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The Entrepreneurial State

Debunking Public vs. Private Sector Myths

Mariana Mazzucato

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Introduction

DO SOMETHING DIFFERENT

> *...our disability is discursive: we simply do not know how to talk about things anymore.*
>
> Tony Judt (2010, 34)

A Discursive Battle

Never more than today is it necessary to question the role of the State in the economy – a burning issue since Adam Smith's *An Inquiry into the Nature and Causes of the Wealth of Nations* (Smith, 1776). This is because in most parts of the world we are witnessing a massive *withdrawal* of the State, one that has been justified in terms of debt reduction and – perhaps more systematically – in terms of rendering the economy more 'dynamic', 'competitive' and 'innovative'. Business is accepted as the innovative force, while the State is cast as the inertial one – necessary for the 'basics', but too large and heavy to be the dynamic engine.

The book is committed to dismantling this false image. In the same way that Mexico was stolen from California and Texas through the purposeful fabricated image of the 'lazy Mexican' under a palm tree (Acuña 1976), the State has been attacked and increasingly dismantled, through images of its bureaucratic, inertial, heavy-handed character. While innovation is not the State's main role, illustrating its potential innovative and dynamic character – its historical ability, in some countries, to play an *entrepreneurial* role in society – is perhaps the most effective way to defend its existence, and size, in a proactive way. Indeed, in *Ill Fares the Land*, Tony Judt (2010) describes that the attack on the welfare state, over the last three decades, has involved a 'discursive' battle – changing the ways we talk about it – with words like 'administration' rendering the State less important and adventurous.

The book seeks to change how we talk about the State, dismantling the ideological stories and images – separating evidence from fiction.

This work is based on a revised and significant expansion of a report I wrote for DEMOS, a UK-based think tank, on *The Entrepreneurial State*. Unlike a more traditional academic piece of writing – that can take years from start to finish – I wrote the DEMOS work in a style similar to the political pamphlets of the 1800s: quickly, and out of a sense of *urgency*. I wanted to convince the UK government to change strategy: to not cut State programmes in the name of making the economy 'more competitive' and more 'entrepreneurial', but to reimagine what the State *can* and must do to ensure a sustainable post-crisis recovery. Highlighting the active role that the State *has* played in the 'hotbeds' of innovation and entrepreneurship – like Silicon Valley – was the key to showing that the State can not only facilitate the knowledge economy, but actively create it with a bold vision and targeted investment.

This expanded version of the DEMOS report (more than double its size) builds on that initial research and pushes it harder, drawing out further implications at the firm and sectoral level. Chapter 5, dedicated entirely to Apple, looks at the whole span of State support that this leading 'new economy' company has received. After looking at the role of the State in making the most courageous investments behind the Internet and IT revolution, Chapters 6 and 7 look at the next big thing: 'green' technology. Unsurprisingly we find that across the globe the countries leading in the green revolution (solar and wind energy are the paradigmatic examples explored) are those where the State is playing an active role beyond that which is typically attributed to market failure theory. And the public sector organizations involved, such as development banks in Brazil and China, are not just providing countercyclical lending (as Keynes would have asked for), but are even 'directing' that lending towards the most innovative parts of the 'green' economy. Questions about whether such 'directionality' should raise the usual worries about the State's inability to 'pick winners' are confronted head on – demystifying old assumptions. The book also looks more explicitly at the collective group of actors that are required to create innovation-led growth and questions whether the current innovation 'ecosystem' is a functional *symbiotic* one or a dysfunctional *parasitic* one. Can a nonconfident State even recognize the difference? Chapters 8 and 9 go deeper into this question by asking how we can make sure that the distribution of the returns (rewards) generated from active State investments in innovation are just as social as the risks taken.

Indeed, some of the very criticisms that have recently been directed at the banks (socialization of risk, privatization of rewards) appear to be just as relevant in the 'real' innovation economy.

The reason I call, both the DEMOS report and the current book, the 'entrepreneurial' State is that entrepreneurship – what every policymaker today seems to want to encourage – is not (just) about start-ups, venture capital and 'garage tinkerers'. It is about the willingness and ability of economic agents to take on risk and real *Knightian* uncertainty: what is genuinely unknown.[1] Attempts at innovation usually fail – otherwise it would not be called 'innovation'. This is why you have to be a bit 'crazy' to engage with innovation... it will often cost you more than it brings back, making traditional cost–benefit analysis stop it from the start. But whereas Steve Jobs talked about this in his charismatic 2005 Stanford lecture on the need for innovators to stay 'hungry and foolish' (Jobs 2005), few have admitted how much such foolishness has been 'seriously' riding on the wave of State-funded and -directed innovations.

The State... 'foolishly' developing innovations? Yes, most of the radical, revolutionary innovations that have fuelled the dynamics of capitalism – from railroads to the Internet, to modern-day nanotechnology and pharmaceuticals – trace the most courageous, early and capital-intensive 'entrepreneurial' investments back to the State. And, as will be argued fully in Chapter 5, all of the technologies that make Jobs' iPhone so 'smart' were government funded (Internet, GPS, touch-screen display and the recent SIRI voice activated personal assistant). Such radical investments – which embedded extreme uncertainty – did not come about due to the presence of venture capitalists, nor of 'garage tinkerers'. It was the visible hand of the State which made these innovations happen. Innovation that would not have come about had we waited for the 'market' and business to do it alone – or government to simply stand aside and provide the basics.

Beyond Fixing Failures

But how have economists talked about this? They have either ignored it or talked about it in terms of the State simply fixing 'market failures'. Standard economic theory justifies State intervention when the social

1 'Knightian uncertainty' refers to the 'immeasurable' risk, i.e. a risk that cannot be calculated. This economic concept is named after University of Chicago economist Frank Knight (1885–1972), who theorized about risk and uncertainty and their differences in economic terms.

return on investment is higher than the private return – making it unlikely that a private business will invest. From cleaning up pollution (a negative 'externality' not included in companies' costs) to funding basic research (a 'public good' difficult to appropriate). Yet this explains less than one-quarter of the R&D investments made in the USA. Big visionary projects – like putting 'a man on the moon', or creating the vision behind the Internet – required much more than the calculation of social and private returns (Mowery 2010).

Such challenges required a vision, a mission, and most of all *confidence* about what the State's role in the economy is. As eloquently argued by Keynes in the *The End of Laissez Faire* (1926, 46), 'The important thing for Government is not to do things which individuals are doing already, and to do them a little better or a little worse; but to do those things which at present are not done at all.' Such a task requires vision and the desire to *make things happen* in specific spaces – requiring not just bureaucratic skills (though these are critical, as pointed out by Max Weber)[2] but real technology-specific and sector-specific *expertise*. It is only through an exciting vision of the State's role that such expertise can be recruited, and is then able to map out the landscape in the relevant space. Indeed, a key part of DARPA's 'secret' – the agency that invented *and* commercialized the Internet within the US Department of Defense (examined in Chapter 4) – has been its ability to attract talent and create excitement around specific missions. And it is no coincidence that a similar agency in today's US Department of Energy, ARPA-E, is not only leading US green investments, but also having fun on the way (welcoming the trial and error process in energy research rather than fearing it) and attracting great brains in energy research (Grunwald 2012).

While many of the examples in the book come from the US – purposely to show how the country that is often argued to most represent the benefits of the 'free-market system' has one of the most interventionist governments when it comes to innovation – modern-day examples are coming more from 'emerging' countries. Visionary investments are exemplified today by confident State investment banks in countries like Brazil and China – not only providing countercyclical lending but also *directing* that lending to new uncertain areas that private banks and venture capitalists (VCs) fear. And here too, like in DARPA, expertise, talent and vision matter. In Brazil, it is no coincidence that BNDES, the State investment bank, is run by two individuals whose background is Schumpeterian innovation economics – and it is their team of experts that have allowed the bold risk taking in key new sectors like biotech and cleantech to occur. The bank is today earning record-level returns in productive, rather than purely speculative, investments: in 2010 its return on equity was an astounding 21.2 per cent (reinvested by the Brazilian Treasury in areas like health and education) while that of the World Bank's equivalent organization, the International Bank for Reconstruction and Development (IBRD), was not even positive (−2.3 per cent). Equally, it is the Chinese Development Bank that is today leading the country's investments in the green economy (Sanderson and Forsythe 2012). While the usual suspects worry that these public banks 'crowd out' private lending (*Financial Times* 2012), the truth is that these banks are operating in sectors, and particular areas within these sectors, that the private banks fear. It is about the State acting as a force for innovation and change, not only 'de-risking' risk-averse private actors, but also boldly leading the way, with a clear and courageous vision – exactly the opposite image of the State that is usually sold.

2 Evans and Rauch (1999) show, for instance, that a Weberian-type State bureaucracy that employs meritocratic recruitment and offers predictable, rewarding long-term careers enhances prospects for growth, even when controlling for initial levels of GDP per capita and human capital.

From 'Crowding In' to 'Dynamizing In'

And this is the punchline: when organized effectively, the State's hand is firm but not heavy, providing the vision and the dynamic *push* (as well as some 'nudges' – though nudges don't get you the IT revolution of the past, nor the green revolution today) to make things happen that otherwise would not have. Such actions are meant to increase the courage of private business. This requires understanding the State as neither a 'meddler' nor a simple 'facilitator' of economic growth. It is a key partner of the private sector – and often a more daring one, willing to take the risks that business won't. The State cannot and should not bow down easily to interest groups who approach it to seek handouts, rents and unnecessary privileges like tax cuts. It should seek instead for those interest groups to work dynamically with it in its search for growth and technological change.

Understanding the unique nature of the public sector – as more than an inefficient 'social' version of the private sector – impacts the nature of the public–private collaborations that emerge, as well as the 'rewards' that the State feels justified to reap (an area I focus on in Chapter 9).

An entrepreneurial State does not only 'de-risk' the private sector, but envisions the risk space and operates boldly and effectively within it to make things happen. Indeed, when not confident, it is more likely that the State will get 'captured' and bow to private interests. When not taking a leading role, the State becomes a poor imitator of private sector behaviours, rather than a real alternative. And the usual criticisms of the State as slow and bureaucratic are more likely in countries that sideline it to play a purely 'administrative' role.

So it is a self-fulfilling prophecy to treat the State as cumbersome, and only able to correct 'market failures'. Who would want to work in the State sector if that is how it is described? And is it a coincidence that the 'picking winners' problem – the fear that the State is unable to make bold decisions on the *direction* of change – is discussed especially in countries that don't have an entrepreneurial vision for the State, i.e. countries where the State takes a backseat and is then blamed as soon as it makes a mistake? Major socioeconomic 'challenges' such as climate change and 'ageing' require an active State, making the need for a better understanding of its role within public–private partnerships more important than ever (Foray et al. 2012).

Images Matter

The cover of this book shows a face of a lion and a pussycat. Which one has 'animal spirits' (Keynes's famous expression) and which one is domesticated and 'lags' behind due to passivity? Which is the State? Which is business? This might be an exaggerated dichotomy but it is one that needs consideration because, as I will argue, we are continuously fed the image of just the opposite: a roaring business sector and purring bureaucratic State sector. Even Keynes, in discussing the volatility of private business investment, fed this contrast by talking about 'animal spirits' as guiding business investment – the image of a roaring lion. But in a secret letter to Roosevelt he also talked about business as 'domesticated animals':

> Businessmen have a different set of delusions from politicians, and need, therefore, different handling. They are, however, much milder than politicians, at the same time allured and terrified by the glare of publicity, easily persuaded to be 'patriots', perplexed, bemused, indeed terrified, yet only too anxious to take a cheerful view, vain perhaps but very unsure of themselves, pathetically responsive to a kind word. You could do anything you liked with them, if you would treat them (even the big ones), **not as wolves or tigers, but as domestic animals by nature**, even though they have been badly brought up and not trained as you would wish. It is a mistake to think that they are more immoral than politicians. If you work them into the surly, obstinate, terrified mood, of which domestic animals, wrongly handled, are so capable, the nation's burdens will not get carried to market; and in the end public opinion will veer their way… (Keynes 1938, 607; emphasis added)

This view, of business not as tigers and lions, but as pussycats means that the State is not only important for the usual Keynesian countercyclical reasons – stepping in when demand and investment is too low – but also at *any* time in the business cycle to play the role of real tigers. Nowhere is this truer than in the world of innovation – where uncertainty is so high. Indeed, the green revolution that is taking off in the world, only happens to coincide with a crisis environment (and in fact the government's relevant investments reach much farther back in time). But even if today were a boom period, there would not be enough investments being made in radical green technologies were it not for the State. Even during a boom most firms and banks would prefer to fund low-risk incremental innovations, waiting for the State to make its mark in more radical areas. But as with all technological revolutions, green technology requires a bold government to take the lead – as this was the case with the Internet, biotech and nanotech.

Providing such leadership, the State makes things happen that otherwise would not have. But whether this role is justified given the characteristics of 'public good' and the role of 'externalities' (both critical to the market failure argument), or whether it is justified due to a broader understanding of the State as a courageous actor in the economic system makes all the difference. The former understanding leads to discussions about the possibilities of the State 'crowding out' (or 'crowding in') private investment, creating a narrow view of what the State is and what policy options are acceptable (Friedman 1979). The latter understanding leads to (more) exciting discussions about what the State can do to raise the 'animal spirits' of business – to get it to stop hoarding cash and to spend it in new path-breaking areas. This makes a big difference in how one imagines the policy 'space'. For a start, it makes the State less vulnerable to hype about what the business sector can (and does) do. It is indeed the weakest States that give in (the most) to the rhetoric that what is needed are different types of 'tax cuts' and elimination of regulatory 'red tape'. A confident government recognizes fully that the business sector might 'talk' about tax but 'walks' to where new technological and market opportunities are – and that this is strongly correlated with areas characterized by major public sector investments. Did Pfizer recently leave Sandwich, Kent (UK) to go to Boston in the US due to the latter's lower tax and lower regulation? Or was it due to the fact that the public sector National Institutes of Health (NIH) have been spending close to $30.9 billion per year in the USA funding the knowledge base on which private pharmaceutical firms thrive?

In economics, the 'crowding-out' hypothesis is used to analyse the possibility that increased State spending reduces private business investment, since both compete for the same pool of savings (through borrowing), which might then result in higher interest rates which reduces the willingness of private firms to borrow, and hence invest. While Keynesian analysis has argued against this possibility during periods of underutilized capacity (Zenghelis 2011), the point here is that *even in the boom* (when in theory there is full capacity utilization), there are in practice many parts of the risk landscape where private business fears treading and government leads the way. In fact, the spending that led to the Internet occurred mainly during boom times – as was the government spending that lead to the nanotechnology industry (Motoyama et al. 2001).

Thus a proper defence of the State should argue that it not only 'crowds in' private investment (by increasing GDP through the multiplier effect) – a correct but limited point made by Keynesians – it does something more. The way that I interpret Judt's challenge is that we must start using new words to describe the State. Crowding in is a concept that – while defending the public sector – is still using as a benchmark the negative: the possibility that government investment crowds out private investment, by competing for the same limited amount of savings. If we want to describe something positive and visionary, a word that is bolder and offensive, not defensive, should be used. Rather than analysing the State's active role through its correction of 'market failures' (emphasized by many 'progressive' economists who rightly see many failures), it is necessary to build a theory of the State's role in *shaping* and *creating* markets – more in line with the work of Karl Polanyi (1944) who emphasized how the capitalist 'market' has from the start been heavily shaped by State actions. In innovation, the State not only 'crowds in' business investment but also 'dynamizes it in' – creating the vision, the mission and the plan. This book is committed to explaining the process by which this happens.

The book tries to change the ways we talk about the State, in order to expand our vision of what it can do – it takes on Judt's 'discursive' battle. From an inertial bureaucratic 'leviathan' to the very catalyst for new business investment; from market 'fixer' to market shaper and creator; from simply 'de-risking' the private sector, to welcoming and taking on risk due to the opportunities it presents for future growth. Against all odds.

Structure of the Book

The book is structured as follows:

Chapter 1 begins by confronting the popular image of the State as a bureaucratic machine with a different image of the State as lead risk taker. The State is presented as an entrepreneurial agent – taking on the most risky and uncertain investments in the economy. Rather than understanding State risk taking through the usual lens of 'market failures' – with the State acting as an inert bandage for areas underserved by the market – the concept of its entrepreneurial risk taking is introduced. The State does not 'de-risk' as if it has a 'magic wand' that makes risks disappear. It *takes on* risks, shaping and creating new markets. The fact economists have no words for this role has limited our understanding of the role the State has played in the past – in areas like Silicon Valley – and the role that it can play in the future, in areas like the 'green revolution'.[3]

Chapter 2 provides background to the discussion by looking at how economists understand the role of innovation and technology in economic growth. Whereas a generation ago, technological advance was seen as something that was externally given in economic models, there is now extensive literature to show that actually it is the rate – and direction – of innovation that drives the ability for economies to grow. The chapter juxtaposes two very different frameworks for understanding the role of the State in innovation-led growth – both framed in terms of different types of 'failures' that the State corrects. The first is the 'market failure' approach, in which the State is simply remedying the wedge between private and social returns. The second is the 'systems of innovation' approach, which looks at R&D spending in a more holistic way, as part of a system in which knowledge is not only produced but also diffused throughout an economy.

3 Contemporary political economists, such as Chang (2008) and Reinert (2007), who specialize in the history of economic policy do of course talk about the role of the State in promoting a 'catching-up' process, or in actively acting countercyclically. Yet these are more in line with a view of the State not as an entrepreneurial risk taker (of *first* resort) but a more passive entrepreneur of last resort.

But even in this second approach the State is mainly fixing failures, this time 'system failures' – with the conclusion being that it is 'facilitating' innovation by 'creating the conditions' for it. These frameworks have provided the justification for increased government spending on innovation, while at the same time – due to the lack of attention on the State as lead risk taker – allowed certain myths to survive. These myths describe the relationship between innovation and growth; the role of SMEs; the meaning of patents in the knowledge economy; the degree to which venture capital is risk-loving; and the degree to which investment in innovation is sensitive to tax cuts of different kinds.

Chapter 3 presents a different view, of an entrepreneurial State acting as a lead risk taker and market-shaper. This is not a substitute for the view espoused in the other two frameworks, but a complement, and one that by being ignored has caused policies informed by the 'failures' approach to be limited in nature, and often more 'ideologically' driven. Examples are provided from the pharmaceutical industry – where the most revolutionary new drugs are produced mainly with public, not private, funds. I also examine the way in which venture capital has 'surfed the wave' of State investments in biotechnology.

Chapter 4 exemplifies the key points on the 'entrepreneurial State' by focusing on the recent industrial policy history of the US, and shows that despite common perceptions, there the State has been extremely proactive and entrepreneurial in the development and commercialization of new technologies. Entrepreneurship by the State can take on many forms. Four examples – the creation of the Defense Advanced Research Projects Agency (DARPA), the Small Business Innovation Research (SBIR) programme, the Orphan Drug Act of 1983, and recent developments in nanotechnology – are used to illustrate this point. It builds on the notion of the 'Developmental State' (Block 2008; Chang 2008; Johnson 1982) pushing it further by focusing on the type of risk that the public sector has been willing to absorb and take on.

While Chapters 3 and 4 look at sectors, Chapter 5 focuses on the history of one particular company – Apple – a company that is often used to laud the power of the market and the genius of the 'garage tinkerers' who revolutionize capitalism. A company that is used to illustrate the power of Schumpeterian creative destruction.[4] I turn this notion on its head.

4 Joseph Schumpeter (1942 [2003]) referred to 'creative destruction' as the process by which innovation changes the status quo, allowing the market shares of firms which introduce new products and processes to grow, and those of the firms that resist change to fall.

Apple is far from the 'market' example it is often used to depict. It is a company that not only received early stage finance from the government (through the SBIC programme, which is related to the SBIR programme discussed in Chapter 4), but also 'ingeniously' made use of publicly funded technology to create 'smart' products. In fact, there is not a single key technology behind the iPhone that has not been State-funded. Besides the communication technologies (discussed in Chapter 4), the iPhone is smart because of features such as the Internet, GPS, a touch-screen display, and the latest new voice activated personal assistant (SIRI). While Steve Jobs was no doubt an inspiring genius worthy of praise, the fact that the iPhone/iPad empire was built on these State-funded technologies provides a far more accurate tale of technological and economic change than what is offered by mainstream discussions. Given the critical role of the State in enabling companies like Apple, it is especially curious that the debate surrounding Apple's tax avoidance has failed to make this fact more broadly known. Apple must pay tax not only because it is the right thing to do, but because it is the epitome of a company that requires the public purse to be large and risk-loving enough to continue making the investments that entrepreneurs like Jobs will later capitalize on (Mazzucato 2013b).

Chapter 6 looks at the next 'big thing' after the Internet: the green revolution, which is today being led by the State, just like the IT revolution was. In 2012 China announced its plan to produce 1,000 GWs of wind power by 2050. That would be approximately equal to replacing the entire existing US electric infrastructure with wind turbines. Are the US and Europe still able to dream so big? It appears not. In many countries, the State is asked to take a back seat and simply 'subsidize' or incentivize investments for the private sector. We thus fail to build visions for the future similar to those that two decades ago resulted in the mass diffusion of the Internet. The chapter looks at which countries in the world are leading with a green vision, and the role of their States – and the 'patient' finance supplied by State development banks – in creating the 'catalytical' early, and risky, investments necessary to make it happen.

Chapter 7 focuses on the role of the 'entrepreneurial' risk-taking State in launching specific clean technologies, in this case wind turbines and solar PV panels. It was State funding and the work of particular State agencies that provided the initial push, early stage high-risk funding and institutional environment that could establish these important technologies. While Chapter 5 emphasized the role of the US entrepreneurial State in leading the IT revolution as well as in establishing the foundations of the biotech industry, this chapter emphasizes the role of countries like

Germany, Denmark and China in directing the green revolution as it spreads across more economies.

Chapters 8 and 9 argue that once we accept the role of the State as lead risk taker – beyond the usual 'market fixing' or 'creating conditions' approach – the question arises as to whether this role is represented in the risk–reward relationship. In so many cases, public investments have become business giveaways, making individuals and their companies rich but providing little (direct or indirect) return to the economy or to the State. This is most evident in the case of pharmaceuticals, where publicly funded drugs end up being too expensive for the taxpayers (who funded them) to purchase. It is also true in the case of IT, where the State's active risk-taking investments have fuelled private profits, which are then sheltered and fail to pay taxes back to the governments that supported them. Chapter 8 illustrates this point focusing in on Apple. Chapter 9 considers the points more generally, arguing that in a period of major cutbacks to reduce budget deficits, it is more critical than ever to engage in a discussion of how the State can ensure that its 'risk taking' earns back a direct return, beyond easily avoided taxation. Precisely because State investments are uncertain, there is a high risk that they will fail. But when they are successful, it is naïve and dangerous to allow all the rewards to be privatized. Indeed, criticism of the financial sector for launching the current economic crisis, reaping massive private returns and then socializing risk through unpopular bailouts is a general and unpopular feature of dysfunctional modern capitalism that should not become the norm.

Chapter 10 concludes by reflecting on how the core argument in the book – the State as an active, entrepreneurial, risk-taking agent – is not always a reality, but a possibility too often dismissed. The 'possibility' is only realized once key assumptions are overturned. From how we envision the State within its own organizations (encouraging departments in the public sector to be entrepreneurial, including the need to 'welcome' rather than fear failure), to the relationship between the State and other actors in the innovation system (e.g. by accepting itself as a more active agent, there will be many instances where the State's role is less about 'nudging' and 'incentivizing' and more about 'pushing'). The State's ability to push and direct is dependent on the kind of talent and expertise it is able to attract. And the irony is that the latter is more of a problem in countries where the State takes a back seat, only 'administering' and not leading with dynamic vision. Unless we challenge the numerous 'myths' of economic development, and abandon conventional views of the State's role in it, we cannot hope to address the structural challenges of the twenty-first century

nor produce the technological and organizational change we need for long-term sustainable and equitable growth.

