The Allocation of Risk and Uncertainty in Infrastructure Investment

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Abstract. Infrastructure is one of the building blocks of regional advantage. In an era of rising national indebtedness, the public sector is increasingly reliant upon private financial interests for the provision and maintenance of infrastructure. Here, the focus is upon the allocation of risk and uncertainty between infrastructure investors and between investors and the public. Drawing upon a stylised infrastructure investment product and a case study of the ‘big battery’ in South Australia, it is shown that private investors may demand that the public sector bear the costs of infrastructure that fall outside of the "normal" risks obtaining when private capital is put to work to provide a public good.

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Introduction

Infrastructure investment is an important ingredient in urban and regional development (Crespo Cuaresma et al. 2014; Hebb and Sharma 2014). This is as true for China and the growing economies of Asia, Africa, and Latin America as it is true for the developed economies of the OECD and beyond (O’Neill 2018a). Whether infrastructure investment leads or lags economic growth is widely discussed (Cosci and Mirra 2018). It is arguable that the financing of infrastructure in the burgeoning cities of 19th century Britain continues to underwrite the economic performance of these cities and their roles as incubators for new economic activities and industries (Cassis 2016; King and Levine 1995). The transformation of many Chinese cities through infrastructure investment is also an attempt to ameliorate the worst effects of unfettered industrialisation and its associated congestion and pollution.

As economic growth has fuelled investment in Chinese cities and regions it has also provided governments the financial resources to invest in the future – witness the Belt and Road initiative which promises to integrate the Chinese heartland with central and western Asia. On the other side of the world, however, the financing of infrastructure investment is highly contested. Nonetheless, there is evidence of significant shortfalls of investment that can affect national “potential” rates of economic growth as well as the quality of life for those living in jurisdictions where infrastructure facilities and services have failed either relatively or absolutely. The infrastructure shortfall in many OECD countries is not only growing but threatens to paralyse governments seeking ways of responding to the growing demands on their capacities and resources (OECD 2017a).

These challenges have prompted debate about the virtues or otherwise of different models of financing infrastructure investment including privatisation, public-private partnerships, and user-pay systems of contemporaneous investment and operation of infrastructure facilities. Looming on the horizon, however, is a fundamental challenge to existing ways of infrastructure financing and provision. In their comment on the “principles to guide investment towards a stable climate”, Millar et al. (2018) identified three such principles that the private sector will have to honour if the goals of the Paris Agreement are to be realised. Their principles separately and together require investment in new energy systems, distribution systems, and environmental management systems. Without investment, the private sector will not meet targets of net zero emissions.

It is also apparent that the inability of Western governments to invest in infrastructure that would transform industries’ and companies’ carbon footprints represents a fundamental threat to our collective future. Here, it is an issue of mobilising public and private financial resources for infrastructure investment in circumstances where governments’ fiscal capacities have been eroded by a combination of increasing indebtedness, relatively low levels of taxation, and the “cold-hearted voter problem” (Clark 1999). These issues are reflected in the infrastructure initiative of President Trump which, characteristically, exaggerated their likely impact while looking elsewhere for the financial resources needed to give life to the US$1 trillion commitment.1

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Here, as elsewhere, it is assumed that investment for the future requires mobilising the global surplus of saving held by private financial institutions (Clark 2017). If so, academics and policymakers require a deeper understanding of infrastructure investment practice and, more specifically, the ways in which investors approach risk and uncertainty. This is one contribution of the paper, anchored in related concerns about how strategy is translated into action (Knight and Paroutis 2016). Along the way, I set-out a definition of infrastructure distinguishing those facilities so identified from other facilities that do not meet the criteria. The third contribution of the paper has to do with identifying the challenges and opportunities of investing in infrastructure via traded securities especially as regards to the components of value inherent in infrastructure facilities (see Knight and Sharma 2016).

Following Merton and Bodie (1995, 2004), a functional definition of infrastructure is presented. An analytical framework is developed focusing upon the allocation of risk and uncertainty in infrastructure investment. In the fourth section of the paper, I consider the three components of value inherent in infrastructure investment and illustrate those components by reference to the design and management of a stylised infrastructure investment product. In the subsequent sections of the paper, this framework is extended to understand the allocation of risk in the South Australian battery farm project. While the contract is not public record, there is sufficient information available to identify the key issues. Finally, implications are drawn for the roles and responsibilities of the public and private sectors in financing infrastructure investment.

This paper brings together investment principles and practices with infrastructure financing. In doing so, I follow all the lead of Coase (1974, 374) when he agreed with his colleagues that "we should try to develop generalisations which would give us guidance as to how various activities should be best organised and financed". But he went on to argue that these "are not likely to be helpful unless they are derived from studies of how such activities are actually carried out within different institutional frameworks." See Smith (2013) for a similar argument with respect to understanding housing markets.

**Infrastructure – Definition and Elements**

There are various ways of defining infrastructure, none of which claim universal acceptability (O’Neill 2018b). Economic theorists suggest that infrastructure are public goods that require collective provision where the ‘consumption’ is not affected by others’ use of infrastructure and others cannot be excluded from its use (Cornes and Sandler 1986). While often cited as the basis for classifying facilities as infrastructure or not, it has also been noted that few facilities would meet such strict criteria. For example, a road could be

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2. See, for example, the initiative led by the European Commission for an “action plan for a greener and cleaner economy”. The Commission estimated that achieving the EU’s sustainability goals of 2030 will require around Euro180 billion “of additional investments a year”. The finance industry is explicitly identified as the most likely source of such investments. See [http://europa.eu/rapid/press-release_IP-18-1404_en.htm](http://europa.eu/rapid/press-release_IP-18-1404_en.htm)

