains to be seen how public funding for renewables will be impacted if and when a business cycle boom sets in.

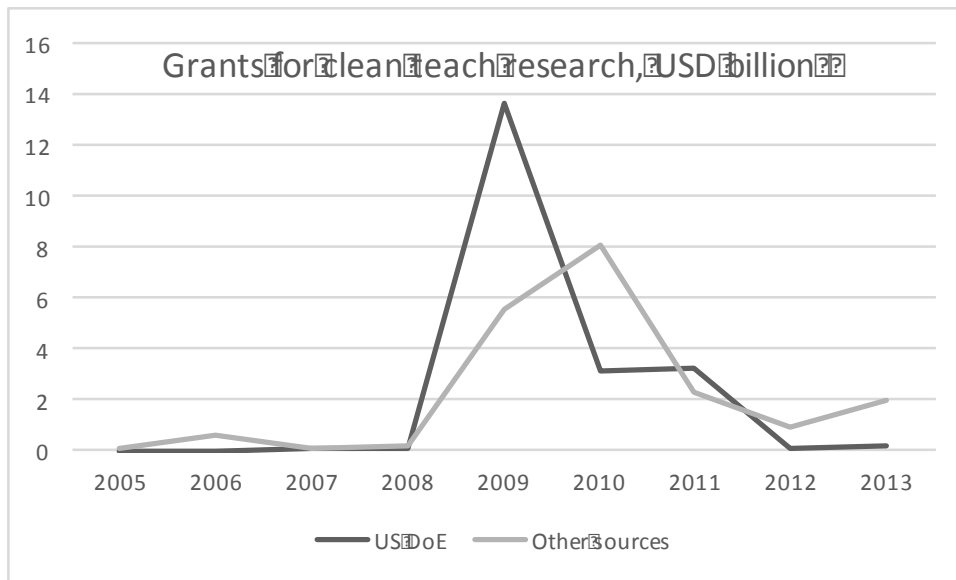


Figure 8 Annual total of grants given for clean energy research, development and demonstration, split into DoE and other grant givers. Datasource: Authors' calculations based on Bloomberg New Energy Finance data.

In sum, the patterns we see in public financing for innovation in renewable energy, and clean tech more generally, are very far removed from the indirect policies recommended by a market-failure approach. A market shaping perspective that sees the state as entrepreneurial and risk taking, and distinguishes public actors with missions highlights these patterns. In spite of these massive interventions, the grand challenge to keep temperature rises to a modest level suggests that even the existing activities have been insufficient to mobilize the finance that is forecast as needed for achieving the mission of limiting global warming. The market-creating and shaping perspective leads to the conclusion that even more active public sector involvement in financing innovation is needed realized the 9% compound annual growth rate in investment, that IRENA estimates is needed over the next 15 years.

It is of course possible to argue that the public financing stymied as opposed to boosted overall financing, and we return to this caveat in our concluding discussion. Yet the evidence also from earlier transformative innovations, the problem that markets first have to be created before they can be corrected, and the seriousness of this and other grand challenges should caution against foregone conclusions. It seems risky not to explore the possibility that public actors that help direct innovation to certain mission-determined outcomes through massive financing of innovation may be an important driver of the transformation of how we produce energy.

5. Conclusion

In this article we have focused on the strategic role of public financing of innovation and the way it can shape and create markets. We have looked at 3 key features of this process: (1) investing along

the entire innovation chain, not only in classic public good areas; (2) the mission oriented nature of the agencies involved, and (3) their lead risk taking role, independent of the business cycle. We have argued that looking at these three features of the system help to see the limits of the traditional market failure framework. We then applied this perspective to the emerging clean technology sector, as an example of transformative innovation needed to confront a societal challenge.

The market-shaping approach suggests that public financing must be proactive and bold, creating directions, and transcending the role envisaged by market or also system fixing approaches. This is even more important for contemporary “societal challenges” where the need for transformative innovation is particularly pressing. For the challenge to mitigate climate change, if the recent international agreements to fight climate change are to have effect, it is important for public organisations financing innovation to be mission-oriented and entrepreneurial. We have shown that public actors are active; yet given the estimated need for investment in this sector, this is not enough. To experience a full blown clean energy revolution, the lessons from the IT revolution are clear: the visible public hand is required; it must be distributed across the whole innovation chain through different actors, and justifications for the investments cannot be limited to periods with low interest rates. Even if the world was experiencing high growth, it would not be enough for tax incentives to incentivize green investments. They would need to be crowded in by public funding, simply because there is as yet no market that can work efficiently with private actors at its centre.