Taken as a whole, the book provides a fuller understanding of the public sector's centrality to risk-taking activities and radical technological change, essential to promote growth and development. It offers a very different description of the State from that envisaged by present economic policymakers, which tends to deny the State's leading role in innovation and production. It also challenges conventional industrial policy, which unduly downplays its scope for pioneering and promoting new technologies. In contrast, it describes scenarios where the State has provided the main source of dynamism and innovation in advanced industrial economies, by pointing out that the public sector has been the lead player in what is often referred to as the 'knowledge economy' – an economy driven by technological change and knowledge production and diffusion. From the development of aviation, nuclear energy, computers, the Internet, biotechnology, and today's developments in green technology, it is, and has been, the State – not the private sector – that has kick-started and developed the engine of growth, because of its willingness to take risks in areas where the private sector has been too risk averse. In a political environment where the policy frontiers of the State are now being deliberately rolled back, the contributions of the State need to be understood more than ever. Otherwise we miss an opportunity to build greater prosperity in the future by emulating the successful public investments of the past.

What is needed is a fully-fledged understanding of the division of innovative labour in capitalism (described in Chapter 1 below), and the role that both the private and public sector play in creating, producing and diffusing innovations. The book focuses on innovation not because this is the only or most important thing the State can invest in. The State's role in guaranteeing basic human rights for all citizens – from public healthcare to public education – as well as creating the necessary infrastructure, legal and justice system that allows the economy to function properly are equally if not more important activities. The focus on innovation is due in part to the fact that it is a point of discussion where the State is most frequently attacked for its role. While the role of the private sector has typically been hyped up, the public sector's role has been hyped down. The State is often being cast as the problem, whether it is investing in new technology or improving market function. A key aspect of the challenge is therefore to rebalance our understanding of how economies really work. Only once that is done can we begin to formulate the kinds of policies that work, rather than reproduce stereotypes and images which serve only ideological ends.

Chapter 1

FROM CRISIS IDEOLOGY TO THE DIVISION OF INNOVATIVE LABOUR

> *Governments have always been lousy at picking winners, and they are likely to become more so, as legions of entrepreneurs and tinkerers swap designs online, turn them into products at home and market them globally from a garage. As the revolution rages, governments should stick to the basics: better schools for a skilled workforce, clear rules and a level playing field for enterprises of all kinds. Leave the rest to the revolutionaries.*
>
> *Economist* (2012)

Across the globe we are hearing that the State has to be cut back in order to foster a post-crisis recovery. The assumption is that, with the State in the backseat, we unleash the power of entrepreneurship and innovation in the private sector. The media, business and libertarian politicians draw from this convenient contrast, and feed into the dichotomy of a dynamic, innovative and competitive 'revolutionary' private sector versus a sluggish, bureaucratic, inertial, 'meddling' public sector. The message is repeated so much so that it is accepted by the many as a 'common sense' truth, and has even made many believe that the 2007 financial crisis, which soon precipitated into a full blown economic crisis, was caused by public sector debt, rather than the truth.

And the language used has been forceful. In March 2011, UK prime minister David Cameron promised to take on the 'enemies of enterprise' working in government, which he defined as the 'bureaucrats in government departments' (Wheeler 2011). The rhetoric fits in with the UK government's broader theme of the Big Society, where responsibility for the delivery of public services is shifted away from the State to individuals operating either on their own or by coming together through the third sector – with the justification that such 'freedom' from the State's influence will reinvigorate such services. The terms used, such as 'free' schools (the equivalent of charter schools in the USA) imply that by freeing schools from the heavy hand of the State, they will be both more interesting to students and also run more efficiently.

The increasing percentage of public services, across the globe, that are being 'outsourced' to the private sector, is usually done using precisely this 'efficiency' argument. Yet a proper look at the real cost savings that such outsourcing provides – especially taking into account the lack of 'quality control' and absurd costs that ensue – is almost never carried out. The recent scandal where the security for London's 2012 Olympics was outsourced to a company called G4S, which then failed due to utter incompetence to deliver, meant that the British Army was called in to provide security during the Olympics. While the managers of the company were 'reprimanded' the company today is still making profits and outsourcing remains on the rise. Examples where outsourcing is resisted, such as the BBC's choice to build the Internet platform for its broadcasting, the iPlayer, in-house has meant that it has been able to keep the BBC a dynamic innovative organization, that continues to attract top talent, retaining its high market share in both radio and TV – what public broadcasters in other countries can only dream of.

The view of the State as enemy of enterprise is a point of view found constantly in the respected business press, such as the *Economist*, which often refers to government as a 'Hobbesian Leviathan' which should take the back seat (*Economist* 2011a). Their prescription for economic growth includes focusing on creating freer markets and creating the right conditions for new ideas to prosper, rather than taking a more activist approach (*Economist* 2012). And in a recent special issue on the green revolution, the magazine explicitly made the case, as quoted in the beginning of this chapter, that while the government should 'stick to the basics', such as funding education and research, the rest should be left to the 'revolutionaries', i.e. businesses. Yet as will be argued in Chapters 4–8, this revolutionary spirit is often hard to find in the private sector, with the State having to take on the greatest areas of risk and uncertainty.

When not lobbying the State for specific types of support, established business lobby groups – in areas as diverse as weapons, medicine and oil – have long argued for freedom from the long arm of the State, which they see as stifling their ability to succeed through the imposition of employee rights, tax and regulation. The conservative Adam Smith

Institute argues that the number of regulators in the UK should be reduced to enable the British economy to 'experience a burst of innovation and growth' (Ambler and Boyfield 2010, 4). In the USA, supporters of the Tea Party movement are united by a desire to limit State budgets and promote free markets. Big pharmaceutical companies, which, as we will see in Chapter 3, are some of the biggest beneficiaries of publicly funded research, constantly argue for less regulation and 'meddling' in what they claim is a very innovative industry.

And in the Eurozone

And, in the eurozone, it is today argued that all the ills of the 'peripheral' EU countries like Portugal and Italy come from having a 'profligate' public sector, ignoring the evidence that such countries are characterized more by a stagnant public sector which has not made the kind of strategic investments that the more successful 'core' countries, such as Germany, have been making for decades (Mazzucato 2012b).

The power of the ideology is so strong that history is easily fabricated. A remarkable aspect of the financial crisis that began in 2007 was that even though it was blatantly caused by excessive private debt (mainly in the US real estate market), many people were later led to believe that the chief culprit was public debt. It is true that public sector debt (Alessandri and Haldane 2009) rose drastically both due to the government-funded bank bailouts and reduced tax receipts that accompanied the ensuing recession in many countries. But it can hardly be argued that the financial crisis, or the resulting economic crisis, was caused by public debt. The key issue was not the amount of public sector spending but the type of spending. Indeed, one of the reasons that Italy's growth rate has been so low for the last 15 years is not that it has been spending too much but that it has not been spending enough in areas like education, human capital and R&D. So even with a relatively modest pre-crisis deficit (around 4 per cent), its debt/GDP ratio kept rising because the rate of growth of the denominator in this ratio remained close to zero.

While there are of course low-growth countries with large public debts, the question of which causes which is highly debatable. Indeed, the recent controversy over the work of Reinhart and Rogoff (2010) shows just how heated the debate is. What was most shocking, however, from that recent debate was not only the finding that their statistical work (published in what is deemed the top economics journal) was done incorrectly (and recklessly), but how quickly people had believed the core result: that debt above

90 per cent of GDP will necessarily bring down growth. The corollary became the new dogma: austerity will necessarily (and sufficiently) bring back growth. And yet there are many countries with higher debt that have grown in a stable fashion (such as Canada, New Zealand and Australia – all ignored by their results). Even more obvious is the point that what matters is surely not the aggregate size of the public sector, but what it is spending on. Spending on useless paperwork, or kickbacks, is surely not the same thing as spending on making a healthcare system more functional and efficient, or spending on top-quality education or ground-breaking research that can fuel human capital formation and future technologies. Indeed, the variables that economists have found to be important for growth – such as education and research and development – are expensive. The fact that the weakest countries in Europe, with high debt/GDP ratios, have been spending very little in these areas (thus causing the denominator in this ratio to suffer) should not come as a surprise. Yet the austerity recipes that are currently being forced on them will make this problem only worse.

And this is where there is a self-fulfilling prophecy: the more we talk down the State's role in the economy, the less able we are to up its game and make it a relevant player, and so the less able it is to attract top talent. Is it a coincidence that the US Department of Energy, which is the lead spender on R&D in the US government and one of the lead spenders (per capita) on energy research in the OECD, has been able to attract a Nobel Prize–winning physicist to run it? Or that those countries with much less ambitious plans for government organizations are more susceptible to crony-type promotions and little expertise within ministries? Of course the problem is not simply of 'expertise', but the ability to attract it is an indicator of the importance it is given within public agencies in a given country.

State Picking Winners vs. Losers Picking the State

We are constantly told that the State should have a limited role in the economy due to its inability to 'pick winners', whether the 'winners' are new technologies, economic sectors or specific firms. But what is ignored is that, in many of the cases that the State 'failed', it was trying to do something much more difficult than what many private businesses do: either trying to extend the period of glory of a mature industry (the Concorde experiment or the American Supersonic Transport project), or actively trying to launch a new technology sector (the Internet, or the IT revolution).

Operating in such difficult territory makes the probability of failure much higher. Yet by constantly bashing the State's ability to be an effective and innovative agent in society, not only have we too easily blamed the State for some of its failures, we have also not developed the accurate metrics needed to judge its investments fairly. Public venture capital, for example, is very different from private venture capital. It is willing to invest in areas with much higher risk, while providing greater patience and lower expectations of future returns. By definition this is a more difficult situation. Yet the returns to public versus private venture capital are compared without taking this difference into account.

Ironically, the inability of the State to argue its own position, to explain its role in the winners that have been picked (from the Internet to companies like Apple) has made it easier to criticize it for its occasional failures (e.g. the Supersonic Transport project). Or even worse, it has responded to criticism by becoming vulnerable and timid, easily 'captured' by lobbies seeking public resources for private gain, or by pundits that parrot the 'myths' about the origins of economic dynamism.

In the late 1970s capital gains taxes fell significantly following lobbying efforts on behalf of the US venture capital industry (Lazonick 2009, 73). The lobbyists argued before the government that venture capitalists had funded both the Internet and the early semiconductor industry, and that without venture capitalists innovation would not happen. Thus the same actors who rode the wave of expensive State investments in what would later become the dot.com revolution, successfully lobbied government to reduce their taxes. In that way the government's own pockets, so critical for funding innovation, were being emptied by those who had depended on it for their success.

Furthermore, by not being confident of its own role, government has been easily captured by the myths describing where innovation and entrepreneurship come from. Big Pharma tries to convince government that it is subject to too much regulation and red tape, while it is simultaneously dependent on government-funded R&D. Small business associations have convinced governments in many countries that they are underfunded as a category. Yet in many countries, they receive more support than the police force, without providing the jobs or innovation that helps justify such support (Hughes 2008; Storey 2006). Had the State better understood how its own investments have led to the emergence of the most successful new companies, like Google, Apple and Compaq, it would perhaps mount a stronger defence against such arguments.

But the State has not had a good marketing/communications department. Imagine how much easier President Barack Obama's fight for US national healthcare policy would have been if the US population knew the important role that the US government had in funding the most radical new drugs in the industry (discussed in Chapter 3). This is not 'propaganda' – it's raising awareness about history of technology. In health, the State has not 'meddled' but created and innovated. Yet the story told, and unfortunately believed, is one of an innovative Big Pharma and a meddling government. Getting the (complex) history right is important for many reasons. Indeed, the high prices charged for drugs, whether they are subsidized by the State or not, are justified by the industry with their alleged 'high R&D costs'. Uncovering the truth not only helps government policies to be better designed but also can help the 'market' system work better.

The emphasis on the State as an entrepreneurial agent is not of course meant to deny the existence of private sector entrepreneurial activity, from the role of young new companies in providing the dynamism behind new sectors (e.g. Google), to the important source of funding from private sources like venture capital. The key problem is that this is the *only* story that is usually told. Silicon Valley and the emergence of the biotech industry are usually attributed to the geniuses behind the small high-tech firms like Facebook, or the plethora of small biotech companies in Boston (US) or Cambridge (UK). Europe's 'lag' behind the USA is often attributed to its weak venture capital sector. Examples from these high-tech sectors in the USA are often used to argue why we need less State and more market: tipping the balance in favour of the market would allow Europe to produce its own 'Googles'. But how many people know that the algorithm that led to Google's success was funded by a public sector National Science Foundation grant (Battelle 2005)? Or that molecular antibodies, which provided the foundation for biotechnology before venture capital moved into the sector, were discovered in public Medical Research Council (MRC) labs in the UK? How many people realize that many of the most innovative young companies in the US were funded not by private venture capital but by *public* venture capital, such as that provided by the Small Business Innovation Research (SBIR) programme?

Lessons from these experiences are important. They force the debate to go beyond the role of the State in stimulating demand, or the worry of 'picking winners'. What we have instead is a case for a targeted,

proactive, *entrepreneurial* State, one able to take risks and create a highly networked system of actors that harness the best of the private sector for the national good over a medium- to long-term time horizon. It is the State acting as lead investor and catalyst which sparks the network to act and spread knowledge. The State can and does act as creator, not just facilitator of the knowledge economy.

Arguing for an entrepreneurial State is not 'new' industrial policy because it is in fact what has happened. As Block and Keller (2011, 95) have explained so well, the industrial directives of the State are 'hidden' primarily to prevent a backlash from the conservative right. Evidence abounds of the State's pivotal role in the history of the computer industry, the Internet, the pharmaceutical-biotech industry, nanotech and the emerging green tech sector. In all these cases, the State dared to think – against all odds – about the 'impossible': creating a new technological opportunity; making the initial large necessary investments; enabling a decentralized network of actors to carry out the risky research; and then allowing the development and commercialization process to occur in a dynamic way.

Beyond Market Failures and System Failures

Economists willing to admit the State has an important role have often argued so using a specific framework called 'market failure'. From this perspective the fact that markets are 'imperfect' is seen as the exception, which means that the State has a role to play – but not a very interesting one. Imperfections can arise for various reasons: the unwillingness of private firms to invest in areas, like basic research, from which they cannot appropriate private profits because the results are a 'public good' accessible to all firms (results of basic R&D as a positive externality); the fact that private firms do not factor in the cost of their pollution in setting prices (pollution as a negative externality); or the fact that the risk of certain investments is too high for any one firm to bear them all alone (leading to incomplete markets). Given these different forms of market failure, examples of the expected role of the State would include publicly funded basic research, taxes levied on polluting firms and public funding for infrastructure projects. While this framework is useful, it cannot explain the 'visionary' strategic role that government has played in making these investments. Indeed, the discovery of the Internet or the emergence of the nanotechnology industry did not occur because the private sector wanted something but could not find the resources to invest in it. Both happened due to the vision that the government had in an area that had not yet been fathomed by the private sector. Even after these new technologies were introduced by government, the private sector still was too scared to invest. Government even had to support the commercialization of the Internet. And it took years for private venture capitalists to start financing biotech or nanotech companies. It was – in these and many such cases – the State that appeared to have the most aggressive 'animal spirits'.

There are many counterexamples that would characterize the State as far from an 'entrepreneurial' force. Developing new technologies and supporting new industries is not the only important role of the State, after all. But admitting the instances where it has played an entrepreneurial role will help inform policies, which are too often based on the assumption that at most the State's role is to correct market failures or facilitate innovation for the 'dynamic' private sector. The assumptions that all the State has to do is to 'nudge' the private sector in the right direction; that tax credits will work because business is eager to invest in innovation; that removing obstacles and regulations is necessary; that small firms – simply due to their size – are more flexible and entrepreneurial and should be given direct and indirect support; that the core problem in Europe is simply one of 'commercialization' – are all myths. They are myths about where entrepreneurship and innovation come from. They have prevented policies from being as effective as they could be in stimulating the kinds of innovation that businesses would not have attempted on their own.

The Bumpy Risk Landscape

As will be explained in more detail in the next chapter, innovation economists from the 'evolutionary' tradition (Nelson and Winter 1982) have argued that 'systems' of innovation are needed so that new knowledge and innovation can diffuse throughout the economy, and that *systems* of innovation (sectoral, regional, national) require the presence of dynamic links between the different *actors* (firms, financial institutions, research/education, public sector funds, intermediary institutions), as well as horizontal links *within* organizations and institutions (Lundvall 1992; Freeman 1995). What has been ignored even in this debate, however, is the exact role that each actor realistically plays in the 'bumpy' and complex *risk landscape*. Many errors of current innovation policy are due to placing actors in the wrong part of this landscape (both in time and space). For example, it is naïve to expect venture capital to lead in the early and most risky stage of any new economic sector today (such as clean technology). In biotechnology, nanotechnology and the Internet, venture capital arrived 15–20 years *after* the most important investments were made by public sector funds.

In fact, history shows that those areas of the risk landscape (within sectors at any point in time, or at the start of new sectors) that are defined by high capital intensity and high technological and market risk tend to be avoided by the private sector, and have required great amounts of public sector funding (of different types), as well as public sector vision and leadership to get them off the ground. The State has been behind most technological revolutions and periods of long-run growth. This is why an 'entrepreneurial State' is needed to engage in risk taking and the creation of a new vision, rather than just fixing market failures.

Not understanding the role that different actors play makes it easier for government to get 'captured' by special interests which portray their role in a rhetorical and ideological way that lacks evidence or reason. While venture capitalists have lobbied hard for lower capital gains taxes (mentioned above), they do not make their investments in new technologies on the basis of tax rates; they make them based on perceived risk, something typically reduced by decades of prior State investment. Without a better understanding of the actors involved in the innovation process, we risk allowing a symbiotic innovation system, in which the State and private sector mutually benefit, to transform into a parasitic one in which the private sector is able to leach benefits from a State that it simultaneously refuses to finance.

Symbiotic vs. Parasitic Innovation 'Ecosystems'

It is now common to talk about innovation 'systems' as 'ecosystems'. Indeed it seems to be on the tongue of many innovation specialists and policymakers. But how can we be sure that the innovation ecosystem is one that results in a *symbiotic* relationship between the public and private sector rather than a *parasitic* one? That is, will increased investments by the State in the innovation ecosystem cause the private sector to invest less, and use its retained earnings to fund short-term profits (via practices like 'share buybacks'), or more, in riskier areas like human capital formation and R&D, to promote long-term growth?

Usually a question like this might be framed in terms of the 'crowding-out' concept. Crowding out is a hypothesis in economics that says that the danger of State investment is that it uses up savings that could have been used by the private sector for its own investment plans (Friedman 1979). Keynesians have argued against the idea that State spending crowds out private investment, by emphasizing that this would only hold in a period of full resource utilization, a state that hardly ever occurs. However, the issues raised in this book present a different view: that an entrepreneurial State invests in areas that the private sector would not invest even if it had the resources. And it is the courageous risk-taking visionary role of the State which has been ignored. Business investment is mainly limited not by savings but by its own lack of courage (or Keynesian 'animal spirits') – the 'business as usual' state of mind. Indeed, firm-level studies have shown that what drives entry behaviour into industries (companies deciding to move into one particular sector) are not existing profits in that sector but projected technological and market opportunities (Dosi et al. 1997). And such opportunities are linked to the amount of State investment in those areas.

But what if that potentially courageous aspect of the private sector is diminished precisely because the public sector fills the gap? Rather than framing the question in terms of 'crowding out', I believe we must frame it in such a way that results in building private–public partnerships that are more symbiotic and less parasitic. The problem is not that the State has financed too much innovation, making the private sector less ambitious. It is that policymakers have not been ambitious enough to demand that such support be part of a more collaborative effort in which the private sector also steps up to the challenge. Instead big R&D labs have been closing, and the R of the R&D spend has also been falling, with BERD (business expenditure on R&D) falling in many countries like the UK (Hughes and Mina 2011). While State spending on R&D and business spending tend to be correlated (the former ups the game for the latter), it is important that policymakers be more courageous – not only in agreeing to 'fund' sectors but also in demanding that businesses in those sectors increase their own stakes and commitment to innovation. A recent study by MIT claims that the current absence in the US of corporate labs like Xerox PARC (which produced the graphical user interface technology that led to both Apple's and Windows' operating systems) and Bell Labs – both highly co-financed by government agency budgets – is one of the reasons why the US innovation machine is under threat (MIT 2013).

The problem is also evidenced in industries, like pharmaceuticals, where there is a trend of increasing public sector investments in R&D, while private sector spending is decreasing. According to Lazonick and Tulum (2012), the National Institutes of Health (NIH) have spent more than $300 billion over the last decade ($30.9 billion in 2012 alone), and become more involved in the D component of R&D, meaning they absorb greater costs of drug development (such as through clinical trials), while private pharmaceutical companies[1] have been spending less on R&D overall, with many shutting down R&D labs altogether. Of course the total R&D spent may be increasing, because the development (D) part is getting increasingly expensive. But this hides the underlying issue. While some analysts have justified the decreasing expenditure on research in terms of low productivity of R&D (increased expenditures, not matched by increased discoveries), others, like Angell (1984, ex-editor of the *New England Journal of Medicine*), have been more explicit in blaming Big Pharma for not doing its share. She argues that for decades the most radical new drugs have been coming out of public labs, with private pharma concerned more with 'me too' drugs (slight variations of existing drugs) and marketing (see Chapter 3 for more details). And in recent years, CEOs of large pharma companies have admitted that their decision to downsize – or in some cases eliminate – their R&D labs is due to their recognition that in the 'open' model of innovation most of their research is obtained by small biotech firms or public labs (Gambardella 1995; *China Briefing* 2012). Big Pharma's focus is thus turned to working with such alliances, and 'integrating' knowledge produced elsewhere, rather than funding R&D internally.

Financialization

One of the greatest problems, which we return to in Chapter 9, has been the way in which such reductions in spending on R&D have coincided with an increasing 'financialization' of the private sector. While causality may be hard to prove, it cannot be denied that at the same time that private pharma companies have been reducing the R of R&D, they have been increasing the amount of funds used to repurchase their own shares – a strategy used to boost their stock price, which affects the price of stock options and executive pay

1 From now on 'pharma' will refer to pharmaceutical companies, and Big Pharma the top international pharma companies.

linked to such options. For example, in 2011, along with $6.2 billion paid in dividends, Pfizer repurchased $9 billion in stock, equivalent to 90 per cent of its net income and 99 per cent of its R&D expenditures. Amgen, the largest dedicated biopharma company, has repurchased stock in every year since 1992, for a total of $42.2 billion through 2011, including $8.3 billion in 2011. Since 2002 the cost of Amgen's stock repurchases has surpassed the company's R&D expenditures in every year except 2004, and for the period 1992–2011 was equal to fully 115 per cent of R&D outlays and 113 per cent of net income (Lazonick and Tulum 2011). The fact that top pharma companies are spending a decreasing amount of funds on R&D at the same time that the State is spending more – all while increasing the amount they spend on share buybacks, makes this particular innovation ecosystem much more parasitic than symbiotic. This is not the 'crowding out' effect: this is free-riding. Share buyback schemes boost stock prices, benefitting senior executives, managers and investors that hold the majority of company stock. Boosting share prices does not create value (the point of innovation), but facilitates its extraction. Shareholders and executives are thus 'rewarded' for riding the innovation wave the State created. In Chapter 9 I look more closely at the problem of value extraction and ask whether and how some of the 'returns' from innovation should be returned to the employees and State that are also key contributors and stakeholders in the innovation process.

Unfortunately the same problem seems to be appearing in the emerging clean technology sector. In 2010, the US American Energy Innovation Council (AEIC), an industry association, asked the US government to increase its spending on clean technology by three times to $16 billion annually, with an additional $1 billion given to the Advanced Research Projects Agency – Energy (Lazonick 2011c). On the other hand, companies in the council have together spent $237 billion on stock repurchases between 2001 and 2010. The major directors of the AEIC come from companies with collective 2011 net incomes of $37 billion and R&D expenditures of approximately $16 billion. That they believe their own companies' enormous resources are inadequate to foster greater clean technology innovation is indicative of the State's role as the first driver of innovation or of their own aversion to taking on risks – or both.

The problem of share buybacks is not isolated but rampant: in the last decade, S&P 500 companies have spent $3 trillion on share buybacks (Lazonick 2012). The largest repurchasers (especially in oil and pharmaceuticals) claim that this is due to the lack of new opportunities. In fact in many cases the most expensive (e.g. capital-intensive) investments in new opportunities such as medicine and renewable energy (investments with high market and technological risk) are being made by the public sector (GWEC 2012). This raises the question of whether the 'open innovation' model is becoming a dysfunctional model. As large companies are increasingly relying on alliances with small companies and the public sector, the indication is that large players invest more in short-run profit gains (through market gimmicks) than long-run investments. I return to this question in Chapters 9 and 10.

