Policy Paper

What will it take to get us a Green Revolution?

No more *Nudging*. *Pushing* on Supply and *Pulling* on Demand[*]

Mariana Mazzucato[†,‡], Gregor Semieniuk[‡], and Jim Watson[‡,§]

SUMMARY

Battling climate change requires efforts on multiple fronts, both on the supply side (e.g. investments in R&D, innovation) and on the demand side (changing consumption and investment patterns, and enabling diffusion and deployment). If green innovation is to be characterised by the kind of technological changes that surrounded the IT revolution, it will require not only massive amounts of *private* spending on R&D, piloting and deployment, but also (and especially) public sector agencies willing to take on risks in the most capital intensive and high risk areas. Crucially, we cannot assume that nudging and incentivising is enough, policies must actively push and pull.

Today, however, we have a crisis on both the public and private side of investment. Energy companies still spend too much on fossil fuels, rather than on renewable energy (only 16% of total energy sector investments flowed into renewables in 2013 (IEA, 2014)), and they have become increasingly financialised—i.e. spending an increasing share of their profits on areas like share buybacks (Lazonick, 2014). On the public side, significant budgets cuts are putting strain on the type of agencies, like ARPA-E (Advanced Research Projects Agency-Energy) in the US Department of Energy (DoE) that could be driving path-breaking innovation, as DARPA (Defense Advanced Research Projects Agency) did for IT. While ARPA-E is important, its 2015 budget of $280m is too small, barely a tenth of DARPA's $3billion budget, and there are not enough equivalent organisations globally.

This paper outlines the policy imperatives needed to produce a real 'green revolution'. Focusing on the discussions at COP21 in Paris, and President Obama's pledge for the US to be a world leader in combating climate change, it starts by reviewing the importance of public sector involvement along the innovation chain and the mode of innovation through mission-oriented programs. After reviewing how innovation funding has come under pressure, it concentrates on recent developments in clean tech R&D, especially in renewable energy generation. It then examines the scope of 'green tech' innovation across sectors and in 'downstream' investments, outlines the

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[*] This policy paper builds on testimony that Mazzucato gave to the US Senate on innovation policy (Mazzucato 2015a).

[†] Corresponding author: m.mazzucato@sussex.ac.uk

[‡] Science Policy Research Unit (SPRU), University of Sussex, UK.

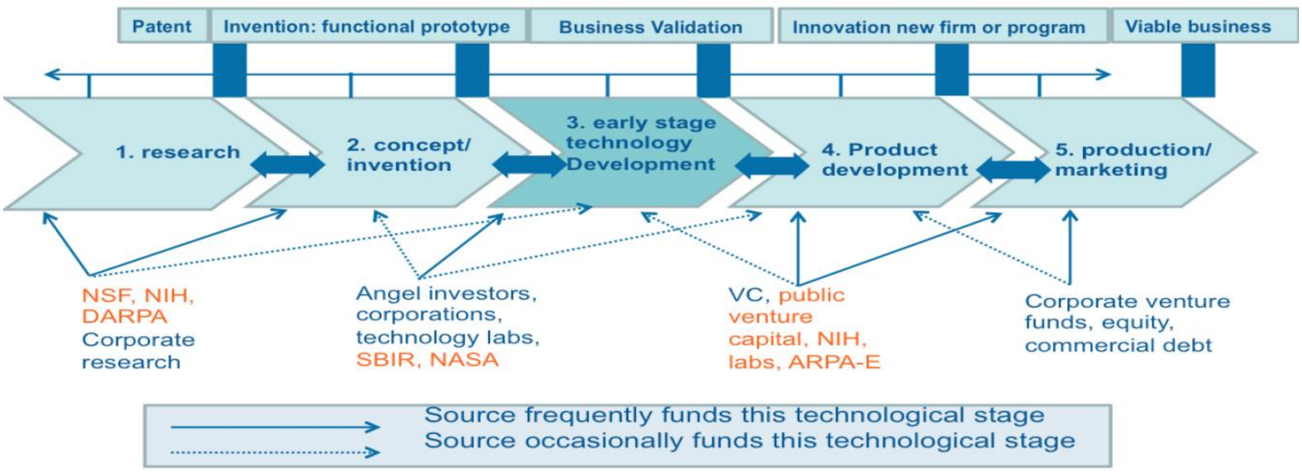
[§] UK Energy Research Centre.

benefits that a portfolio approach to green innovation can provide, and concludes by offering seven key policy recommendations.

1. WHOLE INNOVATION CHAIN

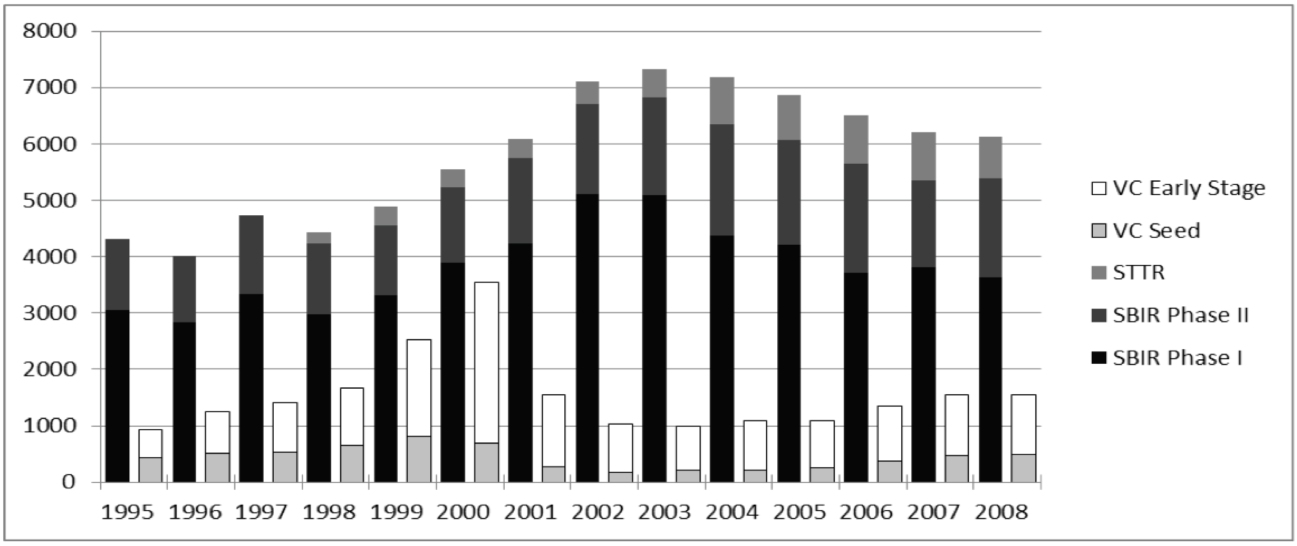
In *The Entrepreneurial State: debunking public vs. private sector myths*, Mazzucato (2013), focuses on the active and strategic public investments that went into making revolutions in IT, biotech and nanotech happen, with two final chapters dedicated to questioning the implications for renewables. These transformations included massive amounts of publicly funded R&D (a classic 'public good' hence subject to 'market failure') which the private sector was unwilling to fund, particularly during the early stages when risk was too high. But what is often ignored by the 'market failure' framework are the complementary public funds that were spent by a network of different institutions downstream in the innovation chain. In other words, the public sector was crucial not only for basic research but also for applied research, and for providing early stage high-risk finance to the companies that were willing to engage with the innovation challenge. Figure 1 indicates in orange some of the key public agencies in the US innovation landscape including National Institutes of Health, NASA, DARPA, Small Business Innovation Research Program, NSF etc. that were active across the entire innovation chain. Downstream investments included using procurement policy to help create markets for small companies, through the SBIR scheme, which historically has provided more early stage high-risk finance to small and medium sized companies than private venture capital (Figure 2) (Block and Keller, 2012).

