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REVIEW ESSAY

Examining the Effectiveness of Support for UK Wave Energy Innovation since 2000. Lost at Sea or a New Wave of Innovation? by Hannon, M., van Diemen, R. and Skea, J., University of Strathclyde, 2017, 140 pp., available at http://dx.doi.org/10.17868/62210

ABSTRACT

This report, funded by UK Engineering and Physical Sciences Research Council and the International Public Policy Institute, has the great merit of being a study of innovation failure, rather than success, and the number of useful lessons it contains is consequently all the greater. From a massive database, it estimates that, between 2000 and 2017, the UK provided close to half a billion pounds of public sector funding to encourage the private sector to try to capture offshore wave energy. Investment by firms must have been even more. There was nothing tangible to show for all this in the end, primarily because of inadequacies 'in government and industrial strategy to support wave energy innovation in the UK, most notably a premature emphasis on commercialisation and a lack of knowledge exchange.' Public funding only partially covered R&D costs, so that developers tried to reach the stage where their equipment could actually produce saleable energy, without enough testing for faults. This attempt to 'go too far too quickly' was compounded by government's investing heavily in test facilities without providing support for developers to use them. Also, reliance on patent protection caused developers to avoid sharing their information. The public sector did learn some lessons. Wave Energy Scotland was established to carry on the work in a much more modest way, but able to offer 100% funding and to insist that research results were shared among developers. In addition, the European Community introduced the Marinet initiative to fund access by developers to test facilities.

Introduction

Most innovation case studies deal with success: 'victory has many fathers but defeat is an orphan.' This impressive report from a team led by Matthew Hannon of Strathclyde University is therefore all the more to be welcomed, since it deals with a massive failure. Ocean energy has been the graveyard of many hopes; only a few years ago Bloomberg Energy Research noted that there is nothing remotely economic to show for 10 years and a billion dollars invested in it. Hannon focuses on the UK's attempt to exploit ocean wave energy.

Hannon and his colleagues assembled a database of no fewer than 444 marine energy research, development and demonstration (RD&D) public grants to 327 organisations operating in the UK between 2000 and 2017 (p.19) to show that 'UK wave energy has been consistently and increasingly funded by the public sector since 2000' (p.86). In this 18-

year period, '£198m has been spent on wave energy-related projects with a further £170m awarded to the installation, operation and maintenance of marine test infrastructure' (p.70). We cannot know how much the existence of public subsidy on this scale tempted British industry and financial institutions to invest in wave energy, but this could easily have been a multiple of the public funding. One former developer told Hannon his firm 'had spent hundreds of millions of pounds of primarily private investment, geared about five or six to one with public' (p.90).

State involvement in industrial innovation

It is now quite widely accepted that politicians and civil servants cannot 'pick winners' for industrial innovation. At the macro level, it was 'belief in the superior wisdom of the State' that was at the root of the failure of the Soviet Union and its allies to keep up with the innovatory power of the Western world (Skidelsky, 1995). In the West, too, the spectacular failures, such as Concorde, occurred when the state apparatus tried to innovate directly itself. There is now so much empirical evidence that countries in which industrial innovation is dominated by the state are less prosperous than those where it is directed by private interests that politicians have broadly taken this lesson on board.

However, many states continue to be involved with industrial innovation by providing funding to encourage research and development because of the increasing importance of science for industry. In the early part of the industrial revolution, innovation scarcely depended on science at all. Steam power, for example, was harnessed by practical men such as Watt and Stephenson long before Clausius produced his theory of thermodynamics to explain it. When this relationship was reversed, public funding of science became a means of advancing industrial development, beginning with Germany's Kaiser Wilhelm (now Max Planck) Institutes, and the *Frauenhofer Gesellschaft*. The former carry out only basic research and are completely funded from taxes. The Frauenhofer deal with applied research and their costs are shared between the state and industry.

US model

The modern pattern for the use of public funds to bring about industrial innovation is President Roosevelt's Office of Scientific Research and Development, with Vannevar Bush in charge, during World War 2. Although its objective was, of course, to develop technologies for winning the war, its subsidies also put US industry into a position of unchallenged strength in terms of new consumer products and the means to produce them. When Howard Florey brought penicillin to America because he could not get enough support for trials in the UK, for example, it was developed there with resources second only in scale to those for the atomic bomb. The huge new antibiotic industry was born. At a more prosaic level, the common component of radar and a microwave cooker is the magnetron. The firms which had been producing radar equipment during the war were thus equipped to start exploiting a world market for a quite new consumer good in peacetime (Kash, 1989). It takes little from the generosity of the Marshall Plan, which set European industry on its feet again after the war, to point out that it was also developing markets for these new products of American firms.