3. The focus of the paper is on the design of infrastructure investment products eschewing wider debate about the desirability (or not) of private sector investment in infrastructure and the social value of finance. Relevant contributions to this debate can be found in Engelen et al. (2011) and Wójcik (2012). Maxfield et al. (2017) provide an empirical analysis of the reach of the financialization thesis.
deemed infrastructure but fail both tests in that congestion can affect others’ use while others may be excluded from its use by virtue of their remote location.\textsuperscript{4}

**Collective benefit, connectivity, and complementarity**

If problematic as a test of infrastructure, some theorists argue that infrastructure should be treated as a public good in that its use confers desirable benefits on individuals and society. By this account, being excluded from its use could harm individual well-being (in the short term) and collective welfare (in the long term). Simply put, an acceptable definition of infrastructure would have it that it is something that confers on individuals and society a **collective** benefit. Another way of defining infrastructure is to rely upon objectification – that is, to suggest that any facility that enhances **connectivity** between individuals and across society should be classified as infrastructure. For example, roads, bridges, airports, mobile phone networks, and the Internet would all meet that criterion.

Some theorists would extend the definition of infrastructure to include Douglass North’s ‘institutions’ (norms and conventions, written and unwritten constitutions et cetera). For the purposes of this paper, however, to be counted as infrastructure a facility should also complement other facilities that, together, add-up to a functional and efficient urban landscape. So, for example, a bridge without a road would fail the test of **complementarity**. At the same time, it is not necessary that such a facility have a monopoly on collective benefit, connectivity and complementarity. In any event, infrastructure monopolies rarely survive technological innovation (witness the failure of UK canal companies in the face of competing railroad companies).

What counts as infrastructure is dependent upon its functionality—that is, the extent to which it meets the criteria established above.\textsuperscript{5} For example, a lighthouse has a collective benefit because it improves the safety of coastal shipping; it contributes to the connectivity of the economy by facilitating the links between local ports and global shipping; and, it enhances economic growth by sustaining complementary activities dependent upon safe and secure shipping and the links between local ports and global shipping. However, the functionality of a lighthouse does not necessarily suggest that these types of facilities need to be provided by public agencies. As Coase (1974) observed many years ago, UK lighthouses can be, and were once, provided by private investors.

**Public interest and government**

In many cases, these facilities are inevitably ‘entangled’ in the public realm (Rodriguez-Pose and Storper 2011).\textsuperscript{6} Investment in a lighthouse is only possible if there is a well-developed

\textsuperscript{4}/. See Cassis et al. (2016, 3) who take a different tack, emphasising the importance, capital intensity and long-life of these facilities thereby eschewing a functional definition for something that relies upon their physicality.

\textsuperscript{5}/. Notice, this definition makes reference to the characteristics of facilities at a point in time. It should be acknowledged that a facility might not begin life with all three attributes but may come to claim such status by virtue of its emerging functionality (see Vickerman 1987 on the probable long-term implications of the Channel Tunnel when considered in the light of related complementary investments).

\textsuperscript{6}/. Being entangled means to “ensnare” or “to interlace or mix up in such a manner that separation cannot be easily made” (Oxford English Dictionary, Clarendon Press, 1989, p. 286). Massey (2000) used the term in a similar way and connected it to the topography of power in contemporary society.
legal regime that protects the property rights of investors. In a similar fashion, lighthouse owners also depend upon the enforcement contract—that is, the agreement between the owners of a lighthouse and those that purchase the services provided by the lighthouse. It is entirely possible that the delivery of lighthouse services depends, in fact, on the existence of an effective regime of property law, corporation law, competition law, financial services law, and land use law (O’Neill 2018c). Here, are two related issues: the coherence of such a legal system and its performance given the costs that lighthouse owners might have to bear if coherence and performance are ineffectual.

Few lighthouses escape direct or indirect regulation. Whereas lighthouse owners rely upon an effective legal regime, they are also likely to be entangled in regulatory regimes that seek a balance between equity and efficiency given the possible market power of dominant providers. As the experience of US state-based public utility commissions demonstrate, these types of regulators can drive down the rate of return to the point where any profit is below the returns available in other jurisdictions and/or investment opportunities. In a number of celebrated instances, the infusion of party-politics into the rates setting process has created long-term capital flight. The regulatory process is ever-present in the calculation of current and expected risk and return (Fabrizio et al. 2007; Fowlie 2010).

The value of a lighthouse is also dependent upon government policies that affect the rate of economic growth. A government-induced recession could reduce consumer demand by dampening trade and the user-fees paid by shipping companies to the lighthouse owner. Over the long-term, a consistent rate of economic growth could sustain year-to-year receipts from shipping companies thereby generating a cumulative rate of return on the lighthouse that is above expectations (compared to the average yearly rate of return). Equally, an intervention that stymied the growth in trade or even precipitated a collapse in the volume of trade could bankrupt the facility owner. This prospect faces the owners of the Channel Tunnel which links the UK with Europe.

Conceptual and Analytical Framework
So as to understand the issues concerning the allocation of risk and uncertainty in infrastructure investment, this section provides a set of conceptual building blocks which frames subsequent analysis. In doing so, I begin with well-accepted definitions of risk and uncertainty and then look either side of those definitions for some of the subtleties otherwise glossed over in standard accounts. This discussion is the basis for understanding the interaction between risk and uncertainty in infrastructure investment.