Figure 1. Mission Oriented Finance along entire innovation chain



Source: Mazzucato (2013) addition to Auerswald/Branscomb, (2003)

Figure 2. Number of SBIR and STTR grants compared to private venture capital

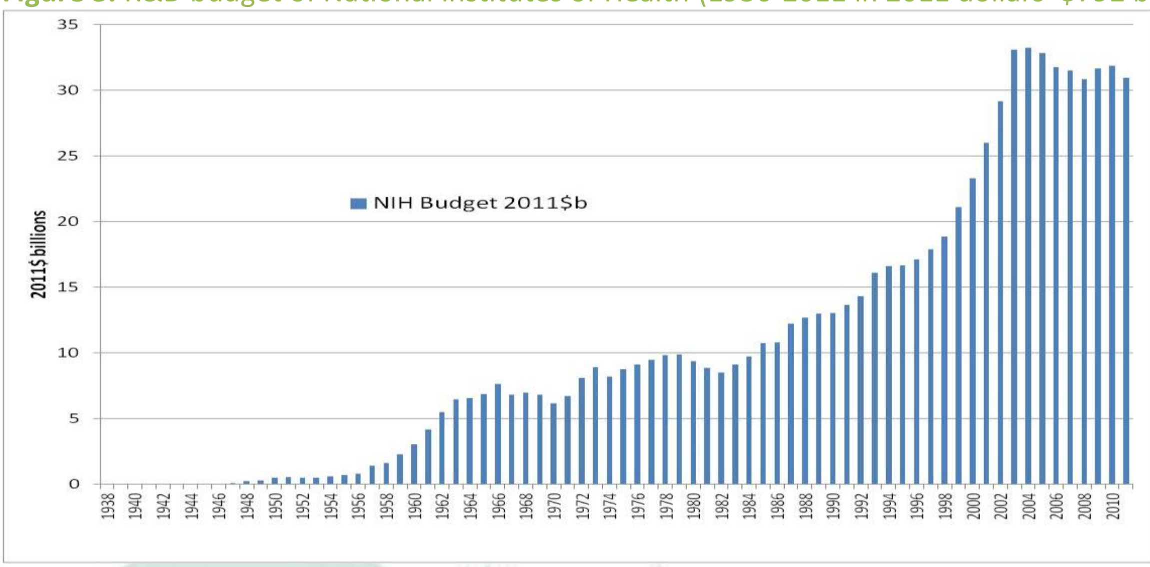


Source: Block and Keller, 2012

2. MISSION ORIENTED POLICIES, AND DECENTRALIZED NETWORK STATE

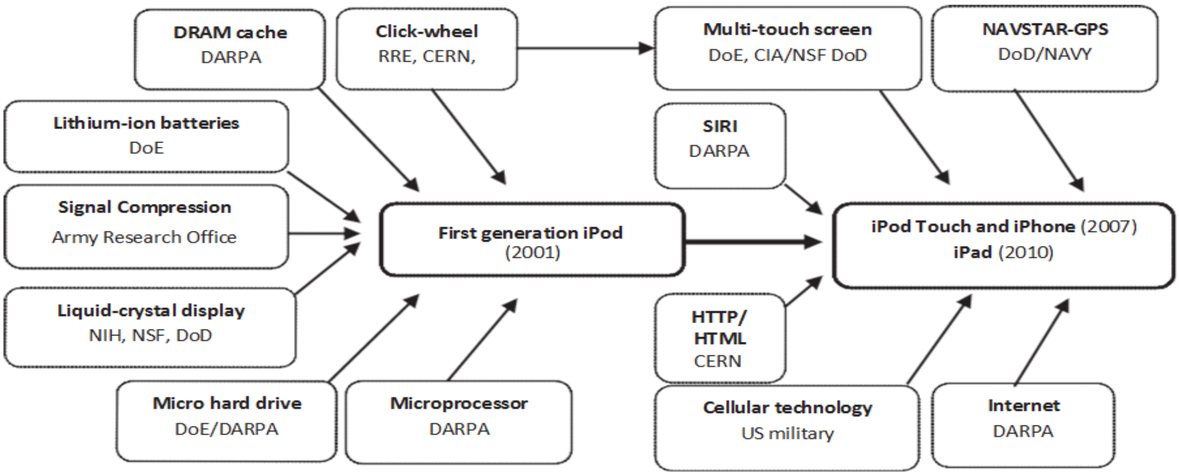
Crucial to this public funding was the nature of the organizations themselves: a decentralized network of strategic *mission oriented agencies*, which were actively creating and shaping markets, rather than just 'fixing them' (Mazzucato, 2015b). Such agencies included the National Institutes of Health (NIH) which have spent billions on health R&D, stimulating what later became the biotechnology revolution. From 1936-2011, the NIH spent $792 billion (in 2011 dollars), and £31bn in 2012 alone (Figure 3). For IT, agencies like DARPA and NASA have been central to the radical innovation that later became key to many 'smart' products. Indeed, Figure 4 shows how almost every technology that makes a 'smart' phone 'smart' and not 'stupid', was publicly financed (the internet, GPS, touch screen display, SIRI).