Other countries followed the American example by providing public funding of innovatory activity, but we are short of objective empirical studies of how successful or unsuccessful this has been. The Hannon report is a fine example of just the kind of research that is needed. He and his team have studied what was hoped would be an entire new industry, considered to be deserving of very substantial public funding, that of capturing offshore ocean wave energy. But despite investment of over a billion of public and private funds over 20 years, there is still no sign of an economically viable means of achieving this. Hannon defines his objective in this enquiry as 'examining the extent to which the failure to deliver a commercially viable wave energy device can be attributed to weaknesses in both government and industry's support for wave energy innovation in the UK' (p.v).

Public sector initiative

It is important to understand that the initiative for this entire project came from politicians and civil servants, not from business people. We are not dealing here with market-driven innovation, as illustrated by what Matthew Boulton is supposed to have said to James Watt of his separate condenser invention: 'It is not worth my while to manufacture in three countries only; but I can find it very worthwhile to make it for the whole world.' (Berg, 1991. p.14). In the wave energy case, individuals, industrial firms and financiers were enticed to invest their creativity, capability and money in ocean energy by promises of two kinds of subsidy from public funds. The first of these took the form of direct payments and the second the promise of extra payment for energy produced from ocean waves. The related investments by the private sector were therefore not made because of an unfulfilled demand or because inventions had appeared which seemed to have potential for generating profit out of such demand. Instead, they were a response to a public policy initiative to encourage the development of a specific alternative to fossil fuels by direct subsidy of projects. According to Hannon, what happened then was based on:

> … a fundamentally over-optimistic view on the part of government and industry, of how quickly wave energy could be commercialised. As a result, the wave energy sector sought to 'fast track' its technology towards commercialisation, focusing its efforts on later stage innovation. This can be illustrated by the raft of government RD&D funding schemes and test facilities that emerged during the mid-2000s, shortly after the UK had re-established its wave energy programme, which were geared explicitly towards full-scale demonstration. The implication was that, whilst almost £200m has been committed to wave energy-related RD&D since 2000 excluding test infrastructure, over a third of this (£69m) was awarded to support late-stage technology demonstration rather than earlier stage R&D. (p.107)

This over-optimism on the part of developers at the outset was despite a general condition that any subsidy could be only a proportion of the total costs of the R&D. According to Hannon, 'an implication of this is that UK wave energy RD&D-funding schemes have limited the intensity or intervention rate of public-funding programmes, achieved in part by requiring applicants to secure private sector match funding alongside public funds' (p.90). This meant:

> … that a large proportion of the UK's budget for wave energy RD&D went unspent because developers could not meet over-ambitious funding criteria and/or struggled after the financial crisis to secure the necessary private sector match funding required to access these public funds (p.86).

Output subsidy

The second government funding policy destined to entice developers to move too quickly to full-scale operation was the non-fossil fuel obligation, which became the Renewable Obligation in 2002. This increases the cost of energy to consumers in order to pay more for energy produced by a new method. It had been a very effective instrument for the development of wind energy in Denmark and Germany (Grubler and Wilson, 2014). By definition, this kind of financial encouragement of innovation can have no direct relevance to early stage innovation. It can help only in the incremental changes that improve the performance of equipment that is already operating reliably. In the wave energy case, its existence was actually harmful because it reinforced the existing pressure from government on developers 'to try to go too far, too soon.' As will be seen below, the government funded the building of elaborate test facilities, but provided no subsidy to help developers use them. It was not surprising, then, that developers should focus their attention on where they hoped to get subsidy, which was by developing full-scale equipment.

Decisions concerning investment in innovation require positive answers to two linked questions: (a) can we solve the technical problems of innovating the invention economically? and (b) if we can, is there a market for what we can then deliver? If the prospect of subsidy contributes to a positive answer to (b), decisions about investing to solve (a) are easier for management to take. To this should be added that (a) is a fulfilling activity for the engineers in a firm, who find this discouraged by the firm's accountants, whose natural focus is on (b). Subsidy for output undermines the power of the 'bean counters.' Boswell records Dr. Johnson saying at the auction of Thrale's Brewery: 'We are not here to sell a parcel of vats and boilers, but the potentiality of growing rich beyond the dreams of avarice.' (Boswell, 1835, p.61). The vision of state support for sales seems to be able to distort business decisions in the direction he had in mind. In the wave energy case, there can be little doubt that the existence of this second type of subsidy did distort business decisions, and in the wrong direction. Moreover, it was almost completely a delusion, since Hannon notes that only three wave power installations ever received any funding at all from this source (p.3).