Basic definitions
Keynes (1921) and Knight (1921) distinguished between risk and uncertainty suggesting that risk is best understood as the probability of a certain event or class of events occurring over a specified time horizon. By contrast, uncertainty is to be understood as obtaining in situations where (a) the probability of a certain event or class of events occurring is simply not known and/or (b) it is not possible to identify what might or might not happen over the future. Zeckhauser (2010, 306–307) distinguished between uncertainty, wherein the relevant probabilities are “unknown” but can be reasonably surmised, and what he termed “ignorance” which is either unknown future states of the world or, in a geographically differentiated market, other states of the world which have not been explored.
Estimation procedures
There are three components in estimating risk. In the first instance, it is assumed that we can identify the relevant events or classes of events that ‘fit’ with the estimation procedure. That is, there are identifiable boundaries around events such that those events deemed irrelevant can be excluded from the analysis. In the second instance, it is assumed that the procedure is based upon a well-defined probability distribution whatever its shape and structure. Third, it is assumed that there is a procedure for updating the underlying distribution and the relevant probabilities of certain events occurring. Normally, analysts invoke Bayes’ theorem although there are other ways of doing so (Pearl 2000).

It is possible that something is uncertain not because it is intrinsically unknowable but because there is insufficient information and knowledge through which to translate the “unobserved” into risk-based tools of analysis. This implies that the boundary between risk and uncertainty is malleable and that uncertainty can be transformed into risk metrics through the application of capabilities and resources. Elsewhere, capabilities are defined in terms of domain-specific skills and expertise whereas resources are defined as the domain-specific material required for decision-making (Clark 2014). By this logic, risk and uncertainty co-exist because capabilities and resources are scarce (or come at a price most people cannot afford).

Whereas Bayes’ rule provides for updating of the underlying distribution of possible events, there can be systemic shocks and unexpected ruptures to underlying causal relationships that render the past distribution irrelevant (at best) or profoundly misleading (at worst). Furthermore, instead of assuming that economic and financial systems return to some steady-state after a systemic shock, these systems can shift in ways that are only ‘known’ after the fact (Lo 2012). Here, uncertainty is manifest in two different ways: being found in events that render risk estimation procedures and modes of response irrelevant and/or self-defeating and in shifts in the underlying properties of economic and financial systems that presage revision of the parameters that describe the system (Haldane and May 2011).

Notwithstanding the costs of uncertainty, Zeckhauser (2010, 307) observed that those organisations and individuals able to cope with uncertainty are likely to reap "extraordinary expected investment returns." He suggested that when planning for the future, flexibility and adaptiveness provides those with the requisite skills and expertise a comparative advantage compared to those who remain wedded to risk measures calibrated against past experience. Whereas resilience is a means of coping with uncertainty, Zeckhauser suggested that uncertainty provides those able to adapt opportunities to realise premium rates of return. Even so, many people are hidebound by behavioural “traps” such as overconfidence and the mis-weighting of probabilities and preferences (Clark 2018).

Risk and return
One of the fundamental building blocks of modern financial theory is the assumed relationship between risk and return: market participants should expect to be compensated for taking higher risks with higher returns (Ho and Lee 2004). This relationship has been calibrated and recalibrated many times over and is a plausible rule of thumb when market pricing is more concerned with ‘value’ than ‘momentum’. Even in situations where market
pricing is subject to unexpected events and systemic shifts in risk metrics prompted by exogenous shocks, baseline expectations are framed around the risk and return nexus when pricing short-term and long-term deviations from the benchmark (see Vives 2008).

Over time, this relationship can be fine-tuned such that market participants frame their expectations in relation to the expected behaviour of other market agents (Arrow 2014; Grossman 2014). In asset classes characterised by information asymmetries, however, the assumed relationship between risk and return may not be sufficient as the basis for framing investment strategy. Equally, some markets in some jurisdictions are more transparent than others in terms of participants’ pricing and trading practices and their expectations. Even in an integrated system of financial markets, such as that which obtains between global financial centres, there can be a significant premium on local information (see Clark and Wójcik 2007; Coval and Moskowitz 1999).7

Managing risk and uncertainty
Sophisticated investors are aware of the potential costs of market mispricing. In response, there are various strategies of discounting the costs of risk including bundling securities into diverse portfolios and shifting risk to those more able to deal with it and/or less informed about their costs and consequences. For many investors, risk holding is a matter of timing in relation to market sentiment and perceived value guarding, wherever possible, the option to sell-out should there be a need to do so (Turner 2012).

Notwithstanding the possible benefits of investing in an uncertain world, sophisticated investors seek ways of imposing a priori limits on those costs (albeit unknown). As well, sophisticated investors use formal agreements including contracts to allocate the costs and benefits of uncertainty in relation to others more able and/or more willing to absorb those costs in exchange for a share of the benefits. In some cases, the willingness to bear the burden of such costs may be the entry ticket into a longer-term investment partnership (Clark and Monk 2017).

Infrastructure Investment – Principles and Practices
The expected value of an infrastructure investment can be decomposed into three components: its location in time and space, the service that it provides, and its optionality.8 These components are closely related in that they are information-intensive (see Sharma and Knight 2016 on the significance of ‘information density’ in infrastructure investment). Nonetheless, they are often distinguished from one another when it comes to adding-up the expected value of an investment.

Location in time and space refers to the current and expected sale price of the facility, taking into account its current location and its’ fit with other economic activities. Infrastructure facilities often have a ‘scarcity’ value in that they are site-specific both in

7/. In effect, there is a premium on investors’ skill and expertise even if it is often difficult in the short-term to distinguish investor competence from luck and/or happenstance (Ben-David et al. 2016; Glode et al. 2012).

8/. Expected risk-adjusted returns are typically judged in relative terms – benchmarked against other similar assets (Shleifer 1985). Benchmarking is a pervasive aspect of the investment management industry (Rosengarten and Zangari 2003), and contributes to cycles of financial speculation and crisis (Shiller 2005).
relation to their operation and performance and in relation to complementary activities located near-at-hand and at a distance. This value depends, in part, on the nature of competition in the sector and on government policy as regards the regulation of these facilities. The economic performance of infrastructure facilities also depends upon their physical form and functionality. Investment in an infrastructure facility may require a large upfront commitment combined with successive rounds of investment designed to upgrade and or maintain the competitive position of the facility in space and time.