Figure 3. R&D budget of National Institutes of Health (1936-2011 in 2011 dollars=$792 billion)



Source: http://officeofbudget.od.nih.gov/approp_hist.html

Figure 4. The publicly funded technology behind 'smart' phones



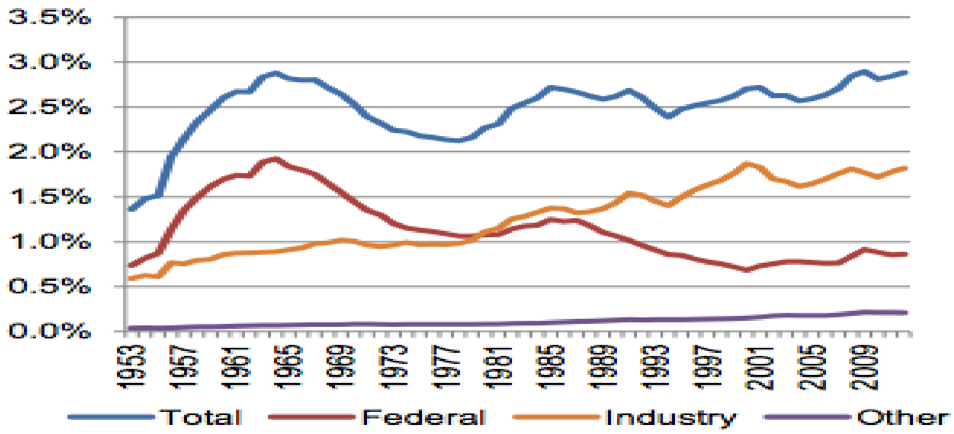
Source: Mazzucato (2013), p. 109, Fig. 13

DARPA was successful due to its ability to welcome risk, encourage trial and error as well as wait patiently for returns to its investment, and its ability to attract top-level scientists into the public sector through temporary 5-year contracts. Organizations like DARPA in the Department of Defense (DoD) and ARPA-E in DoE are 'mission driven', set to actively create new technological landscapes rather than just fix existing ones (Mowery, 2010). The organizations 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' picking of 'directions' can take place. From putting a man on the moon in the past, to fighting climate change today, the key issue is for society to engage with missions, and create dynamic links between public and private institutions that can together battle the hundreds of homework problems underneath each mission (Mazzucato, 2015b).

3. BASIC AND APPLIED RESEARCH: PUBLIC AND PRIVATE WOES

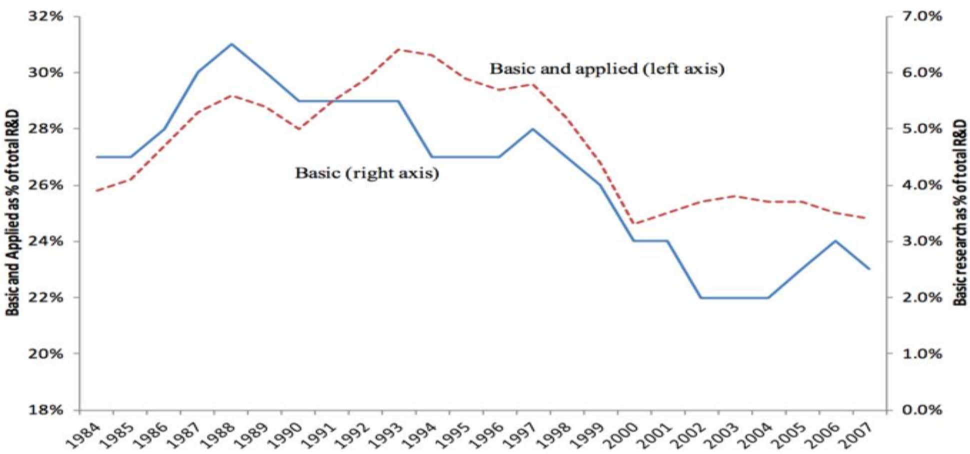
Historically, publicly funded R&D has been both basic and applied. This is crucial due to the non-linear innovation chain: there are feedback effects between basic and applied. Yet, as argued recently when giving evidence to the Senate on the role of innovation on economic growth (Mazzucato 2015b), there are two key problems today: (a) a reduction in public spending on R&D (Figure 5 below); and (b) a reduction in basic research carried out by the private sector (Figure 6). The former has been caused by the obsession with public 'deficits' (leading to sequestration and cuts to public budgets for R&D); and the latter by an increased short-termism in the private sector (Lazonick, 2014). This is evident even within R&D of which the *development* spending has steadily increased as a share of GDP while basic and applied research spending has stagnated (see Figure 7). The net result is that the US is being outcompeted internationally in R&D spending (figure 8).