Lack of knowledge transfer

The Hannon study also cites lack of knowledge transfer between the parties which received subsidy as a cause of failure of the public investment in ocean wave energy. Freedom to copy means that improvements can be adopted quickly by competitors, leading to convergence of efforts towards the best designs. This did not happen in the wave energy case. In the absence of a market for their devices, Hannon claims. the main commodity of wave energy technology developers was the intellectual property (IP) of their technology (p.132). Consequently, there was a culture amongst developers of secrecy in order to protect their intellectual property rights, stifling collaboration. Little or no open and honest exchange of lessons learnt took place to inform the priorities for future innovation. Hannon notes that 'Between 2000 and 2013, the UK filed 152 wave energy patents. This followed an increasing trend, with the annual number of patents growing from three in 2000 to 20 in 2008' (p.57).

Managers apparently thought in terms of future monopoly profits from their patents, which in turn meant both sticking to the design which was believed to be protected by these, and unwillingness to give licences or to share information with competitors. This attitude even harmed Hannon's research, because

> Outputs from publicly funded later stage wave energy RD&D projects have not traditionally been made available for public consumption because of issues around IP protection and private sector match funding (p.109).

The value of patents was clearly overestimated by both patentees and those responsible for evaluating their applications for funding. As reality dawned, Hannon notes, 'the number of UK wave energy patent filings dropped significantly after 2010, with less than half the number of patents filed in 2013 (eight patents) than 2010 (20 patents)' (ibid.).

Design convergence

Hannon is, of course, right to see the value developers placed on their patent protection as an important factor inhibiting convergence towards an optimum design. However, this is at least as likely to be attributable to employees' awareness of the difficulty of the tasks in which they were involved, and of failures by their own firms as well as competitors. Most technological transfer, essential for such convergence, has been 'on the hoof,' that is, by individuals leaving one firm to go to another or to found or help in founding a new firm. These individuals carry tacit information with them. Such movement, of course, happens only when an industry is developing rapidly, as when Detroit became the centre of US automobile production within 10 years of the Olds Motor Co. setting up there. More recently, almost all the entrepreneurs who made Silicon Valley had at one stage worked in just one firm, Fairchild Semiconductor (Klepper, 2010). Conversely, if development is slow, as was the case with wave energy, demand for skills is limited and the risks of changing jobs are seen to be high. The consequence is that the tacit knowledge relating to new ideas and approaches remains where it originates, and is not passed on to others who might take it up more successfully. Worse, those who do not move become a force against abandonment of a project that is going nowhere.

University research

Once the government decided to spend on wave energy, it was inevitable that universities would want their share; indeed, some of them had been involved in the technology for years. Among these were Queens University, Belfast, where the first shoreline wave device, the Limpet, originated (it still exists in Scotland) and the University of Edinburgh, where Stephen Salter developed early sophisticated devices for offshore wave energy capture. Hannon has calculated that a large proportion of public investment in wave energy went to universities. He finds that Edinburgh received £16.3m, but that four other universities each obtained £5.9m or more. Over the period, the total of all university marine (not just wave) energy funding was £87m, around a fifth of the total public sector investment (p.25).

The principal output of university research is, of course, scientific publications. Hannon's analysis of the period 2000–2016 finds that the UK rapidly increased its number of these on wave energy, with 21 times more papers in 2016 than in 2000 (p.56). There is surely a lesson for all students of industrial innovation here: the positive correlation of growth in paperwork with failure in actual hardware development.

Test infrastructures

Both the universities and industry naturally argued for facilities where they could test equipment; elaborate and expensive tanks for this were built with public money. These test facilities, apart from being expensive, involved considerable duplication. What contributed greatly, however, to the ultimate failure of the public investment in wave energy, was that the government made no corresponding provision for the cost of using the facilities. As Hannon *et al*. put it,

> Consequently, some developers struggled to secure the necessary private sector funds to utilise test facilities … set up by government as private sector entities to insulate government from financial risk, meaning that *they were not legally incorporated to offer government subsidised testing* (p.104, emphasis added).