Notice, there can be a high degree of certainty as regards the purchase price of an infrastructure facility and, in all likelihood, a good understanding of the probable future commitments required as regards maintaining the competitive value of the facility. However, as the investor looks-out beyond the near-term (5 to 10 years), the risks associated with holding the facility and realising a viable return on future rounds of investment increase. Indeed, when technological issues are taken into account, risk can morph into uncertainty such that the infrastructure investor imposes an a priori limit on the holding time of the facility.

The revenue value of a facility refers to the flow of income that comes from the use of the facility. Here, there are two key issues. Notwithstanding the scarcity value of an infrastructure facility, its purchase price and expected value may also be affected by the expected income generated by use of the facility. Indeed, in some circumstances, infrastructure investors may pay a premium for control of a facility precisely because the income generated is valuable in its own right. Who pays for the use of such a facility varies by jurisdiction. In some cases, the cost of use is directly attributed to the user in the form of the toll or similar charge. In other cases, government and/or private industry may pay on behalf of individual users.

Earned income from such facilities is valuable in its own right. It is also a means of maintaining and, where appropriate, upgrading the quality of the facility over time. Here, the issue is not simply gross income but net income taking into account the desired longer-term quality of the facility. As is apparent, however, having control of such a facility is not always associated with the right to set user-fees consistent with long-term investment objectives. In some jurisdictions, user fees are subject to a rate-setting process controlled by the government of the day. Not surprisingly, infrastructure investors may seek long-term contracts that cover both control of the facilities and the process where user fees are set.

Nonetheless, there may well be uncertainty over the integrity of such contracts. Expropriation is a real threat in some circumstances. In other circumstances, governments may use their political powers to affect earned income short of expropriation and/or the violation of contracts. Here, there is a risk that the quality of the infrastructure facility will degrade over time especially if the investor choses a limited commitment to the facility.

There is a relationship between the value attributed to location and the value attributed to revenue. Figure 1 provides four possible investment options wherein it is suggested that a facility located at ‘A’ would appear to be a highly undesirable investment and shunned by the investment community. By contrast, a facility located at ‘D’ would appear to be a highly desirable investment and sought by many investors. Given the uncertainty of an
infrastructure facility at ‘A’ the expected rate of return would have to be very high indeed to attract willing investors. By contrast, options ‘B’ and ‘C’ provide a choice set wherein investors can trade-off their revenue goals in relation to the long-term expected value of the asset. Some institutional investors are willing to compromise on revenue for long-term capital appreciation.

Notwithstanding modest expectations as to the revenue derived from managing a facility (option B), the expected future value of such a facility may be so significant that investors are willing to put aside their preference for short-term returns. This strategy comes with certain risks including the threat of expropriation. Here, investors are very much reliant upon the integrity of property rights and contract (see Wójcik et al. 2018 on the broader significance of this issue for financial markets). Option C comes with the implication that holding such a facility is all about maximising short-term returns – given the expected future value of such a facility, investors may be unwilling to own it outright and seek ways of sharing ownership or opting-out of ownership via some leasehold arrangement. In these circumstances, the quality and performance of the facility may degrade over time if maintenance fails to keep pace with its use.

The expected value of an infrastructure facility may also be affected by its optionality. In general terms, to hold an option is to hold an opportunity at some point in the future to buy or sell an economic entitlement. Normally, this is associated with trading shares in public and private markets and is subject to previously agreed conditions as to when such an option becomes ‘live’ and what are the obligations on both sides to such a contract (Harris 2003). Risk management works well in markets where assets are divisible – e.g. a block of shares could run from 1 share to millions. Infrastructure facilities are, however, lumpy and more difficult to divide into small parts.

Risk can be managed in a number of ways. Partnerships are a common means of distributing risk and, in certain conditions, provide a mechanism through which investors can sell to one-another a portion of their holdings. Likewise, investors can access infrastructure via traded and un-traded portfolios of infrastructure assets held and managed by third parties. In some cases, these instruments require investor commitment over certain periods of time with or without exit options and associated penalty clauses. For some investors, optionality is highly desirable. For other investors, being able and willing to pass on optionality is often accompanied by active ownership and a claim for a higher long-term rate of return.

The relationship between investors’ preferences for optionality in relation to certainty is summarised in Figure 2. This relationship is summarised in two limit cases: where certainty is low, investors desire a high degree of optionality (option B), and, where certainty is high, investors may be content with a low degree of optionality (option C). In between, there are circumstances where certainty is low and optionality is also low (option A) and where certainty is high and optionality also high (option D). The implications are as follows:
investors can demand a higher premium to invest in A type cases, drive down the rate of return in D type cases, demand contracts with escape clauses in B type cases, and may be willing to take contracts without escape clauses in C type cases.

**Infrastructure Products – Design and Performance**

Given the significance of climate change and the Paris Agreement, governments have sought ways of discounting their countries’ long-term CO2 emissions. One strategy has been to shift a portion of energy production from coal-fired to renewable sources including solar and wind facilities. As Knight (2012a, 2012b) observed, these strategies often have distinctive regional footprints being highly dependent upon the physical geography of wind and sun. Here, the design and performance of a renewable infrastructure product is discussed paying particular attention to the allocation of financial risk and uncertainty.\(^9\)

**Key characteristics**

Rather than identify specific products and their sponsors, the discussion is kept rather general so as to aid insight rather than debate the specifics of particular product providers. Typically, these types of products have three key characteristics. First, providers bundle together as many as 20-30 renewable energy facilities into a single investment product which is offered to institutional investors. Second, investors purchase units in the product which translates into shares of the revenue generated and the final closure or sale price of the facilities in proportion to their holdings (compared to other unit holders). Third, investors are locked-in to the product for as much as 10 years – redemption is costly and purposively difficult.

