Commercial Building Learning Rates

Final Report

Prepared for: Department of Industry, Innovation and Science

Client representative: Mike Dodd

Date: 3 August 2016

Rev 02

Inspired thinking embracing
the challenges of a changing world.

pitt&sherry

Prepared by: .... Date: 3 August 2016

Philip Harrington

Reviewed by: .... Date: 3 August 2016

Mark Johnston

Authorised by: .... Date: 3 August 2016

Philip Harrington

Revision History					
Rev No.	**Description**	**Prepared by**	**Reviewed by**	**Authorised by**	**Date**
00	Final Report	PH	MJ	PH	5/7/2016
01	Final (web accessible)	PH	MJ	PH	27/7/2016
02	Final (web accessible)	PH	MJ	PH	3/8/2016

Table of Contents

List of figures

List of tables

Acknowledgement

pitt&sherry wishes to acknowledge with appreciation the significant input into this project by Veryan Hann, PhD candidate, UTAS.

Executive Summary

'Learning rates' refer to the rate at which the extra costs that typically occur in new or innovative products, decrease over time as production volume increases. The rate of learning reflects how quickly firms adapt, adopt new technologies and techniques, and revise their designs and/or production processes.

Learning rates are critically important in the context of benefit cost analysis and regulation impact assessment of commercial building energy performance requirements. This is because the level or stringency of energy performance requirements that are deemed cost effective will vary significantly depending upon learning rate values used. If the regulatory change induces high costs and those costs persist through time, then that the regulatory change may not appear cost effective. If on the other hand the regulatory change induces small additional costs, and/or if any costs are temporary and effectively overcome by innovation, then the regulatory change may be cost effective.

Our international literature review found that industry learning is widely recognised around the world. It is used in industry as a key performance indicator, and it is also used in policy design, notably in Europe and North America. While numerous terms are used around the world in the place of learning – like experience, improvement or progress – they all describe broadly the same underlying phenomenon. A more neutral term might be the 'innovation rate', as it is ultimately the rate of innovation in designs, construction processes, products and materials that determines the size and persistence of additional costs.

Learning rates in the specific context of Australian commercial buildings appear to be poorly documented. The literature and case studies appear weighted towards residential buildings, and the best commercial building references are not from Australia. We conclude therefore that there is an urgent need for original research to quantify learning rates in this sector ahead of any benefit cost or regulation impact assessment being undertaken for the 2019 National Construction Code.

To this end we identify three possible methodologies. The first involves working with quantity surveyors to identify how key cost elements relating to energy performance have evolved through time, particularly following changes to Code energy performance requirements. The second involves capturing data on how the costs and cost premiums associated with 'beyond Code' energy performance ratings (NABERS, Green Star, CBD) have evolved through time. The third involves working with statistical data on the value of non-residential building work done, normalising that data for a range of extraneous factors, and examining data for deviations from trend attributable to Code-induced cost imposts.

The approaches have different strengths and weaknesses that are discussed in the body of the Report. An overall caution is that it is not clear that a learning rate observed in response to a *past* regulatory change would equally apply to a *future* one – particularly if those two changes are a decade or more apart. It is likely that the wider availability of energy efficient technologies, new learning through education and continuous professional development initiatives, and the wider availability of information on global best practices via the internet and trade journals will all have improved the ability of the commercial building industry to respond quickly and innovatively to new building standards. In that sense, an historical value for learning might be considered a lower bound for the future. Since past RIS's in this area have assumed no learning at all, it would be better to establish one or more historical observations to ground future RIS analysis, rather than to proceed by way of assumption.

We tested the degree of support for the first two methodologies with a limited number of industry and academic stakeholders, and also asked if alternative ones would be preferred (Method 3 was developed later). There was a clear preference for the second approach, but several stakeholders expressed concern about whether the second method would be directly applicable to a Code change as distinct from a market-led performance change. No additional methodologies were proposed, but we note that consultations were limited and it is possible that additional views could be captured through a wider consultation process.

Overall, noting the critical importance of learning rates on observations of future cost effective energy performance requirements, and also noting the paucity of existing research in this field, we encourage the Department to pursue all three methods if time and funding allows. This would ensure that there is a range of quantitative observations that could inform future RIS processes, including a central value (potentially an average of the research results) and also sensitivity values for ‘low’ and ‘high’ sensitivity analysis. It would ensure that stakeholder preferences are taken on board by government, thereby not disenfranchising any particular stakeholder groups.

If time and/or funds are strictly limited, we suggest that Method 3 be prioritised, due to its lower cost, shorter timeline but also its large sample size and the robustness of the underlying data. We would identify Method 1 as the second priority, notwithstanding its higher cost and longer timeframe, given its direct relevance to the key research question. Method 2 would also provide valuable insights, and is well supported by stakeholders, and should be undertaken if possible.

1. Introduction

1.1 Scope

This study was commissioned by the Department of Industry, Innovation and Science to help inform the consideration of possibly increasing the minimum energy performance stringency requirements in the National Construction Code (NCC) in 2019, as set out in the National Energy Productivity Plan Work Program.

The context for this study includes that, first, learning rate assumptions were an important and controversial element of the regulation impact assessment that underpinned past NCC energy performance requirements. It is likely that industry stakeholders will again identify this as an important issue in the lead up to the 2019 possible date for new Code requirements.

The literature review below helps to explain why learning rates can be controversial. The literature refers to a 'perception gap' about the costs and benefits of high performance (or 'green') buildings, that is at least in part attributable to the extent of real world experience that stakeholders have with those buildings. The literature suggests that those with no or less direct experience with such buildings consistently over-estimate the costs and under-estimate the benefits, compared to those with more experience. For example, the World Green Building Council (WGBC) produced a report in 2013 that found that, '*while there can be additional costs associated with building green as compared to a conventional building, the cost premium is typically not as high as is perceived by the development industry'* (WGBC, 2013, p.8). The study compares industry estimates of increased costs (between 0.9% to 29%) to actual costs incurred for a range of 'green' building types (-0.4% to 12.5%) (WGBC, 2013, p.26).

A key recommendation in the 2015 Report *Monetary Benefits of Ambitious Building Energy Policies* (commissioned by the Global Buildings Performance Network, GBPN) also underpins this study:

> *it is economically much more efficient to promote the proliferation of very high performance buildings rather than to focus on accelerated investment into "shallow" energy efficiency improvements during the building retrofit or construction.*

The second major recommendation from this international report is to incentivise education and training of 'construction professionals' which is a direct policy and economic investment into accelerating learning in the sector (Urge-Vorsatz et al 2015, p.18-19).

The GBPN report however, modelled an extraordinarily high learning rate of 50%, whereby "specific investment costs are assumed to decrease by 50% by 2050 as compared to their 2005 value". This was because "the learning factor is applied only to the advanced buildings because cost learning is only assumed for these best-practices that are at the early phases of their market introduction and deployment, as opposed to conventional buildings with mature markets" (Urge-Vorsatz et al 2015, p.91).