Figure 5. R&D as a share of GDP by funder



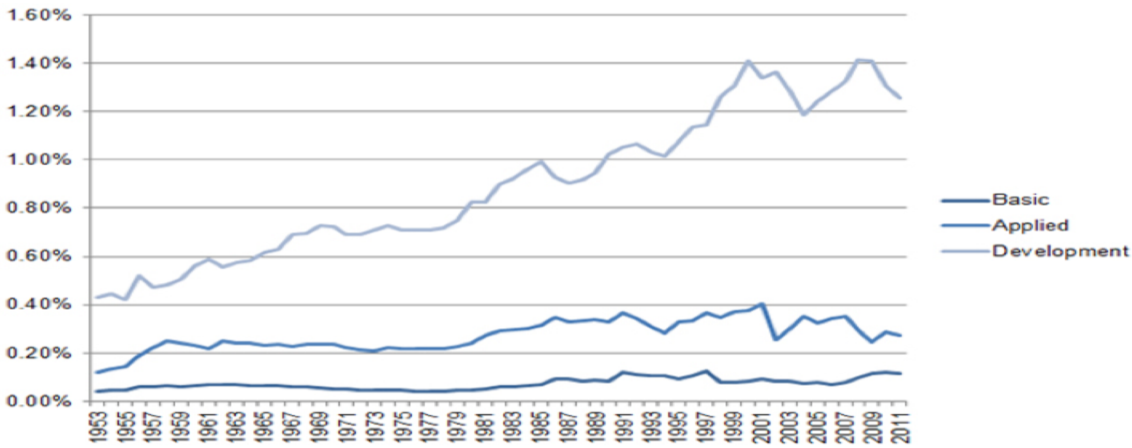
Source: National Science Foundation, 2011

Figure 6. Share of research in total non-Federal R&D



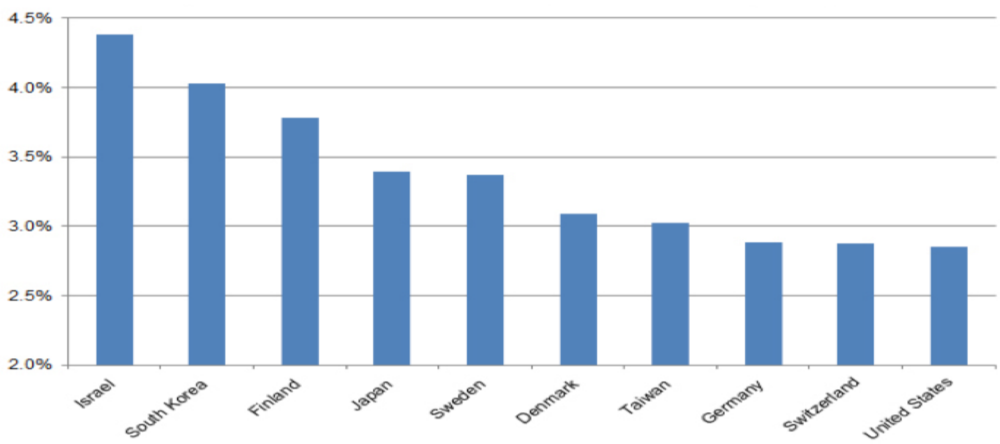
Source: NSF/Division of Science Resources Statistics, Survey of Industrial R&D: 2007 (Arora et al. 2015)

Figure 7. Industry investment in R&D as a share of GDP, by type 1953-2011



Source: National Science Foundation, Science and Engineering Indicators, 2015 (Muro & Andes, 2015)

Figure 8. Top 10 Countries for R&D as % of GDP, 2011



Source: NSF data, from Muro and Andes (2015)

4. THE GREEN DIRECTION

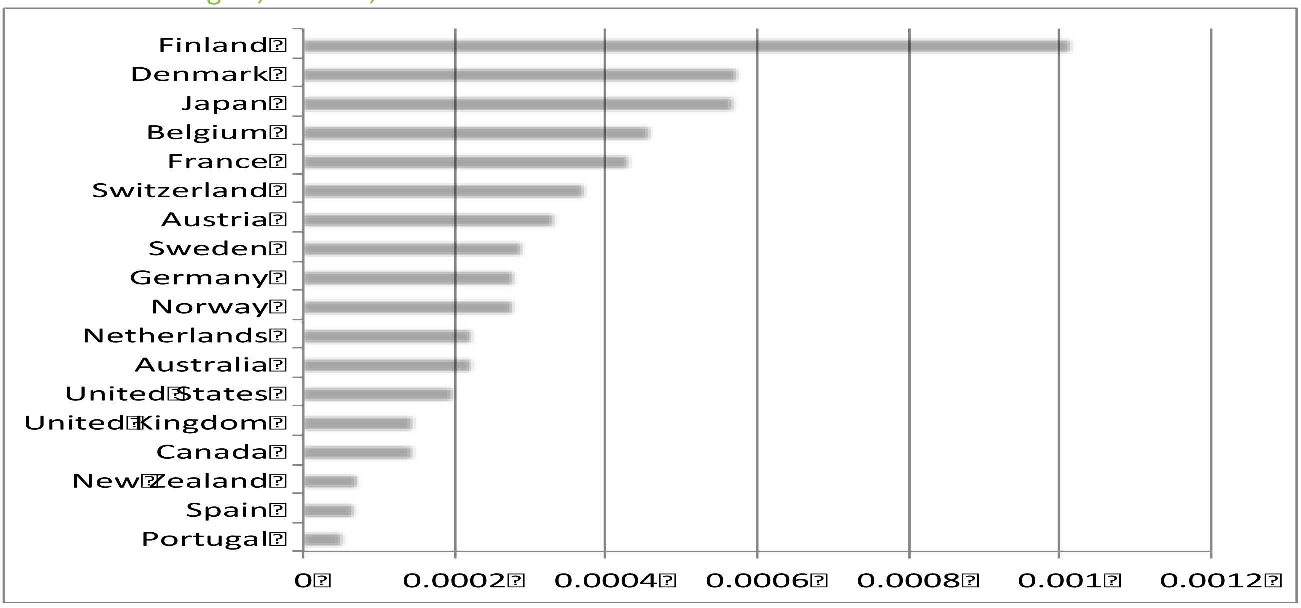
The fall in R of R&D spending, by both public and private actors, is creating serious challenges for the ability of "green-tech" to emulate the radical innovation that characterized biotech, nanotech and the Internet. On top of this, energy is also receiving a falling share of R&D in the US: while public R&D on energy made up 11% of the total public R&D budget in 1981, it is only 4% of the budget in 2015 (IEA 2015a). It means we need a hefty amount of public and private sector money across the entire innovation chain, pushing the frontiers of technology. In 2014, about $29billion were spent on green R&D globally, out of which $12billion went to renewable energy generation R&D and another $17 billion spent on energy efficiency R&D (BNEF 2015).

Drawing lessons from IT means understanding the decentralized network of public mission oriented agencies that are fundamental for enabling experimentation and learning. And the need for a portfolio of different types of investments, precisely because some will likely fail.