Interviews

Hannon *et al*. carried out 33 interviews with current and former civil servants, CEOs and engineers from firms, consultants and academics. Among their comments was the argument that, because the UK was spending heavily on wave energy, those who controlled this spending also thought it was a world leader in the technology. 'This was reinforced by a culture of being inward-looking which led to failure to learn lessons from other countries and bias towards the merits of its own technology' (p.98). Some interviewees pointed out the harm from:

> UK wave energy funding being split across three different layers of government (i.e. devolved administration, the UK and the EU) with numerous different autonomous bodies operating at each government level with distinct but often overlapping remits. The lack of a central co-ordinating body made for a highly complex and poorly co-ordinated policy landscape … (p.84)

For their part, developers claimed that they were simply reacting to public and private sector funding offered to advance the technology as quickly as possible. Civil servants countered that funds were made available on the basis of developers' highly optimistic claims about the promise of wave energy. The report concludes that:

> An overwhelming emphasis was placed on undertaking full-scale device demonstration, with a view to 'fast tracking' progress to commercial array-scale projects before the underpinning early- to mid-stage R&D had been performed. … developers were simply reacting to public and private sector funds made available to progress the technology as quickly as possible [and there] was a poor understanding of the scale of the innovation challenge from both sides and the time and funds necessary to overcome it, as well as a lack of rigorous, objective procedures to review the credibility of funding proposals. The outcome was that developers over-promised in order to secure funds and subsequently under-delivered in terms of technological progress and deployment, in turn eroding investors' confidence in wave energy and reducing their levels of investment, triggering the collapse of leading firms (e.g. Pelamis) and further undermining the sector's legitimacy (p.86).

Other complaints identified serious flaws in the arrangements for selecting which applications to fund. An important reason for this, the researchers were told, was the small pool of people qualified for this task (p.97). This was presumably an aspect of 'the culture of being inward-looking' and 'thinking that the UK was a leader in the technology' referred to earlier, since there were many experts in other countries who could have been called upon.

It was particularly unfortunate for the UK wave energy project that its start roughly coincided with a worldwide shift from technological to financial innovation; the laws of property have been changed so as to make the latter kind of innovation much more profitable (Kingston, 2017). One aspect of this was that those who controlled investment in technology became very impatient to get quick results. An illustration of this is that, before its demise, General Electric UK, which by then controlled a large share of British engineering, would only research projects with a timescale of no more than five years. In the wave energy case, in order to secure private funds to match the public subsidy, developers had to present an attractive investment case to such investors as Original Equipment Manufacturers or Venture Capitalists. This typically meant claiming that the technology could enjoy widescale deployment and reach commercialisation in a relatively short time, and according to one interviewee,

> This often meant promising 1MW devices and a route to market that would take years, not decades, even if the developers were unsure whether these targets were realistic: 'You tell

> investors what they want to hear, whether it's the truth or not … Investors don't want a 10-year journey that involves a lot of preliminary testing …' (p.90)

Developers also fooled themselves as well as potential investors about the scale of the offshore wave challenge:

> We just didn't let them see anything bigger than 10m waves. They're still big waves, but we made a risk-based decision not to do it because it was too likely [the equipment] would all get smashed up. (p.102)

Another of the report's conclusions from its interviews is that it became impossible for the industry to recover from its false start:

> This haste to commercialise has had various negative impacts. Firstly, moving quickly to full-scale device demonstration without substantial testing meant that lessons from these stages were never learnt. Furthermore, any lessons about the technology's fundamental design learnt at the demonstration stage could not easily be acted upon because at full scale the device design had already become 'locked-in' because of the sheer amount of time and money invested in it. Additionally, the large size and cost of the machines meant developers were quite conservative in their approach to testing because of the associated costs of device failure. (p.98)

Or, as another interviewee put it, more succinctly:

> To get access to subsidy, people had no choice … they cut steel and built something to go in the water and it broke. (p.104)

Reflections on the report's data

Twenty years before this particular research funding started, a think tank in the Cabinet Office had stressed the need for learning how to fund projects which were considered to be in the public interest, but which were to be carried through by the private sector with public financial support (Advisory Council for Applied Research and Development, 1979). The wave energy case shows how little progress has been made in this direction. Those responsible tried to bring the resources of private firms to bear by offering:

- a contribution to R&D costs (£198m) which was only a proportion of these costs and which placed a premium on full-scale operation over stage-by-stage testing;
- full payment to build test centres (£179m), but no subsidy for using them;
- massive subsidy for university research (£87m) which resulted in a large number of research papers, few apparently of practical value to developers; and
- subsidised payment for energy produced, which again placed a premium on full-scale operation, since nothing less could access it.

The decision to provide public funding for ocean wave energy capture was a political one, with the civil service tasked with putting the policy into effect. Neither politicians nor civil servants are likely to have had any experience with actual industrial innovation before taking up their careers. University curricula in Britain began to include innovation as a subject only in the 1970s, so that none of those who were at a level to be able to influence policy in 2000 would even have been exposed to ideas about innovation as students.