In a recent update of **pitt&sherry's** 2012 study, *Pathway to 2020 for increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis,* we established that of all the parameters that affect observations of the cost effective level of energy performance requirements for commercial buildings, it appears that learning rates are the most sensitive. That is, modest differences in learning rate values can have a significant impact on the level or stringency of the energy performance requirement that is deemed cost effective.

This observation is consistent with international literature that recognises the importance of learning rates.

> *The importance of learning rates for economic analysis of technology can be compared with that of discount rates in cost benefit analysis.*' (Jamasb & Köhler 2007, p.15).

> *The power of the learning curve is so significant that it plays a major role in many strategic decisions related to employment levels, costs, capacity, and pricing'* (Prentice Hall, 2006, p.773).

Further, learning rates are used for

> *strategic decision making by managers directly related to competitive cost structures* (Hax, and Majluf, 1982), and

> *there is overwhelming empirical support for such a [learning rate] experience relationship from all fields of industrial activities.* (IEA, 2000, p.11).

The European Commission produced a policy report on learning curves[1] in 2012. The fundamental aim of the report was to identify how learning curves could be used to enhance policy support in innovation. The European Commission report highlights the critical role of innovation as a key driver of economic vitality and as a process requiring policy support.

There appears to be a deficit of objective and relevant quantitative research, at least in Australia, about what learning rates actually are in the commercial building field. Unless this deficit is rectified, there is a risk that assumptions, rather than evidence, will be used in cost benefit analysis and regulation impact assessment. In past Regulation Impact Statement (RISs), the assumption was made that the learning rate is 0%. It is likely that this assumption was a major factor underpinning levels of energy performance requirements that, on objective analysis, were very conservative (pitt&sherry, 2012). The opportunity costs associated with the actual, conservative requirements having been selected over more stringent but still cost effective requirements has not been calculated, but would be likely to be very large.

Against this background, this project is designed to:

- examine the available literature;
- describe the phenomena known as 'industry learning' (or a host of similar phrases, as noted below);
- offer a working definition;
- define one or more practically-implementable methodologies to quantify the rate;
- capture and summarise the views of a limited number of key stakeholders, specifically regarding preferred methodologies for quantifying learning rates.

[1] Learning curves and other key terms are defined in Section 2.

2. Literature Review

This section first reviews literature that offers insights into what 'learning' means, including definitions of the term and related terms. We then set out a range of references that provide case study observations of learning rates. Finally, we note some limitations and draw some conclusions.

2.1 Defining Learning

It has long been known that repetition of a task can lead to improved efficiency in performing that task and/or to an improved rate of output. In other contexts, this phenomenon might be described simply as 'practise makes perfect'. Wright (1936) made the first empirical observations of the relationship between practise and efficiency/output. He noted that while the phenomenon was very common across a range of industry types, the actual progress or learning rate varied between sectors. Wright (1936) observed the relationship of a decrease in costs by 20% with a doubling of cumulative production over time. Wright drew his observations from the aircraft industry; however the relationship has been observed across other sectors from photovoltaics to construction IEA, (2000), Couto & Texiera, (2005), Everett & Farghal, (1994), Jamasb & Köhler (2007), Mályusz & Pém, (2012), McDonald & Schrattenholzer (2001), Ritter, & Schooler, (2002), Schoots et al., (2008), Thomas et al., (1986), and Wene, (2000).

Learning curves are also referred to as Experience Curves, Improvement Curves, Progress Functions and Progress Ratios. Definitions of these terms across the literature are inconsistent, as set out below.

Learning Curve/Rate

'Learning curve' is the most common term in the literature used to describe this investigated phenomena.

The term 'learning curve' is used by the following authors; Couto & Texiera, (2005), Everett & Farghal, (1994), Jamasb & Köhler (2007), Mályusz & Pém, (2012), McDonald & Schrattenholzer (2001), Ritter, & Schooler, (2002), Schoots et al., (2008), Thomas et al., (1986), and Wene, (2000). The majority of these authors refer back to Wright (1936) and the following definition summarises the term as applied by those authors:

> *The ... learning curve, or experience curve, is a log-linear equation relating the unit cost of a technology to its cumulative installed capacity... A characteristic parameter is the "learning rate," defined as the fractional reduction in cost for each doubling of cumulative production (Rubin, et al., 2015).*

Experience Curve

The experience curve is described by the International Energy Agency (IEA) in the following way:

> *Experience curves... provide a simple, quantitative relationship between price and the cumulative production or use of a technology. There is overwhelming empirical support for such a price experience relationship from all fields of industrial activities'* (IEA, 2000, p.10).

Further, the IEA contextualises the experience curve in that it is 'strategic long-range' and that it is not reliable 'for short term decision making'. The IEA graphs world market data for photovoltaic modules between 1976 and 1992 – this double-log plot is a straight line – where the

> *data indicate[s] a steady, progressive decrease in prices through cumulative sales, which are used as the measure of the experience accumulated within the industry. The relationship remains the same over three orders of magnitude'* (IEA, 2000, p.11).

The International Energy Agency (IEA) applied 22 field studies and 108 cases in the manufacturing sector and found a median progress ratio of 82% (meaning a reduction to 82% *of* the initial cost, equivalent to a reduction *by* 18%) for each doubling of production. Progress ratios vary with sector and appear to be faster with components, less mature industries (IEA,2000, p.14) or where cumulative capacity is fast to rise or where new technologies enter the field. Lower progress ratios (steeper curves) lead to quicker break-even points compared to investment costs. The reason for this is that for a steeper curve a cumulative doubling of production the cost falls off more rapidly. Solar PV is one oft-cited example (IEA, 2000, p.15). The definition applied by the IEA is the Wright model, *learning by doing*.

Improvement curve

Johnson's (2015) presentation on 'improvement curves' does not define this term, and he appears uses the terms learning slopes, progress curves, progress rates, learning curves and improvement curves as a substitute for the term improvement curve.

Progress function

Johnson (2015) and Dutton & Thomas (1984) define **progress functions** on a more granular level (at a unit cost level) compared to experience curves which are more general, at an industry level.

> *The term progress functions (or curves) is separate from experience curves; the latter, though sometimes used at the level of a firm, often are used to describe progress at an industry level. Experience curves also often use price as a proxy to capture progress effects (Boston Consulting Group, 1970), whereas progress functions are expressed in unit costs*. (Dutton & Thomas, 1984, p.235).

Progress ratio

The progress ratio has been defined as follows:

> *...a progress function states: "When cumulative volume doubles, the cost per unit declines to p% of original cost"; "p" is termed the progress ratio* (Dutton & Thomas, 1984, P.238).

Similarly,

> *...unit costs decrease with increasing experience. The idealized pattern describing this kind of technological progress in a regular fashion is referred to as a learning curve, progress curve, experience curve, or learning by doing (*McDonald & Schrattenholzer, 2001, p.255).

The European Commission (2012) identifies various types of learning: *Learning by doing; learning by researching; learning by using; learning by scaling; and learning by copying (EC, 2012, p.9).* The effects of these learning processes are not simple to separate. Most commonly, in the literature, the learning curve relates to *learning by doing*.