Yet here again we are challenged. As shown in figure 9, the US is currently not playing the international leadership role in terms of investing in clean technology R&D, as it did in IT and the private sector is lagging behind (Figure 10). The latter is not so surprising given the massive amounts of share buybacks in energy with the oil major Exxon spending 59% of its net income over 2003-12 on share buybacks, and GE, a major wind turbine manufacturer, spending 52%, making them the biggest and tenth biggest buyers of their own shares among US firms (Lazonick 2014).

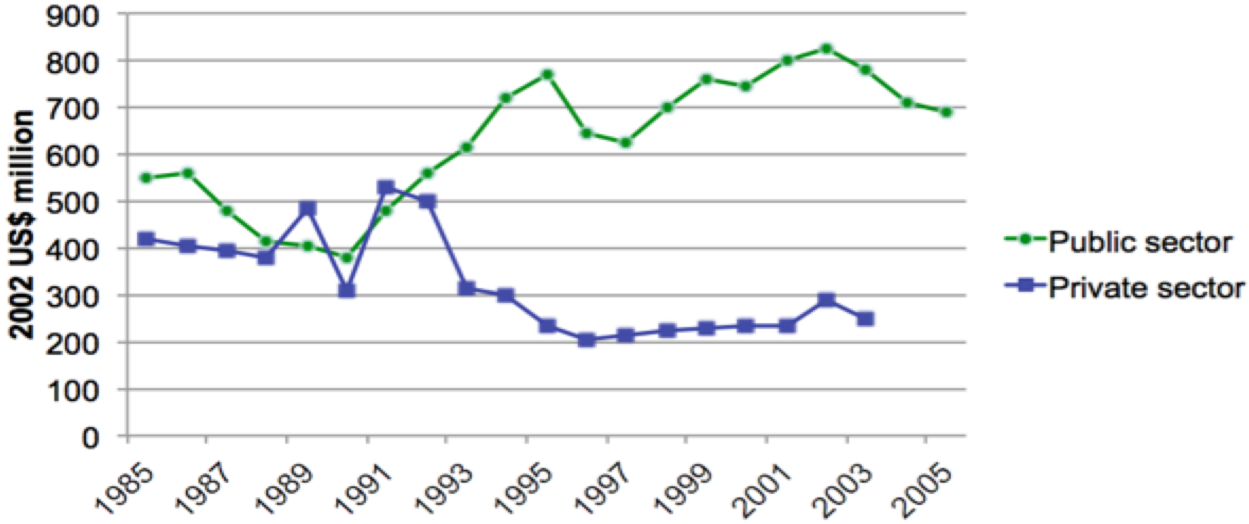
Finally, the quality of R&D also matters. While private actors are willing to invest in R&D for the more mature renewable technology wind, it is the public sector that is driving R&D in the more risky marine energy technology sector (see Figure 11). This division of labour is to be expected, but it also raises the need for more bold and strategic public agencies dedicated to R&D in path-breaking areas—not the case with the effect of austerity in Europe and sequester in the US.

Figure 9 Government funded clean technology R&D, % of GDP, including energy efficiency, renewable energies, nuclear, fuels cells and transmission.



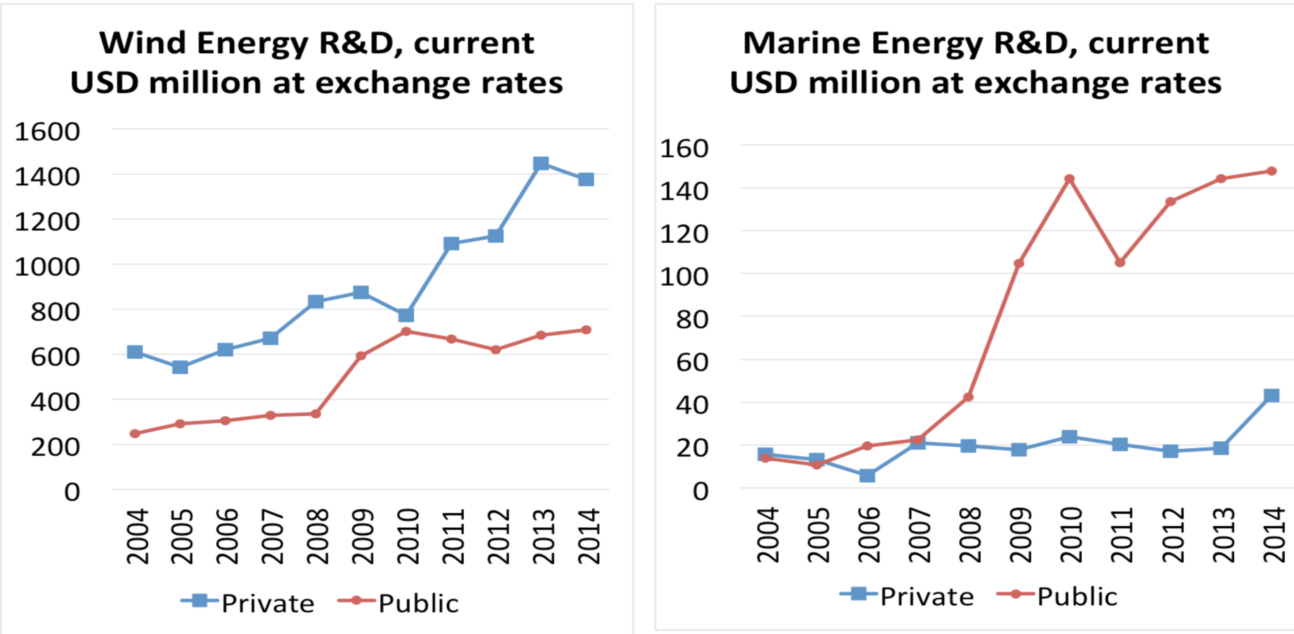
Source: R&D database underlying IEA (2015a), summing over all government R&D categories except 'fossil fuels'.