Wave energy compared with offshore oil and gas

At the same time, the traditional defence of a generalist civil service, with high intellectual ability as the condition for entry and promotion, is that its members are able to bring impartial and logical analysis to bear on a wide range of issues. In the wave energy case, this should have led to considerable scepticism about the viability of all offshore wave energy capture approaches, based on one simple economic principle: Ocean wave energy is wind energy concentrated, so that equipment that is positioned in the ocean to capture it has to be engineered to survive extreme storms, as oil and gas rigs are. But these rigs can make money for their owners even from the enormous level of investment they require, because the energy from their output is both concentrated and continuous. In contrast, any energy which could be obtained from ocean wave installations is *inherently both diffuse and discontinuous*. Consequently, as long as the price of energy is set by fossil fuels, offshore ocean wave energy can *never* be competitive. Even if technical success could be achieved, therefore, it would have to receive permanent ongoing subsidy on the basis of mitigating the harm of climate change.

Paying attention to this might not have prevented funding of research into offshore wave energy capture, but it might have tempered optimism. In the face of this logic, then, it seems extraordinary that any funding programme to capture wave energy would have been anything other than ultra-cautious. In fact, British policy threw caution to the winds and money at the project.

Low R&D subsidy rates are self-defeating

The fast-tracking towards full-scale equipment was underpinned, the report rightly claims, by 'poor understanding of the innovation challenge' (p.ix). However, this ignorance was compounded by near-total failure to understand and take into account the factors which business people have to weigh up when investing their resources. The decision that funding could only cover part of a developer's research cost was self-defeating: a £42m 2007 scheme set conditions that could not be met at all, so that no awards were made under it. This was followed by another in 2009, for £22.9m, from which only £9.6m could be awarded, and then by a third scheme in 2012, which found no takers for £20m (p.34). A £10m prize launched in 2008 also went unspent because it required developers to demonstrate electrical output from an array of about 20 devices over a continuous two-year period, which no firm was within sight of achieving (p.115).

It is very difficult to understand public funding of £179m worth of elaborate test facilities without provision to help developers use them. On the face of it, this seems to have been a reprehensible failure; in fact, a mindless one. If developers could not get public funds to help them carry out small scale trials, but could get them for building full scale equipment, they were naturally tempted by what was on offer. Their full-scale devices then failed because of faults which would have been identified if trials had been carried out earlier.

An explanation may be that EU state aid law prohibits government funding distorting market competition by giving some parties an advantage over others. Ocean energy research was also going on in other EU countries and UK developers would have an advantage if their access to test facilities was uniquely subsidised. In fact, because all EU facilities were underused, the European Commission developed its 'Marinet' programme to provide funding for access to them. This began in 2011, paying for up to eight weeks' work in any of 39 test facilities in 12 countries. However, its structure reflects the bifurcation of objectives which characterises all EU research funding, which is that it wants to have research done, but it also wants its money to be spread over Community countries. For this reason, developers can obtain Marinet funding to access test facilities only outside their own country, which might not have suited the UK firms. In any event, Marinet came too late for them; by then belief in the future of offshore wave energy was draining away.

Bureaucracy and innovation

Hannon and his colleagues declare that the wave energy case shows that technology innovation relies on policy innovation:

> Paramount to successful energy innovation policy making is the iterative process of policy design, experimentation, 'learning by doing' and subsequent refinement based on lessons learnt, which represents its own discrete form of innovation …This process of policy innovation is reliant upon the presence of personnel with the capacity and appetite to develop innovative policies (i.e. policy entrepreneurs) …and a culture that rewards policy innovation rather than discouraging it. (p.111)

However, this is precisely what bureaucracies, especially public ones, are ill-equipped to do. This report is consequently especially useful for understanding why so many well-intentioned public interventions fail, especially when they relate to innovation. This happens even when the civil servants involved are doing their best in what they see as the public interest. It is at its worst, of course, when they are concerned only for their own promotion, and are therefore ready to mirror half-baked ideas, whether from politicians or their superiors, which will advance it. This is the primary reason why it has been next to impossible to stop investment in politically-endorsed projects, even when it has long become clear that they are heading towards disaster. Wave energy is just one example.

Investment in innovation that succeeds is only very partly financial, since the most important component of it remains investment of individual creativity, even in large firms. Nothing can change the reality that innovators are special people, characterised by the imagination to see the possibilities of a new idea, who at the same time know enough about how the world works to obtain and deploy the resources needed to turn the idea into reality. As well as having both these abilities, they also have to able to act in the face, not just of risk (which is uncertainty quantified), but of uncertainty itself (which is the state of being without any rational basis for acting at all). This is why bureaucracy and innovation are antagonistic; bureaucracy can operate only on the basis of information. This antagonism extends to the people involved, with bureaucrats fearing innovators because they are disruptive and innovators resenting bureaucrats' failure to share their imagination.