Now that 'new' industrial policy is back on the agenda, with many nations trying to 'rebalance' their economies away from finance and towards 'real' economy sectors, it is more important than ever to question exactly what this rebalancing will entail (Mazzucato 2012a). While some have focused on the need for different types of private–public partnerships that can foster innovation and economic growth, what I'm arguing here (and will focus on more in Chapters 8 and 9) is that we need to be more careful to build the type of partnerships which increase the stakes of all involved, and which do not lead to similar problems that the financialization of the economy led to: socialization of risk, privatization of rewards.

The work of Rodrik (2004) has been particularly important in highlighting the need to rethink public and private sector interactions, and to focus more on processes rather than policy outcomes. His focus is on the types of exploratory processes that allow the public and private sectors to *learn* from each other, especially the opportunities and constraints that each face (Rodrik 2004, 3). He takes this to mean that the problem is not which types of tools (R&D tax credits vs. subsidies) or which types of sectors to choose (steel vs. software), but how policy can foster self-discovery processes, which will foster creativity and innovation. While I agree with Rodrik's general point about the need to foster exploration and trial and error (and this is in fact a core tenet of the 'evolutionary theory of economic change', which I review in the next chapter), I believe that the history of technological change teaches us that choosing particular sectors in this process is absolutely crucial. The Internet would never have happened without it being forcefully 'picked' by DARPA, and the same holds for nanotechnology which was picked by the NSF and later by the National Nanotech Initiative (both discussed in Chapter 4). And, most importantly, the green revolution will not take off until it is firmly picked and backed by the State (as will be discussed in Chapters 6 and 7).

Coming back to Keynes's (1926) fundamental point about the essential role of government, what we need to ask is: how can horizontal and vertical tools and policies 'make things happen' that would not have otherwise? The problem with R&D tax credits is not that they are specific policy tools, but they have been designed wrongly and do not increase private investments in R&D. Evidence shows that targeting R&D labour rather than R&D income (through credits) is much better for that (Lockshin and Mohnen 2012). And the problems with throwing money at a particular area like life sciences is not that it was 'picked' but that it was not first transformed to be less dysfunctional before it was supported. When so many 'life science' companies are focusing on their stock price rather than on increasing their side of the R in R&D, simply subsidising their research will only worsen the problem rather than create the type of learning that Rodrik (2004) rightly calls for.

Chapter 2

TECHNOLOGY, INNOVATION AND GROWTH

You can see the computer age everywhere but in the productivity statistics.
Solow (1987, 36)

In a special report on the world economy, the *Economist* (2010a) stated:

> A smart innovation agenda, in short, would be quite different from the one that most rich governments seem to favor. It would be more about freeing markets and less about picking winners; more about creating the right conditions for bright ideas to emerge and less about promises like green jobs. But pursuing that kind of policy requires courage and vision – and most of the rich economies are not displaying enough of either.

This view is also espoused by some 'progressive' academics, who argue that the State is limited to creating the 'conditions for innovation':

> …accepting that the state will have a vital role in ensuring that market conditions reach the 'just right' balance which will spur innovation and that adequate investment is available for innovators. (Lent and Lockwood 2010, 7)

This is the view that asks little of government other than correcting market failures – such as through investment in basic science, education and infrastructure. The 'appropriate' role of the State is not a new debate, but it is one that benefits from a broader understanding of the academic literature on the role of innovation in creating economic growth.

Over two hundred and fifty years ago, when discussing his notion of the 'Invisible Hand', Adam Smith argued that capitalist markets left on their own would self-regulate, with the State's role being limited to that of creating basic infrastructure (schools, hospitals, motorways) and making sure that private property, and 'trust' (a moral code) between actors, were nurtured and protected (Smith 1904 [1776]). Smith's background in politics and philosophy meant that his writings were much more profound than the simple libertarian economics position for which he is usually acknowledged, but there is no escaping that he believed that the magic of capitalism consisted in the ability of the market to organize production and distribution without coercion by the State.

The path-breaking work of Karl Polanyi (who had a doctorate in law but is considered an important economist) has instead shown how the notion of the market as self-regulating is a myth unsupported by the historical origins of markets: 'The road to the free market was opened and kept open by an enormous increase in continuous, centrally organized and controlled interventionism' (Polanyi 2001 [1944], 144). In his view, it was the State which imposed the conditions that allowed for the emergence of a market-based economy. Polanyi's work has been revolutionary in showing the myth of the State vs. market distinction: the most capitalist of all markets, i.e. the national market, was forcefully 'pushed' into existence by the State. If anything it was the more local and international markets, which have pre-dated capitalism, that have been less tied to the State. But capitalism, the system that is usually thought of being 'market' driven, has been strongly embedded in, and shaped by, the State from day one (Evans 1995).

John Maynard Keynes believed that capitalist markets, regardless of their origin, need constant regulation because of the inherent instability of capitalism. Keynes contended that the stability of capitalism was dependent on keeping all of the four categories of spending (aggregate demand) in GDP in balance with one another: business investment (I), government investment (G), consumption spending (C), and net exports (X−M). A key source of extreme volatility was found in private business investment. The reason it is so volatile is that far from being a simple function of interest rates or taxes,[1] it is subject to 'animal spirits' -- the gut-instinct assumptions made about future growth prospects in an economy or specific sector by investors (Keynes 1934). In his view, this uncertainty constantly creates periods of under- or overinvestment, causing severe fluctuations in the economy that are compounded by the multiplier effect. According to Keynes, unless private investment is balanced by increased government spending, declines in consumption and investment will lead to market crashes and depressions, which were indeed a frequent fact of life before Keynes's ideas found their way into post–Second World War economic policies.

1 The insensitivity of investment to taxes is the reason that the 1980s-style 'supply-side' economics had little effect on investment and hence GDP, and a large effect on income distribution (no 'trickle-down' effect).

Keynesians have argued forcefully for the importance of using government spending to boost demand and stabilize the economy. Economists, inspired by the work of Joseph Schumpeter (1883–1950), have gone further, asking that the government also spend on those specific areas that increase a nation's capacity for innovation (reviewed further below). Support for innovation can take the form of investments made in R&D, infrastructure, labour skills, and in direct and indirect support for specific technologies and companies.

On the left side of the political spectrum, investments into programme areas that increase productivity have been less fashionable than simple spending on welfare state institutions such as education or health. But welfare state institutions cannot survive without a productive economy behind it that generates the profits and tax receipts that can fund such entitlements (Nordhaus and Shellenberger 2011; Atkinson 2011). While progressive redistributional policies are fundamental to ensuring that the results of economic growth are fair, they do not in themselves cause growth. Inequality can hurt growth but equality does not alone foster it. What has been missing from much of the Keynesian left is a growth agenda which creates and simultaneously redistributes the riches. Bringing together the lessons of Keynes and Schumpeter can make this happen. This is why the last chapters of this book focus on the need to better understand why innovation and inequality can go hand in hand, and how this requires realigning the risks and rewards of economic growth to put a stop to one of the unfortunate consequences of modern-day capitalism: risks that are socialized and rewards that are privatized, not just in the financial sector but also in manufacturing.

In general, there has been a lack of connection between Keynesian fiscal spending and Schumpeterian investments in innovation. The lack of connection is due in no small part to Keynes advocating 'useless government'; that is, that State intervention into an economy was based primarily on temporary spending that could occur in any manner (even if it was hiring workers to dig up treasure hidden in an abandoned coal mine)[2]. Indeed, this is the micro–macro connection that is still missing in modern-day economics. Yet empirically the connection is there. Not only is it true that productive investments generate growth, but that when spending is more 'directed' towards, say, the IT revolution in the 1980s and 1990s, and perhaps the green revolution in the years to come, the Keynesian multiplier effect is stronger. As Tassey argues:

> ...the highest order problem is the long-term inadequacy of productivity enhancing investments (technology, physical, human and organizational capital). Increasing the demand for housing does have a multiplier effect on that industry's supply chain, but this effect pales compared to the leverage from investment in technology for hardware and software that drive productivity in many industries. Equally important, the jobs created by a technology-driven supply chain are much higher paying – but, they must be sustained over entire technology life cycles. (2012, 31)

Keynes focused on the need for the State to intervene in order to bring stability and prevent crises, certainly a pressing issue in today's circumstances.[3] But in order to understand the dynamics of such

2 This refers to Keynes's provocative statement that: 'If the Treasury were to fill old bottles with bank-notes, bury them at suitable depths in disused coal-mines which are then filled up to the surface with town rubbish, and leave it to private enterprise on well-tried principles of laissez-faire to dig the notes up again (the right to do so being obtained, of course, by tendering for leases of the note-bearing territory), there need be no more unemployment and, with the help of repercussions, the real income of the community, and its capital wealth, would probably become a good deal greater than it actually is' (1936, 129). Keynes was referring to the fact that in times of underutilized capacity, even such apparently useless actions could get the economic engine going. However, the point of this book is to highlight how the State has, even in the boom periods such as the 1990s, provided important directionality in its spending, increasing the animal spirits of the private sector by investing in areas that the private sector fears.

3 Indeed, the application of Keynesian analysis to the theory of economic crises, with a proper understanding of finance in this dynamic, was developed by Hyman Minsky. Minsky (1992) focused on the *financial* fragility of capitalism by highlighting the way that financial markets cause crises to occur. Financial bubbles followed cycles of credit expansion, and exaggerated growth expectations were followed by retraction, causing bubbles to burst and asset prices to collapse. Like Keynes, he believed that the State had a crucial role in preventing this vicious cycle and stabilizing growth.

investments, it is fundamental to better understand different perspectives on the theory of economic growth first, and then to establish the role of technology and innovation in driving that economic growth.

Technology and Growth

While growth and the wealth of nations has been the lead concern of economists since Adam Smith, in the 1950s it was shown by Abramovitz (1956) and Solow (1956) that conventional measures of capital and labour inputs could not account for 90 per cent of economic growth in an advanced industrialized country such as the United States. It was assumed that the unexplained residual must reflect productivity growth, rather than the quantity of factors of production. And still today there is immense debate among economists over which factors are most important in producing growth. This debate is reflected in politics, where different views about growth are espoused with great vehemence, often ignorant of the underlying theoretical assumptions and origins driving those views.

For years, economists have tried to model growth. Neoclassical economics developed its first growth model in the work of Harrod and Domar (Harrod 1939; Domar 1946), but it was Robert Solow who won the Nobel Prize for his growth 'theory'. In the Solow growth model, growth is modelled through a production function where output (Y) is a function of the quantity of physical capital (K) and human labour (L), *ceteris paribus* – other things remaining equal. Included in 'other things' was technological change.

$$Y = F(K, L)$$

While increases in K and L would cause movements *along* the production function (curve), exogenous (unexplained) changes in technical change would cause an upward shift in the curve (allowing both K and L to be used more productively). When Solow discovered that 90 per cent of variation in economic output was not explained by capital and labour, he called the residual 'technical change'. Abramovitz, who knew much more about the social conditions that support technical change than Solow, famously called the residual a 'measure of our ignorance' (Abromovitz 1956).

If the underlying model was found to be so deficient that it could not explain 90 per cent of the dependent variable it was describing, then it should have been thrown out and a new model developed. This was indeed what many, such as Joan Robinson (Harcourt 1972) had been arguing for decades. Robinson and others were highly critical of the production function framework. Instead of getting rid of the bad old model, however, technical change was simply added into it. Solow's theory (1956) became known as 'exogenous growth theory' because the variable for technical change was inserted exogenously, as a time trend A (t) (similar to population growth):

$$Y = A(t)\,F(K, L)$$

As economists became more aware of the crucial role that technology plays in economic growth, it became necessary to think more seriously about how to include technology in growth models. This gave rise to 'endogenous' or 'new growth' theory, which modelled technology as the endogenous outcome of an R&D investment function, as well as investment in human capital formation (Grossman and Helpman 1991). Rather than assuming constant or diminishing marginal returns as in the Solow model (every extra unit of capital employed earned a smaller return), the addition of human capital and technology introduced *increasing returns to scale*, the engine of growth. Increasing returns, which arise from different types of dynamic behaviour like learning by doing, can help explain why certain firms or countries persistently outperform others – there is no 'catch-up' effect.

Although new growth theory provided a rational argument for government investment, it did not lead to it explicitly. This is because new ideas were treated as endogenous to the firm, not as part of the institutional organization required to transform ideas into products. Nevertheless, the increasing emphasis on the relationship between technical change and growth indirectly led government policymakers to focus on the importance of investments in technology and human capital to foster growth. The result was *innovation-led growth* policies to support the knowledge economy, a term used to denote the greater importance of investing in knowledge creation in promoting economic competitiveness (Mason, Bishop and Robinson 2009). Studies that showed a direct relationship between the market value of firms and their innovation performance as measured by R&D spending and patent success supported these policies (Griliches, Hall and Pakes 1991).

From Market Failures to System Failures

In their ground-breaking *An Evolutionary Theory of Economic Change*, Nelson and Winter (1982) argued that the production function framework

(exogenous or endogenous) was in fact the wrong way to understand technological change. Building on the work of Joseph Schumpeter (1949, 1942 [2003]), they argued for an 'evolutionary theory' of production (and economic change), which delved inside the 'black box' of the production function in order to understand how innovation occurs and affects competition and economic growth. In this approach, there is no assumption of 'representative agents' (as in standard growth theory) but rather a constant process of differentiation among firms, based on their different abilities to innovate because of different internal routines and competencies. Competition in this perspective is about the coevolution of those processes that create constant differences between firms and the processes of competitive selection that winnow in on those differences, allowing only some firms to survive and grow.

Rather than relying on laws of 'diminishing returns', which lead to a unique equilibrium, and assumptions about the 'average' firm, this approach focuses on dynamic increasing returns to scale (from the dynamics of learning by doing, as well as the kind of 'path-dependent' dynamics described by David 2004), and on different types of processes that lead to persistent differences between firms that do not disappear in the long run. The question is then: which firms survive and grow? Selection does not always lead to 'survival of the fittest' both due to the effect of increasing returns (allowing first-mover advantages which then 'stick') and also to the effects of policies which might favour certain types of firms over others. It might also be that selection dynamics in product markets and financial markets are at odds (Geroski and Mazzucato 2002b).

But most importantly, in this perspective innovation is firm specific, and highly uncertain. The 'evolutionary' and Schumpeterian approach to studying firm behaviour and competition has led to a 'systems of innovation' view of policy where what matters is understanding the way in which firms of different type are embedded in a system at sectoral, regional and national levels. In this systems view, it is not the quantity of R&D that matters, but how it is distributed throughout an economy, often reflective of the crucial role of the State in influencing the distribution (Freeman 1995; Lundvall 1992). Schumpeterian economists criticize endogenous growth theory because of its assumption that R&D can be modelled as a lottery where a certain amount of R&D investment will create a certain probability for successful innovation. They argue that in fact innovation is an example of true Knightian uncertainty, which cannot be modelled with a normal (or any other) probability distribution that is implicit in endogenous growth theory, where R&D is often modelled using game theory (Reinganum 1984). By highlighting the strong uncertainty underlying technological innovation, as well as the very strong feedback effects that exist between innovation, growth and market structure, Schumpeterians emphasize the 'systems' component of technological progress and growth.[4] Systems of innovation are defined as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman 1995), or 'the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge' (Lundvall 1992, 2).

The emphasis here is not on the stock of R&D but on the circulation of knowledge and its diffusion throughout the economy. Institutional change is not assessed through criteria based on static allocative efficiency, but rather on how it promotes technological and structural change. The perspective is neither macro nor micro, but more meso, where individual firms are seen as part of broader network of firms with whom they cooperate and compete. The system of innovation can be interfirm, regional, national or global. From the meso perspective the network is the unit of analysis (not the firm). The network consists of customers, subcontractors, infrastructure, suppliers, competencies or functions, and the links or relationships between them. The point is that the competencies that generate innovation are part of a collective activity occurring through a network of actors and their links or relationships (Freeman 1995).

The causation that occurs in the steps taken between basic science, to large-scale R&D, to applications, and finally to diffusing innovations is not 'linear'. Rather, innovation networks are full of feedback loops existing between markets and technology, applications and science. In the linear model, the R&D system is seen as the main source of innovation, reinforcing economists' use of R&D stats to understand growth. In this more non-linear view, the roles of education, training, design, quality control and effective demand are just as important. Furthermore, it is

4 The emphasis on heterogeneity and multiple equilibria requires this branch of theory to rely less on assumptions of representative agents (the average company) and unique equilibria, so dear to neoclassical economics. Rather than using incremental calculus from Newtonian physics, mathematics from biology (such as distance from mean replicator dynamics) are used, which can explicitly take into account heterogeneity, and the possibility of path dependency and multiple equilibria. See M. Mazzucato, *Firm Size, Innovation and Market Structure: The Evolution of Market Concentration and Instability* (Northampton, MA: Edward Elgar, 2000).

better able to recognize the serendipity and uncertainty that characterizes the innovation process. It is useful for understanding the rise and fall of different economic powers in history. For example, it explains the rise of Germany as a major economic power in the nineteenth century, as a result of State-fostered technological education and training systems. It also explains the rise of the United States as a major economic power in the twentieth century as a result of the rise of mass production and in-house R&D. The United States and Germany became economic powers for different reasons but what they had in common was attention to developing systems of innovation rather than a narrow focus on raising or lowering R&D expenditures.

The general point can be illustrated by contrasting the experience of Japan in the 1970s and 1980s with that of the Soviet Union (Freeman 1995). The rise of Japan is explained as new knowledge flowing through a more horizontal economic structure consisting of the Ministry of International Trade and Industry (MITI), academia and business R&D. In the 1970s Japan was spending 2.5 per cent of its GDP on R&D while the Soviet Union was spending more than 4 per cent. Yet Japan eventually grew much faster than the Soviet Union because R&D funding was spread across a wider variety of economic sectors, not just those focused on the military and space as was the case in the Soviet Union. In Japan, there was a strong integration between R&D, production and technology import activities at the enterprise level, whereas in the Soviet Union there was separation. Crucially, the Soviet Union did not have, or permit, business enterprises to commercialize the technologies developed by the State. Japan had strong user–producer linkages, which were nonexistent in the Soviet system. Japan also encouraged innovation with incentives provided to management and the workforce of companies, rather than focusing mainly on the ministries of science. Johnson (1982) argues that the 'Japanese miracle' was in essence the presence of a Developmental State,[5] or, the coordination of the Japanese

5 Chalmers Johnson (1982) was one of the first authors to conceptualize the 'Developmental State', when he analysed the State-led industrialization of Japan. Johnson argued that, in contrast to a (supposedly) hands-off, regulatory orientation in the US, the Japanese 'Developmental State' directly intervened in the economy, with strong planning promoted by a relatively independent State bureaucracy, which also promoted a close business–government relationship, whereby governmental support, protection and discipline resulted in a private elite willing to take on risky enterprises. Subsequent elaborations of the 'Developmental State' concept can be found in, among others, Wade (1990), Chang (1993), Evans (1995), Woo-Cumings (1999) and Chang and Evans (2000). Recently, contrary

economy through deliberate and targeted industrial policy instituted by MITI. Yet, Lazonick (2008, 27–8) adds that, 'the contribution of the developmental state in Japan cannot be understood in abstraction from the growth of companies' (such as Toyota, Sony or Hitachi); aside from the Japanese State's public support for industry, 'it was the strategy, organization, and finance, internal' to Japan's leading firms that transformed them 'from entrepreneurial firms into innovative firms' and that 'made them successful' in challenging the competitiveness of the world's most advanced economies. Equally important were the lessons learned by Japanese people that went abroad to study Western technologies for their companies, and relationships between those companies to US firms. These companies benefitted from the lessons of the US 'Developmental State', and then transferred that knowledge to Japanese companies which developed internal routines that could produce Western technologies and eventually surpass them. Japanese conglomerates were among the first foreign companies to license the transistor from AT&T (Bell Labs) in the early 1950s. As a result key connections were made with Western companies such as GE, IBM, HP and Xerox. Particular sectors like electronics were targeted forcefully, and the organizational innovation adopted by Japanese firms embodied a flexible 'just-in-time' and 'total quality' production system (which was a necessity to avoid unused capacity and waste, and deal with the lack of natural resources in Japan) that was applied to a wide variety of economic sectors with great success.

Table 1 compares the Japanese and Soviet systems of innovation. It is important in this context to highlight that the MITI's industrial policy was beyond the 'picking winners' idea that many opposed to industrial policy cite today. Japan's approach was about coordinating intra-industrial change, inter-sectoral linkages, inter-company linkages and the private–public space in a way that allowed growth to occur in a holistic and targeted manner. The Japanese model, which was an alternative to the more vertical 'Fordist' model of production in the US, characterized by rigidity and tense relations between trade unions and management, caused a more solid flow of knowledge and competencies in the economy that provided an advantage to the horizontally structured and flexible Japanese firms. While on opposite ends of the political spectrum, the

to Johnson's (1982) original view, Block (2008) showed the existence of an often 'hidden' Developmental State in the US, a view similarly espoused by Reinert (2007) and Chang (2008).

Table 1. Contrasting national systems of innovation: Japan and the USSR in the 1970s

Japan	USSR
High gross domestic expenditure on R&D (GERD)/GNP ratio (2.5%)	Very high GERD/GNP ratio (c. 4%)
Very low proportion of military or space R&D (<2% of R&D)	Extremely high proportion of military or space R&D (>70% of R&D)
High proportion of total R&D at enterprise level and company financed (approx. 67%)	Low proportion of total R&D at enterprise level and company financed (<10%)
Strong integration of R&D, production and technology import at enterprise level	Separation of R&D, production and technology import, weak institutional linkages
Strong user–producer and subcontractor network linkages	Weak or nonexistent linkages between marketing, production, and procurement
Strong incentives to innovate at enterprise level that involve management and workforce	Some incentives to innovate made increasingly strong in 1960s and 1970s but offset by other negative disincentives affecting management and workforce
Intensive experience of competition in international markets	Relatively weak exposure to international competition except in arms race

Source: Freeman (1995). Note: Gross domestic expenditures on research and development (GERD) are all monies expended on R&D performed within the country in a given year.

production model in the USSR and the USA were equally 'rigid', allowing the Japanese model to supersede both.

Regional systems of innovation focus on the cultural, geographical and institutional proximity that create and facilitate transactions between different socioeconomic actors. Studies focusing on innovative milieu such as industrial districts and local systems of innovation have demonstrated that conventions and specific socioinstitutional factors in regions affect technological change at a national level. Specific factors might include interactions between local administrations, unions and family-owned companies in, for example, the Italian industrial districts.

The State's role is not just to create knowledge through national labs and universities, but also to mobilize resources that allow knowledge and innovations to diffuse broadly across sectors of the economy. It does this by rallying existing innovation networks or by facilitating the development of new ones that bring together a diverse group of stakeholders. However, having a national system of innovation that is rich in horizontal and vertical networks is not sufficient. The State must also lead the process of industrial development, by developing strategies for technological advance in priority areas.

This version of the State's role has been accepted in a consensus between multiple countries that are attempting to catch up with most technologically advanced economies. There is a whole literature devoted to the role of the so-called 'Developmental State', where the State is active not only in Keynesian demand management but also in leading the process of industrialization. The most typical examples are the East Asian economies, which through planning and active industrial policy were able to 'catch up' technologically and economically with the West (Amsden 1989). In states that were late to industrialize, the State itself led the industrialization drive. It took on developmental functions, for example by targeting certain sectors for investment, placed barriers to foreign competition until such time as companies in the targeted sectors were ready to export, and then provided assistance finding new export markets for companies. In Japan, for example, Johnson (1982) illustrates how the MITI worked to coordinate Japanese firms in new international markets. This occurred through investments made in particular technologies (picking winners), and the creation of specific business strategies meant to win particular domestic and international markets. Furthermore, the Japanese State coordinated the finance system through the Bank of Japan as well as through the Fiscal Investment Loan Program (funded by the postal savings system).

Chang (2008) offers similar illustrations for South Korea and other recently emerged economies. China has engaged in a targeted industrialization strategy too, only joining the World Trade Organization once its industries were ready to compete, rather than as part of an International Monetary Fund–backed industrialization strategy. The Chinese strategy showed the weaknesses of the Washington Consensus on development, which denied the State the active role that it played in the development of major industrialized nations such as the United States, Germany and the United Kingdom.

If there is strong evidence that the State can be effective in pursuing targeted catch-up policies by focusing resources on being dominant in certain industrial sectors, why is it not accepted that the State can have

a greater role in the development of new technologies and applications beyond simply funding basic science and having an infrastructure to support private sector activity?