Two caveats to these statements are in order. First, there is no automatism whereby public involvement in financing innovation leads to superior outcomes; what we have argued against here is the assumption that public sector financing is systematically inferior to that by private actors. While the examples above focus on public investments that have led to important successes (e.g. the Internet, GPS, shale gas, blockbuster drugs), there are also government investments that end in failure. These include investments in products like the Concorde aircraft, which ultimately failed commercially; in the discovery of new drugs (of which most attempts fail); or the provision of guaranteed loans to companies which then might go bankrupt. A recent example of the latter includes the guaranteed loan of \$528 million provided by the US Department of Energy to the company Solyndra for the production of solar cells. This was followed by the company’s bankruptcy when the price of silicon chips fell dramatically, leaving the taxpayer to pick up the bill (Wood, 2012). As stressed above, however, any venture capitalist will argue that attempts to innovate require exploring new and difficult paths, and that occasional failure is part of that journey. Innovation is intrinsically uncertain (Dosi and Egidi, 1991) and results in failures from time to time. This trial-and-error process, in which tolerance of failure is also the road to success, is accepted in the private sector. Failure of government investments, on the contrary, is regarded as a sign of incompetence (The Economist, 2010). If the government acts as lead risk taker, then it should be accepted that there are failures, as long as there are successes. It is important then, not to categorically dismiss public financing because some of the projects fail, but to ask what are well-designed policies for public financing of innovation.

Part of the problem is that the focus on market failure has led to relatively little research and insight on 'good practice', and we see here an important area of research to be advanced.

A second caveat regards the motivations behind public sector financing. Public choice theory and related new public management theory have highlighted the problems associated with *government failure* arising from rent seeking, whereby public officials are captured by vested private interests (Tullock et al., 2002). Rents arise when value is extracted through special privileges (Krueger, 1974), and when a company or individual grabs a large share of wealth that would have been produced without their input (Stiglitz, 2012 p. 32). Then financing for innovation could go to those special interests that are not the best innovators but those with the best connections to the public funding agencies. Our lens, far from denying this problem, sheds a different light on it. The question is whether rent-seeking is more problematic with a weak, passive state than with a strong one. It could be that rent-seeking is even more common when the public sector only attempts to facilitate rather than create additionality through mission oriented policies that crowd in the private sector, making private investments happen that would not have anyway, a problem discussed in the economic development literature (Khan and Kwame, 2000). Or whether it is more problematic when theory tells a wrong story about who the innovators are (e.g. the 'entrepreneurs' or the venture capitalists), excludes the risk taking role of the public sector. Thus if the State is described as simply fixing markets, not actively shaping and creating them, it may over time also become less confident, and more easily corruptible by different actors who call themselves the 'wealth creators'. It is these actors who can then convince policymakers to hand out favours in order to increase their 'private' wealth. In the US, capital gains tax fell by 50 percent in five years at the end of the 1970s as a result of pressure from the National Venture Capital Association (Lazonick and Mazzucato, 2012). More recently instead, big tech corporations have been lobbying the US government substantially more than Wall Street's biggest financial companies (Bloomberg, 2016c). In fact, some rent-seeking may be encouraged precisely by the problematic assumptions regarding the role and value of public investment.

The article has emphasised the need of innovation for patient strategic capital that is not found in the private sector, both due to the short-termism of the private financial system, but also due to the properties of innovation: highly uncertain, cumulative, collective and with very long lead times. This leads to a depth and breadth of public investment that is broader than traditional perspectives admit. In particular we emphasised how the impact of *mission oriented* public investment along the entire innovation chain, and across the phases of the business cycle, is something that the green tech industry can learn from the experiences in sectors like biotech and ICT. The theoretical contribution of such evidence is that economic policy should be more about market shaping and creating than just market or system 'fixing'.

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