**Risk mitigation**

So as to limit the risks faced by the provider and its investors, the product is based upon three organising principles. First, established facilities are chosen from countries that have well-defined property rights and modes of adjudication when dealing with conflicts over land use and the performance of service contracts. Second, facilities are chosen that met certain standards in terms of the age of the facility, the nature of its technology, and its past performance. Third, facilities are chosen in jurisdictions where there is either credible government commitment to renewable energy sources and/or policies like subsidies aimed at sustaining the long-term market for renewable energy resources.

In each case, the investment manager seeks to limit the scope of certain risks while avoiding other risks and uncertainties. For example, by focusing upon established facilities with track records of performance, the investment manager avoids the risks and uncertainties associated with building and operating a new facility. By focusing upon facilities of a certain age and technological configuration, the investment manager seeks to exploit its existing knowledge and understanding of these types of facilities while protecting, as much as possible, the final value of the facilities when the investment product is wound-up. While

\(^9\) This account of relevant infrastructure investment products is meant to be illustrative rather than specific to a particular investment manager and/or their clients. Related products are provided by a number of major investment management companies including investment banks. Using a specific product would shift the focus of the discussion from the allocation of risk and uncertainty in these products to their specific properties.
governments are notorious for short-termism, investment managers prefer facilities that can be linked with governments’ climate change commitments.

**Risk management**

The performance of this kind of investment product depends, in part, upon the separate and collective performance of the facilities in the portfolio. As indicated above, it is expected that the facilities will be sold or passed on to other investors when the investment product closes. So as to protect the value of these facilities, the investment manager uses service contracts with specialist operations and management companies to ensure high standards of performance along with effective management of the facilities. But, this risk management strategy also introduces another type of risk – that is, the risk that providers will not honour the contracts for services at a level consistent with expected operating performance and the expected close-out values of the assets. Oversight and monitoring of service contracts are essential in realising the risk-adjusted rate of return.

Underpinning the performance of these investment products are contracts with the energy grid providers to take the energy produced from the facilities at a certain price. In some cases, these providers are private entities subject to government regulation. In other cases, the grid providers are government utilities. Whereas energy grids may be circumscribed by national borders, there have been moves across Western Europe and elsewhere to integrate the production and distribution of energy across borders so as to stabilise energy generation and consumption. In this regard, the rate of return on each facility and for the entire financial product is determined by the cost-effective production of energy.

To be more precise, the investment manager has three related tasks: first, optimising energy production at each facility; second, doing so in ways that are cost-effective both with respect to the short term and the long-term value of the asset, and; third, smoothing the flow of energy produced at each facility and across the bundle of facilities such that the rate of return benefits from continuity in production. In effect, the investment manager seeks to discount the likelihood of unexpected events that would disrupt the production process either at individual facilities or across the bundle of facilities. When considered over the long-term, the rate of return on the investment product benefits from low levels of volatility in the production of energy.

**Governing risk and uncertainty**

Whereas the investment manager reports to investors on a quarterly and annual basis the rate of return on the investment product, investors have an interest in ensuring that the investment manager is effective in each of the three related tasks (as above). At a minimum, this requires transparency and disclosure on key variables affecting the short-term and long-term value of the assets making-up the investment product. In this regard, there are intermediaries like investment consultants that act on behalf of investors (see Allen and Santamero 1998 on the theory of financial intermediation). Given the long-term commitment of investors to the investment managers of these types of products, ensuring oversight is a key ingredient in realising expected returns.  

10/ Intermediation is common throughout the global financial services industry suggesting that realising a planned rate of return is as much dependent upon optimising and governing the chains of intermediaries that makeup the production process (see Arjaliès et al. 2017; Clark and Monk 2017).
However, there are at least three sources of uncertainty as regards the expected long-term risk-adjusted rate of return. Since these types of energy infrastructure facilities typically rely on the flow of wind and sun, the price investors are willing to pay for access to these types of facilities depends upon predictive models of the short-term and long-term flow of wind and sun. While these models are readily available, on a day-to-day and on a month-to-month basis there are significant stochastic elements in any predictive model of wind flow and the received intensity of the sun. Better predictive models are obviously preferred over lesser models. However, these types of models can still contain an uncertain component that simply cannot be modelled.

A second source of uncertainty has to do with estimating the exit value of each facility and the bundle of facilities. These types of investment products are vulnerable to the entry of new competitors that bring with them infrastructure facilities with higher levels of technological sophistication. While it is widely assumed that wind and solar facilities have an operating life of somewhere between 20 and 30 years, technological innovation could simply make existing facilities uncompetitive and, perhaps, obsolete. Given the pace of innovation in clean-tech, a lock-in period of 10 years could see existing facilities priced out of the market. Equally, government policy could change over this period of time to give advantage to other sources of energy and new generations of energy-generating infrastructure. Policymakers have an incentive to encourage technological innovation especially as regards meeting national CO2 commitments.

The third source of uncertainty has to do with staying too long in a facility or a set of related facilities such that the investor becomes responsible for the costs of decommissioning both the facility and its adjoining sites. These costs should be relatively minor compared to the costs of exit from large-scale fossil fuel facilities such as coal-fired power stations. Furthermore, the costs of decommissioning a single wind and/or solar facility are, in principle, well-known prior to the acquisition of these types of facilities. However, there remain uncertainties as regards future government policy pertaining to the decommissioning and remediation of these facilities and their sites and there are uncertainties as regards the recycling and/or disposal of the component parts that make-up these types of facilities.

These uncertainties can become acute when the investor holds not just one facility but a set of facilities of similar age and technological sophistication. Not surprisingly, investors prefer to sell-on these facilities before these issues become important. Even so, potential buyers of such facilities may demand a significant discount on their purchase price.