Figure 10. Renewable energy R&D investments in US (in current US$ million, 2002)



Source: Nemet and Kammen (2007), "U.S. energy research and development: Declining investment, increasing need, and the feasibility of expansion", Energy Policy, 35(1),746-755

Figure 11 Global renewable energy investments in wind and marine energy R&D (in US$ million, 2002)



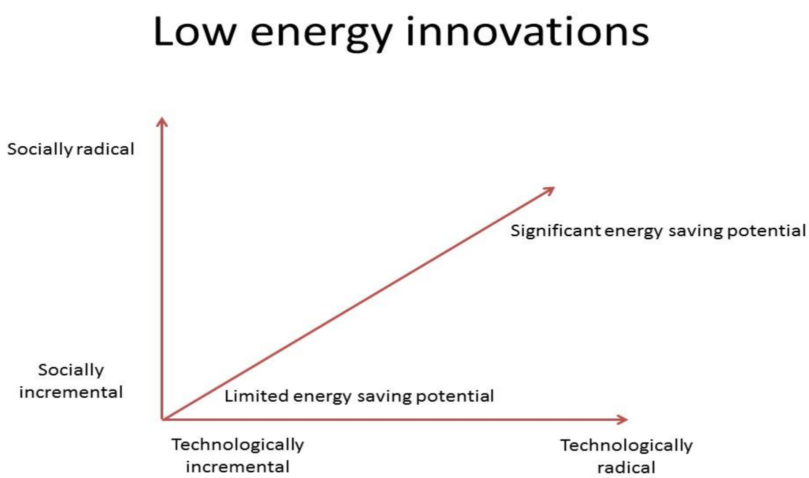
Source: Mazzucato and Semieniuk, (2016), using BNEF and IEA data

5. THE SCOPE OF ENERGY INNOVATION: SUPPLY, DEMAND AND NETWORKS; UPSTREAM AND DOWSTREAM

The wide range of innovations required to shift to more sustainable energy systems have been analysed in great detail, for example by the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA).

Within these wide portfolios, innovation comes in many guises: from incremental to radical (more efficient coal fired power plants vs. smart grids); and is social / organizational as well as technological (more efficient cars vs. car clubs, see Watson et al. 2015). Figure 12 summarises these dimensions, and how they could be combined, using the example of 'low energy innovations' that could reduce energy demand.

Figure 12 Low energy innovations



Source: SPRU, Centre on Innovation and Energy Demand (2013)

The figure also reminds that green innovation is not confined to low carbon energy supply options and smarter energy networks. Historically, government funding for innovation and R&D around the world was mainly focused on energy supply technologies, yet energy efficiency is often the cheapest and fastest way of mitigating climate change in the short term, offering multiple benefits for business, households and the economy.

However, the apparent attractiveness of energy efficiency in some assessments (e.g. in 'McKinsey curves') does not mean that energy efficiency will simply be implemented without government policy intervention. Energy efficiency opportunities are not always taken up due to factors such as high up-front costs and 'bounded rationality' in decision-making by firms and households. It is also important to take into account the 'rebound effects' that are sometimes associated with efficiency improvements in products. This means that the impact on energy demand may be partly offset by increased consumption as the cost of energy services falls (Sorrell, 2015).

A significant and growing share of government energy R&D budgets have been devoted to energy efficiency over the last two decades. It is crucial that we do not see the choice as either spending on low carbon supply technologies and infrastructures or energy efficiency. Both are essential for the green technology revolution (IEA 2015b).

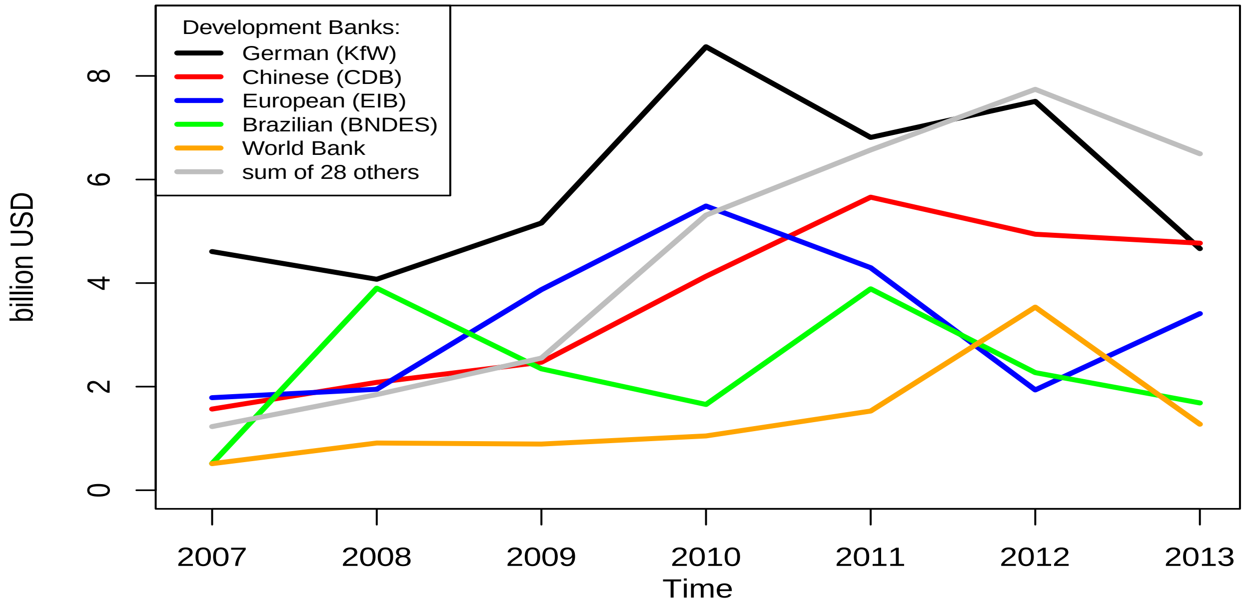
Just as the scope of innovation crosses sectors, any particular innovation process also spans several stages. Innovation does not follow a straightforward trajectory from lab-based R&D to commercial deployment. There are many dynamic feedback effects and connections between stages of innovation, and it is often carried out by networks of firms and other actors.

Discussions on clean energy innovation focus on the need for more public support for R&D due to there being a clear 'market failure': that private firms under-invest in R&D because they can't capture all the returns. Yet, basic and applied R&D must also be complemented downstream by patient finance for the firms willing to engage in uncertain innovation and commercialization. There are good arguments that more government R&D spending is warranted to tackle climate change. This has been recently argued in the UK by Nick Stern and other proponents of a new 'Global Apollo' project (King et al, 2015). However, the pattern and type of spending also matters.