Wright's observation describes a *learning by doing* process, where experience and scale lead to the identification of opportunities for streamlining existing production processes. This can be expressed as higher output and/or reduced cost per unit of output.

The concept of learning curves is widely accepted for policy deployment; that learning curves are implicit to policy assumptions; and that direct and indirect effects of policy assumptions are linked to learning curves (EC, 2012, p.6).

In general, two aspects define an accelerated learning rate – new, or emerging technologies have a fast progress function; and smaller (simpler) products have faster progress functions. This is because doubling a cumulative capacity occurs very rapidly for smaller component manufacturing or single material technology; for example, the learning rate in window glazing and technology has been very rapid (Jakob &, Madlener, 2004, p.156). Despite this, learning curves can also be fast for more complex (larger) products that are accumulating from a small base.

2.2 Generalised Models for Proficiency Curves/Innovation Rates

For the plot below experience is on the x-axis and can be measured in terms of time or capacity. The y-axis is learning or proficiency and can be represented in terms of reducing cost over an output cycle.

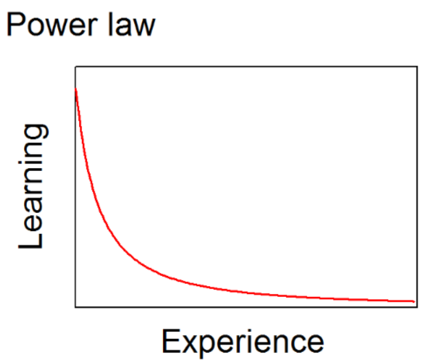


Figure 1: The Power Law

The Power Law in Figure 1 is the specific example of costs against cumulative capacity, observed by Wright (1936). The reason for this is that it describes incremental reduction in costs (learning) per doubling of cumulative capacity. When both scales (x- and y-axes) are plotted logarithmically; that is as a log-log or double-log plot, a straight line relationship is observed. This is diagrammatically observed in the Figures below.

Experience curves can be shown in linear-linear or log-log forms. The latter is useful as the experience curve can be shown as a straight line when using a logarithmic scale, which is shown in the transformation from the linear plot to the double-log plot below in Figure 2.

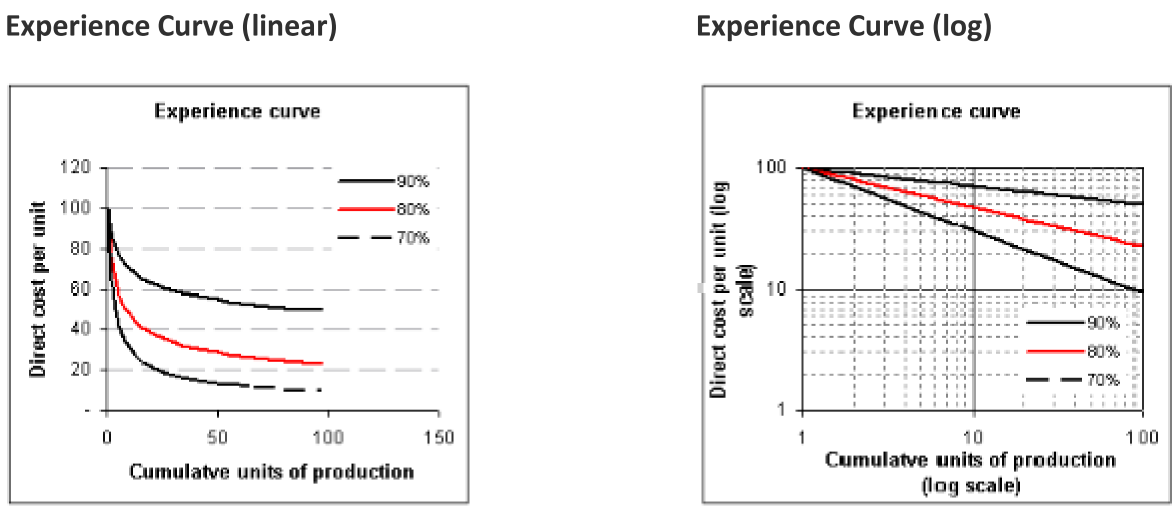


Figure 2: *The Experience Curve the Linear-Linear form (left) and the Log-Log form (right).*

Drawings attribution: Alan Fletcher [Fletcher Studios] 2013

The plots above are basic hypothetical plots which demonstrate the significant effect of the drop in direct cost due to different learning rates of 10%, 20% and 30%. That is, if the cost reduces to 90% of its original cost with a doubling of production; then the learning rate is 10%. Most commonly, across sectors it is observed generally to be in the order of 20%. The curves below are based on the basic experience curve, with some modification.

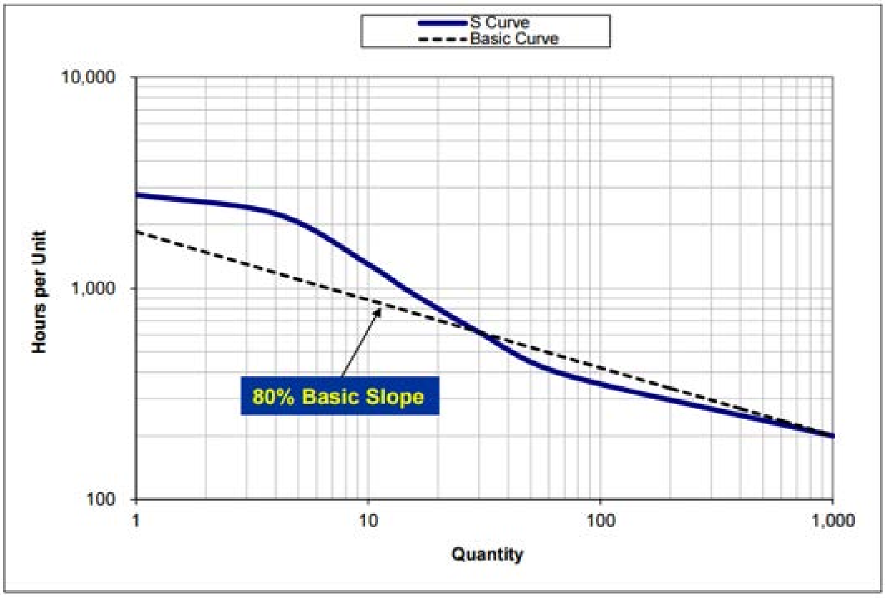


Figure 3: ***S-Curve & Basic Slopes***

[from Johnstone (2015) based on Cochran (1960). Where the total cost is the same for both curves – as a measured as area under the slope, which takes into account the logarithmic scale].