**Green Infrastructure**

Institutional investment is about the allocation of risk and uncertainty (Ho and Lee 2004). As indicated in the previous section, the allocation process does not exhaust risk and uncertainty so much as mitigate and manage these elements in accordance with the short-term and long-term objectives of investors and investment managers. Furthermore, it was shown that investment in infrastructure can involve trade-offs—in circumstances where the long-term value of an infrastructure asset is uncertain, investors may seek higher revenue
flows in compensation. There remain, however, a number of fundamental issues to be resolved.

**Market failure**

It was also shown that the investment management industry is predisposed to invest in established, brownfield infrastructure facilities with expected ‘lives’ extending beyond the investment mandates joining investors with investment managers. In part, this is a response to risk and uncertainty in that more is known about the structure and performance of brownfield infrastructure facilities. While information and knowledge of these facilities are not always in the public domain, due diligence is likely to reveal the relevant material. Furthermore, the existence of third-party information and knowledge about the performance of these types of facilities shifts the assessment of risk and uncertainty from informed judgement to models of performance that can be interrogated for their stability.

The preference for long-lived brownfield facilities can mean that investors shun new infrastructure developments outside of the knowledge and information available about existing facilities. Just as importantly, whereas realising a risk-adjusted rate of return on existing facilities can be achieved through the oversight of investment managers and the set of service providers bound by contract, few investment managers have the expertise to design and build infrastructure facilities. This type of investment involves the choice of technology, project management, and the translation of blueprints into functioning and efficient facilities. Managing the associated risks and uncertainties associated with project development requires domain-specific skills and experience.

At the other end of the market, where the value of existing brownfield facilities is increasingly subject to doubt because of technological change, the obsolescence of capital, and the rundown in operating efficiency, institutional investors are very wary of holding these assets. Given the risks and uncertainties associated with (actual and/or potential) decommissioning, institutional investors run the risk of significant losses both for themselves and for their clients. Large investment groups with experience at both ends of the market and experience with project management may well prosper in these circumstances. But, this part of the market is more about investment banking than portfolio investment.

**The supply of certainty**

Notwithstanding market failure at both ends of the market for infrastructure, it is arguable that the middle part of the market has been very successful if measured in terms of the volume of capital committed and the returns distributed to investors. Success has been made possible by the stability of energy grids and the existence of facilities that can guarantee energy flow even if alternative sources of energy like the sun and wind are subject to predictable and not so predictable short-term variations in energy flow. In, many cases, the stability of existing energy grids has been a precondition for ensuring certainty in the distribution of energy over time and space.

Energy grids have also been opened to institutional investors – these types of facilities have been acquired and bundled together in portfolios of infrastructure assets in much the same
way as indicated above. And, as suggested above, these types of assets are well-understood by investors both in terms of revenue flows, asset values, and the derived risk-adjusted rates of return. Even so, these types of infrastructure facilities are often more important to national energy systems than specific energy generation facilities. Certainty of performance is a key ingredient in realising not only the value of such an investment but also realising economic growth and development.

The expected long-term value of these types of facilities depends on continuity in the performance of integrated cross-jurisdictional energy production and distribution systems. Likewise, providing certainty in the flow of energy depends upon production systems that can either compensate almost immediately for the failure of flow in one part of the system and/or can provide on an on-going basis the base-load of the system. In many jurisdictions, these functions are provided by fossil-fuel energy generation facilities that rely upon known technologies, established sites of production, and integrated systems of distribution. In effect, the success of clean-tech infrastructure has relied upon sources of energy that these facilities are designed to replace.

These types of infrastructure facilities have also attracted private investment. In part, the value of these facilities is to be found in their strategic importance to economic growth and the willingness of governments to pay the price for certainty. In part, there is also a notional scarcity value implicit in this type of facility given the run-down of older fossil-fuel energy facilities and the willingness of government to reduce the operating capacity of these types of facilities in favour of clean-tech. There remains, however, an ever-present risk for investors: just as investment managers are wary of investing at the margin of the market for energy, these groups are also wary of the risks of ‘holding’ facilities that will be (in the future) redundant and/or could be made unexpectedly redundant (stranded).

Certainty providers
In effect, governments have sought ‘certainty providers’ that are attractive to institutional investors. Depending on the jurisdiction, these can be found in natural resources such as tidal estuaries, large river systems, and reservoirs that can harness the inflow and outflow of water systems. At one level, these types of infrastructure facilities are attractive to institutional investors because the risks associated with operation and management well-defined with considerable knowledge and information about how to realise optimal performance (and revenue). Historically, these types of public works have lasted for many years – even centuries.

Investors have realised that even these types of facilities carry risks given the differential geographical impact of climate change. In response, governments have returned to nuclear power only to find that private investors are also concerned about the risks and uncertainties associated with the design and building of new facilities, managing those facilities over the long-term, and then decommissioning over the millennia. Whereas institutional investors may well take a share of the construction and operation phases of these projects, they have not been willing to absorb long-term risks and uncertainties. This option seems unlikely to provide certainty over the coming 10 to 20 years as fossil fuel generation facilities are decommissioned in the face of international commitments.
Investment and Innovation

Certainty providers come in various forms. Consider the initiative led by the South Australian government: it faced the problem of underwriting the performance of public and private investment in alternative energy sources. Notwithstanding reliable sources of wind energy, this energy source was found to be unreliable in conditions otherwise assumed consistent with a high degree of reliability. In fact, neither wind nor sun sources of energy are able to perform at the margin – where wind-speeds exceed the capacity of turbines to absorb the level of energy available and where solar cells are unable to cope with very high temperatures. In South Australia it was also found that wind energy tends to die-off later in the day at precisely the time when demand for energy tends to peak.