Non-symmetrical rewards and punishments

An important root of these difficulties is that those who make decisions in bureaucracies, whether of a firm or of the state, are not spending their own money. For someone who is doing so, the reward/punishment balance is symmetrical. But for those spending other people's money, this balance is not symmetrical. Such a person will share only partially in a success, but may lose heavily in terms of career for failure that can be attributed to them. Hannon *et al.* provide evidence of fear of this imbalance in operation.

First, bureaucrats have an inherent preference for capital projects over current expenditure because the timescale which reveals success or failure is so much longer. If decisions cannot be avoided, then it is safer to make or influence them in respect of bricks and mortar and equipment than it is in relation to people, since people are unpredictable and troublesome. Hannon *et al.* note, for example, that the test facilities were set up by government as private sector entities to insulate government from financial risk. In fact, this risk was to the career paths of the civil servants who were formulating the conditions for subsidy, and who foresaw that they could be held responsible for overseeing, not just the building of the test facilities, but also their use, which was much more problematic. That the conditions they chose nullified the whole point of building the facilities by denying developers financial help to use them, was of secondary importance within this career-path value-system.

Bias from risk avoidance

The avoidance of risk in decisions taken by identifiable officials also causes a bias towards making awards to larger firms. Such firms are 'safer' in that if anything goes wrong, the civil servant can claim that he or she could not have been expected to 'second guess' such a firm's expertise. This defence is not available for awards made to smaller firms. The report records that only two firms out of 34 'accounted for 49% (£24.4m) of the £49.2m awarded to wave energy developers for experimental development or demonstration of wave energy technology devices since 2000′ (p.25). For the same reasons, bureaucrats also find it easier to approve funding for theoretical research in universities than for research involving actual attempts to innovate (where failure tends to become evident quickly).

This report is a powerful endorsement of the view that a major cause of failure in public sector support for innovation, not just in the UK, but also everywhere outside the United States, is the preference for only partial funding of research costs. This has the same root in bureaucrats' desire to minimise the risk to their careers, and it has three very unfortunate results. First, it forces innovators to divert their vital creative energy towards seeking the counterpart funding they need. Second, it gives an advantage to those, whether individuals or firms, that can access such funding rather than those who are psychologically better able to innovate. And third, it means that innovators (who only very rarely get it right the first time) cannot try again because they will have spent their money matching the public award.

Innovation is rarely a linear process

Most public bureaucracies are simply concerned with keeping an existing show on the road, but there are a few, and increasingly parts of others, that are involved with innovation. Members of these naturally try to inject order into a process that is inherently disorderly, the classic example being NASA, the National Aeronautics and Space Administration of the US, when it had to try to catch up with Russia's Sputnik. To do this, it developed what is known as a technological innovation system (TIS) which had nine technological readiness levels (TRLs). These ranged from basic theoretical concept (TR1) to actual product proved in its mission (TRL9). This concept was adopted by the Organisation for Economic Cooperation and Development and then became part of the basic structure of the EU's Horizon 2020 research funding programmes. This is not surprising, because TRLs put flesh on the concept of *linear* innovation, which suits the bureaucratic need for information-based, orderly arrangements. These start with basic research, some of which it is hoped will lead to applied research, out of which in turn something of commercial value may eventually emerge.

However, since innovation is an activity that is carried on in the *absence* of information, and even without knowing what information may be needed to turn an idea into reality, the linear concept is misleading. Fundamental research rarely leads to anything that can be commercialized, even in the medium term. Much more often, decisions are made to innovate and it is subsequently discovered that progress cannot be made without more theoretical knowledge. A classic case of this is the first passenger jet aircraft, the de Havilland Comet, which was well into commercial service before it became clear from analysing its crashes that not enough had been known about the causes of metal fatigue at the time of its design. NASA's own TIS failed it in the case of the Challenger spacecraft.

Hannon and his colleagues used the TIS concept to structure their research task, but in the end had to conclude that 'The case of wave energy highlights how a TIS may indeed follow a non-linear and more challenging developing path …' (p.xv). Héder (2017) has discussed the harm done to public support for industrial innovation in practice by bureaucratic attempts to escape from the inevitable messiness of attempts to turn ideas into reality.