The basic slope is the log-log curve or double-log curve. The basic slope is a direct application of Wright's observation - it is the experience curve equation. The S-Curve is more complicated and takes into account changing rates as technology matures. It is a description formulated by Johnstone (2015). The S-curve indicates a pattern where initial progress is slow due to technological hurdles and the need for innovation to overcome these. Once this occurs, progress accelerates rapidly. Progress may slow again once the product becomes more mainstream, due to saturation effects. Johnstone (2015) identifies that S-Curves and Basic Slopes can be constructed from historical, actual data and that these slopes could be identified as a forecast by extrapolation through standards (including standard operating procedures). This method uses hours as the measure of 'effort' however cost could also be used with equal validity.

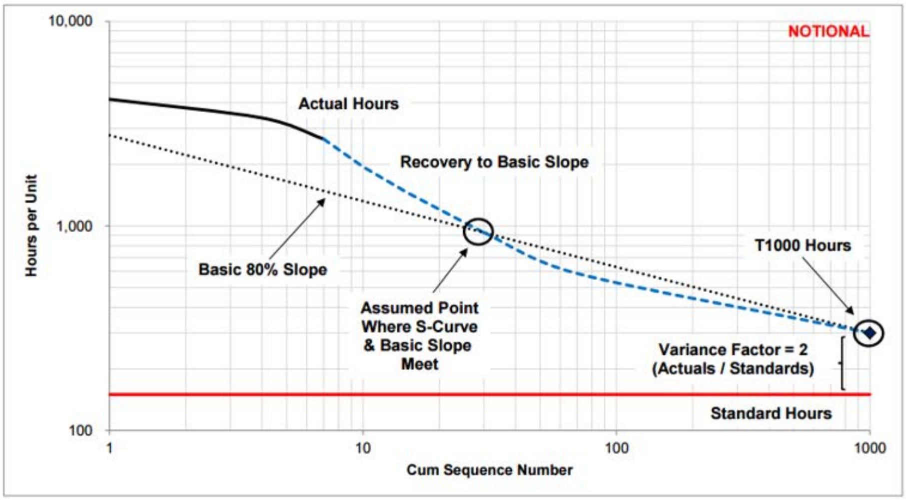


Figure 4: *Curve Projections*

Source: Johnstone (2015)

2.2.1 The Experience Curve Equation

$Ct = C_0 (Pt / P_0)^{-a}$

Where:

C = cost at time zero and t (corrected for inflation).

P = accumulated volume of production at time zero and t.

a= constant, reflecting the elasticity of unit costs to accumulated volume.

Where doubling of production results in the cost reduction to 85%; then for an 85% curve, the constant ‘a’ calculates to a=0.234 where ‘a’ is the cost to volume constant.

The 85% curve means that for each doubling of capacity, costs are reduced *to* 85% of original costs.

A study of 42 learning rates in energy technology industries was conducted by McDonald and Schrattenholzer (2001). It found that an ‘80% curve’ is common, meaning that for each doubling of production, costs reduce *to* 80% of their original value. Mathematically, this is the same as a reduction *by* 20%). This study also suggests that *learning rates and progress ratios for new technologies are faster than old technologies.*

2.2.2 Commercial Buildings – the Basic Curve

Everett et al (1994) found that the linear (or Wright) model of learning most closely predicted future behaviour, and it is assumed for this study to be appropriate for the commercial building sector. This would be plotted on a log-log scale.

For commercial buildings, the learning curve can be described as a power function (the most common type) – it measures cost reduction from the power function of cumulative output; that is Equation 1. Then, the learning effect on cost reduction is the percentage cost improvement for each doubling of cumulative capacity; this is Equation 2.

Equation 1 $LR = 1-2^{-\varepsilon}$

Equation 2 $c = \alpha.Cap^{\varepsilon}$

where

c = unit cost (e.g. $/m^2)

Cap = deployment (cumulative capacity / output)

ε= learning elasticity

LR = learning rate

(Adapted from Jamasb & Köhler 2007)

In 2014, Malyusz and Pem furthered learning curve theory – they compared and tested known models and applied it to data collected from the construction industry, with a special focus on roofing insulation. The results aligned with the Wright model with learning rates in the region of 20% - a reduction to 80% of the original cost.

2.2.3 First, Second and Third Order Learning

At a conceptual level, the extent of learning related to policy change has been described in the literature as *First order, Second order* and *Third order* (Hall, 1993). *First order* relies on simple, reactionary responses, for example, a response to a changed *level* of a policy setting only. A *Second order* results from considered responses in different types of policy instruments, and they can form substantial changes. *Third order* changes can be systemic. A case study of a British regulatory shift over a long period (1970-89) demonstrated a cascade of alterations of key policy components, and then policy instruments, and then the 'hierarchy of goals behind policy' changed. This is described as an uncommon event, and because of the scale and depth of the change it is described as 'third order'. (Hall, 1993, p.279).

The local example, detailed in Section 2.2 of this report, of a New South Wales *Green Star* shopping centre development provides evidence that developers can employ all three levels of thinking in solving sustainability and economic issues:

> *The Ponds Shopping Centre stands as a prime example of what is possible through a genuine, holistic commitment to sustainable design. The project has allowed us to demonstrate that 6 Star Green Star retail is not only achievable, it's also worth doing from a financial perspective* -Paolo Bevilacqua (GBCA, 2016).

2.3 Case Studies

2.3.1 Global Buildings Performance Network

The Global Buildings Performance Network (GBPN) is a global network on building research institutes active in China, Europe, India, South East Asia and the United States. Its website notes, "The GBPN was founded in 2010 with the mandate to advance knowledge and expertise globally on building energy performance and the structures to achieve it. It is coordinated by a global centre based in Paris, and is represented regionally with an office in Beijing and partner organisations in Brussels, Washington D.C."

In January 2015 GBPN published a major study entitled *Monetary Benefits of Ambitious Building Energy Policies*. This study aimed "to quantify the global and regional cost implications of implementing large-scale energy efficiency improvements in buildings as compared with the status-quo under certain scenarios". The scenarios focus on the deployment of very advanced (very low energy, passive or nearly zero energy) new construction and retrofits (Deep efficiency scenario), as well as more moderate improvements in building energy performance (Moderate efficiency scenario with less energy saved in retrofits and less ambitious performance levels in new construction). This study notes (p. 36):

Technology learning is an important factor to consider in any cost analysis of emerging technologies and know-how (Fleiter et al. 2009). Technology learning - a decrease in the cost once the production doubles, occurs due to two reasons – economy of scale and the learning effect. In this study this concept is used in the following way: while the number of advanced new and retrofit buildings is growing and their market uptake is on increase, but a large market penetration is still far from being achieved, the costs of such buildings are expected to be decreasing over time during wider technology diffusion and acceptance.

Specifically, the study (p. 37)

...assumes that the specific investment cost of the advanced new construction, as well as that of advanced retrofit, decreases by 50% by 2050 as compared to their 2005 values.

We note that this reduction applies to absolute cost observations (Euro/sqm) rather than incremental costs relative to standard or default buildings. The study also assumes that adopted of an 'integrated design process' approach to new building development leads to rapid learning when 'advanced' building performance levels are targeted, while slower learning occurs in the moderate efficiency scenario as there is less requirement for innovation.