Myths about Drivers of Innovation and Ineffective Innovation Policy

The fact that economics was putting so much emphasis on innovation in the growth process caused policymakers, since the 1980s, to begin paying much more attention to variables like R&D and patents as a predicator of innovation and therefore of economic growth. For example, the European Union's Lisbon Agenda (2000) and its current Europe 2020 strategy (EC 2010) set a target for 3 per cent of the EU's GDP to be invested in R&D, along with other policies meant to encourage the flow of knowledge between universities and business – and a stronger link between financial markets and innovative firms of different size.

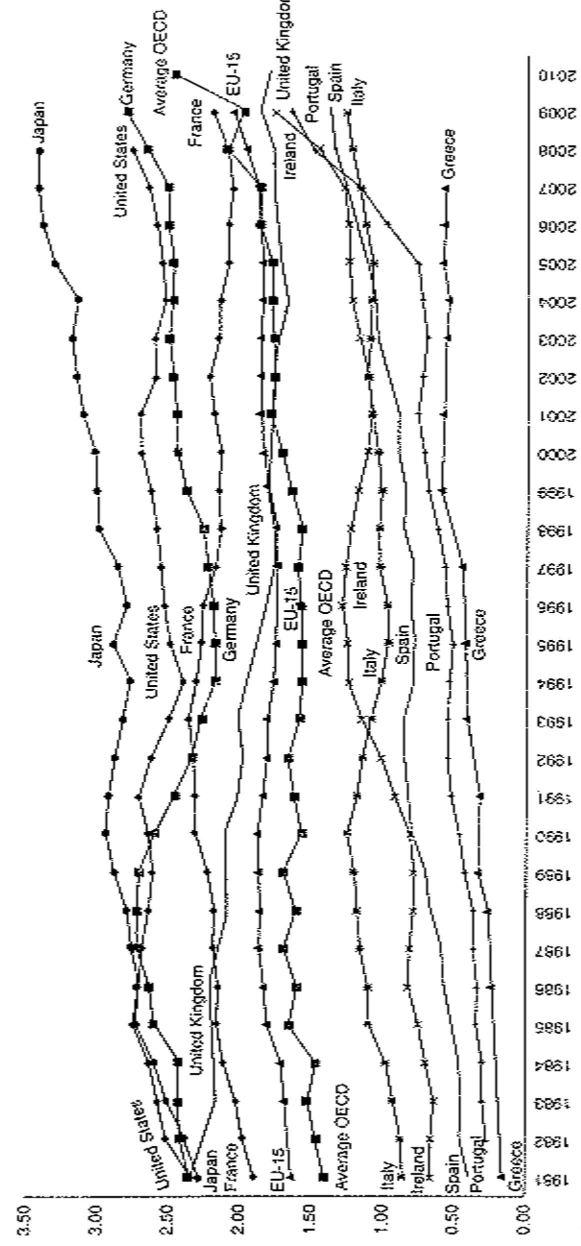
While countries within the OECD continue to differ greatly in their R&D spending (Figure 1 below), what is interesting is that those European countries that have suffered the most from the financial crisis, which later turned into a sovereign debt crisis, were also countries that have the lowest R&D expenditures. This of course does not mean that it is their low R&D intensity that caused their problems, but it is surely related. In the case of Italy, in fact, its high debt/GDP ratio (120 per cent in 2011) was not due to too much spending but spending in the wrong places. Its deficit for many years was relatively mild, at around 4 per cent. But its lack of investment in productivity-enhancing R&D and human capital development meant that its growth rate remained below the interest rate that it paid on its debt, thus making the numerator of the debt/GDP ratio grow more than the denominator. The fact that EU countries spend so differently on areas that create long-run growth is one of the reasons that they were each affected so differently by the economic crisis. The numerous approaches to growth were a reason that there was such little solidarity when it came time to help each other out. German 'falks' feel that German tax money should not be used to bail out the Greeks. However, they err in thinking that the Greeks are spendthrifts. The reforms that are required to make the European project work require not only 'structural' reforms (increasing the propensity to pay tax, labour market reform etc.) but also, and especially, increases in public and private sector investment in research and human capital formation that produce innovation. Getting support for such policies is virtually impossible under the current new 'fiscal compact', which limits spending by European member states to 3 per cent of GDP without differentiating between the spending that, through innovation and capital investments, can lead to future growth.

While low spending on R&D is a problem throughout much of the European 'periphery', it is also true that if a country has lower than average R&D spending, this is not necessarily a problem if the sectors that the country specializes in are not sectors in which innovation occurs necessarily through R&D (Pierrakis 2010). For example, the UK specializes in financial services, construction and creative industries (such as music) – all with relatively low needs for basic R&D. And there are many industries, especially in the service sector, that do no R&D at all. Yet these industries often employ large numbers of knowledge workers to generate, absorb and analyse information. If, all other things equal, these industries represented a smaller proportion of GDP, it would be easier for an economy to reach the 3 per cent target for R&D/GDP (which characterized both the European Commission's Lisbon Agenda and the current EC 2020 agenda). But would the performance of the economy be superior as a result? It depends on how these industries contribute to the economy. Are these 'low-tech' industries providing important services that enhance the value-creating capabilities of other industries or the welfare of households as consumers? Or are they, as is often the case in financial services, focused on extracting value from the economy, even if that process undermines the conditions for innovation in other industries (Mazzucato and Lazonick 2010)?

One of the problems that such simple targets encounter is that they divert attention from the vast differences in R&D spending across industries and even across firms within an industry. They can also mask significant differences in the complementary levels of R&D investments made by governments and businesses that are also required to generate superior economic performance.

The National Systems of Innovation perspective described above highlights the important role of intermediary institutions in diffusing the knowledge created by new R&D throughout a system. An even greater problem with R&D-based innovation policies is the lack of understanding of the complementary assets that must be in place at the firm level that make it possible for technological innovations to reach the market, e.g. infrastructure or marketing capabilities.

Figure 1. Gross R&D spending (GERD) as a percentage of GDP in OECD, 1981–2010



Source: OECD (2011).

There have been many myths created around innovation-led growth. These have been based on wrong assumptions about the key drivers of innovation, from R&D, to small firms, venture capital and patents. A brief discussion of these follows. I call them 'myths', though they are perhaps more clearly called false assumptions leading to ineffective innovation policy.

Myth 1: Innovation is about R&D

The literature on the economics of innovation, from different camps, has often assumed a direct causal link between R&D and innovation, and between innovation and economic growth. While the systems of innovation literature referred to above has argued strongly against the linear model of innovation, much innovation policy still targets R&D spending at the firm, industry and national levels. Yet there are very few studies which prove that innovation carried out by large or small firms actually increases their growth performance -- that is, the macro models on innovation and growth (whether 'new growth' theory models or the 'Schumpeterian' models) do not seem to have strong empirical 'micro foundations' (Geroski and Mazzucato 2002a). Some company-level studies have found a positive impact of R&D on growth (Geroski, Machin and Toker 1992; 1996, Yasuda 2005) while others found no significant impact (Almus and Nerlinger 1999; Bottazzi et al. 2001; Lööf and Heshmati 2006). Some studies have found even a negative impact of R&D on growth, which is not surprising: if the firms in the sample don't have the complementary assets needed, R&D becomes only a cost (Brouwer, Kleinknecht and Reijnen 1993; Freel and Robson 2004).

It is thus fundamental to identify the company-specific conditions that must be present to allow spending on R&D to positively affect growth. These conditions will no doubt differ between sectors. Demirel and Mazzucato (2012), for example, find that in the pharmaceutical industry, only those firms that patent five years in a row (the 'persistent' patenters) and which engage in alliances achieve any growth from their R&D spending. Innovation policies in this sector must thus target not only R&D but also different attributes of firms. Coad and Rao (2008) found that only the fastest-growing firms reap benefits from their R&D spending (the top 6 per cent identified in NESTA's 2009 report 'The Vital 6%'). Mazzucato and Parris (2011) find that the relationship between R&D spending and fast-growing firms only holds in specific periods of the industry life-cycle, when competition is particularly fierce.

Myth 2: Small is Beautiful

Finding that the impact of innovation on growth is indeed different for different types of firms has important implications for the commonly held assumption that 'small firms' matter (for growth, for innovation and for employment), and hence that many different policies that target SMEs are needed to generate innovation and growth. Hughes (2008) has shown that in the UK SMEs received close to £9 billion in direct and indirect government support, which is more than the police force receives. Is this money well spent? The hype around small firms arises mainly from the confusion between size and growth. The most robust evidence available emphasizes not the role of small firms in the economy but to a greater extent the role of *young* high-growth firms. NESTA, for example, showed that the firms most important to growth in the UK have been the small number of fast-growing businesses that, between 2002 and 2008, generated the greatest employment increase in the country (NESTA 2011). And while many high-growth firms are small, many small firms are not high growth.[6] The bursts of rapid growth that promote innovation and create employment are often staged by firms that have existed for several years and grown incrementally until they reached a take-off stage. This is a major problem since so many government policies focus on tax breaks and benefits to SMEs, with the aim of making the economy more innovative and productive.

Although there is much talk about small firms creating jobs, and increasingly a focus of policymakers, this is mainly a myth. While by definition small firms will create jobs, they will in fact also destroy a large number of jobs when they go out of business. Haltiwanger, Jarmin and Miranda (2010) find that there is indeed no systematic relationship between firm size and growth. Most of the effect is from age: young firms (and business start-ups) contribute substantially to both gross and *net* job creation.

Productivity should be the focus, and small firms are often less productive than large firms. Indeed recent evidence has suggested that some economies that have favoured small firms, such as India, have in fact

6 Not to mention the statistical effect of being small: while a one-person micro-enterprise that hires an additional employee will display a 100 per cent growth in employment, a 100,000 person enterprise that hires 1,000 employees will show 'only' a 1 per cent increase in employment. And yet, it is obvious which of these hypothetical firms contributes more to a decrease in unemployment at the macro-level.

performed worse. Hsieh and Klenow (2009), for example, suggest that 40–60 per cent of the total factor productivity (TFP) difference between India and the United States is due to misallocation of output to too many small and low-productivity SMEs in India. As most small start-up firms fail, or are incapable of growing beyond the stage of having a sole owner-operator, targeting assistance to them through grants, soft loans or tax breaks will necessarily involve a high degree of waste. While this waste is a necessary gamble in the innovation process (Janeway 2012), it is important to at least guide the funding process with what we know about 'high growth' innovative firms rather than some folkloristic notion of the value of SMEs as an aggregate category – which actually means very little.

Bloom and Van Reenen (2006) argue that small firms are less productive than large ones because they are less well managed and subject to provincial family favouritism. Furthermore, small firms have lower average wages, fewer skilled workers, less training, fewer fringe benefits and higher instances of bankruptcy. They argue that the UK has many family firms and a poor record of management in comparison with other countries such as the US and Germany (2006). Among other reasons, this is related to the fact that the tax system is distorted by giving inheritance tax breaks to family firms.

Some have interpreted as a result that it is high growth rather than size that matters, and that the best that government can do is to provide the conditions for growth through policies that foster innovation. Bloom and Van Reenen (2006) argue that instead of having tax breaks and benefits target SMEs, the best way to support small firms is to 'ensure a level playing field by removing barriers to entry and growth, among firms of all sizes, enforcing competition policy, and strongly resisting the lobbying efforts of larger firms and their agents'. But as we will see in Chapters 3 and 5, often the most innovative firms are precisely those that have benefitted the most from direct public investments of different types, making the association between size and growth much more complex.

The policy implication is that rather than giving handouts to small companies in the hope that they will grow, it is better to give contracts to young companies that have already demonstrated ambition. It is more effective to commission the technologies that require innovation than to hand out subsidies in the hope that innovation will follow. In an era where budget deficits are constraining available resources, this approach could yield significant taxpayer savings if, for example, direct transfers to

firms that are given just because of the size of a company were ended, such as small business rate relief for smaller companies and inheritance tax relief for family firms (Schmidt 2012).

Myth 3: Venture Capital is Risk Loving

If the role of small firms and R&D is overstated by policymakers, a similar hype exists in relation to the potential for venture capital to create growth, particularly in knowledge-based sectors where capital intensity and technological complexity are high.

Venture capital is a type of private equity capital focused on early stage, high-potential growth companies. The funding tends to come either as seed funding or as later-stage growth funding where the objective of venture capitalists is to earn a high return following a successful IPO, merger or acquisition of the company. Venture capital fills a funding void that exists for new firms, which often have trouble gaining credit from traditional financial institutions such as banks. Such firms thus often have to rely on other sorts of funding such as 'business angels' (including family and friends), venture capital and private equity. Such alternative funding is most important for new knowledge-based firms trying to enter existing sectors or for new firms trying to form a new sector.

Risk capital is scarce in the seed stage of firm growth because there is a much higher degree of risk in this early phase, when the potential of the new idea and its technological and demand conditions are completely uncertain (see Table 2). The risk in later phases falls dramatically.

Figure 2 shows that the usual place where it is assumed venture capital will enter is the stage of the invention-innovation process (second and third stage above). In reality the real picture is much more non-linear and full of feedback loops. Many firms die during the transition between a new scientific or engineering discovery and its successful transformation into a commercial application. Thus moving from the second to the third phase shown in Figure 2 is often referred to as the valley of death.

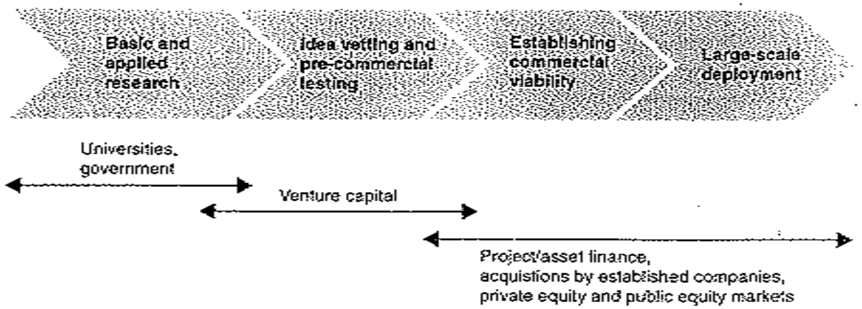
Figure 2 does not illustrate how time after time it has been public rather than privately funded venture capital that has taken the most risks. In the US, government programmes such as the Small Business Innovation Research (SBIR) programme and the Advanced Technology Program (ATP) within the US Department of Commerce have provided 20–25 per cent of total funding for early stage technology firms (Auerswald and Branscomb 2003, 232). Thus, government has played a

Table 2. Risk of loss for different stages at which investments are made (%)

Point at which investment made	Risk of loss
Seed stage	66.2%
Start-up stage	53.0%
Second stage	33.7%
Third stage	20.1%
Bridge or pre-public stage	20.9%

Source: Pierrakis (2010).

Figure 2. Stages of venture capital investment



Source: Ghosh and Nanda (2010, 6).

leading role not only in the early stage research illustrated in Figure 2, but also in the commercial viability stage. Auerswald and Branscomb (2003) claim that government funding for early stage technology firms is equal to the total investments of 'business angels' and about two to eight times the amount invested by private venture capital.

Venture capital funds tend to be concentrated in areas of high potential growth, low technological complexity and low capital intensity, since the latter raises the cost significantly. Since there are so many failures in the high-risk stages of growth, venture capital funds tend to have a portfolio of different investments with only the tails (extremes) earning high returns – a very skewed distribution.

Although most venture capital funds are usually structured to have a life of ten years, they tend to prefer to exit much earlier than ten years because of the management fees and the bonuses earned for high returns. Early exits are preferred in order to establish a winning track record and raise a follow-on fund. This creates a situation whereby venture capital funds therefore have a bias towards investing in

projects where the commercial viability is established within a 3-to-5-year period (Ghosh and Nanda 2010). Although this is sometimes possible (e.g. Google), it is often not. In the case of an emerging sector like biotech or green tech today, where the underlying knowledge base is still in its early exploratory phase, such a short-term bias is damaging to the scientific exploration process which requires longer time horizons and tolerance of failure. Venture capital has succeeded more in the US when it provided not only committed finance, but managerial expertise and the construction of a viable organization (Lazonick 2012).

The problem has been not only the lack of venture capital investment in the most critical early seed stage, but also its own objectives in the innovation process. This has been strongly evidenced in the biotech industry, where an increasing number of researchers have criticized the venture capital model of science, indicating that significant investor speculation has a detrimental effect on the underlying innovation (Coriat, Orsi and Weinstein 2003; Lazonick and Tulum 2011; Mirowski 2011). The fact that so many venture capital backed biotech companies end up producing nothing, yet make millions for the venture capital firms that sell them on the public market is highly problematic. It creates a need to question the role of venture capital in supporting the development of science and also its effect on the growth process. The increased focus on patenting and venture capital is not the right way to understand how risky and long-term innovations occur. Pisano (2006) in fact claimed that the stock market was never designed to deal with the governance challenges presented by R&D-driven businesses. Mirowski (2011, 208) describes the venture capital–backed biotech model as:

> …commercialized scientific research in the absence of any product lines, heavily dependent upon early-stage venture capital and a later IPO launch, deriving from or displacing academic research, with mergers and acquisitions as the most common terminal state, pitched to facilitate the outsourcing of R&D from large corporations bent upon shedding their previous in-house capacity.

The problem with the model has been that the 'progressive commercialization of science' seems to be unproductive, generating few products, and damaging to long-term scientific discoveries and findings over time.

An alternative view is presented in Janeway (2012) who argues that stock market speculation is necessary for innovation. However, what he describes as a semi-natural element of capitalism was instead a result of a hefty political process, of lobbying (Lazonick 2009). NASDAQ was put in place to provide a speculative market on which high-tech start-ups could be funded but also exit quickly. And without NASDAQ, launched in 1971, VC would not have emerged as a well-defined industry in the 1970s. The coevolution of VC and NASDAQ is a result of the policy space being 'captured'. Another element not emphasized in Janeway, is the degree to which the 'rewards' to VC have been disproportional to the risks taken. His own VC company, Warburg Pincus, made millions in a game that he admits was about entering after the State did the hard work. While he says that the period of speculation was necessary, he does not confront the issue of how VC was justified in capturing such high returns. And neither that VC is itself becoming one of its own worst enemies by being such adamant lobbyists for a lower public purse (via lower taxes), which will not be able to fund the future innovations for VC to piggyback on.

Myth 4: We Live in a Knowledge Economy – Just Look at all the Patents!

Similarly to the myth that 'innovation is about R&D', a misunderstanding exists in relation to the role of patents in innovation and economic growth. For example, when policymakers look at the number of patents in the pharmaceutical industry, they presume it is one of the most innovative sectors in the world. This rise in patents does not however reflect a rise in innovation, but a change in patent laws and a rise in the strategic reasons why patents are being used. In ICT there has been a shift in the use of patents from the development and protection of proprietary technologies, resulting from in-house R&D, to cross-licensing in open systems, with the purpose of buying in technology (and the related patents) produced elsewhere (Chesbrough 2003; Grindley and Teece 1997). This has caused the R&D budgets of large companies, such as IBM, to fall at the same time that their patent numbers rose (Lazonick 2009, 88–9). Not recognizing these dynamics cause a focus on the number of patents to be misguided.

The exponential rise in patents, and the increasing lack of relationship this rise has had with actual 'innovation' (e.g. new products and processes), has occurred for various reasons. First, the types of inventions that can be patented has widened to include publicly funded research, upstream research tools (rather than only final products and processes), and even

'discoveries' (as opposed to inventions) of existing objects of study such as genes. The 1980 Bayh–Dole Act, which allowed publicly funded research to be patented rather than remain in the public domain, encouraged the emergence of the biotechnology industry, as most of the new biotech companies were new spinoffs from university labs receiving heavy State funding. Furthermore, the fact that venture capital often uses patents to signal which companies to invest in means that patents have increased in their strategic value to companies seeking to attract financing. All these factors have caused the number of patents to rise, with most of them being of little worth (e.g. very few citations received from other patents), and with most not resulting in a high number of innovations, e.g. new drugs in pharma (see Figure 5 in Chapter 3). Thus directing too much attention to patents, rather than to specific types of patents, such as those that are highly cited, risks wasting a lot of money (as argued below for the patent box case).

Researchers have argued that many of the recent trends in patents, such as the increase in upstream patents for things like 'research tools' have caused the rate of innovation to fall rather than increase as it blocks the ability of science to move forward in an open exploratory way (Mazzoleni and Nelson 1998). The effect has been especially deleterious to the ability of scientists in the developing world to repeat experiments carried out in the developed world. Prevented from replicating results, they cannot build on those experiments with their own developments, thus hurting their ability to 'catch up' (Forero-Pineda 2006).

Notwithstanding the fact that most patents are of little value, and that patents play a controversial role in innovation dynamics, different government policies continue to assume that patents have a strong link to ongoing high-tech R&D and must be incentivized to create innovation-led growth. In October 2010, George Osborne (the UK's chancellor of the exchequer, a role equivalent of the minister of finance or secretary of the treasury in other countries) announced a 'patent box' policy beginning in 2013, which will reduce the rate of corporation tax on the income derived from patents to 10 per cent. This of course fits with the current government's belief that investment and innovation can be easily nudged through tax policy. The same policy has recently been introduced in the Netherlands.

The Institute for Fiscal Studies (IFS) has argued against this policy, claiming that the only effect it will have is to reduce government tax revenue (by a large amount) without affecting innovation (Griffith et al. 2010).

It is argued that R&D tax credits are enough to address the market failure issue around R&D, and that the patent box policy is instead poorly targeted at research, as the policy targets the income that results from patented technology, not the research or innovation itself. Furthermore, the authors maintain that the patent box policy will also add complexity to the tax system and require expensive policing to ensure that income and costs are being appropriately assigned to patents. They claim that the great uncertainty and time lags behind creating patentable technologies will counteract the incentives. Since international collaborations are increasingly common, there is no guarantee that the extra research that is incentivized will be conducted in the country introducing the policy.

Myth 5: Europe's Problem is all about Commercialization

It is often assumed that Europe's main disadvantage in innovation as compared to the US is its lack of capability for 'commercialization' (see Figure 2) which stems from problems with the 'transfer' of knowledge. In fact, EU problems don't come from poor flow of knowledge from research but from the EU firms' smaller stock of knowledge. This is due to the great differences in public and private spending on R&D. While in the US R&D/GDP is 2.6 per cent, it is only 1.3 per cent in the UK. In Italy, Greece and Portugal – the countries experiencing the worst effects of the eurozone crisis – R&D/GDP spending is less than 0.5 per cent (Mazzucato 2012b).

If the US is better at innovation, it isn't because university–industry links are better (they aren't), or because US universities produce more spinouts (they don't). It simply reflects more research being done in more institutions, which generates better technical skills in the workforce (Salter et al. 2000). Furthermore, US funding is split between research in universities and early stage technology development in firms. Getting EU universities to do both runs the risk of generating technologies unfit for the market.

Thus there is not a problem of research quality in universities in Europe, nor in the collaboration between industry and universities, which probably occurs more frequently in the UK than the US. Nor is there a problem in universities generating firms, which again occurs more frequently in Europe than in the US (although there are major concerns about the quality of the firms that are generated, Salter et al. 2000; Nightingale 2012). If European firms lack the ability to innovate then technology transfer policies are like pushing a piece of string.

More generally, in the economics of innovation literature, there is often talk of the 'European Paradox' – the conjecture that EU countries play a leading global role in top-level scientific output, but lag behind in the ability to convert this strength into wealth-generating innovations. Dosi, Llerena and Labini (2006) support the points made above by providing evidence that the reason for European weakness is not, as is commonly claimed, the lack of science parks or interaction between education and industry. It is a weaker system of scientific research and the presence of weaker and less innovative companies. Policy implications include less emphasis on 'networking' and more on policy measures aimed to strengthen 'frontier' research or, put another way, a better division of labour between universities and companies, where universities should focus on high-level research and firms on technology development.

An alternative view – often voiced – is that Europe lacks sufficiently speculative stock markets to induce VC investment (Janeway 2012). While there are surely problems with the European venture capital industry (Bottazzi and Da Rin 2002), and there is perhaps not an equivalent to NASDAQ, this view ignores how the overly speculative US model undermines innovation. The problem is that the ideology surrounding both the role of VC, the role of the stock market and innovation, and the analysis of where innovation comes from, has prevented a 'healthy balance' of speculation and investment to be sustainable over time.