Getting the laws right

An aspect of the general replacement of technological innovation by financial innovation is that the resulting slower growth in real wealth forces politicians to provide more opportunities to bureaucrats to intervene in the economy. This report provides further evidence that they are unable to do this well. What bureaucrats can do, however, and in fact are the only people on whom we can rely for it, is draft laws, especially the crucial laws of property. Indeed, were they not to do this, the laws would reflect no public interest, and would be shaped only by those who would benefit from them. If we do not get the laws right, intervention cannot work, but to the extent we can get them right (however limited this may be) intervention becomes unnecessary.

An illustration from this report is intellectual property, which the authors blame for developers' unwillingness to share information (p.96). Their reliance on their patents could lead nowhere, since this system is no longer well suited for protection of mechanical inventions. It needs to be replaced by grants measured by time instead of money and/or protecting innovation directly (Kingston 2010, Chapters 9, 11). In fact, 'The entire worldwide corpus of intellectual property law, for example, was developed to underwrite innovation, but now its use to move money through tax havens for tax avoidance and evasion is far more economically important' (Kingston, 2017, p.vii). This is why every government department desperately needs an elite group whose sole task would be to draft either amending or new legislation, to offer a clear alternative to both interest-driven laws and bureaucratic intervention (Kingston, 2017, p.145).

The future

In light of the revelations of this report, it would be a brave politician, civil servant, developer or academic who would propose another attempt at harnessing UK offshore wave energy. Yet the report is not altogether without hope. Its extensive investigative work justifies several policy recommendations. The first of these calls for acknowledgement that 'UK support for wave energy has been historically low and intermittent' (p.109). This may seem a surprising admission in the light of the scale of public and private sector losses identified, but UK funding was never equal to the challenge of economic capture of ocean wave energy. This is why the report also urges that steps be taken to ensure that UK firms retain access to EU innovation finance after Brexit. The need for the private sector to match funding in order to obtain public subsidy must be eliminated, the report insists, and an innovation voucher scheme should be introduced to give developers access ('free at the point of use') to the test facilities in which the state has invested so heavily.

New policies

In wave energy innovation, the learning process for politicians and civil servants proved very costly for investors and taxpayers, but it did result in changed policies. In Scotland, 'an explicitly wave energy focused, 100% funded, earlier stage innovation programme called Wave Energy Scotland (WES) was established, with an objective and transparent stage-gated funding allocation procedure' (p.86). The report emphasises the enormous harm done in the wave energy project by requiring applicants for public funding to match public subsidy for research either wholly or partially. Indeed, this was probably the biggest single factor in both public and private financial losses:

> The need to secure private sector investment to be awarded public grants has placed intense pressure on wave energy developers to 'fast track' their innovation timeline and avoid knowledge exchange in a bid to protect their patents. (p.110)

As noted earlier, the report also blames poor information sharing between developers. In recognition of this problem, WES 'requires developers to licence their intellectual property (IP) and, if they do not do this after a pre-determined period of time, WES has the right to do so on their behalf' (p.38).

Hannon *et al.* claim that WES emerged because 'government reflected upon and learned lessons from the successes and failures of past energy policy' (p.111). Since so much of the earlier failure was caused by limiting public funding to only part of a developer's costs, the move to 100% funding is a major step in the right direction. At the same time, it must be wondered why this lesson had to be learned so expensively? It had been available to the world ever since 1982 in the astonishingly successful small business innovation research programs (SBIR) in the US. These programs now put nearly \$3bn a year into seed funding for new ideas that might lead to industrial products.

One hundred per cent funding of R&D

Why is WES, the current embodiment of the last of the UK public sector actors left standing, now able to offer 100% funding, when none of its predecessors could? If EU state aid law had been the problem, then another change in WES's structure points towards the answer. Its Calls are open to the world so that none of its awards can be claimed to discriminate in favour of British firms. If this is indeed the explanation, such a change might have saved the entire UK wave energy project by avoiding the focus on full-scale, only partially-tested equipment, which destroyed it.

The designer and innovator of SBIR, Roland Tibbetts (a civil servant, incidentally), went even further than the 100% level in prescribing that 7% of any award need not be accounted for. This was a gesture to recognise that innovation requires personal commitment on the part of managers, and that this commitment inevitably involves their distraction from the firm's ordinary work, which must involve a cost for it. He also insisted that not only the direct costs of research should be reimbursed but also the firm's normal rate of overhead, no matter how high this might be. And he was aware of the need for information sharing at this level of innovation, since all reports are made public after two years.