Indeed, the study highlights the critical role of design – specifically, changing designs – as a key learning effect (p. 37):

Another important reason for the learning effect is a major change in the design methodology, which means moving away from the conventional, linear approach to building design towards the integrated design process (IDP). IDP means that different processes of design, planning, construction and commissioning are closely interlinked.

It is worth noting that a key recommendation of this study is framed around learning:

The extent and rate of deployment of advanced buildings depend both on the availability of high efficiency building elements and on the preparedness of the construction industry. Therefore it is recommended that governments ensure that all construction professionals involved in the construction process of advanced buildings...have the necessary education and training so that advanced buildings can be deployed at a large scale" (p. 19).

2.3.2 The Green Building Council of Australia

The Green Building Council of Australia (GBCA) has a number of case studies showcasing high energy- and cost- efficient builds. Two examples described below are for diverse examples - a large and complex shopping centre in New South Wales; which is a 'global-first 6 star' and a very small office in Adelaide that has achieved 5.5 stars.

2.3.2.1 The Ponds Shopping Centre - New South Wales

Taking its place among the world's most sustainable retail complexes, The Ponds Shopping Centre in Sydney's north west achieved a global-first 6 Star Green Star – Retail Centre Design v1 in 2015 (GBCA, 2016).

Together, the sustainability measures implemented at The Ponds Shopping Centre equated to a cost of around $290,000 – less than one per cent of the project's overall cost. This small green premium is expected to produce operational savings of $45,000 per annum. For building owner ISPT, sustainability is part of a pragmatic, long-term approach to investment - Sam Curry, ISPT's General Manager – Retail Services.

2.3.2.2 dsquared Office Fit out - South Australia

This Adelaide office space and CitySwitch signatory achieved a 5.5 Star NABERS Energy rating. It is only 100 square metres and was a cost efficient fitout–

> *one of the smallest Green Star-rated fitouts, but with 5 Star Green Star – Interiors certification, one of the greenest'* (GBCA, 2016).

2.3.2.3 Further GBCA research

We also note that the GBCA is currently conducting research looking at the cost of Green Star, based on data provided by Green Star certified projects, using the Financial Transparency Innovation Challenge. The Green Star Financial Transparency Innovation Challenge was launched in 2014, with the aim of increasing the amount of information available to industry on the costs and benefits of sustainable building (correspondence with GBCA , June 30, 2016).

2.3.3 Western Australia – Commercial Buildings

Australian building policy expert, Elizabeth Bazen, notes that measures such as State government procurement of higher star rated offices led to an increase in their supply at no additional cost:

> *Western Australia was an early adopter of NABERS (ABGR) office rating, and this was because 4 star buildings were required within WA State Government office tenancies – this kick started the commercial building industry for Western Australia, as it drove competition, and hence, innovation and adoption'* (Bazen, 2016).

The policy Bazen refers to was for buildings of 1000m^2 or more having a mandatory 4 star NABERS rating from 2006 (Government of Western Australia, 2004, p.22). The policy gave industry a 2-year lead-in time for implementation, it also required mandatory audits and disclosure. Lead-in time provides industry time for planning; audits and disclosure provide improved compliance.

Reinforcing this experience, the Green Building Council of Australia, (GBCA, 2013, p.28) quotes a sustainability manager on the initial cost of 4 Green Star rated industrial builds:

> *...we've revised our design approach, costs have come down, and we think a 4 Star Green Star rating requires an additional investment of two to three per cent on base design which will comfortably provide a return on investment within a few years.*

Benefit cost analysis outlined in the Australian Building Codes Board (ABCB) RIS2009 relating to regulatory impact, was based on three scenarios - 50% and 100% increased costs and a decrease in costs by 20%. Even for the 20% reduction in costs the Benefit Cost Ratio (BCR) was a modest 1.1. (RIS2009, p.139).

2.3.4 Residential Case Studies

The majority of references in the literature were to residential buildings. These are included for reference. The UK Department of Housing and Local Government, for example, found:

> *The major cost of the options is the increase in construction costs of meeting the energy standards of the higher levels of the Code. Some work has been commissioned by the Housing Corporation and English Partnerships on the costs of delivering Code level 3, or a 25% improvement in energy/carbon levels, which estimates the costs to be around 2-3%, or around £2,000 per dwelling, on the basis of current technologies. Some developers have indicated that such improvements can be achieved without additional cost through new techniques and materials, e.g. using off-site or modern methods of construction using concrete panels. This largely corresponds to similar estimates in other countries although there is some anecdotal evidence to suggest that these costs could be reduced through the*

adoption of different construction methods. (UK Dept of Communities and Local Government, 2006, p.34)

While relating to residential buildings, the same UK Department noted:

The costs of achieving the improvement in standards is in most cases modest. Increases in building costs in the order of a few percentage points are typical.(UK Dept of Communities and Local Government, 2006, p.36)

Construction case studies observed in Portugal revealed

...the effect of learning in repetitive building projects may lead to important gains in productivity – too important to be neglected.

The case studies reflected that the production data on average followed *"gains caused by the learning effect"* (Couto and Texiera, 2005, p.362).

Moreover, key findings for the Department of Climate Change and Energy Efficiency (2012a) Report <u>Identifying Cost Savings through Building Redesign for Achieving Residential Building Energy Efficiency Standards</u>*:*

Current popular designs as constructed by Australia's largest volume builders can meet the 6 star energy efficiency standard with reduced construction cost if the design is modified to best suit the climate and orientation rather than increasing the building specifications, eg. insulation levels. Results of this study show an average increase in energy efficiency of 1 star, and an average decrease in total construction cost of nearly 2%, compared to the original design (DCCEE, 2012a, p.11)

A study conducted by McLeod & Fay (2010) showed that, for residential buildings,

Thermal performance ratings of 5–6 star houses can be achieved for less cost than a standard designed 4 star.

In this study reduced glazing area offset increased insulation costs to achieve the higher star rating. It is important to note that for this study some materials were considered 'atypical' however as code stringency increases and that it was concluded

the use of materials and methods needed to meet compliance will become more widespread. As a result, their cost is likely to decrease over time. (McLeod & Fay, 2010, p.313)

This is a direct and applied, industry learning effect.

In Western Australia, the 6 star requirements were introduced in 2011, lagging the adoption of 6 stars in the Building Code of Australia by 12 months. There was debate on the cost implication of the increase from 5 to 6 stars.

An increase in energy efficiency doesn't necessarily mean an increase in building cost. If you get the basics right, and design the house well from the outset, there should be minimal additional costs. For houses priced about $200,000 or below, the price increase is likely to be a maximum of about 2% or as low as 0.2%, according to local independent research. (Green Star Consulting, 2012).

On the other hand, builders were surveyed at the time of the RIS2009 development. Some responded with concern that additional costs could increase by as much 300%. Western Australia's Building Commission decided to manage industry concerns by making the 6 star level being voluntary for 12 months arguing that:

Western Australia is capitalising on industry learning insomuch as to not be faced with these predicted hefty additional costs.