Myth 6: Business Investment Requires 'Less Tax and Red Tape'

While there is a research component in innovation, there is not a linear relationship between research and development, innovation and economic growth. While it is important that the frontiers of science advance and that economies develop the nodes and networks that enable knowledge to be transferred between different organizations and individuals, it does not follow that subsidizing the activity of R&D per se within individual firms is the best use of taxpayers' money. Although it is common sense that there is a relationship between a decision to engage in R&D and its cost (see Myth 1), qualitative surveys of the effectiveness of the R&D tax credit for both large and small firms provide little evidence that it has positively impacted on the decision to engage in R&D, rather than simply providing a welcome cash transfer to some firms that have already done so.[7] There is also a potential problem under the current R&D tax credit system, in many countries, that it does not hold firms accountable as to whether they have conducted new innovation that would not otherwise have taken place, or simply pursued routine forms of product development. In time, therefore, as the entrepreneurial State is built, it would be more effective to use some of the expenditure on R&D tax credits to directly commission the technological advance in question. Recently, the Netherlands has introduced an R&D tax credit that targets not the income from R&D (easily fudged) but R&D workers – and this has been found to be more effective, creating the kind of 'additionality' that income-based R&D tax credits don't (Lockshin and Mohnen 2012).

More generally, as Keynes emphasized, business investment (especially innovative investment) is a function of 'animal spirits', the gut instinct of investors about future growth prospects. These are impacted to a greater extent not by taxes but by the strength of a nation's science base, its system of credit creation, and its quality of education and hence human capital. Tax cuts in the 1980s did not produce more investment in innovation; they only affected income distribution (increasing inequality). For this same reason, 'enterprise zones' which are focused almost exclusively on tax benefits and weakened regulation are not *innovation* zones. It would be best to save that money or to invest it in properly run science parks for which there is better evidence that innovation will follow (Massey, Quintas and Wield 1992).

It is important for innovation policy to resist the appeal for tax measures of different kinds – such as the patent box discussed above, or R&D tax credits – unless they are structured in such a way that will lead to investments in innovation that would not have happened anyway, and real evidence confirms it. Most of all, it is essential for policymakers to be wary of companies that complain about 'tax and red tape', when it is clear that their own global actions reflect a preference for areas of the world where the State is spending precisely in those areas that create confidence and 'animal spirits' regarding future growth possibilities.

This chapter has argued that many of the assumptions that underlie current growth policy should not be taken for granted. Over the last decade or so, policymakers searching for proxies for economic growth

7 See HMRC, *An Evaluation of R&D Tax Credits* (2010) for an example of this.

have looked to things they can measure such as R&D spending, patents, venture capital investment, and the number of small firms that are assumed to be important for growth. I have attempted to demystify these assumptions and now turn to the largest myth of all: the limited role for government in producing entrepreneurship, innovation and growth.

Chapter 5

THE STATE BEHIND THE iPHONE

Stay hungry, stay foolish

Steve Jobs (2005)

In his now well-known Stanford University commencement address, delivered on 12 June 2005, Steve Jobs, then CEO of Apple Computer and Pixar Animation Studios, encouraged the graduating class to be innovative by 'pursuing what you love' and 'staying foolish'. The speech has been cited worldwide as it epitomizes the culture of the 'knowledge' economy, whereby what are deemed important for innovation are not just large R&D labs but also a 'culture' of innovation and the ability of key players to change the 'rules of the game'. By emphasizing the 'foolish' part of innovation, Jobs highlights the fact that underlying the success of a company like Apple – at the heart of the Silicon Valley revolution – is not (just) the experience and technical expertise of its staff, but (also) their ability to be a bit 'crazy', take risks and give 'design' as much importance as hardcore technology. The fact that Jobs dropped out of school, took calligraphy classes and continued to dress all his life like a college student in sneakers is all symbolic of his own style of staying young and 'foolish'.

While the speech is inspiring, and Jobs has rightly been called a 'genius' for the visionary products he conceived and marketed, this story creates a myth about the origin of Apple's success. Individual genius, attention to design, a love for play, and foolishness were no doubt important characteristics. But without the massive amount of public investment behind the computer and Internet revolutions, such attributes might have led only to the invention of a new toy – not to cutting-edge revolutionary products like the iPad and iPhone which have changed the way that people work and communicate. Like the discussion of venture capital in Chapter 2, whereby venture capital has entered industries like biotechnology only after the State had done the messy groundwork, the genius and 'foolishness' of Steve Jobs led to massive profits and success, largely because Apple was able to ride the wave of massive State investments in the 'revolutionary' technologies that underpinned the iPhone and iPad: the Internet, GPS, touch-screen displays and communication technologies. Without these publicly funded technologies, there would have been no wave to foolishly surf.

This chapter is dedicated to telling the story of Apple, and in doing so, asks questions that provocatively challenge the ways in which the role of the State and Apple's success is viewed. In Chapter 8 we ask whether the US public benefited, in terms of employment and tax receipts, from these major risks taken by such an investment of US tax dollars? Or were the profits siphoned off and taxes avoided? Why is the State eagerly blamed for failed investments in ventures like the American Supersonic Transport (SST) project (when it 'picks losers'), and not praised for successful early stage investments in companies like Apple (when it 'picks winners')? And why is the State not rewarded for its direct investments in basic and applied research that lead to successful technologies that underpin revolutionary commercial products such as the iPod, the iPhone and the iPad?

The 'State' of Apple Innovation

Apple has been at the forefront of introducing the world's most popular electronic products as it continues to navigate the seemingly infinite frontiers of the digital revolution and the consumer electronics industry. The popularity and success of Apple products like the iPod, iPhone and iPad have altered the competitive landscape in mobile computing and communication technologies. In less than a decade the company's consumer electronic products have helped secure its place among the most valuable companies in the world, making record profits of $26 billion in 2011 for its owners. Apple's new iOS family of products brought great success to the company, but what remains relatively unknown to the average consumer is that the core technologies embedded in Apple's innovative products are in fact the results of decades of federal support for innovation. While the products owe their beautiful design and slick integration to the genius of Jobs and his large team, nearly every state-of-the-art technology found in the iPod, iPhone and iPad is an often overlooked and ignored achievement of the research efforts and funding support of the government and military.

Only about a decade ago Apple was best known for its innovative personal computer design and production. Established on 1 April 1976

Table 3. Apple's net sales, income and R&D figures between 1999 and 2011 (US$, millions)

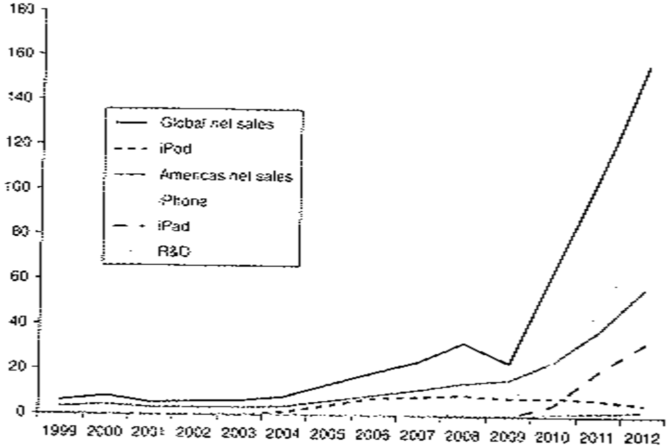
	Net sales							
Year	Global	Americas	iPod	iPhone	iPad	Net Income	R&D	Sales/ R&D (%)
2011	108,249	8,315	7,453	47,057	20,358	25,922	2,429	2.24
2010	65,225	24,498	8,274	25,179	4,958	14,013	1,782	2.73
2009	36,537	16,142	8,091	6,754	n/a	5,704	1,333	3.65
2008	32,479	14,573	9,153	1,844	n/a	4,834	1,109	3.41
2007	24,006	11,596	8,305	123	n/a	3,495	782	3.26
2006	19,315	9,307	7,676	n/a	n/a	1,989	712	3.69
2005	13,931	6,590	4,540	n/a	n/a	1,335	534	3.83
2004	8,279	4,019	1,306	n/a	n/a	276	489	5.91
2003	6,207	3,181	345	n/a	n/a	69	471	7.59
2002	5,742	3,088	143	n/a	n/a	65	430	7.49
2001	5,363	2,996	n/a	n/a	n/a	(25)	430	8.02
2000	7,983	4,298	n/a	n/a	n/a	786	380	4.76
1999	6,134	3,527	n/a	n/a	n/a	601	314	5.12

Note: Apple's annual net sales, income and R&D figures were obtained from company's annual SEC 10-K filings.

in Cupertino, California by Steve Jobs, Steve Wozniak and Ronald Wayne, Apple was incorporated in 1977 by Jobs and Wozniak to sell the Apple I personal computer.[1] The company was originally named Apple Computer, Inc. and for 30 years focused on the production of personal computers. On 9 January 2007, the company announced it was removing the 'Computer' from its name, reflecting its shift in focus from personal computers to consumer electronics. This same year, Apple launched the iPhone and iPod Touch featuring its new mobile operating system, iOS, which is now used in other Apple products such as the iPad and Apple TV. Drawing on many of the technological capabilities of earlier generations of the iPod, the iPhone (and iPod Touch) featured a revolutionary multi-touch screen with a virtual keyboard as part of its new operating system.

1 In 1977, at the time of incorporation, Ronald Wayne sold his stake in the company to Jobs and Wozniak for $800.

Figure 10. Apple net sales by region and product (US$, billions)



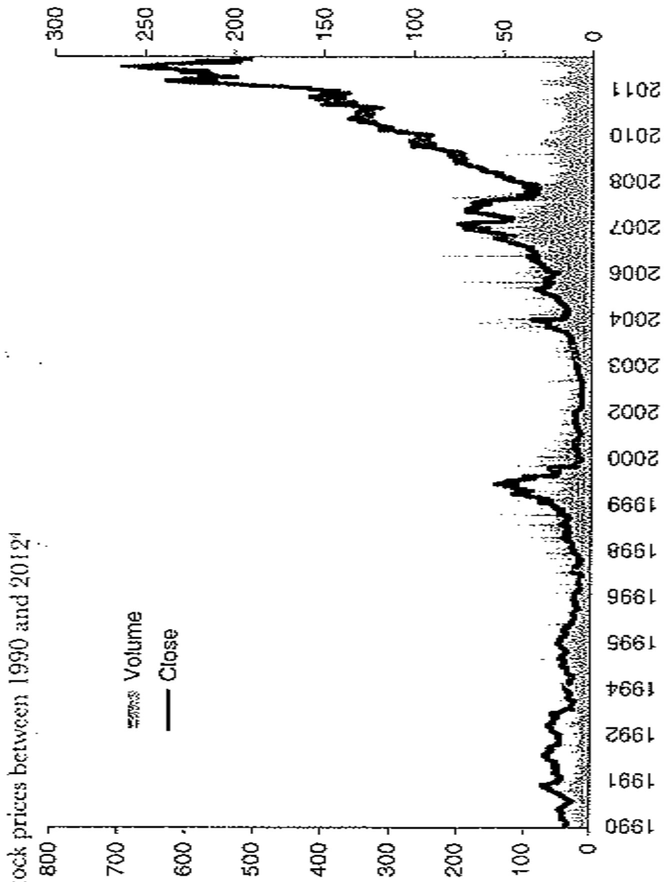
While Apple achieved notable success during its 30-year history by focusing on personal computers, the success and popularity of its new iOS products has far exceeded any of its former achievements in personal computing.[2] In the 5-year period following the launch of the iPhone and iPod Touch in 2007, Apple's global net sales increased nearly 460 per cent. As Table 3 illustrates, the new iOS product line represented nearly 70 per cent of the overall net sales of Apple in 2011.

The success and popularity of Apple's new products was quickly reflected in the company's revenues. In 2011, Apple's revenue ($76.4 billion) was so big that it surpassed the US government's operating cash balance ($73.7 billion) according to the latest figures from the US Treasury Department available at that time (BBC News 2011). This surge in Apple's revenues was quickly translated into better market valuations and increased popularity of shares of Apple stock listed on the NASDAQ. As shown in Figure 11, Apple's stock price has increased from $8/share to $700/share since the iPod was first introduced by Steve Jobs on 23 October 2001. The launch of iOS products in 2007 enabled the company to secure a place among the most valuable companies in the US.[3]

2 When Apple first went public in 1980, its IPO generated more capital than any IPO since Ford Motor Company in 1956. This created more instant millionaires (around 300) than any other company in history (Malone 1999).

3 When Apple stocks were traded at peak levels on 10 April 2012, the surge in the stock prices pushed the company's overall market value to $600 billion. Only a few companies in the US such as GE ($600 billion in August 2000) and Microsoft ($619 billion, on 30 December 1999) have ever seen this incredible level of

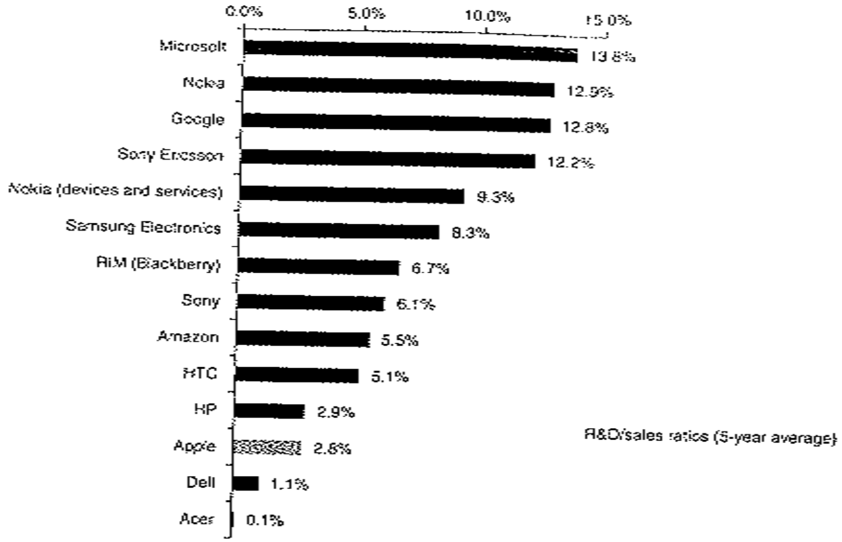
Figure 11. Apple stock prices between 1990 and 2012[4]



valuation (Svensson 2012). At the time of this writing, Apple's market value surpassed its long-time rival Microsoft's (nominal) record of a $619 billion valuation, as Apple stocks traded at a new peak of approximately $700/share between 18 and 19 September 2012.

4 Source: Yahoo! Finance, available online at http://finance.yahoo.com/charts?s=AAPL#symbol=aapl;range=19900102,20121231;compare=;indicator=split+volume;charttype=area;crosshair=on;ohlcvalues=0;logscale=off;source=undefined;Charts/Interactive (from 1 January 1990 to 31 December 2012).

Figure 12. Productive R&D or free lunch?



Source: Retrieved from Dediu and Schmidt's article (2012) 'You Cannot Buy Innovation', Asymco, 30th January. Note: The author's calculations are based on the leading smartphone developers' 5-year average R&D figures between 2006 and 2011.

As indicated by Figure 10 and documented in company financial reports, the rampant growth in product sales following the launch of the iOS family of products paved the way for Apple's successful comeback from its wobbly conditions in the late 1980s. Interestingly, as the company continued to launch one new product after the next with increasing success, the company's financial reports reveal a steady decline in the global sales/R&D ratios, which indicate the portion of funds allocated to R&D activities in comparison to global product sales was falling over time (see Table 3). It could be argued that this is simply a testament to how unprecedented and exponential growth in product sales was relative to the annual growth of R&D expenditures. It could also be interpreted as the expected outcome of steady investment in R&D efforts. However, when viewed in the context of just how competitive the product markets are for consumer electronic products, these rather unimpressive R&D figures stand out. Long-time Apple analyst Horace Schmidt approaches this issue from a different angle by comparing Apple's R&D figures against that of the company's rivals. According to the data compiled by Schmidt (2012) and presented in Figure 12, Apple ranks in the bottom three in terms of the portion of sales allocated for supporting R&D activities among 13 of its top rivals.

Schmidt therefore inquires how Apple manages to get away with such a relatively low rate of R&D (as a percentage of sales ratios) in comparison to its competitors while still outpacing them in product sales. Many Apple experts explain this marginal R&D productivity as the company's success in implementing effective R&D programmes in a fashion that can only be seen in small technology start-ups. There is no doubt that Apple's ingenuity in engineering design, combined with Steve Job's commitment to simplicity, certainly contributed to its efficiency. But, the most crucial facts have been omitted when explaining this figure, which is that Apple concentrates its ingenuity not on *developing* new technologies and components, but on *integrating* them into an innovative architecture: its great in-house innovative product designs are, like that of many 'smart phone' producers, based on technologies that are mostly invented somewhere else, often backed by tax dollars. The following section will provide historical background on technologies that enabled the future glory of the company.

Surfing through the Waves of Technological Advancements

From its humble beginnings selling personal computer kits to its current place as the leader in the global information and communications industry, Apple has mastered designing and engineering technologies that were first developed and funded by the US government and military. Apple's capabilities are mainly related to their ability to (a) recognize emerging technologies with great potential, (b) apply complex engineering skills that successfully integrate recognized emerging technologies, and (c) maintain a clear corporate vision prioritizing design-oriented product development for ultimate user satisfaction. It is these capabilities that have enabled Apple to become a global powerhouse in the computer and electronics industry. During this period prior to launching its popular iOS platform products, Apple received enormous direct and/or indirect government support derived from three major areas:

1) Direct equity investment during the early stages of venture creation and growth.
2) Access to technologies that resulted from major government research programmes, military initiatives, public procurement contracts, or that were developed by public research institutions, all backed by state or federal dollars.

3) Creation of tax, trade or technology policies that supported US companies such as Apple that allowed them to sustain their innovation efforts during times when national and/or global challenges hindered US companies from staying ahead, or caused them to fall behind in the race for capturing world markets.

Each of these points is elaborated on in the following section, as the histories of key technological capabilities underlying Apple's success are traced.

From Apple I to the iPad: The State's very visible hand

From the very start, Jobs and Wozniak sought the support of various public and private funding sources in their effort to form and develop Apple. Each believed in the vision in their mind: that enormous value could be captured from the technologies made available mostly as a result of the prior efforts of the State. Venture capital pioneers and Silicon Valley legends such as Don Valentine, founder of Sequoia; Arthur Rock, founder of Arthur Rock & Company; Venrock, the venture capital arm of the Rockefeller Family; and Fairchild and Intel veteran Mike Markkula were among the first angel and equity investors who bought into their vision (Rao and Scaruffi 2011). In addition to the technologies that were going to help Apple revolutionize the computer industry, the company also received cash support from the government to implement its visionary business ideas in the computer industry. Prior to its IPO in 1980, Apple additionally secured $500,000 as an early stage equity investment from Continental Illinois Venture Corp. (CIVC), a Small Business Investment Company (SBIC) licensed by the Small Business Administration (a federal agency created in 1953) to invest in small firms (Slater 1983; Audretsch 1995).

As briefly discussed in Chapter 4, the emergence of personal computing was made possible by the technological breakthroughs achieved through various public–private partnerships established largely by government and military agencies (Markusen et al. 1991; Lazonick 2008; Block 2008; Breakthrough Institute 2010). When Apple was formed to sell the Apple I personal computer kit in 1976, the product's key technologies were based on public investments made in the computer industry during the 1960 and 1970s. Introduction of silicon during this period revolutionized the semiconductor industry and heralded in the start of a new age when access to affordable personal computers for

wider consumer markets was made possible. These breakthroughs were the result of research carried out in various public–private partnerships at labs including those at DARPA, AT&T Bell Labs, Xerox PARC, Shockley and Fairchild, to name a few. Silicon Valley quickly became the nation's 'computer innovation hub' and the resulting climate stimulated and nurtured by the government's leading role in funding and research (both basic and applied) was harnessed by innovative entrepreneurs and private industry in what many observers have called the 'Internet California Gold Rush' or the 'Silicon Gold Rush' (Kenney 2003; Southwick 1999).

There are 12 major technologies integrated within the iPod, iPhone and iPad that stand out as features that are either 'enablers', or that differentiate these products from their rivals in the market. These include semiconductor devices such as (1) *microprocessors* or *central processing units* (CPU); (2) *dynamic random-access memory* (DRAM); as well as (3) *micro hard drive storage* or *hard drive disks* (HDD); (4) *liquid-crystal displays* (LCDs); (5) *lithium-polymer* (Li-pol) and *lithium-ion* (Li-ion) batteries; (6) *digital signal processing* (DSP), based on the advancement in *fast Fourier transform* (FFT) algorithms; (7) the *Internet*; (8) the *Hypertext Transfer Protocol* (HTTP) and *Hypertext Markup Language* (HTML); (9) and *cellular technology and networks* – all of which can be considered as the core enabler technologies for products such as the iPod, iPhone and iPad. On the other hand, (10) *global positioning systems* (GPS), (11) *click-wheel* navigation and *multi-touch screens*, (12) and *artificial intelligence with a voice-user interface program* (a.k.a. Apple's SIRI) are innovative features that have drastically impacted consumer expectations and user experiences, further enhancing the popularity and success of these products. The following sections take a closer look at the core technologies and features that Apple has managed to ingeniously integrate, initially in the iPod and later in the iPhone and iPad.

How State-funded research made possible Apple's 'invention' of the iPod

Shortly after introducing the first generation iPod in 2001, Apple began to create waves of new innovative products (e.g. the iPhone, iPad) that would eventually revolutionize the entire mobile entertainment industry. The iPod, a new portable handheld device, allowed consumers to store thousands of songs without using any cassettes or CDs. In the early 2000s, this new Apple device was gaining popularity among consumers and replacing portable devices such as Sony's Walkman and Discman in the market. This novel application of existing magnetic storage technology therefore enabled Apple to take on an iconic rival such as Sony, and eventually to rise to the top of the music and entertainment market (Adner 2012). The success of iPod in gaining a competitive market position was important in two major aspects: (1) the success was going to set the stage for Apple's comeback from years of stagnant, if not declining, growth; and, (2) the popularity of this new product would constitute precedence to a family of new innovative Apple iOS products. While this much is often known and noted, the fact that much of Apple's success lies in technologies that were developed through government support and -funded research is an often overlooked story to which I now turn.

Giant magnetoresistance (GMR), SPINTRONICS programme and hard disk drives

A rare instance of public recognition of the role played by State-backed technological research in paving the way for Apple products occurred during the 2007 Nobel Prize ceremony. European scientists Albert Fert and Peter Grünberg were awarded the 2007 Nobel Prize in Physics for their work in developing giant magnetoresistance (GMR). The GMR is a quantum mechanical effect observed in thin-film layered structures, for which the main application has been in magnetic field sensors used in hard disk drives (HDD) and other devices. In his ceremony remarks, Börje Johannson (2007), a member of the Royal Swedish Academy of Sciences, explained what the invention of GMR meant for society by attributing the existence of the iPod to this major scientific breakthrough.

Invention and commercialization of the micro hard drive is especially interesting since the technology development process from its origin to its current form illustrates the role of government not only in establishing the science base for innovation, but also in facilitating the advancement of abstract ideas into manufactured and commercially viable products (McCray 2009). What started as two separate and independent academic, State-funded and -supported research projects in physics in Germany and France culminated into one of the most successful technology breakthroughs in recent years, worthy of the Nobel Prize. Following this scientific breakthrough that Dr Fert and Dr Grünberg achieved, other researchers successfully expanded the size of data storage in conventional hard disk drives during the 1980s and 1990s, breaking new ground for future research and technological advancement. (Overbye 2007).

While the major scientific breakthrough in GMR was accomplished in Europe, the US government played a critical role in the basic research as well as commercialization of this technology. Dr Peter Grünberg's laboratory was affiliated with Argonne National Laboratory (the US Department of Energy's largest R&D lab, located in Illinois) and received critical support from the Department of Energy (DoE) prior to his discovery (DoE 2007). Based on these developments in hard disk technology, companies such as IBM and Seagate moved quickly to translate the new knowledge into successful commercial products (McCray 2009). Despite the advances taking place in the hard drive industry at the time, they would experience similar competitive challenges faced by the semiconductor industry in the late 1980s, which I discuss in the following section on semiconductor devices.