For some reason, which may be connected to the different origins of their civil services, it has been next to impossible to transplant these brilliant ideas across the Atlantic. For example, the EU was pressed for many years to copy SBIR, yet when it finally did so for Horizon 2020 in the form of its small and medium enterprises instrument (SMEI), its normal funding share is limited to seventy per cent.[1] In Horizon 2020, the EU has also seriously damaged its research capacity by moving away from funding a recipient's normal overhead rate to a fixed reimbursement rate of 25%. This reflects the same bifurcation of EU policy objectives already noted in its Marinet programme. It brings about a shift of public funding of research from advanced to poorer member states, but it must also entail a lowering of research quality.

SBIR provides another valuable lesson, which is illustrated in the report's discussion. Little of university wave energy research seems to have been of practical use to the developers who were 'getting metal wet'. The most likely reason is that university researchers themselves decided upon the topics. Of SBIR awards, in the first stage of up to $US 150,000, one-third can be spent on 'consultancy' (which is generally university research) and in the second stage the proportion can be up to half of an award of up to $US 1 million. The topics are decided by the firm commissioning the research, which ensures that the university's contribution is single-mindedly focussed on the ultimate objective of a commercial product. The academics are prevented from exploring any side track, no matter how interesting to them this might be.

Shoreline wave energy

The level at which Wave Energy Scotland (WES) is operating is a far cry from the lavish expenditures studied by Hannon and his colleagues. Since 2014, WES has spent £28m on 62 projects from 11 different countries. But its Calls have tended to be only for sub-systems, such as control means, or materials and structures. These can only become relevant when the basic problem of capturing wave energy has been solved. The time may have come, therefore, for a much more modest approach, limited to the wave energy at the shoreline, which, of course, is very much less than that offshore. The first attempt to harvest it involved building a chamber on a cliff in Islay in Scotland. Within this the up-and-down movement of waves (oscillating water column – OWC) acts as a piston to drive an air turbine. This almost fell victim to the nemesis of all ocean energy capture attempts, the exceptional storm. It was built behind a coffer dam and was fortunately completed just before the dam was destroyed in this way. Experience with a larger version in the Azores, called Pico, confirmed that this approach had no future, apart from which environmental considerations would never allow a multiplicity of such installations on sites which are often protected areas of natural beauty.

There is an alternative, however, which would not be open to these objections. This is to use modern rock engineering techniques to form the OWC chambers in cliffs below the waterline. Not only would these be invisible and silent, but they would also be safe from damage since the cliffs have withstood exceptional storms over geological time. Research on this approach began in Ireland with Swedish and US rock engineering consultants (Marine Institute, 2000) and aspects of it have also been studied by the University of Exeter and by the Electricity Authority of the Faroe Islands (Carr *et al.*, 2016). It is all the more promising because of recent developments in chemical storage of energy which would eliminate the need to extend electricity grids to the remote sites where these chambers would be located. The cost of a pilot unit to establish the economics of the concept would be a fraction of the small change from the losses of trying to capture offshore wave energy, as revealed in this splendid piece of research produced by Hannon and his colleagues.

Note

1. See https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument (accessed March 2018).

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References

Advisory Council for Applied Research and Development. (1979) *Industrial Innovation*, HMSO, London.
Berg, M. (ed) (1991) *Markets and Manufacture in Early Industrial Europe*, Routledge, Abingdon.
Boswell, J. (1835) *The Life of Samuel Johnson*,Vol. 8, John Murray, London.
Carr, D., Gill, L. and McNabola, A. (2016) 'Development of a high resolution wave climate modelling methodology for offshore, nearshore and onshore locations of interest', *International Journal of Marine Energy*, 16, pp.30–40. doi:10.1016/j.ijome.2016.05.007
Grubler, A. and Wilson, C. (eds) (2014) *Energy Technology Innovation: Learning from Historical Successes and Failures*, Cambridge University Press, New York.
Héder, M. (2017) 'From NASA to EU: the evolution of the TRL scale in public sector innovation', *Innovation Journal*, 22, pp.1–3.
Kash, D. (1989) *Perpetual Innovation*, Basic Books, New York.
Kingston, W. (2010) *Beyond Intellectual Property: Matching Information Protection to Innovation*, Edward Elgar, Cheltenham.
Kingston, W. (2017) *How Capitalism Destroyed Itself: Technology Displaced by Financial Innovation*, Edward Elgar, Cheltenham.
Klepper, S. (2010) ''The origin and growth of industry clusters: the making of Silicon Valley and Detroit', *Journal of Urban Economics*, 67, 1, pp.15–30. doi:10.1016/j.jue.2009.09.004
Marine Institute, Galway, Ireland. (2000) *Exploiting the Irish Wave Energy Resource*. Report of Research on the Rock Engineering Approach to the Capture of Ocean Wave Energy by Trinity College, Dublin.
Skidelsky, R. (1995) *The World After Communism*, Macmillan, London.

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