History is full of examples of the importance of public downstream support. Elon Musk's Tesla S car benefited from a DoE $465m guaranteed (by the tax payer) loan. It was a success. Solyndra received a $500m guaranteed DoE loan, and later went bust. While the Solyndra bankruptcy received national attention, the public funding to Tesla didn't. And yet the existence of failures next to success is a normal feature of the highly uncertain innovation process. This is why a portfolio approach across the entire innovation chain is crucial, along each phase of the innovation process. The Chinese government has understood this and is investing in its most innovative renewable companies: *Yingli Green Energy* received $1.7 bn from 2008 through 2012 with a $5.3 bn line of credit opened for it. Other supported Chinese energy companies are LDK Solar ($9.1 bn), Sinovel Wind ($6.5 bn), Suntech Power ($7.6 bn) and Trina Solar ($4.6 bn). Meanwhile the Chinese Development Bank and a group of large Chinese state-owned utilities are financing the biggest deployment of wind and solar PV parks the world has seen to date.

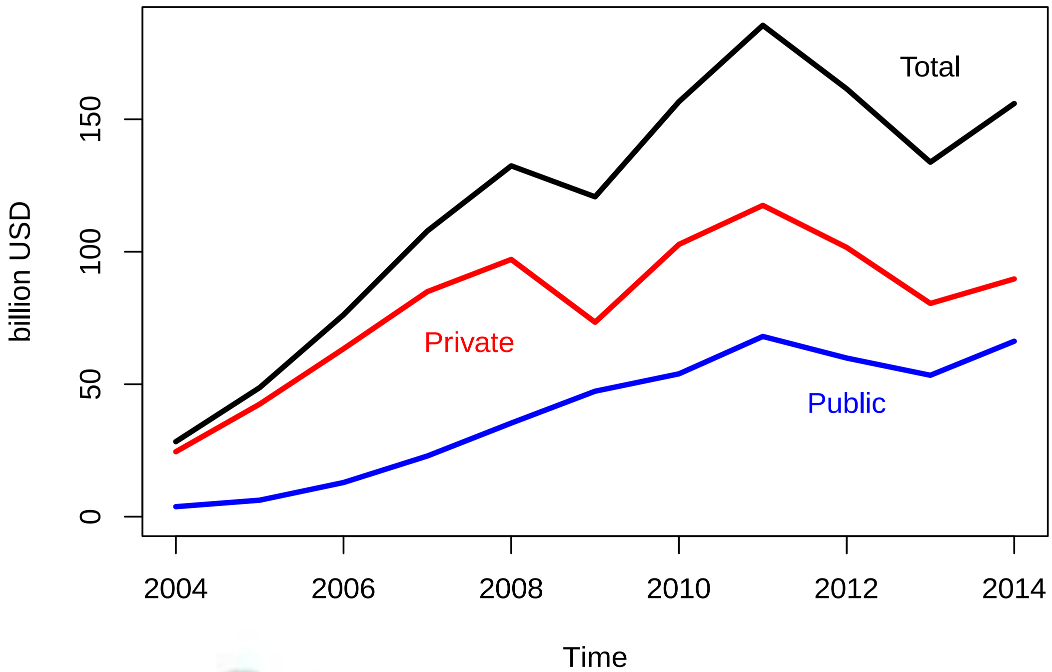
Using Bloomberg New Energy Finance (BNEF) data, Mazzucato and Semieniuk (forthcoming, 2016) show that public development banks have become the single biggest providers of green asset finance. In the renewable energy sector alone, they provide more than 15% of total asset finance, and four of them are among the top ten investors into renewables (Figure 13). In general, a closer look at sources of financing reveals that not only do publicly owned companies and agencies play an important role in asset financing (Figure 14), but that public investors are those whose portfolios include higher-risk investments on average, with the most risky portfolios held predominantly by public investors (Mazzucato and Semieniuk, 2016).

Figure 13: Asset finance for renewable energy by public development banks in US$ billion, 2007-13



Source: Mazzucato and Semieniuk (2016), based on BNEF (2014b). Estimates exclude small distributed capacity less than 1 MW, large hydro, and refinancing & acquisition activities.

Figure 14 : Global annual asset finance for renewable energy split up into private and public contributions in US$ billion, 2004-14



Source: Mazzucato and Semieniuk, 2016, data from BNEF. Estimates exclude small distributed capacity less than 1 MW, large hydro, and refinancing & acquisition activities.

6. A WIDE RANGE OF INNOVATIONS IS NEEDED: A PORTFOLIO APPROACH

Figure 15 reflects the overall pattern of spending by OECD governments on energy R&D. It shows that, overall, the portfolio has become more diverse over time – and spending levels have risen and fallen with trends in the oil price. The figure excludes R&D by non-OECD countries, with spending in China having risen significantly. Private sector R&D spending remains dominated by R&D spending in fossil fuels by oil and gas companies, though the data on private sector R&D is far from comprehensive (Skea et al, 2015).