In an Australia wide residential case study, a survey of 28 builders estimated increasing to 6 stars had increased construction costs by an average $3,500, with the largest estimate of $8,500, with one builder reporting no increased costs with meeting higher regulations. Approximately 50% of surveyed builders said they had been able to reduce costs, since higher energy efficiency standards had been introduced. (DCCEE, 2012a, p.51).

A case study under NATHERS of residential housing trial in Adelaide used 12 house designs and a handful of builders. At the end of the project it was found the average star rating was 6.4; and the average cost per star as $3,415.

Belusko and O'Leary's (2010) estimate of increased cost to 6 star is still a

> *modest 1-2% of total construction and development costs* [using] *currently available technologies* (Belusko & O'Leary, 2010, p.36).

This was an assessment in 2010 for 6 star build. Belusko and O'Leary used a Method 2 style assessment (Method 2 is presented in Section 4 of this report) in their South Australian case studies; the study demonstrated a negligible cost increase from 5 to 6 stars in some cases. We contacted one of the authors who confirmed this.

> *In Victoria new houses after 2004 were required to be built to a five-star standard, at the time the average standard was 2.2, and concerns were raised about increasing the stringency at that time* (Greenlivingpedia, 2011).

A 2008 Victorian Master Builders Association (MBA) survey estimated:

> *A five-star minimum energy rating had added $7,600 to the cost of a new house, and that six and seven-star ratings would add $10,000 and $14,000, respectively* (Greenlivingpedia, 2011).

However, in practise, some builders found that costs of compliance were much lower – that meeting the new requirements of five-star were an additional $1,000 to $2,000 and that the:

> *six-star option has added about 1% to 2%, which equates to $4,350 extra for a house priced at the Melbourne median of $435,*000 (Craig, 2008).

In another Victorian example, three years later a NatHERS 9-star house was built with:

> *the cost of the entire project, including design and build, totalling $420,000* (Vorrath, 2012).

The design and engineering phase is considered to be a critical aspect of managing and minimising new build construction costs (Thomas, 2016, Watson, 2016, and Sustainable Energy Association of Australia, 2012). Well planned and integrated planning, design and construction proved to reduce the cost differential from 4.5 star and 5 star to effectively zero – this demonstrates one of the mechanisms whereby for industry learning takes place (Thomas 2016).

It is also the case that some field studies of compliance costs have noted actual costs were lower than estimated in the 2009 RIS. Industry learning and new technologies in these instances drove design adaptation from 2009 so that the step from 5-Star to 6-Star was have been available (to those willing to learn) at lower cost than estimated in the RIS.

A 2011 report produced for the Department of Climate Change and Energy Efficiency by energy consultants Wilkenfeld and Associates found the general approach of the BCA 2010 RIS excluded the genuine possibilities that alternative methods, including learning and technology reduce costs while meeting targets could be employed. It also assumed no change to house plans, only to material specifications. In addition it was noted that:

> *labour costs may come down as a result of experience and 'learning' by builders, and the relative costs of materials and components may fall due to changes in demand prompted by the regulation* (Wilkenfeld, 2011, p.54).

2.4 Key Assumptions and Limitations

The literature we reviewed does include some remarks that speak to limitations of learning curves, or underlying assumptions. These are set out below.

- The possibility that learning rates can slow:

  > *In general, the power function fit appears to be robust, regardless of the methods used (Newell & Rosenbloom, 1981)….If learning follows an exponential, then learning is based on a fixed percentage of what remains to be learnt. If learning follows a power law, then learning slows down'* (Ritter & Schooler, 2002, p.5)

- Learning curves are averaged curves – in the sense that measuring one participant it would be more irregular – however, over a statistically significant sample, the curve smooths.
- The EC highlights a number of criticisms that learning curve analysis has received; such as high uncertainties, the blunt and aggregated treatment of data (components are not treated separately), market effects such as prices may not be easily teased out, and the impact of learning effects may be overstated for extrapolating future calculations (European Commission, 2012, p.6).
- Learning rates vary (EC, 2012, p.12). Despite this, the relationship between learning rate and production and reduced costs can be quantified in an aggregated way.
- There are other limitations such as variability across jurisdictions, across technologies and components, and that over different time the learning rates may change, and it has been suggested that scenario analysis (in the sense of a range of learning rates could be calculated – eg 75%, 80%, 85% and 90% to assess outcomes based on those scenarios) as a good way to deal with this challenge.
- It is recognised that little qualitative research has been done in this area and that even less from a quantitative point of view, however understanding and applying technology learning would help drive increased energy efficiency in commercial buildings.
- The rule of 'three and four'. This is a market share equilibrium assumption about market structure defined by the Boston Consulting Group in 1976, because market or industry structure is known to affect learning rates: The so-called 'rule of three and four' refers to the company size and market share affecting the innovation rate and that the equilibrium for innovation is approximately a ratio of 4:2:1. This hypothesis, developed by Boston Consulting Group (Henderson, 1976), is that if the largest market player (company) is roughly twice as large as its' next competitor, which in turn is twice as large as the next competitor, and that the market mix is predominantly a handful or large players – this rough proportion reflects the ideal conducive conditions for increased innovation and learning in the commercial building sector (Reeves, et al 2012, Henderson, 1976). In Australia, the residential building sector has a greater number of smaller players absorbing total market share, however, the commercial building sector has a *smaller number of larger players* absorbing the market share (McLeod, 2016). Therefore, according to Reeves, et al 2012, and Henderson, (1976), Australia would be expected to have enhanced innovation conditions (hence, greater learning and reduced costs) for the commercial building sector than for the residential sector. It can be noted here that the residential sector is still advancing compared to the commercial sector in regard to rate of increased energy performance over time – hence, this is another indicator of unharnessed potential in the commercial building sector.
- The 'rule of thumb' 20% learning rate (a 20% reduction in costs for a cumulative doubling of production) is a 'plausible proxy' based on the literature, and observed rates, however it needs to be carefully applied because if it errs on the high side, it may be necessary for some technologies to apply an 'artificially imposed a floor price' so that cost reductions are not unrealistic (Jamasb & Köhler 2007, p.5). It is considered a rule of thumb because the measure of 'effort' inputted is reduced to 80% of the

original repetition. For example, the effort parameter is reduced to 80% labour or 80% costs or 80% time input based on the last repetition is the closest average across all sectors and activities; from rates of successful heart transplants to reduced construction costs.

- Data collection is required to test and refine the models, noting that there is a lack of accurate and comprehensive data for testing Wright's model in various industries (Jamasb & Köhler 2007, p.11).
- Recent work by Johnstone (2015) warns of the difficulty and reliability of estimating learning curves from past industry experience, however Johnstone's work indicates the curves can be approximated to a 'basic curve' (Wright's model). That is; while learning rates are more likely to be an S-curve over a development cycle within industry; and that the slope best estimates 80%; this means a 20% reduction in costs for a doubling in cumulative capacity/production.