The solution was the South Australian Grid-Connected Battery Facility (SABF).\(^\text{11}\) Provided by the Tesla Motor Corporation, the SABF was designed and built to ensure "a secure and resilient power system" (Essential Services Commission of South Australia 31st July 2017). Much has been written about this initiative, including commentary on reasons why Tesla made such a commitment. Important for this paper, is the project Agreement joining the South Australian government and the battery provider (July 6\(^\text{th}\) 2017). The Agreement was dominated by the specification and allocation of the risks associated with the contract. In large part, the allocation of risks was skewed towards the government.

The Agreement was framed by reference to common law, SA law and Australian federal law (page 9). Provision was made, however, for the appointment of an Independent Engineer responsible for “witnessing and certifying the Performance Tests” of the facility (Section 7.3) along with the option to appeal to an Expert. In many respects, the Agreement was consistent with contract law and the customary tendering practices of government. Section 5 on “Risk and ownership” itemised relevant risks and the responsibilities of the contactor.

- Section 5.1 (a) (b): the contractor was deemed responsible for the risks and costs associated with the site, its suitability, the development of the project, the commissioning of the facility, its performance and participation in the national grid.
- Section 5.2 (a) (b): the contractor was deemed solely responsible for all expenses and liabilities in relation to the project and its’ performance.
- Section 5.3: the contractor was excluded from the right to claims over and above the agreed contract payment notwithstanding any subsequent risks or costs.
- Section 5.4: the contractor was deemed to hold all leasehold rights as well as related risks and costs of the site.

In Section 11, the Agreement set-out the conditions and requirements as regards the “Performance Validation and Testing” of the facility. It established testing stages, and the role of the Independent Engineer in ensuring that the facility achieved standards of performance as detailed in this section and in Section 8 of the Agreement. Furthermore, Sections 8.6, 8.7, and 8.8 provided government with the right to impose on the contractor

\(^{11}\) The world’s largest lithium-ion battery at 100mw was paired with the adjacent Hornsdale Wind Farm owned and operated by Neoen (a French company). It was designed to provide power for up to 30,000 homes over 1 hour in the event of a blackout and contribute to the national grid. For more details see the following: https://www.theguardian.com/australia-news/2017/dec/01/south-australia-turns-on-teslas-100mw-battery-history-in-the-making; http://reneweconomy.com.au/tesla-big-battery-outsmarts-lumbering-coal-units-after-loy-yang-trips-70003/
directions to accelerate performance validation in accordance with the agreed date by which the facility would provide services to South Australia and the national grid.

The Agreement focused on commissioning, performance, and capacity in accordance with an agreed timetable. By relying upon the Tesla Corporation for the SABF, the state government took on considerable political risks. Tesla also took on significant risks: specifically, in applying and operationalising their battery technology in a far-off jurisdiction without the benefit of extensive trials in settings where performance was not the single most important measure of value. For Elon Musk, like the Premier of South Australia, his reputation and the reputation of (respectively) the company and the government were put ‘in play’ when the “big battery” was proffered as the solution to the lack of certainty.

The facility was officially opened in early December 2017. Almost immediately, it was deemed a success. On December 17th 2017, one of the country’s largest coal-fired power stations (Loy Yang in Victoria) suddenly failed with a loss of 560MW from the national grid. The SABF responded virtually instantly, significantly ahead of the base-load coal-fired stations on the eastern seaboard. This is shown in Figure 3 where energy frequency in the grid is represented on the left-hand axis of the box, suddenly falling from a peak of 50.07 (Hz) at approximately 1:58.5am to 49.575 (Hz) at 1:59.35am. At that point, the ‘big battery’ (HPR) entered the grid with output (represented on the right-hand side of the box) through to approximately 2:02.5am. Thereafter, the Gladstone coal-fired power station in Queensland entered the system and brought grid frequency back to 50.00 (Hz) at 2:04.9am.12

[Insert Figure 3 about here]

Here lie four important implications. First, a large set of similar facilities spread along the eastern seaboard and reliant upon different geographies of wind and sun could, in fact, replace the small set of mega-facilities reliant upon fossil fuels. For investors, concerned about being trapped in ‘stranded assets’ and drawn to investment products that are bundles of facilities rather than single-site mega facilities, this would seem to be a desirable way of realising a risk-adjusted rate of return. For governments, the Tesla battery represents a very different way of ensuring certainty in energy generation appropriate to household demand while linking private finance to the achievement of governments’ international climate change objectives and targets.

A second implication concerns the viability of the mega coal-fired facilities. With the incursion of new competitors into the eastern Australian market for energy, the rationale for continuing to rely upon large coal-fired facilities has turned on their base-load capacity. Furthermore, it would appear that being able and willing to add at a moment’s notice ‘extra’ energy into the grid could attract a market premium thereby underwriting the costs of maintaining on-line operating capacity over and above the ‘normal’ demand at any point in the 24-hour cycle. The fact that the SABF is able to get to the grid faster than the base-load

facilities suggests that the older facilities may see a decline in earned income and, by extension, an increase in the average and marginal costs of operation.

Third, one such facility is unlikely to drive-out the existing base-load suppliers.\textsuperscript{13} But, a large set of such facilities would surely threaten the economic viability of large coal-fired power stations and the regions and communities that rely upon them for employment and income. Going further, over the longer-term it is possible that community-based battery facilities could themselves be supplanted by household storage units that purchase energy from other households via the grid and sell to the grid their excess energy. That is, the decentralisation energy production and consumption may, at the limit, become so local that the option for investment is found not in energy generation and storage but in the ‘poles and wires’ that string together different geographies of energy potential.