In his 2009 study, McCray details how DARPA's war-related missions to create and sustain an innovation ecosystem for producing superior defence technologies was transformed during peace time by the new mission of transforming those prior investments into technologies supporting economic competitiveness. McCray (2009) documents that the Department of Defense (DoD) initiated the Technology Reinvestment Program (TRP) and allocated $800 million to upgrade the nation's existing technological capabilities following the Cold War. Through TRP, DARPA targeted dual-use technologies that would benefit the military as well as produce commercially viable technologies such as SPINTRONICS.[5] McCray (2009) especially documents the increase in scientific research efforts and publications taking place during DARPA's support for SPINTRONIC during 1990s. McCray (2009, 74) also argues that the role DARPA played in the advancement of this technology was not 'insignificant', simply because the programme was initiated during the time when Japanese competition in computer electronics was pushing computer giants such as IBM and Bell Labs to downsize spending on basic research.

Solid-state chemistry and silicon-based semiconductor devices

Since the launch of the first iPod, the first major new Apple product has evolved many times and also inspired the design of the future iPad

5 *SPIN TRansport electrONICS (SPINTRONICS)*, initially called the 'Magnetic Materials and Devices' project, was a public–private consortium. It consisted of DARPA and industry leaders but was initiated (and funded) by DARPA in 1995, with the total government investment of $100 million during its existence.

and iPhone. Among the factors that have made the iPod, iPhone and iPad possible today are the small microchips that enable handheld smart devices to process large amounts of information and pass it through memory in a virtual instant. Today, central processing units (CPUs) depend on integrated circuits (ICs) that are considerably smaller in size and feature much larger memory capacity in comparison to the integrated circuits once used for processing needs and first designed by Jack Kilby and Robert Noyce in the 1950s. The invention of new silicon-based ICs led to technological developments in various fields in electronics. Personal Computers (PCs), cellular technology, the Internet, and most of the electronic devices found on the market today utilize these smart, tiny devices. The journey of ICs from Bell Labs, Fairchild Semiconductor and Intel into devices such as iPhone or iPad was aided by procurement by the US Air Force and NASA. As the sole consumers of the first processing units based on this new circuit design, defence contracts helped fund the development of the infant microprocessor industry and those introducing complementary electronic equipment and devices that were simply unaffordable in regular commercial markets. Large-scale demand for microprocessors by the US Air Force was created by the Minuteman II missile programme. NASA's Apollo mission pushed the technological envelope, requiring significant improvements in the production process of microprocessors and also greater memory capacity. In turn, each of the government agencies helped to drive down the costs of integrated circuits significantly within a matter of years.[6]

Although the US was the home for early innovation in semiconductors, throughout the 1980s, Japan was developing advanced manufacturing capabilities and competitive memory products at a faster pace.[7] Given the significant role of semiconductors in defence technologies, the DoD considered the industry vital to its military capabilities and national security. Growing fears that the manufacturing equipment essential for production of these technologies, now vital to national defence, would be imported from countries like Japan spurred the DoD to act. The result was the Strategic Computing Initiative (SCI)

6 Lower costs became visible when the price of a microchip for the Apollo program fell from $1,000 per unit to anywhere between $20 to $30 per unit within just few years (Breakthrough 2010).

7 Roland and Shiman (2002, 153) document Japan's significant progress in the global chip market as having 0 per cent market share as opposed to the US's 100 per cent share in 1970s, to 80 per cent global market share in 1986.

which allocated over $1 billion to support research efforts in advanced computer technologies between 1983 and 1993 (Roland and Shiman 2002). Additionally, the manufacturing of highly advanced technologies such as microprocessors had significant economic implications that required collaborative efforts between the government and industry. Recognizing the unique opportunity that semiconductor manufacturing would provide, and fearful of the consequences of lagging behind newly emerging competitors in semiconductor manufacturing such as Japan, the federal government gathered competitive domestic manufacturers and universities together to form a new partnership, the Semiconductor Manufacturing Technology (SEMATECH) consortium.

This move, to advance US-based semiconductor manufacturing technology and capability above and beyond that of the nation's competitors, was part of an overall effort to promote US economic and technological competitiveness globally. The process of organizing collaborative effort between semiconductor companies through SEMATECH was a challenge for the government. In order to make this partnership more appealing, the US government subsidized SEMATECH R&D with $100 million annually. Over time, the members of the consortium came to recognize the benefits of the R&D partnership fostered by SEMATECH. The extensive knowledge sharing efforts that took place among members of SEMATECH helped them avoid duplicating research efforts and translated into less R&D spending. The advanced performance and affordability of microprocessors and memory chips today are to a great extent the result of years of government intervention and supervision (Irwin and Klenow 1996).

From capacitive sensing to click-wheels

As the pioneer of personal computers, Steve Jobs was on his second mission for re-revolutionizing them. His vision for Apple was to prepare the company for the post-computer era, in what he envisioned and often acknowledged in his interviews and media appearances as the new era of the consumer–computer relationship. During an interview at the 2010 D8 conference, Steve Jobs explained his vision of the future for computing by using the analogy of rapid urbanization and its effects on changing consumer views and the need for transportation (Jobs 2010). During his talk, Jobs redefined Apple's overall strategy as building a family of products around the concept of fragmented computing needs by different uses. Jobs often acknowledged his trust in the data processing technologies that had enabled Apple to come up with compact portable devices. It was these processing technologies leading to the portable iOS products that eventually replaced desktop computers. To do this, Apple had begun to work on building a periphery of portable iOS devices, with the Mac becoming the 'digital hub' that would integrate the entire product family together (Walker 2003).

Despite his strong opposition to tablet computers in the 1980s and 1990s, upon his return to Apple in the late 1990s, Jobs had decided that the time was right to focus once again on tablets. Underlying this shift in perspective was the fact that technology in semiconductor devices, batteries and displays had progressed significantly. However, a challenge still remained given the absence of sophisticated technology to successfully replace the *stylus pen*, a feature that Jobs had long despised and considered an inconvenience (Isaacson 2011, 490). The emergence of more sophisticated applications such as inertia scrolling, finger tracking and gesture-recognition systems for touch-screen-enabled displays presented Jobs and his team with the possibility of moving forward (and far beyond the stylus pen). Jobs and his team thus gathered experts together that could integrate these new technologies. The end results included replacing buttons and roll-balls on devices, developing a new navigation system, and enhancing input techniques on touch-screens.[8]

The iPod's click-wheel component that allowed users to navigate quickly through their music library was part of Apple's earlier attempts to implement touch-based features with finger scrolling. In addition to the micro hard disk drive for the storage of memory intensive digital records, the finger scrolling click-wheel feature also differentiated the iPod from the majority of other available portable music players. Although the application of finger scrolling was something novel at the time, the technology behind this feature had been around for decades. The click-wheel significantly benefitted from the *capacitive sensing* technology widely applied in the design of various other products.[9] In fact, the click-wheel feature was not the only feature of Apple products that benefitted from

8 During his TV interview on 30 April 2012, Tony Fadell, who was in the original iPod design team, revealed the challenges Apple was facing with finding ways to replace buttons on the new gadget. Available from: http://www.theverge.com/2012/4/30/2988484/on-the-verge-005-tony-fadell-interview (accessed 12 April 2013).

9 *Capacitive sensing* is a technology that draws on the human body's ability to act as a capacitor and store electric charge.

capacitive sensing. The iPod Touch, iPhone and iPad's *multi-touch screen* also embodies the same principles of finger(s)-operated scrolling on a glass screen.

E. A. Johnson, considered the inventor of capacitive touch-screens, published his first studies in the 1960s while working at Royal Radar Establishment (RRE), a British government agency established for R&D of defence-related technologies (Buxton 2012). One of the first notable developments of the touch-screen was at the European Organization for Nuclear Research (CERN) by Bent Stumpe and his colleague Frank Beck in 1973 (CERN 2010). Samuel Hurst's invention of resistive touch-screens was another notable breakthrough. Hurst's invention came right after leaving Oak Ridge National Laboratory (a national research laboratory in Tennessee established in 1943 and the site of the Manhattan Project and first functional nuclear reactor) for two years to teach at the University of Kentucky (Brown et al., n.d.). While at University of Kentucky, Hurst and his colleagues developed the first resistive touch-screens. Upon his return to Oak Ridge, they started a new company in 1971 to commercialize the new technology and produced the first functioning version in 1983 (Brown et al., n.d.). Earlier work on touch-screens in the 1970s and 1980s, such as that conducted by Johnson, Stumpe, Hurst and others continued in different public and private research labs, creating the foundations for today's important multi-touch applications (Buxton 2012). Among various other factors, moving from touchpads with limited functionality to multi-touch screens was a major leap forward for Apple in the smartphone race. Along with the other technological advancements they exploited, Apple has not only helped redefine the markets it competes from within but has also defined a different path for growth.

The Birth of the iPod's Siblings: The iPhone and iPad

Apple's new vision included radical redefinitions of conventional consumer products and was a great success. The introduction of the iPod generated over $22 billion in revenues for Apple. It was the company's most important global product until the iPhone was introduced in 2007. The cohesion of aesthetic design, system engineering and user experience combined with great marketing helped Apple rapidly penetrate and capture market share in different consumer electronics markets. Apple's new generation of iPods, iPhones and iPads have been built under the assumption that new consumer needs and preferences can be invented by hybridizing existing technologies developed after decades of government support. As a pioneer of the 'smartphone' revolution, Apple led the way in successfully integrating cellular communication, mobile computing and digital entertainment technologies within a single device. The iconic iPhone dramatically altered consumer expectations of what a cellular phone was and can do. With the introduction of the iPad, Apple transformed the portable computer industry that had been dominated for decades by laptops, netbooks and other devices. By offering a slimmer handheld device equipped with a large touch-screen and virtual keyboard, with solid Internet browsing and multimedia capabilities, along with broad compatibility across other Apple products and applications, the iPad virtually created a new niche and captured it at the same time. In less than a decade, Apple singlehandedly came to dominate the consumer electronics industry, a testament to Apple's ingenuity in consumer-oriented device product design and marketing, as well as their organizational capabilities in managing complex 'systems integration' (Lazonick 2011).

From click-wheels to multi-touch screens

Development of touch-screen displays recognizing multi-touch gestures was one of the most important technologies integrated into Apple's devices and for their successful introduction of pocket-sized portable devices such as the iPod. The technology allowed human–machine interaction through a new interface that allowed fingers to navigate the glass surface of LCD displays included with handheld devices. As with the *click-wheel* feature, the technology behind this ground-breaking new way to interface with electronic devices relied on earlier basic and applied research that had been supported by the State. During the 1990s, touch-screen technology was incorporated into a variety of products by numerous computer developers, including Apple, but the majority of the touch-screen technologies available during these earlier days were only capable of handling single-touch manipulation.[10] The introduction of multi-touch scrolling and gestures was developed by Wayne Westerman and John Elias at the University of Delaware (Westerman 1999).

10 As a world-renowned expert on touch-screen technology, Bill Buxton provides an extensive archive of electronic devices with touch-screen applications. The list of Apple products with the touchpad feature can be seen online at http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/ (accessed 12 April 2013).

Wayne Westerman was a doctoral candidate under the supervision of Professor John Elias studying neuromorphic systems at the (publicly funded) University of Delaware, as part of the National Science Foundation (NSF) and Central Intelligence Agency/Director of Central Intelligence (CIA/DCI) Post-Doctoral Fellowship programme (Westerman 1999). Following the completion of Westerman's PhD, he and Elias commercialized this new technology after founding the FingerWorks company. Their new product, called 'iGesture Numpad', enabled many computer users to enter input by applying 'zero-force' pressure on an electronic screen with no need of additional devices such as a keyboard or a mouse. The underlying scientific base and patent application for the new finger tracking and gesture identification system was built on the earlier studies on *capacitive sensing* and *touch-screen* technologies. FingerWorks' successful attempt to translate prior touch-screen research into a commercial product was quickly recognized by Apple, which was interested in developing a multi-touch navigation capability on a fully glass LCD display for the new generation iOS products. FingerWorks was acquired by Apple in 2005 prior to the launch of Apple's first generation iPhone in 2007, and today this new technology lies at the heart of the coveted multi-touch screen featured on Apple's iOS products. As a result, Westerman and Elias, with funding from government agencies, produced a technology that has revolutionized the multi-billion dollar mobile electronic devices industry. Apple's highly comprehensive intellectual property portfolio had benefitted, once again, from technology that was originally underwritten by the State.

Internet and HTTP/HTML

Although the iPhone appears to be a 'cool' gadget with its cutting-edge technology features and hardware components, what makes a phone 'smart' is its ability to connect phone users to the virtual world at any point in time. With the artificial intelligence application named SIRI on board, the iPhone appears to be attempting to outsmart its users. After replacing the handset-industry-standard keypads with touch-screens, SIRI is Apple's attempt to transform input entry and navigation interfaces. As Apple's 'smartphone' continues to evolve into an even smarter device, it is important to recognize and value the underlying and necessary intelligence and technological capabilities that have smart-wired, if you will, this smart device. If hardware, software, memory and the processor were to be the body, soul and brain of a computer, what does the Internet, Hypertext Transfer Protocol (HTTP) or Hypertext Markup Language (HTML) mean to any computer or smart device? Or, what would a computer or smart device be worth in the absence of Internet or without cellular communication capability? Answers to these questions can help us understand the value of the networking capabilities of smart devices. But more importantly, they can help us understand the value of support efforts that the government played in the process of inventing and developing cellular technology, the Internet and satellites.

During the Cold War era, US authorities were concerned about possible nuclear attacks and the state of communication networks following the aftermath of possible attacks. Paul Baran, a researcher at RAND – an organization with its origins in the US Air Force's project for 'Research and Development', or RAND for short – recommended a solution that envisioned a distributed network of communication stations as opposed to centralized switching facilities. With a decentralized communication system in place, the command and network system would survive during and after nuclear attacks (Research and Development 2011).[11] The technological challenges of devising such a network were overcome thanks to the various teams assembled by DARPA to work on networking stations and the transmission of information. Although DARPA approached AT&T and IBM to build such a network, both companies declined the request believing that such a network was a threat to their business; with the help of the State-owned British Post Office, DARPA successfully networked various stations from the west to east coast (Abbate 1999). From the 1970s through the 1990s, DARPA funded the necessary communication protocol (TCP/IP), operating system (UNIX) and email programs needed for the communication system, while the National Science Foundation (NSF) initiated the development of the first high-speed digital networks in the US (Kenney 2003).

Meanwhile, in the late 1980s, British scientist Tim Berners-Lee was developing the Hypertext Markup Language (HTML), uniform resource locators (URL) and uniform Hypertext Transfer Protocol

11 Other goals of the new network project were (a) to save computing costs, as government contractors across the US would be able to share computer resources; and (b) to advance the 'state-of-the-art' in data communications to enable transfer of information between machines over long distances. An additional goal (c) was to foster collaboration between contracted researchers in different locations.

(HTTP) (Wright 1997). Berners-Lee, with the help of another computer scientist named Robert Cailliau, implemented the first successful HTTP for the computers installed at CERN. Berners-Lee and Cailliau's 1989 manifesto describing the construction of the World Wide Web eventually became the international standard for computers all over the world to connect. Public funding has played a significant role for the Internet from its conception to its worldwide application. The Internet is now in many ways a foundational technology that has affected the course of world history by allowing users all over the globe to engage in knowledge sharing and commerce using computers and popular smart gadgets such as the iPhone, iPod or iPad.

GPS and SIRI

Another great feature that an iPod, iPhone or iPad offers is global positioning system (GPS) integration. GPS was an attempt by the DoD to digitize worldwide geographic positioning to enhance the coordination and accuracy of deployed military assets (Breakthrough Institute 2010). What initially began in the 1970s as a strictly military-use-only technology is now widely available to civilians for various uses. In fact, civilian use of GPS quickly outnumbered military utilization following the release of GPS for public applications in the mid-1990s. Yet, even today, the US Air Force has been at the forefront of developing and maintaining the system, which costs the government an average of $705 million annually.[12] An iPhone user can search for a nearby restaurant or an address, based on the NAVSTAR GPS system, which consists of a 24-satellite constellation providing global navigation and timing data for its users. This technology, as well as the infrastructure of the system, would have been impossible without the government taking the initiative and making the necessary financial commitment for such a highly complex system.

Apple's latest iPhone feature is a virtual personal assistant known as SIRI. And, like most of the other key technological features in Apple's iOS products, SIRI has its roots in federal funding and research. SIRI is an artificial intelligence program consisting of machine learning, natural language processing and a Web search algorithm (Roush 2010). In 2000, DARPA asked the Stanford Research Institute (SRI) to take

12 The DoD estimates that, in 2000 dollars, the development and procedure of the system cost the Air Force $5.6 billion between 1973 and 2000 (DoD 2011). The figure does not include military user equipment.

the lead on a project to develop a sort of 'virtual office assistant' to assist military personnel. SRI was put in charge of coordinating the 'Cognitive Assistant that Learns and Organizes' (CALO) project which included 20 universities all over the US collaborating to develop the necessary technology base. When the iPhone was launched in 2007, SRI recognized the opportunity for CALO as a smartphone application and then commercialized the technology by forming 'SIRI' as a venture-backed start-up in the same year. In 2010, SIRI was acquired by Apple for an amount that is undisclosed by both parties.

Changing industry standards from keypad to touchpad input and adding GPS navigation was a significant achievement when iPhone was first introduced. A second game-changer for cell phone, media player and tablet computer developers was the introduction of multi-touch screens and gesture recognition. With SIRI, Apple introduced another radical idea for a device input mechanism that has been integrated within various iOS features and applications. The introduction of SIRI has launched a new round of redefining standards of human–machine interaction and creates a new means of interaction between the user and the machine. Steve Jobs often acknowledged the potential of artificial intelligence and his interest in the future of the technology. During his 2010 interview with Walt Mossberg and Kara Swisher (2010) at the California D8 conference, Jobs had shared his excitement about the recent acquisition of SIRI by Apple, and talked about the great potential the technology offered. Once again, Apple is on the verge of building the future for information and communication industry based on the radically complex ideas and technologies conceived and patiently fostered by the government.

Battery, display and other technologies

The story of the liquid-crystal display (LCD) shares great similarities with the hard disk drive, microprocessor and memory chip (among other major technologies) that emerged during the Cold War era: it is rooted in the US military's need to strengthen its technological capabilities as a matter of national security. Rising competition from the Japanese flat panel display (FPD) industry was a concern for the DoD because the US military's future demand for the technology could not be met solely by the Japanese suppliers. Given this determination, the DoD began implementing a variety of programmes geared towards strengthening the industry's competitiveness, including the formation of an industry

consortium and deployment of new resources for the improvement of manufacturing capabilities and commercial products.

The major breakthrough in LCD technology came about during the 1970s, when the thin-film transistor (TFT) was being developed at the laboratory of Westinghouse under the direction of Peter Brody. The research carried out at Westinghouse was almost entirely funded by the US Army (Hart and Borrus 1992). However, when management at Westinghouse decided to shut down the research, Brody sought out possible funding opportunities elsewhere in the hopes of commercializing this technology independently. In the process of appealing for contracts to ramp up the production of TFT displays, Brody contacted a number of top computer and electronic companies including Apple and others such as Xerox, 3M, IBM, DEC and Compaq. All these major private companies refused to sign on with Brody largely because they doubted his ability to build the manufacturing capability necessary to provide the product at a competitive price compared to his Japanese counterparts (Florida and Browdy 1991, 51). In 1988, after receiving a $7.8 million contract from DARPA, Brody established Magnascreen to develop the TFT-LCD. This advancement in the LCD technology became the basis for the new generation displays for the portable electronic devices such as microcomputers, phones, etc.

Florida and Browdy argued that this pattern of the inability of private actors to build or sustain manufacturing capabilities in various high-technology fields presented a broader problem with the nation's innovation system:

> The loss of this [TFT-LCD] display technology reveals fundamental weaknesses of the U.S. high-technology system. Not only did our large corporations lack the vision and the persistence to turn this invention into a marketable product, but the venture capital financiers, who made possible such high-technology industries as semiconductors and personal computers, failed too. Neither large nor small firms were able to match a dazzling innovation with the manufacturing muscle needed for commercial production. (1991, 43)

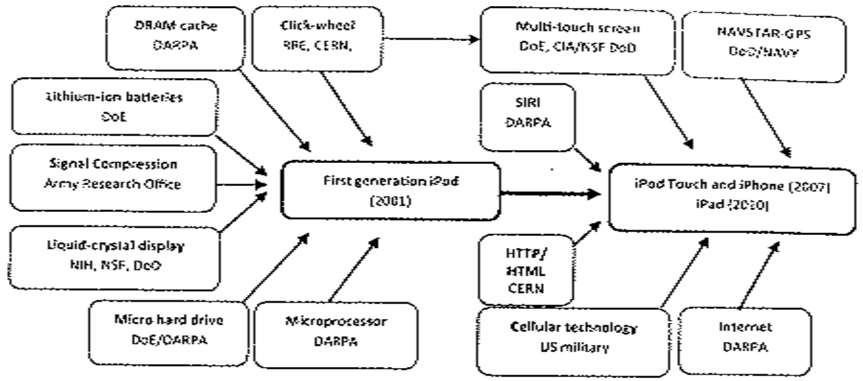
In an attempt to retain the manufacturing of TFT-LCDs in the US, the Advanced Display Manufacturers of America Research Consortium (ADMARC) was established by the major display manufacturers with initial funding appearing from the National Institute of Standards and Technology's (NIST) Advanced Technology Program (ATP)

(Florida and Browdy 1991). The industry also received additional assistance from the US government in the form of antidumping tariffs (while at the same time touting the 'free competition' line), as well as funds and contracts provided by various military or civilian agencies that supported many start-ups in the US as part of an effort to develop manufacturing capabilities of TFT-LCDs in the 1990s (OTA 1995).

The lithium-ion battery is another example of a US-invented but Japanese-perfected and manufactured-in-volume technology. John B. Goodenough who pioneered the early research on lithium-ion battery technology received his main funding support from the Department of Energy (DoE) and National Science Foundation (NSF) in the late 1980s (Henderson 2004; OSTI 2009). Major scientific breakthroughs accomplished at the University of Texas at Austin were quickly commercialized and launched in 1991 by the Japanese electronics giant Sony. In a 2005 working paper for the National Institute of Standards and Technology (NIST), Ralph J. Brodd (2005) identified issues with the advanced battery industry innovation model that were similar to the issues within the TFT-LCD industry. Another major scientific success faded away without greater value being captured in the form of US-based high-volume manufacture. Brodd's study identifies the factors hindering the volume production of lithium-ion batteries in the US, but particularly placed emphasis on the short-termist approach of US corporations and venture capitalists. Brodd (2005, 22) argued that their short-termism was based upon achieving rapid financial returns (in comparison to their Japanese competitors' focus on maximizing market share in the long run), which often discouraged them from any interest in building the domestic manufacturing capabilities while encouraging outsourcing of manufacture as an option.

Absence of a battery technology that met the storage capacity needs of increasingly powerful electronic devices posed one of the greatest challenges that the electronics industry faced following the revolution in semiconductor devices. The invention of lithium-ion technology enabled portable devices to become much slimmer and lighter as battery capacity increased relative to size. Once again, the federal government stepped in to assist smaller-battery companies through a variety of agencies and programmes that invested in the industry in an effort to develop the necessary manufacturing capabilities (Brodd 2005) – not only for electronic devices but, equally or even more importantly, for 'zero-emission' electric vehicles. The US government has been actively involved with the energy

Figure 13. Origins of popular Apple products



Source: Author's own drawing based on the OSTP diagram 'Impact on Basic Research on Innovation' that illustrates the benefits of basic research on innovation (2006, 8).

industry for decades as part of a broader effort to address economic and social needs, which is extensively discussed in Chapters 6 and 7.

State-of-the-art iOS products are highly complex electronic devices. Despite the fundamental differences in use, each device embodies numerous technologies that are often present in all the devices. Cellular technology is available for most of Apple's devices with the exception of its iPod media players. Cellular communication technology received enormous government support in its early days. The Breakthrough Report (2010, 5) examines the role of the US military in advancing the radiotelephony technology in the twentieth century. The Office of Science and Technology Policy (2006, 8) also documented the role of State support in the digital signal processing (DSP) technology that came about following scientific advancements in the application of the fast Fourier transform (FDT) algorithm during the 1980s. This new signal processing approach enabled real-time processing of sound (such as during a two-way phone call) as well as real-time processing of large audio or multimedia files that can improve the quality of their playback. DSP is considered be a core feature of iOS products with a media player function (Devlin 2002).

Did the US Government 'Pick' the iPod?