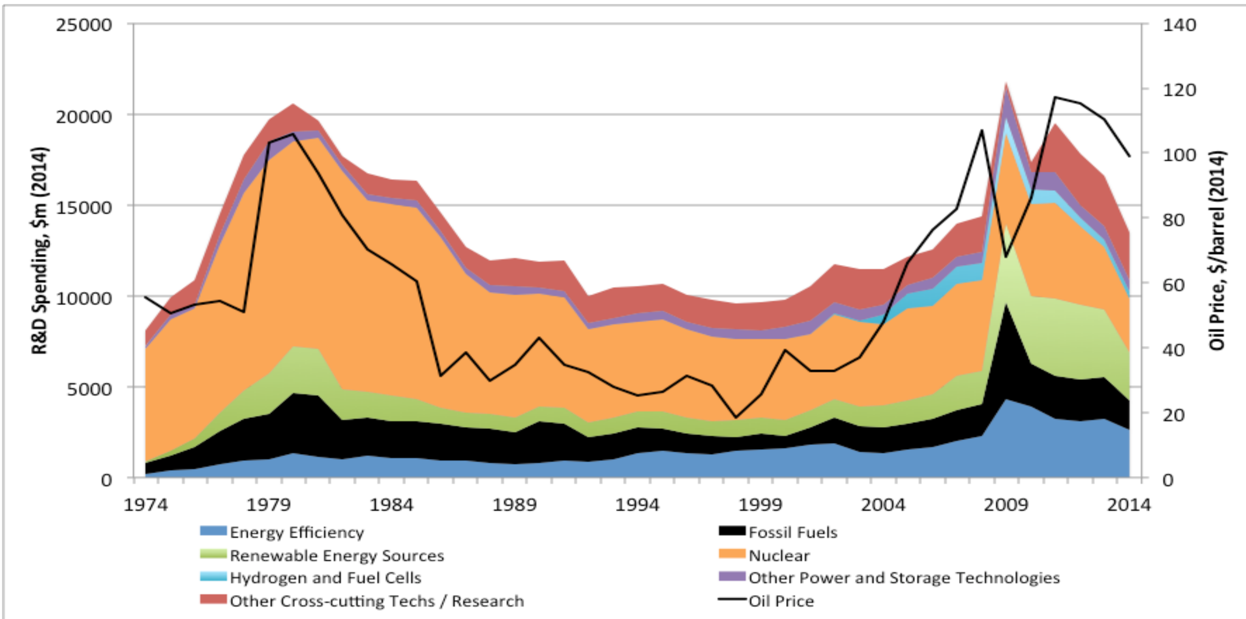
The emphasis by many governments on a portfolio approach is understandable. Rather than trying to identify the set of necessary technologies ex ante, the climate change challenge requires keeping options open in areas like energy efficiency and smarter energy systems as well as energy supply technologies such as solar, wind, biofuels, CCS and nuclear. This variety is critical so that if any one area suffers, there are other sources available. Some of these areas will require specific mission-oriented programmes for R,D,D&D (research, development, demonstration and deployment). However, given that individual countries will have particular resource endowments, industrial specialisms and limited budgets, some prioritisation of national innovation portfolios is both sensible and necessary.

Within these portfolios, R&D is not an alternative but a complement to support for demonstration and commercialisation. There is often a symbiotic relationship between R&D and demonstration / early deployment – and it is the latter that has driven a lot of the cost reductions we have seen in technologies like solar PV through economies of scale and learning by doing. Therefore, to transform the technology landscape, R&D needs to be complemented by targeted public support for demonstration, scaling up new technologies and for deployment / commercialization. Increases in energy funding have to be coherent and proportional over the entire innovation trajectory.

Additionally, investment is required in enabling technologies (e.g. energy storage, smart meters/controls) and energy systems or infrastructures (e.g. district heating and smarter grids) to accelerate the transition towards a low carbon economy. Most of these already exist in some form (at least for a 2050 timescale), though for some the costs and performance is not yet sufficient to compete with incumbent fossil-fuel based technologies.

Effectively, these separate programmes have to be thought together as a portfolio of investments into the 'green revolution', some of which may ultimately contribute more than others to the aim of decarbonizing the economy. But since it cannot be known ex ante, which ones are the more successful technologies, the portfolio approach is needed. That this focus on a broad set of measures and sectors additionally may have positive spill-overs into the investment behavior of the private financial sectors and benefit overall growth and technological progress can only be mentioned in passing (for more see Perez 2015, Mazzucato and Perez 2014).

Figure 15. Energy R&D spending by OECD member governments



Source: International Energy Agency (2015)

7. POLICY IMPLICATIONS: WHAT SHOULD GOVERNMENTS DO, APART FROM SPENDING MORE?

1. **It is essential that we radically increase the amount of R,D,D&D spending across the entire innovation chain of a diverse set of low carbon energy choices, from basic research through applied research to demonstration, market creation and deployment.** This should be seen through the lens of portfolio investing which means that many projects will fail. Devising investment portfolios so returns from the successful investments, can help cover inevitable losses in the less successful ones, is a crucial issue (Mazzucato, 2015).

2. **Building the kind of mission oriented dynamic public institutions that can attract top talent (as DARPA and ARPA-E have in the past) to better engage dynamically with the private sector is also essential**. Critically, Bill Gates is right when he claims that such an increase in R&D for renewable energy must be led by government as it was for IT (Bennet, 2015). And the announcements at the 2015 Paris Climate Negotiations that the US and 18 other countries have pledged to double funds for clean energy research to a total of $20bn over five years, complementing the private funds via the Breakthrough Energy initiative by Gates and Zuckerberg also announced at COPS21, is a great start.

3. **Definancialization of energy companies should become more central to green innovation policy:** energy subsidies, including incentives for low carbon technology deployment and cost reduction, could be made conditional on a greater percentage of company profits being reinvested in low carbon energy R&D and less on share-buybacks.

4. **As with IT, low carbon energy R&D must be complemented by patient long term committed finance for companies willing to engage with uncertainty**. While R&D is critical, it will not reduce risks sufficiently for investors in many new technologies that could fall into the 'valley of death' between R&D and deployment. The 3-5 year cycles of exit-driven VC is not sufficient and it is crucial to get the entire financial sector more engaged with financing deployment and diffusion.

5. **While pricing carbon is important, it will be insufficient to support change on the scale and speed required to tackle climate change.** A single carbon price would be very hard to achieve, and would have different effects in different markets (e.g. householders considering vehicle choices vs firms investing in new power plants).

6. **More attention should be paid to demonstration and early deployment funding.** For example, the smart grid trials in the UK that have demonstrated combinations of new technologies and have also investigated consumer choices and responses; and policies in a number of countries (e.g Germany, the US, the UK) that have supported deployment and rapid cost reduction in solar PV.

7. **More mission-oriented R&D programmes may be crucial for specific advances in those areas that can achieve the scale required to meet a large share of world's energy needs.** Currently there are proposals for such programmes in some renewables, energy storage and transmission (King et al. 2015) and in areas like nuclear fusion (E Mazzucato 2015), though this technology has not yet lived up to its promise, despite decades of large-scale funding. It is crucial, however, that governments have sufficient institutional capacity to inform funding priorities for such programmes and to make decisions about whether to continue with current priorities or to change course.

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