Fourth, it is ironic that the ‘big battery’ is too fast for the grid for its contribution to be effectively measured or registered for payment. Media estimates suggest that 30-40 percent of its response to disruptions in energy frequency has not been compensated \cite{age2018}. If this is a systemic property of the grid then it would appear that the grid itself is a constraint on innovation in energy generation and distribution. The implication here is that to make good on the flexibility and efficiency of the “big battery” will require investment in the grid whether by governments and/or by investors that have a share in the operating performance of the grid. Even so, private investors in the grid may baulk at such a commitment given risk and return calculations that have not taken into account the disruptive effects of alternative energy facilities.

There remain, of course, many issues to be resolved including the reliability of the operation and management of the SABF and similar facilities and long-term financial returns on such projects taking into account the costs of reinvestment. However, the SABF is an intervention that could reframe what is possible regarding the reconciliation of energy production with climate change over the long-term \cite{shah2017}.

\textbf{Implications and Conclusions}

In many OECD countries, centralised production and distribution systems of energy was the solution to local energy needs providing certainty in supply along with local employment. All this was made possible by the exploitation of fossil fuel deposits, notwithstanding the attendant pollution and negative externalities which are, in many cases, conveniently ignored through the premium which is placed on certainty of supply. As it turns out, these externalities have come to impose a shadow over the development potential of fossil-fuel dependent regions and threaten humanity’s prospects over the coming century. Certainty of supply has come with a heavy price.

\textsuperscript{13}/. See the critical comments of a government minister of the ‘big battery’ invoking the value of the coal-fired power stations. \url{https://www.teslarati.com/tesla-big-battery-gets-mocked-australia-resource-minister/}

\textsuperscript{14}/. Unclear, at present, is the operating life of the facility, its performance over time especially in environmental conditions that impose significant stress on wind and sun energy facilities. Also unclear is whether this type of facility can be scaled-up to serve major metropolitan regions such as Melbourne and Sydney and underwrite the stability of the eastern seaboard grid.
Over the last 10 years or so, there has been a reawakening of interest in the energy demand supply question prompting successive rounds of investment and innovation in alternative systems of supply. If often framed, now, with respect to the imperatives driving national and international commitments to the mitigation of climate change, technological innovation in alternative energy sources has had a long gestation period. Indeed, just as we are able to map technological and process-based innovation around the world, we are also able to identify leading regions and sectors in clean-tech as well as the expanding geographical surface of applications and implementation. The brief case study regarding the use of Tesla’s battery technology in South Australia is a case in point.

For many commentators, however, the pace of innovation and implementation is too slow given the threat of climate change. Whereas innovation in energy supply was, by default, allocated to energy generation utilities, it would seem that the organisational and regulatory frameworks underpinning those systems of supply are not fit for purpose. Indeed, public utilities have been slow to invest in new technologies and slow to accommodate other modes of energy production which are decentralised rather than centralised, technology-led rather than production-led. At the same time, it would seem that the capacity of governments to invest in new kinds of local, national and supra-national energy systems is limited and is likely to be more limited as rising public and private indebtedness takes its toll on fiscal and monetary policies (OECD 2017a, OECD 2017b).

In this context, it has been argued that institutional investors have a significant role to play in funding solutions to the energy – climate change challenge. Indeed, it has been suggested that the fact that these investors are not encumbered by past commitments as many public utilities are means that these investors may well play a key role in underwriting technological change in energy production and distribution systems. If desirable, I have argued in this paper that whether or not institutional investors have an appetite for investment in this sector depends on the nature and scope of the risks and uncertainties involved in such commitments. In doing so, I have provided a definition of infrastructure, a stylised account of investment management in infrastructure facilities, and a mapping of the risk preferences of these types of investors.

A number of implications can be drawn from this analysis. Most obviously, the analytical framework underpinning this paper rejects commonly-held assumptions that infrastructure facilities are necessarily public goods in the sense that they are properly provided by public investors. While the public goods framework as it applies to the provision of infrastructure has some merit, the abstract nature of this type of framework precludes a deeper understanding of what counts as infrastructure and what types of infrastructure can be provided by private investors. Throughout, the analytical framework emphasises risk and uncertainty suggesting that this lens is a crucial means of understanding the financial motives and preferences of institutional investors. While the distinction made between risk and uncertainty is widely accepted in academic research, this distinction is not always understood in public policy or in contemporary debate over the climate change conundrum.

In doing so, I identify both the likely scope of institutional investment in energy production and distribution and identify circumstances in which institutional investors are unlikely to play a role. At issue, is the allocation of risk and uncertainty such that institutional investors
are able to deploy risk mitigation and risk management strategies so as to realise their investment objectives. These types of strategies are commonplace, and underpin contemporary investment theory and practice. Recognising these investment practices is important when it comes to initiating the search for financial commitments to new forms of energy production and distribution that have a deliberate clean-tech element.

But, there is a paradox at the heart of the issue. Given the interest of institutional investors in portfolio-based risk management strategies it is more likely that institutional investors will make commitments to smaller scale and decentralised energy production facilities than they are likely to make new commitments to single-site, centralised production and distribution facilities. It is not surprising, therefore, that it is increasingly difficult to garner commitments from institutional investors to invest in single site large-scale nuclear power facilities. Indeed, it is difficult to see why institutional investors would make a commitment to such a facility given the concentration of risk associated with such large-scale investments and given the range of uncertainties attending to both the technology and, ultimately, the afterlife of these facilities.

Whereas private investment in infrastructure is deemed antithetical to the public interest, by some, my argument is that institutional investors could well play a larger role in local and regional based solutions to the provision of energy. But, as indicated above, these types of investors have a fundamental interest in risk mitigation and risk management shifting to others any uncertainties. Here, then, is a significant role for the public sector.

References


Figure 1. Premium on Infrastructure

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<tr>
<td></td>
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<td>Revenue Low</td>
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Source: Author

Figure 2. Two Dimensions of Value

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Source: Author
Figure 3. ‘Big battery’ frequency response.