In a 2006 policy document where former US president George W. Bush laid out the nation's innovation strategy, the various component technologies that were featured in the first generation iPod were linked to their origins as part of the basic and applied research funded by US tax dollars (OSTP 2006). Although lacking substantial context and/or literal figures, the report does include a diagram illustrating the origins of iPod's component technologies such as its hard disk drive, Li-ion battery, LCD, DRAM cache, signal processing, etc. Figure 13 expands on the OSTP diagram by further mapping out the tech components featured in later Apple products like the iPod Touch, iPhone and iPad.

Fostering an Indigenous Sector

In addition to government efforts nurturing the science base and fostering innovation in the US, the US government has also played a critical role in protecting the intellectual 'property' of companies like Apple, and ensuring that it is protected against other trade right violations. The federal government has actively fought on behalf of companies like Apple to allow it secure access to the global consumer market, and it is a crucial partner in establishing and maintaining global competitive advantage for these companies (Prestowitz 2012). Although US-based corporations define themselves as transnational entities whose existence transcend political borders, Washington is the first place they usually turn to when conflicts in the global market arise. Accessing foreign markets protected by trade restrictions was only possible with US government acting as a backer and vanguard. For example, in the 1980s Apple had difficulties entering the Japanese market. The company called on the US government for assistance arguing that it was the government's obligation to assist the company in opening the Japanese market to US products by appealing to the Japanese government (Lyons 2012). When unfettered global competition hit home, companies such as Apple were backed by the government to ensure that intellectual property laws were carefully enforced all over the world. The added protection created for Apple by local and federal authorities continues to provide this form of subsidy, which allows the company to continue innovating.

Additionally, the US government has been providing various other types of tax and procurement support that greatly benefits American companies such as Apple. According to a Treasury Department document, companies (including Apple) overall claimed $8.3 billion in research and experiment (R&E) tax credits in 2008 (Office of Tax Policy 2011). Additionally, California provides generous R&D tax packages for

which computer and electronics companies are the largest applicants (Ibele 2003).[13] Since 1996, Apple has reportedly claimed $412 million in R&D tax credits of all kinds (Duhigg and Kocieniewski 2012).

Government procurement policies have supported Apple through various critical stages, which made it possible for the company to survive in the midst of ferocious competition against its competitors. Public schools in the US have been loyal Apple customers, purchasing their computers and software each year since the 1990s.[14] Klooster (2009) argues that public schools were a critical market for Apple as it reeled from its Apple III and Lisa product flops in the late 1980s. Provisions in the (post–financial crisis) 2009 American Recovery and Reinvestment Act (ARRA) provided incentives to benefit computer and electronics companies in the US. For instance, among various other incentives, through a small change in the scope of IRS 529 plans, 'computer technology and equipment' purchases were defined as a qualified education expense, which is expected to boost up Apple's computer, tablet and software sales.[15]

In sum, 'finding what you love' and doing it while also being 'foolish' is much easier in a country in which the State plays the pivotal serious role of taking on the development of high-risk technologies, making the early, large and high-risk investments, and then sustaining them until such time that the later-stage private actors can appear to 'play around and have fun'. Thus, while 'free market' pundits continue to warn of the danger of government 'picking winners', it can be said that various US government policies laid the foundation that provided Apple with

13 According to a 2003 state of California legislative report assessing the results of California's research and development tax credit (RDC) programme, SMEs are the largest applicants in terms of number of claims (over 60 per cent of the applicants), while larger companies have the largest share of claims in total value (over 60 per cent of the total value of RDC claims).

14 Apple's share of the total educational computer purchases of US elementary and high schools reached 58 per cent in 1994 (Flynn 1995). Educators have also welcomed Apple's new 'textbook initiative', which is expected to reduce textbook prices significantly by increasing school use of virtual textbooks. These virtual textbooks would require iPad use and would be expected to increase Apple's iPad sales in the coming years.

15 Section 529 of the Internal Revenue Code (US tax code) includes certain tax advantages, also known as 'qualified tuition programs' or 'college savings plans'. A legislative amendment in 2011 allowed parents and students to use the funds in their college saving accounts for purchasing computers, computer equipment and accessories (including iPads). None of these purchases were considered eligible school expenses for account withdrawals before (Ebeling 2011).

the tools to become a major industry player in one of the most dynamic high-tech industries of the twenty-first century so far. Without the frequent targeted investment and intervention of the US government it is likely that most would-be 'Apples' would be losers in the global race to dominate the computing and communications age. The company's organizational success in integrating complex technologies into user-friendly and attractive devices supplemented with powerful software mediums should not be marginalized, however it is indisputable that most of Apple's best technologies exist because of the prior collective and cumulative efforts driven by the State; which were made in the face of uncertainty and often in the name of, if not national security, then economic competitiveness.

In Chapter 8, I will return to Apple, to ask what the State received back in return for the entrepreneurial, risky investments it made in both Apple the company, as well as in all the 'revolutionary' technologies that make the iPhone so 'smart'. As we will see, this is perhaps the most crucial question policymakers must ask themselves in the twenty-first century; when on the one hand we want an 'active' State with the courage to lead the next technological 'green revolution'; while on the other hand, the State has to create a revolution with constrained budgets and pressure to pursue austerity measures. Finding a solution to this 'risk–reward nexus' will be key to this dilemma.

Chapter 7

WIND AND SOLAR POWER: GOVERNMENT SUCCESS STORIES AND TECHNOLOGY IN CRISIS

We are like any international company: we deal with government. With the Chinese government, German government, U.S. government, with many international governments. And of course we get support from government in the form of research and development grants and government subsidies to grow. I think almost every US solar company obtained a grant from US government as well, and German companies get subsidies from the German government. Because this is a very young industry which requires government support. But the industry is on the verge of becoming independent from government subsidy. We believe that by 2015, 50% of countries will reach grid parity – meaning no subsidy from the government.

Shi Zhengrong, CEO,
Suntech Power (2012)

While Chapter 6 looked at how different countries are making the investment in the R&D, manufacturing and diffusion of a 'green industrial revolution'; sowing the seeds of change to such a major economic and social shift is not without its challenges. In this chapter, I attempt to delve deeper into the interaction of policy and economic development by providing historical examples of how (in)effective innovation policies can be, and how the State plays an important role in promoting radically new technologies – not merely by inventing new tax credits, but by getting and staying involved in every aspect of the wind and solar power business. As a result, we see that the State is playing a role in the invention of technology, its development, its successful manufacture and its deployment. I will look at the recent history of wind technologies, following the energy crisis of the 1970s. I then present a brief history of pioneering solar energy companies. Both sections show that behind many wind and solar firms, and their core technologies, was the active visible hand of the State, which, as shown in previous chapters, also contributed to the emergence of the Internet, biotech, nanotech and other radical technology sectors. It was particular State agencies that provided the initial push and the early stage high-risk funding, and that created an institutional environment that could establish these important technologies. These sections emphasize that the US approach (with historical origins) resulted in many benefits of State investment being seized by countries other than the US, such as Germany, Denmark and China.

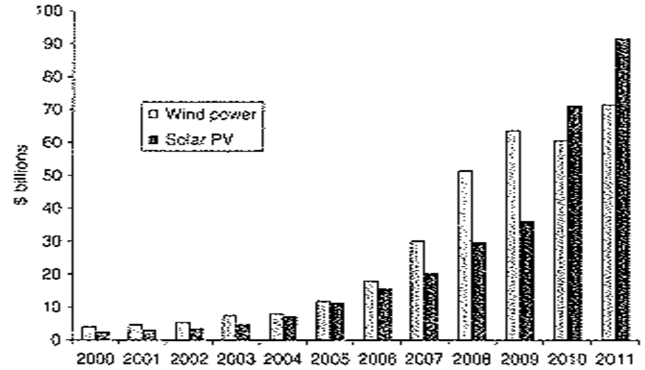
Were it not for the commitments of governments around the world to R&D and the diffusion of technologies like wind turbines and solar PV panels, the energy transformation taking off in the last decade would not have occurred. The 'push' has required major regulatory shifts, financial commitments and long-term support for emerging companies. It is not always clear how to connect the dots between dominant firms and their technologies and the efforts of governments around the world, but it is clear that *no* leading clean technology firm emerged from a pure 'market genesis', that is, as if the State played no role at all. This is a reality I explore in the second part of this chapter.

Yet the clean technology revolution appears to be at a crossroads, if not in crisis. Based on lessons from history, in the concluding section I return to the myths discussed in Chapter 2, and use them to debunk some 'clean technology myths', showing that contrary to common sense perception: (a) R&D is not enough; (b) VC is not so risk loving; and (c) small is not necessarily beautiful. In order for the crossroads to be decided and a green direction to be taken, government policies must overcome the naïve perspective pushed by these myths and distorting ideologies.

Wind and Solar Power: Growth Powered by Crisis

The apparent willingness of the State to accept the risk of clean technology development has had a positive impact. In the last few decades wind turbines and solar photovoltaic (PV) panels have been two of the most rapidly deployed renewable energy technologies on the planet, spawning growing industries that are emerging in many regions of the world. In 2008 $194 billion was directed at emerging clean technologies in an effort to provide badly needed economic

Figure 17. The global market for solar and wind power (US$, billions), 2000–2011



Source: Pernick et al. (2012).

stimulus to counteract the global economic crisis (NSB 2012, 62). An unofficial global 'agreement' was thus reached out of the economic crisis, and that agreement was that the time for clean technologies had come (again). A green energy revolution seemed to be within the realm of possibilities.

Yet it is easy to overstate the progress being made across clean technology sectors as uniform. While wind markets contracted in 2010, in large part as a result of the unfolding financial crisis in the United States (now the second largest wind power market in the world behind China), solar markets nearly doubled in size between 2009 and 2010, surpassing wind power for the first time in history. Figure 17 shows that the growth of these markets has been rapid. Together, wind and solar power represented a $164 billion global market in 2011, compared to just $7 billion in 2000.

Wide-scale deployment of solar PV panels and wind turbines are two technological solutions for meeting future energy needs and mitigating climate change. Like the technologies behind Apple's iPod, iPhone and iPad (see Chapter 5), the 'ecosystem' of innovation in clean technology is one in which the public sector has taken the leading role. Wind and solar power technologies have been the fruit of major government investments that catalysed their historical development around the world.

While the US and China possess the largest quantity of wind capacity deployed worldwide, Denmark produced the leading manufacturer of wind turbines decades ago: Vestas. In the US leading manufacturers also emerged during the 1980s, but each was lost through acquisition or bankruptcy.[1] Germany's solar resources are inferior to those of the United States, yet it remains the world leader of deployed solar PV power. China has emerged as the world's major solar PV manufacturing region, successfully out-competing US, Japanese and European rivals that led in prior decades.

What must be explained is how a country like the US can become a leading market, but fail to produce a leading manufacturer, and conversely, how a country like China can produce a leading manufacturer in the absence (until recently) of a domestic market. What distinguishes these nations has nothing to do with their 'comparative advantages' as producers of wind turbines or solar PV panels, and it has nothing to do with a natural abundance of wind or sun. Historically, the development of wind and solar power has reflected differences in government policies meant to *foster* these power sources. For some countries, this is a process that has unfolded over many decades. For others, it is a process of 'catching-up' – but no matter the case, it is the tools deployed by government that have supported and attempted to drive outcomes. The international histories of wind power technology development and of leading wind and solar companies provide examples of the extent to which those industries have benefitted directly (and indirectly) from different kinds of public funding and support.

From the First 'Wind Rush' to the Rise of China's Wind Power Sector

The first 'Wind Rush' (1980–85) had as a backdrop the energy crises of the 1970s. A number of countries actively invested in utility-scale wind turbines as a solution to mitigating fossil-dependence in electricity generation. In the 1970s, Denmark, Germany and the United States started massive wind energy R&D projects. The goal was typically to build 1 MW and larger machines, creating designs that could be commercialized and exploited by existing large firms typically

1 Several factors contributed to the decline of US companies. Falling fossil fuel prices in the 1990s did not help renewable energy companies to survive. Power purchase contracts negotiated in the 1980s with favourable pricing terms also matured, exposing many developers to major revenue reductions for the electricity they sold. In the case of Kenetech, warranty losses incurred from their newest turbine model were substantial, and other firms were vulnerable to the uncertainty emerging from the decision to liberalize energy generation markets.

involved in aerospace technology or agricultural machinery (Soppe 2009; Heymann 1998; Nielsen 2010). The US outspent Germany and Denmark on wind energy R&D, and despite enlisting the National Aeronautics and Space Agency (NASA) to lead the programme, failed to produce a viable commercial design. Germany's attempt met a similar fate. Only Denmark is credited with succeeding in transforming government-funded R&D into a commercial success story, giving it a valuable advantage during the wind industry's formative years.

Heymann (1999, 661) credits the success of Danish industry less with the technological push of State-supported R&D collaboration, arguing that Danish craftsman ultimately produced reliable designs that scaled over time. Kamp (2002, 205) and Nielsen (2010, 176) draw the point of divergence between nations to the decision of the Danes to pursue and develop technology based upon a prior wind turbine design called the Gedser, which was a robust and reliable three-bladed horizontal-axis machine. Developed by Johannes Juul, testing of the Gedser had been financed in its early days by the Danish ratepayer-owned SEAS utility and the Association of Danish Utility Companies (Heymann 1998, 650; Kamp 2002, 130). Later, the government of Denmark and the US provided millions to test the Gedser design as part of efforts to develop wind turbines for modern energy grids (Kamp 2002, 133). Despite the example of the Gedser, the US and Germany pursued lighter-weight, aerodynamically efficient, but often unreliable designs based on prototypes originally conceived around the Second World War in Germany and the US.

Denmark's push into wind turbines included State-sponsored prototype development which brought large manufacturers in to develop experience with the technology and create a functional supply chain. Companies like Bonus and Vestas were able to purchase patents generated by the Danish research programme and smaller-scale wind turbine pioneers, giving them control over collective knowledge and learning taking place. They then applied their experience producing farm equipment and superior capital to produce robust machines on a larger scale and eventually seek vertical integration (Kamp 2002; Heymann 1998). Denmark's R&D activities overlapped with investment tax credits that were phased out over a decade. The tax credits helped launch a domestic market for wind energy, while California state and federal incentives created export opportunities for Danish producers.

'Big government' R&D in the US and Germany was largely dubbed a 'failure' precisely because reliable wind turbine designs that could be successfully commercialized were not produced immediately as an outcome of their programmes. Obviously, if governments are willing to take the big risks that business will not take, they are bound to fail sometimes and succeed others. But if they do not do it, they will not succeed at all. However, that particular failure led to a renewed emphasis in the US, under the Reagan administration, of government as characteristically unable to 'pick winners', an ideology often used by conservative economists and policymakers to limit or reject government intervention into the clean technology industry.[2]

Unlike the US (which drastically slashed funding for the wind programme), Germany did not give up on publicly funded R&D measures despite their 'failures', but expanded on them by publicly funding industrial and academic R&D, as well as funding a demonstration programme that allowed for controlled testing of German designs (Soppe 2009, 11). In reviewing this history, Soppe (2009, 12) adds that Germany also promoted several different development paths, by funding development of turbines of different sizes (as opposed to biasing funds in favour of huge machines, like the US did initially). Denmark's programme was less expensive and more successful, attributable in part to the entry of heavy-farm manufacturers like Vestas, which understood rugged design vis-à-vis aerospace emphasis on light weight and maximum efficiency.

Whether we judge it a success or failure, the actions of these governments signified that wind energy was again in demand, and while the US struggled to maintain a dominant manufacturing presence, it succeeded in establishing a dominant market – 'pushing' not merely 'nudging' one into existence – into which private firms could enter

2 Such a view ignores various facts: (1) the fact that many large, private companies which had competency working with high-technologies were partners in that failure. These companies included such giants as Lockheed Martin, General Electric, MAN, Westinghouse and Growian. Each acted as a contractor under the US or German programmes; (2) the role that impatient finance, such as with venture capital in solar power, plays in speeding up the process of technological development or contribution to its failure. Indeed, wind turbine technology was not well understood, and rapidly scaling turbine designs in an attempt to maximize productivity of the technology would have to occur at a pace slower than envisioned at the time. In effect, the government and business community underestimated the challenge at hand, though critics tend to focus on the failure of government and not of finance; and that (3) failure is hard to judge unless we have proper metrics to be able to understand the spillover effects that investments have, even when there is no final product. These international projects did establish networks of learning between utilities, government R&D, the business community and universities.

with confidence. Once again the '*lion-esque*' State leads the way for the 'domesticated' animals – the private companies – to act.

Ironically, favourable conditions for wind energy created by the US government and the state of California were not just opportunities for US-born companies. They also attracted Vestas of Denmark, which became the turbine supplier of choice for the Zond Corporation, a California-based wind energy developer. With few proven wind turbine models available to choose from, Zond became a wind turbine importer, ordering over 1,000 turbines from Vestas, almost single-handedly financing the early growth of that company's wind business. In like fashion, when the tax programme ended in California at the end of 1985, Zond refused to pay for its last shipments of wind turbines (which had been delayed in shipping), contributing to Vestas' bankruptcy. To survive, Vestas abandoned its farm machinery business and quickly re-emerged as an exclusive producer of wind turbines, becoming a world leader. Without the government support of the United States and the state of California at the time, and the leniency of the Danish government allowing Vestas to restructure, Vestas would likely not have become a leading world producer.

Of the handful of new companies emerging in the US to capitalize on the call to bring wind energy to America, it was US Windpower (later renamed Kenetech) that would become an early leader and technological ancestor to General Electric's (GE) wind turbine division – one of the largest in the world. Kenetech's strategic choices were influenced by government investments made in wind energy. Originally founded in Massachusetts, Kenetech moved to California in response to the ample policy support provided. It had derived components of its business plan, knowledge of wind technology and its working prototype technology from the University of Massachusetts–Amherst, a public university with an active wind power programme partly funded by the DoE. Kenetech was also one of the first wind companies to utilize computers to electronically control and regulate their turbines, optimizing the performance and reliability of designs which were otherwise less robust than their Danish counterparts.[3] Kenetech remains one of the few US-based wind turbine manufacturers to have grown from a seed stage to an initial public offering (IPO), but which, in 1996, ended in bankruptcy due to major warranty losses incurred following the release of a state-of-the-art, variable-speed

3 Moreover, as discussed in Chapter 5, the Apple II, which ran Kenetech's first projects, would also not have been possible without government investments.

wind turbine. According to Ruegg and Thomas (2009, 37–8) GE has the largest number of patent families linking back to DoE-funded research, but Kenetech was one of a very small number of a companies with more than five. Ruegg and Thomas draw 'extensive links' between DoE research and leading wind power companies, suggesting that DoE research 'has been particularly influential on technology developed by General Electric and Vestas, the two leading global manufacturers of utility-scale turbines' (2009, 41–2).

Unlike Vestas, Kenetech did not enjoy lenience from the US government or from its investors, and about 1,000 people lost their jobs when the company folded. Zond Corporation purchased Kenetech's variable-speed wind turbine technology and developed wind turbines with the assistance of the DoE. Zond was later (partially) acquired by Enron (in 1997), and when Enron collapsed in scandal, General Electric (GE) purchased Zond's technologies to quickly become one of the world's largest wind turbine suppliers. From that point forward, the powerful combination of government subsidies for wind power markets granted at the federal and state levels, along with the resources, stability and technology of a big corporation, made GE 'America's champion' wind producer (Hopkins 2012). To date, though threatened worldwide by Chinese competition, GE dominates the US market for wind turbines, and the technologies developed by the contribution of both State and business support (such as through Kenetech and Zond) create an important but also easily forgotten story of technological development. The US wind industry tells a story of how innovation and positive economic growth occurs as a result of State support for business.

The basic science of wind power was advanced by the DoE through national labs and universities over the years, which drove down the cost of wind power and boosted reliability in a number of ways. Knowledge of aerodynamics was of particular importance, given that wind turbine operating environments are unlike those of planes or helicopters. Advanced computer modelling boosted the reliability and efficiency of turbine designs, and frequent industry collaborations yielded newer models with better capacity factors (a rough proxy of efficiency). Advanced mapping of wind resources also provided wind power developers with accurate siting information that could aid in their project design. After spending $1.2 billion, the cost of wind energy fell from approximately 30–50 cents/kWh in the 1970s to as little as 3 cents/kWh in the 2000s (aided by State-funded R&D for airfoil design and other turbine components), while the efficiency of turbines more than tripled, their operating availability reached nearly 100 per cent, and expected life spans reached 30 years.

The importance of government support is seen most starkly through the consequences of its withdrawal: when the United States government abandoned subsidies for wind power development in the mid-1980s, and slashed the DoE's R&D budget in a backlash against attempts to promote energy innovation, the domestic market stagnated and momentum for the industry shifted to Europe, or, more accurately, to Germany. Germany's federal Ministry for Research and Technology launched a programme to develop 100 MWs of wind power in 1989. Combined with a feed-in tariff (FIT) programme, which provided above-market prices for wind power and a 70 per cent tax credit to small producers, Germany began its reign as the hottest market for wind power development in the world (Lauber, Volkmar and Mez 2006, 106). Combined with greenhouse gas (GHG) reduction targets, and the intention of meeting renewable energy development goals with domestic manufacturing, Germany also set aside national and state funding of approximately $2.2 billion to support continued wind energy R&D. Germany's long-term approach to wind energy development gained momentum in the 1990s and continues today, enabling the emergence of leading manufacturers while providing stable annual growth in deployed wind capacity. The 20-year investment horizons provided by government incentives are twice as long as those in the US, reducing market uncertainty and boosting investor confidence.

China was a relative latecomer to wind power technology, despite having pushed investment in renewable energy in the 1980s as a technical solution for rural electric infrastructure development (Mia et al. 2010, 440). China's partially State-owned Goldwind, a major wind turbine manufacturer, was established in 1998, and initially licensed German technology from Jacobs (a company later purchased by REpower) and Vensys Energiesysteme GmbH (Lewis 2007, 15). Goldwind turbines benefitted from aggressive Chinese domestic content rules, which were enacted in 2003 to require 70 per cent local content in all wind turbines sold in China (Martinot 2010). This effectively shut the door on foreign firms in the country; while China's dominant wind manufacturers strengthened their domestic supply chain and presence.

Chinese wind power developers also received 25-year fixed price contracts that were set through a 'concession' programme (competitive bidding). Wind projects had access to low-cost financing, and after

2005, China began to publicly fund R&D and projects with grants or favourable loan terms. China has also prioritized reducing its overall energy intensity (the relationship between energy consumption and GDP), and established goals for renewable energy development. At this time, China is seeking 1,000 GWs of wind power development by 2050. The effect has been clear, which is that China rapidly surpassed the United States as the world's biggest wind energy market in 2010. Met predominantly with the output of domestic wind turbine manufacturers, China has also eroded the global market shares of other companies around the world.

Solar Power Companies and the Origin of Their Technologies

Many of the same policy shifts driving the California wind market of the 1980s provided the catalyst for a global market for solar PV panels to emerge. Bell Labs had invented the first crystalline-silicon (C-Si) solar PV cell back in 1954 while it was still a part of the AT&T regulated monopoly. The first major opportunities for solar PV technology were created by the DoD and NASA, which purchased solar cells made by US-based Hoffman Electronics to power space satellites.[4] While the space race made the government a spare-no-expense and cost-be-damned customer for early solar manufacturers, the transition of solar PV technology to Earth was facilitated in part by the cost and performance advantage it had in markets for remote power applications, leading to diverse applications such as signal lighting on offshore oil rigs, corrosion protection for oil drilling, remote communication towers and road signs (Perlin 1999). In most cases, however, the existence of such lighting was a result of regulation, and the choice of solar PV/battery power for oil rigs was based in part by the EPA making it illegal for oil companies to dispose of spent batteries in the ocean in 1978 (Perlin 1999, 62).

There are several modern governmental initiatives helping to establish leading solar PV firms and markets around the world. Many examples of innovative emerging firms can be found in the US, where First Solar, Solyndra, Sunpower and Evergreen each developed state-of-the-art C-Si or thin-film solar technologies.