2.5 Analysis and Conclusions

Our review of the national and international literature in this field suggests some key conclusions.

The first is that there is widespread recognition and use of learning rates to understand (or influence via policy) the rate of innovation of new and higher performance products and technologies, specifically leading to unit cost reduction through time.

While a variety of terms are used – learning rates, industry learning, learning curves, experience curves, progress ratios, progress curves, etc – they appear to be more or less interchangeable. The key phenomenon they all describe is a reduction in unit costs as production volume doubles. Underlying this process is learning or innovation. The literature denotes many types of learning – learning by doing, learning by researching; learning by using; learning by scaling; and learning by copying – and all contribute to the outcome of unit cost reduction. Other sources refer to the importance of design innovation as a learning phenomenon. Sources agree that rate of learning is generally faster with new technologies than established ones, and may also follow an 'S curve', with the rate of learning varying through time.

There are a number of cautions in the literature, with the key one being that 'rules of thumb' about learning need to be tested with real data rather than assumed. In this context we note that the literature refers to many kinds of industrial products and not often to buildings. While the general phenomenon of learning appears in many sectors, and appears generally applicable, the extent to which it is evident in commercial buildings should be tested with specific research.

We note that the GBPN reference – which is extensively peer reviewed international research – asserts that we should expect faster learning with higher standards, and lower learning with lower standards, as the first situation forces a higher rate of innovation. For this reason, it finds that the overall savings and the cost effectiveness of savings are higher with higher standards than with lower standards. This observation should be taken into account when applying observations about past learning rates to potential future regulatory changes: if the 'hurdle rate' is different, so may be the learning rate.

Another caution that arises is that the literature deals with changes in absolute, real (that is, after inflation) unit production costs, and not incremental costs, which is the construct used in benefit cost analyses and regulation impact assessments. The absolute costs of production of any product will never fall to zero, as there are always resources consumed in the production process that must be paid for. However, incremental costs represent just the *additional* costs associated with achieving a new regulatory performance standard relative to the costs that would otherwise have been incurred, and these can fall to or even below zero. For example, where a new higher performance product effectively replaces an older, lower performance one, technical innovation and increasing economies of scale can see the unit costs of the new product fall to no more, or even less, than the old standard. This can occur because the production equipment used to produce the old product may be retired as demand for that product falls, and replaced by new production equipment for the new product (Figure 5). We could take an example from telephony – mobile phones originally cost many time more than fixed landlines, but now the opposite is true, at least at the cheaper end of the market – in such a case, the relative (or incremental) cost of the mobile phone will be negative.

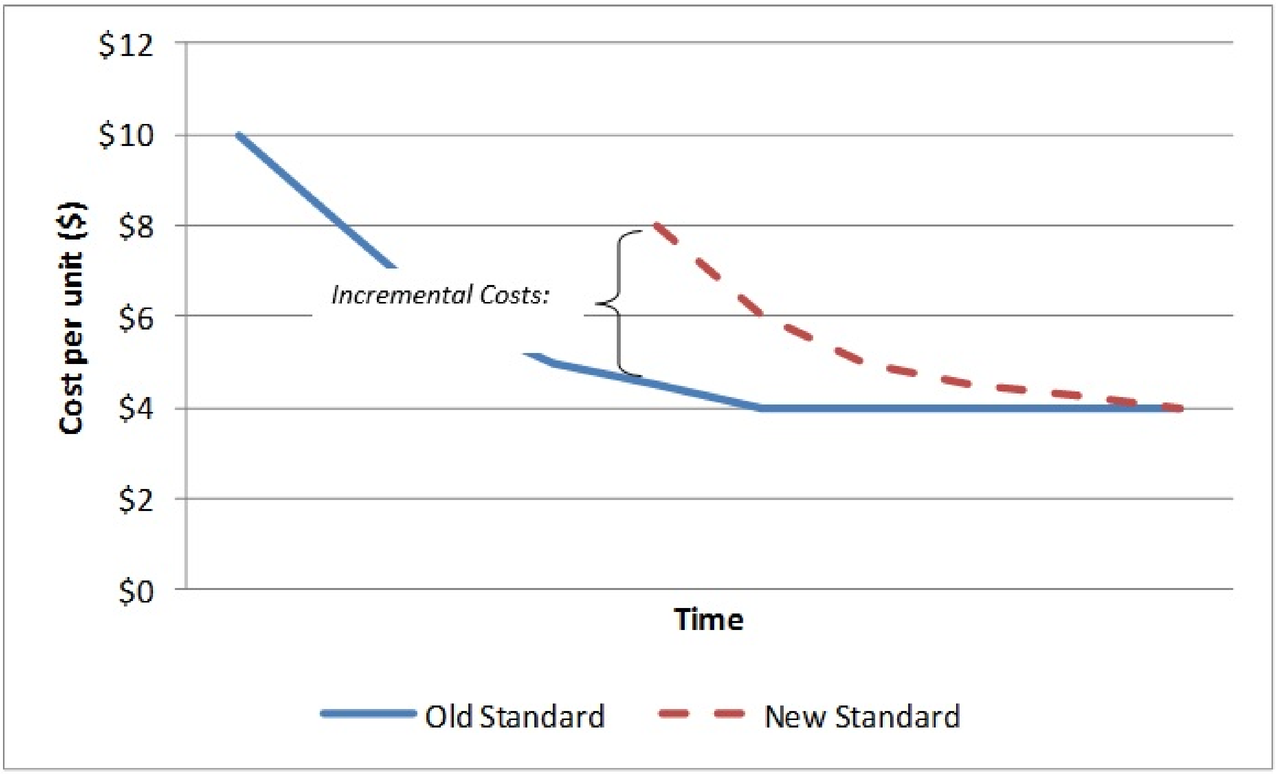


Figure 5: Learning Effects Leading to Zero Incremental Costs

Indeed, innovation in the product itself, or in the production process, or both, could see unit costs for the new product fall below those of the old product (Figure 6).