4 Hoffman had acquired the original Bell Labs patent through acquisition of National Fabricated Products in 1956.

First Solar emerged out of the search for commercialized cadmium telluride (CdTe) thin-film solar PV panels and became a major US-based CdTe thin-film producer. First Solar dominates the US market for thin-film solar PV panels, and has produced record-setting technology and low-cost manufacturing, which have enabled the company to generate over $2 billion in revenue each year since 2009. First Solar's patents have 'extensive links' to prior DoE research (Ruegg and Thomas 2011, 4–11), and early development of First Solar's leading CdTe technology was a result of founder Harold MacMaster working in collaboration with the University of Toledo's State-funded solar research facilities, scientists and the National Renewable Energy Laboratory (NREL). First Solar's partnership with the NREL reaches back to 1991, when the company was still known as Solar Cells. The collaboration resulted in the development of high-rate vapour transport deposition, a superior means of manufacturing glass CdTe thin-film panels, which First Solar began to produce in 2003 (NREL 2012). This innovation amounted to major cost reductions of CdTe panels over time, as the process was perfected. Even now, First Solar remains one of the larger solar PV manufacturers on the planet.

Described in greater detail in the previous chapter, Solyndra had been founded by Chris Gronet, a Silicon Valley scientist with experience in the semiconductor industry. Building on national research conducted on copper indium gallium (di)selenide (CIGS) solar PV, Gronet and his employees developed innovative technology with state and federal support behind them. Able to deposit CIGS onto tubular glass gave Solyndra's solar PV panels a unique look – while also enabling them to capture direct and reflected light without add-on tracking systems. Additionally, Gronet's panels had a trick interlocking system that made them easy to install – reducing their cost relative to other technologies.

SunPower is a leading manufacturer of high performance C-Si solar PV panels with world-record-setting technology. This is also owed in part to prior investments of the State. SunPower's success ties back to DoE research patents, in this case related to solar PV shingles, module frames and shingle systems (Ruegg and Thomas 2011). Established in 1985 by Dr Richard Swanson, SunPower had early R&D support from the DoE and the Electric Power Research Institute (EPRI) while developing technology at Stanford University.

Evergreen Solar was a spinoff of the now defunct Mobil Solar, started when a group of scientists 'defected' from the company to develop a rival vision of string-ribbon wafer technology. Evergreen grew with the aid of the government, attracting $60 million in Massachusetts state subsidies, the highest ever offered to a single company by the State. Promising to create manufacturing jobs for Massachusetts, Evergreen was easily lured to China which offered favourable loan terms from its public-owned banks to subsidize a new plant. In obtaining this financing, Evergreen agreed to share its innovative technology with its partner Jiawei Solar (Sato 2011). Despite accumulating nearly a half-billion in losses over its history, Evergreen completed a $42 million IPO in 2000, and enriched its executives with $36 million in compensation and stock sales (and this value is based on the limited data available). In other words, public support helped deliver value to VCs and top executives, but failed to create promised economic benefits for the US, while possibly transferring innovative technology to China. The state of Massachusetts tried to sue Evergreen to recover some of their money (Haley, Usha and Schuler 2011, 36), an indication that policymakers are not always as passive a steward of taxpayer dollars as assumed, and rightly want to capture the benefits of the industries they underwrite with taxpayer dollars.

Suntech of China was a global market share leader in C-Si solar PV manufacturing in 2011.[5] Suntech has benefitted from the import of PV manufacturing equipment from bankrupt US companies (and the acquisition of Japan's MSK corporation), the abundant and willing public finance of national and local Chinese banks, and booming European markets for solar PV. Founder Zhengrong Shi received his PhD and established many important relationships at the University of New South Wales, Australia, which hosts world-leading solar researchers such as Professor Martin Green, with whom Shi would develop technology before incorporating some into his firm's products. Shi studied solar PV and spent 13 years in Australia, working for Pacific Solar, which was a joint-venture between the University of New South Wales and an Australian utility company, before returning to China (Flannery 2006). Shi had been lured by the city of Wuxi, which offered him $6 million to set up solar PV manufacturing there in 2000 (Crouch 2008). Suntech's Pluto C-Si technology is a derivative of record-setting PERL C-Si technology developed at the University of New South Wales, and the company has actively sought to incorporate aspects of this foreign technology into its commercial products. As such, its products

5 Details on Suntech are based on a forthcoming piece of work by Matt Hopkins and Yin Li, 'The Rise of the Chinese Solar Photovoltaic Industry and its Impact on Competition and Innovation'. This piece of work is for an upcoming book on Chinese innovation tentatively titled *Is China Becoming an Innovation Nation?*

are quickly approaching the high performance of rivals like US-based SunPower.

Suntech, like most Chinese solar PV manufacturers, depended on the presence of large export markets to grow. It generates a substantial share of its revenues from European markets for solar PV, which are driven by strong feed-in tariffs (FIT) and other supportive government policies that spend billions encouraging domestic development of solar PV. It has also benefitted from policy support in China, however, which granted the company a preferential 15 per cent tax rate, millions in grants, and a $7 billion line of credit from the Chinese Development Bank (which followed millions in committed local government finance), which had otherwise made $47 billion in favourable loan terms available to Chinese solar companies in 2010 (Pentland 2011).

It has been this large amount of committed public finance and other public investments that made the difference to Chinese solar PV manufacturers, who have the resources needed to grow as well as the commitment of its government to help them when weather shifts in global markets as it begins building a stronger domestic market for solar PV power. Already a leader in solar hot water heating, China is showing early signs that a domestic market will take off, thanks to rapid policy response and trade tensions emerging from tensions surrounding China's rapid rise in global solar PV markets (Choudhury 2012).

Solar Bankruptcies: Where There's a Will There's a Way

But at the time of this writing, Wuxi Suntech (a wholly owned subsidiary of Suntech Power Holdings) has declared bankruptcy. Just days after defaulting on a $541 million bond payment to investors in March of 2013, investors sued, and the fallout is raising serious questions about the future of China's young solar industry. Once hailed as the 'Sun King' by *Forbes* in 2006, a holder of 15 patents in solar technology, with a genuine rags-to-riches life story, Shi's legacy as the world's first solar billionaire and one of the wealthiest persons in the world at one point is rapidly deteriorating as accusations of mismanagement accompany attempts to oust him from the executive offices and board of the company he once founded (Flannery 2006). Now expected to be taken over by State-owned Wuxi-Guolian, the company has divided its assets into the subsidiary Wuxi Suntech, with foreign investors being routed through Suntech Power, making them 'structurally subordinate' to the public banks that have been pumping up the firm with patient capital (Bradshaw 2013).

Forcing Suntech into insolvency means that Shi, who holds a 70 per cent interest in Suntech Power (and 30 per cent of its shares overall), and the rest of its major shareholders are likely to lose an estimated $1.28 billion invested in Suntech's stocks and bonds, while the company's nationalization attempts to protect the interest of thousands of workers, the public banks backing the firm, and the State. Public banks, for their part, hold the majority of the company's estimated $2.2 billion in debt.

The outcome of China's Suntech bankruptcy stands in stark contrast with that of US-based Solyndra. Facing bankruptcy, Solyndra underwent emergency reorganization and received a last-minute $75 million capital injection from its private investors prior to its bankruptcy (the government had insisted that the funds come from private backers). The DoE's loan programme executive director Jonathan Silver (a former venture capitalist) worked for 'taxpayer safety' while CEO Brian Harrison (formerly of Intel and who had replaced Chris Gronet in 2010) worked to gut a 'bloated' R&D department and complete an advanced, fully automated new factory with DoE funds on a cost-cutting mission, and as a result both sales and costs were initially moving in the right directions (Grunwald 2012, 414–15). As noted in greater detail above, the capital injection came with the not-insignificant caveat that private investors would be first in line to reclaim losses should the company fold. Yet all parties involved also knew that the company 'would be more valuable in bankruptcy if it had a completed plant' (Grunwald 2012, 415). Even without additional funding from the US government, then, the attempt to rescue Solyndra is badly botched politics (and economics) at its finest even if it could be described as a heroic and gutsy fourth-quarter play.

It is interesting to push the comparison between Suntech and Solyndra further. Solyndra was overwhelmingly funded by private interests, while Suntech was funded by public interests. Both companies have failed, yet the outcome expected of each was the 'same' – that each would create jobs and massive profits and compete for wealth with other countries, the main measures of success we care about. Yet, competition occurred within a global context – that is, a global industry which finds its policy support, like its firms, functioning in different places all around the world, presumably to maximum performance. Yet Solyndra's production and Suntech's production were each, in a manner of speaking, competing for that next German customer. Both firms from the US and China committed the same mistakes. They scaled too rapidly, and did not have

the market for their own domestic energy grids – each country possessing gigantic 1 TW domestic market capable of providing a near-limitless opportunity for firms that, ironically, die for a lack of customers that can absorb their output. With such amazing infrastructure already in place, would anyone else think it was absurd if GM, Ford and Chrysler went bankrupt for a lack of roads?

Yet Solyndra has disappeared from the world, while Suntech as yet survives. Suntech's fate is not to be decided by its investors, however – who naturally prefer to have funds returned over all other considerations. Solyndra's failure highlights the 'parasitic' innovation system that the US has created for itself – where financial interests are always and everywhere the judge, jury and executioner of all innovative investment dilemmas. Perhaps, done differently, and with an eye to the value of economic development beyond short-term financial performance, Solyndra would have grown to hundreds of thousands of employees, with billions in revenue like GE. Suntech's fate, on the other hand, will be decided by the State, which has made the larger investments in the firm, and which proceeds into bankruptcy with a much broader perspective of Suntech's position in the Chinese economy and its future. Suntech was preserved by the State during the downturn, and its 20,000 jobs have already become critical to the Jiangsu province, which may experience a painful structural adjustment should the firm be liquidated, shuttered and forgotten (imagine firms like Google with its 54,000 employees, or Facebook with its 4,600, suddenly shuttering). Solyndra was too 'small to survive' (versus too big to fail) to warrant a 'bail-out', yet the government had, as it always has, the ability to 'rewrite the rules' and could have weighed the cost of letting Solyndra fail against letting it succeed. It might have even, as with Suntech, considered firing the executives responsible for its financial decline. One way to calculate such a cost would be to ask what 1,000 jobs are worth to the future revenues of the government, or better yet what those revenues are worth when the company becomes a major employer like Facebook, Google or GE.

We'll continue to spend our time imagining success until we recognize that innovation unfolds as part of a global process, not an individual or even organizational process (though that is critical to grasp). Clean technology is already teaching us that changing the world requires coordination and the investment of multiple States, otherwise R&D, support for manufacturing, and support for market creation and function remain dead ends while the Earth literally suffocates on the industries we built a century ago.

One of the biggest challenges for the future, in both cleantech and whatever tech follows it, will be to make sure that in building collaborative ecosystems, we do not only socialize the risks but also the rewards. It is only in this way that the innovation cycle will be sustainable over time, both economically and politically. Politically it is important for taxpayers to understand how they benefit from the massive State investments that build the foundation for future private profits. As jobs are increasingly global, rather than resisting this with nationalistic dogma, there are concrete ways for returns from State investments to be captured so that the citizens who funded technological development can be sure to share in the gains. It is to this theme that I turn to in the next chapter.

Competition, Innovation and Market Size (Who's Complaining?)

I argued above that the state of California was a partial reason for the growth and (early) success of Vestas – the current world-leading wind turbine manufacturer. In similar fashion, the growth of US and Chinese firms have depended, to an extent, on the resource commitment and leadership of Germany's policies. Germany's distributed solar power generation approach made it the world leader in solar PV development however. By revising its feed-in tariffs (FIT) policy in 2000 to provide better pricing for solar PV (and to set unique pricing for other renewable technologies according to their expected performance), Germany made solar PV competitive with traditional power sources and even wind energy. At the same time, Germany also established a '100,000 roofs' programme to encourage residential and commercial investment in the technology. The action kicked the solar PV industry into high gear, and Germany grew its solar PV capacity from just 62 MWs in 2000 to over 24,000 MWs by 2011. This is similar to completing 24 nuclear power plants in about 10 years – a remarkable feat that would never occur given ordinary nuclear power plant construction times (and public opposition to them).

Also similar to the California phenomenon described above, Germany's forward-thinking policies have been both a blessing and a curse. On the one hand, Germany's growing market enabled the rapid growth of dominant domestic manufacturers to emerge (such as Q-Cells). But it also provided growth opportunities for competing firms from the US, China and elsewhere, which relied on Germany to absorb their expanding production capacity. At the same time, these and other

countries have not followed suit in establishing equally strong domestic markets for solar PV despite observing the German example. The excess capacity created in part by the 'start and stop' of solar PV policies in places like Spain is currently crippling solar companies around the world. Q-Cells, once a German champion, is now property of Korea's Hanwha Group (Reuters 2011).

Meanwhile, the rise of China as a regional centre for major solar PV manufacturers has had a serious fallout on the industry as a whole, prompting a 'trade war' in the United States and Europe, manifest in the form of tariffs levied against Chinese solar PV producers.[6] But while US and European companies find themselves unable to compete, the US government, for example, has reacted with calls to end support for clean technology development when struggles point out, if anything, that more is needed. The trade war only serves to strengthen the myth that industrial development occurs through invisible market forces that cannot be created or controlled by government to socially beneficial outcomes. With the government acting as 'referee' in the trade dispute, China's public support for clean technology industry development is framed as 'cheating', rather than effective. At the same time, multiple countries are attempting to capture the global market for clean technology with similar policies that include direct and indirect support for firms, or, in other words, if China is cheating, they are as well. Plummeting solar PV prices are supposed to be a good thing – they will eventually position solar PV to compete favourably with fossil fuels. But in this case, falling prices (and shrinking profit margins) frustrate many and ignore the shortcomings of industrial policy in countries like the US, which we could describe as lacking an adequate supply of patient capital conducive to innovative firm formation and growth, as well as a long-term vision for energy transition (Hopkins and Lazonick 2012). What is separating China from its international peers is its courage to commit to renewable energy and innovation in the short *and* long run.

Some argue that there is a risk that the rapid growth of Chinese wind and solar companies potentially stifle innovation (W. Liu 2011). The charge is that Chinese companies reduce costs and grab market share with older technologies, setting a technological direction which prevents newer technologies from penetrating world markets. If this is proven to be the case, then governments should heed the signal that more needs to be done to ensure that critical energy innovations can establish

6 At the time of writing, Europe was still undecided on tariffs.

themselves in markets that are becoming crowded with competing technologies. These complaints seem to ignore that there are advantages to C-Si technology – such as the presence of abundant raw materials for their manufacture. Other approaches rely on rare earths and such a supply is limited. Furthermore, these complaints ignore the reality that US innovations produced by companies like Innovalight (now owned by DuPont) or 1366 Technologies can be incorporated into Chinese panels (and are).[7] In any case, at some point convergence towards a dominant design is needed before mass diffusion of solar power can be achieved.

Conclusion: Clean Technology in Crisis

There is nothing 'accidental' about clean technology development or the formation of markets for renewable energy. There are no 'genius' firms or entrepreneurs acting independently of their society or simply in reaction to the fear of climate change or a privileged knowledge of future profits. Rather, clean technology firms are leveraging technologies and cashing in on the prior investments of an active public sector, and responding to clear market signals proclaimed by progressive government policies about the desired change, and to the availability of support for clean technology industrial growth. The hope is that innovation will produce economic wealth, employment opportunities and a solution for climate change.

While the performance of countries has varied tremendously over the decades, it is obvious that Germany has provided a glimpse of the value of long-term support, China has demonstrated that a rapid scale-up of manufacturing and deployment is possible, and the United States has shown the value of R&D but also the folly of permitting uncertainty, shifting political priorities and speculative finance to set the clean technology development agenda. Governments leading the charge into clean technology do not have to allow themselves to be cheated when investments go sour. Nor should they expect that taxpayers will happily bear the full risks of investing in these technologies and establishing markets without a clear future reward to be gained.

The challenge moving forward is to create, maintain and fund a long-term policy framework which sustains momentum in the clean energy sector building up over the last decade. Without such long-term commitments, it is likely that clean technology will become a missed opportunity for many nations. Such a framework would include demand-side policies to promote increased consumption of solar and wind energy, as well as supply-side policies that promote manufacture of the technologies with 'patient' capital.

7 1366 Technologies developed radically low-cost multi-crystalline silicon manufacturing equipment – with the aid of the US's new ARPA-E programme (discussed in Chapter 6), which had contributed $4 million to development.

The challenges of developing clean technologies go far beyond establishing risky public sector energy innovation hubs, such as ARPA-E seeks to become. Governments must reduce the risk of commercializing energy innovations while establishing and managing the risks of competing in diversified and global energy markets. When difficulty has arisen in the past, such as when wind or solar markets faltered following retraction of US support for renewables in the late 1980s, the tendency has been to focus on how government investment is flawed, while the role of business in contributing to that failure is ignored, or written off as part of the 'natural' behaviour of competitive markets. Worse, some interpret difficulties as proof that a technology 'can't compete' or will never compete with incumbent technology and should be shelved rather than exploited. This would go against the historical record, which suggests that all energy technologies have needed and benefitted from lengthy development periods and long-term government support. What matters more is that the effort continues as if the future of the planet depended on it – because it does. Addressing the challenge thus requires overcoming a worldview based on myths, referred to in Chapter 2 above.

Myth 1: It's all about R&D

R&D contributing to clean technologies like wind and solar power has occurred on a global scale for decades, as a result of significant public investments and learning, and the leveraging of a broad community which has been inclusive of educational and business knowledge networks. The technology works as a result, and improvements in cost and efficiency have proceeded despite the unequal commitments of governments and businesses over time. The cost of energy they produce has also fallen over the long term, while fossil fuel prices continue to be volatile and rise over time.

Some firms may conduct important R&D for decades and remain money losers without a clear commercial prospect in the pipeline. As shown by the history of First Solar, the government's role in pushing innovations out of the lab and into markets does not end with R&D but can include a role in overcoming commercialization barriers, such as a lack of production capabilities. Likewise, First Solar's VCs needed to endure challenges and an investment horizon which stretched their commitment.

As many argue, the challenges faced by clean technologies are therefore seldom technical; they are *political* (and social) and include a need for greater commitments of patient capital by governments and businesses around the world. R&D works, but it is not enough. Nurturing risky new industries requires support, subsidy and long-term commitments to manufacturing and markets as well. Governments must also confront the reality that for most developed nations, the deployment of clean technologies is occurring within a well-developed infrastructure. The clean slate approach is not possible, meaning that investment is intended to manage a transition to clean technology, one that threatens fossil and other energy industries that have the benefit of a longer development period and significant sunk costs. Finally, not all in the business community are shy about calling for an active government role in clean technology. Yet the time is overdue to begin discussing what the real role of business is in technological development beyond funding R&D. The failure of clean technology companies is also a business failure, not merely a policy failure, and it delays the exploitation of important new energy technologies. Worse, it may hand those technologies to other nations with similar objectives.

Myth 2: Small is beautiful

While many large conglomerates like GE, Exxon, GM or British Petroleum have had a role in clean technology development in the past, many look to smaller start-ups for evidence of the coming 'revolution' in the energy sector. Yet these small firms tend also to be young, and incubate for long periods before taking off commercially.

As argued by Hopkins (2012) and summarized above, GE 'inherited' the prior investments of the State and innovative firms in its rise as a major wind turbine manufacturer. GE also announced in 2011 (but has since delayed) a $600 million investment in Colorado in thin-film solar PV, using CdTe technology similar to First Solar's. As with their entry into the wind power business, their entry into solar PV will have strong ties to the prior investments of the State. Yet GE's own resources are vastly superior to those of small start-ups, which include billion dollar R&D budgets, billions in annual profit available to reinvest in core technologies, complementary assets such as a vast global network, and, as with the wind industry, significant rapport and reputation that reduce its 'risk' to investors. The investments of GE might ensure a more enduring solar industry presence for the US in the future, in similar fashion as its entry to wind power became in 2002. For renewable energy scale matters, and larger firms can more easily supply enormous energy grids spanning the continents. Perhaps most importantly, large firms like GE more easily win the confidence of investors and utilities, given their extensive operating history, financial resources, experience with electricity infrastructure and vast social networks. It is not so coincidental that wind projects picked up to a feverish pace following GE's entry to the wind energy business.

Yet we should not underestimate the role of small firms nor assume that only big firms have the right resources at their disposal. Small firms that grow into big firms, such as Amazon, Google or Apple, are active promoters of their own business models, often to the frustration of 'legacy' industries which one could argue would never have taken the same technologies so far, so fast. The willingness to disrupt existing market models is needed in order to manifest a real green industrial revolution, and it is possible that start-ups, lacking the disadvantage of sunk costs, are the right actors for the job.[8]

Myth 3: Venture capital is risk loving

The United States is the VC capital of the clean technology world, allocating billions to the sector each year – far more than the rest of the world combined. VC financiers are 'impatient capitalists', however – they are driven primarily to generate financial returns for themselves over all other considerations. Many are not interested in sustaining the risks of technological development over a long-term period, preferring instead to cut their losses and resume a search for high returns elsewhere. VCs want to finance technologies with low capital requirements that are

8 It should be subject to a debate whether public support for energy innovation is meant, in the long term, to be 'handed off' to large firms that could have made their own investments. Subsidies should be preventing innovative newcomers from going 'bust'. If the point of government R&D is to promote innovation, then it is wasteful to not examine how the competitiveness of would-be manufacturers could be improved. Also, while many oil companies have contributed to solar PV innovations in the past, for example, it is unclear how they would be willing to shift to that technology and abandon the technologies which provide their major sources of revenue. In fact, as solar PV markets have become more competitive, past leaders like BP Solar pulled out rather than staying the course.

close to market penetration. VCs also lack the resources to fully finance the growth of clean technology companies, which are capital intensive and competing within very complex markets. The billions they pour into companies across clean technology sectors is little, for example, compared to the hundreds of billions of State funding committed to financing renewable energy projects.

The success of companies like First Solar was built over several decades, during which VCs entered at a relatively late stage and exited soon after the IPO was completed. Much of the risk of investing in First Solar was taken on by the US government, which actively promoted their solar technology through to commercialization. Subsidies supporting a domestic market and a market in Europe, coupled to First Solar's position as a dominant thin-film producer make it hard to imagine how such a company could fail. Yet the value extraction provided, and even promoted, by equity-driven investment and compensation methods ensures that VCs, executives and top managers of firms can reap massive gains from stock performance, whether short lived or not. This perverse incentive not only redistributes the investment in innovation away from its other core stakeholders (governments, schools, workers), but it risks undermining firm performance. Rather than make the risky investment in future innovation, those in positions of strategic control squander resources in a search for financial returns.

At the same time many US firms have gone bust, less for lack of innovative technology and more for lacking access to additional capital to continue operations following uncertainty in markets or a sudden reversal of fortune. This encouraged Evergreen to 'follow the finance' out of the US and into China. Spectrawatt and Solyndra were undone by a lack of available capital as well. Despite common global market conditions, China's companies benefit from a system of public finance that will not quit before they do. When VCs do not take the risks, then is up to the State to fill in the vacuum.

Building a green innovation ecosystem (symbiotic not parasitic)

Innovation cannot be pushed without the efforts of many, and it cannot proceed without a long-term vision that sets the direction and clarifies objectives. When government policies fail, public dollars can be wasted and promising technologies may fail to meet their potential, because politicians or taxpayers refuse to commit more resources.

When businesses fail, thousands of jobs can disappear, investors lose confidence and the reputations of the technologies are scarred. Uncertainty and stagnation can prevail, while the potential for promising new solutions vanishes. With government and business activities so intimately linked, it is often impossible to point blame accurately. At the root of it, there is only collective failure.

What should be clear is that the green energy revolution that has been experienced so far is a result of a complex long-term multi-decade-long technological development and diffusion process that unfolded on a global scale. The process has benefitted from major government investments that encouraged the establishment of new firms and supported their growth by creating market opportunities. The variety of policies was meant to produce technological development, market efficiency, scale and efficient regulation. Overarching this process is a broad call to accelerate economic growth through innovation in clean technologies that mitigate climate change and promote energy diversity. The long-term vision is to transform our current productive system into a sustainable green industrial system. That is a mission set on producing long-lasting benefits to the public while delivering on a promise of superior economic performance.

Key to the future of the green revolution taking off will be the building of innovation ecosystems that result in *symbiotic* public–private partnerships rather than parasitic ones. That is, will increased investments by the State in the ecosystem cause the private sector to invest less, and focus its retained earnings on areas like boosting its stock prices rather than on human capital formation and R&D?

The next chapter goes back to the case study of Apple computers, to ask whether the active State investments in innovation – which have benefitted specific companies like Apple (at both the company level as well as the key underlying technologies used) – have created results for the State which can be justified by the taxpayer funds that were invested. Larger tax receipts? More jobs? Or greater future investments by Apple in innovation? Only by asking these questions can we make sure that the entrepreneurial State does not become a naïve one.