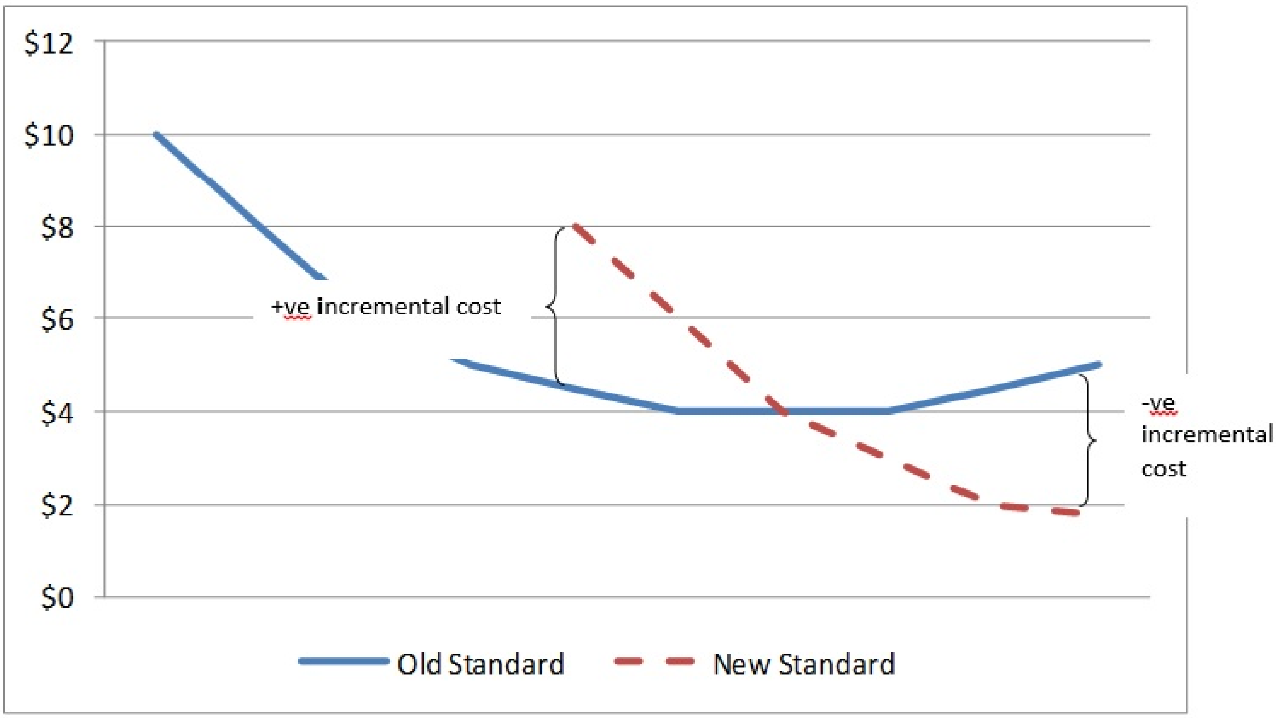


Figure 6: Learning Effects Leading to Negative Incremental Costs

A hypothetical building industry example could be high-performance glazing, for example. Initially, higher performance glazing has small production volumes and higher unit costs that the conventional product. However, were the higher performance glazing to be effectively mandated, for example by a Code change, demand for the product would rise quickly, requiring and enabling producers to transfer production capacity to the new product. The use of new production equipment and techniques, growing economies of scale and increasing competition (including from overseas producers) would also place downward pressure on unit costs, to the point where they could fall below those of the original, lower performance product. Indeed, as demand for the latter declines, its unit production costs could start to increase, as the whole supply chain moves away from that product and it acquires niche status. In markets where high performance glazing is the norm, such as California, it is often quipped that if someone order single glazing, it would attract a significant price premium, as it the order would require one-off production techniques without any economies of scale.

We also note that the question of industry structure is identified as a factor that can affect the rate of innovation and learning. It is suggested that a more concentrated or oligopolistic industry structure, with a small number of dominant players, may be optimal from the perspective of learning and innovation. The two key factors at work here are understood to be the financial capacity of firms to undertake innovation and to bear associated risks, and second, the rate of spread of innovation and changed industry practices. In this context sector wide learning or experience curves are more relevant for assessing the expected response to a Code change than progress ratios relating to individual firms. The former would take into account the speed of transmission of innovation from firm to firm, or the average rate of innovation of all firms, whereas progress ratios could be affected by propriety technologies and intellectual property issues.

A second key conclusion is that there appears to be little quantitative research designed specifically to quantify past learning rates in the commercial building sector, in Australia or overseas. For the most part, we find ‘rules of thumb’ or assumptions in the literature. For example, the GBPN global buildings model uses a median assumption of 50% learning for advanced buildings, although the mathematical basis of this value is not defined in the report (it is not clear whether this value is applied for each doubling of production, as per the literature, or rather is applied as a total reduction of 50% in incremental costs over the period to 2050). In principle, the literature implies that there would be significant scope for learning in commercial buildings, in response to a regulatory stimulus such as a lift in energy performance requirements, as the volume of new buildings at the higher performance level will double very rapidly in the early months and years.

Noting the cautions in the literature about basing learning rates on assumption, the lack of directly applicable research on learning rates specifically applicable to the energy performance of commercial buildings in Australia suggests that original research will be required to establish a plausible range of rates.

3. Potential Methodologies and Recommendations

3.1 Study Design Considerations

The literature review above has confirmed that there is little research available to inform an analysis of learning rates specifically applicable to energy performance requirements in the Australian commercial building sector. However it has clarified that the key targets for such research would be to identify data that specifically relates changes in incremental costs attributable to achieving a given energy performance requirement, and how those incremental costs change over time, particularly as the number of new buildings meeting the energy performance standard increases through time, accompanied by learning and innovation of different kinds.

It is worth setting out that there are inherent challenges in quantifying commercial building learning rates. An overarching factor is that direct observation of incremental costs is not possible. First, the costs of construction of commercial buildings are invariably considered commercial-in-confidence, but they can be estimated using a variety of techniques. Second, even if all elements of a building were transparently costed, there would remain the problem of attribution – that is, which of these cost elements is attributable exclusively to the higher energy performance requirements? While it may be possible to identify certain elements, such as higher performance glazing or additional insulation materials, to an even greater extent than for residential buildings, commercial buildings are complex systems: the overarching factors determining the energy performance of the overall structure are therefore not the individual elements so much as the design of the building and its key systems and the specific manner in which the various elements are integrated into a whole building.

Relatedly, the energy performance requirements in the NCC for commercial buildings are specific to each individual building, via an analogous 'reference building' of the same design, which only ever exists as a modelling construct. That construct is not transparent to parties outside the immediate construction process. This complicates compliance auditing, as noted above, but it also contributes to a lack of information in the public domain regarding the link between construction cost and building energy performance for new commercial buildings.[2]

Further, to a much greater degree than for residential buildings, commercial buildings are 'one-off' purpose designed buildings. Therefore there is little opportunity to capture data on the costs of identical or like buildings 'before and after' a regulatory change. Learning rates may therefore best be observed in a statistical manner, taking into account the energy performance and incremental cost of large numbers of buildings. However, as this data is not captured or disclosed, we are reliant on either goodwill, or possibly payment, to collect and analyse this data for RIS purposes. Even if payment is offered, there may be complications regarding the ultimate ownership of this data, and therefore additional time and cost involved in clarifying permissions to share data. We note that residential building performance ratings under NatHERS have since July 2014 all been collected and stored in a centralised database. This at least opens the possibility of this data being used for RIS analysis purposes. The Department might wish to consider the public policy value that could be created by establishing a similar reporting requirement for all commercial buildings.

Another issue is that in Australia there have only been two points at which energy performance requirements have applied to commercial buildings: in 2006 and in 2010. Methodologies to establish learning rates could potentially focus on these regulatory changes, however we note that the first energy performance standard (2006) was set very low, with a benefit cost ratio estimated at 4.9:1, which suggests it would have induced

[2] Information on the energy performance of some building types is available through NABERS and CBD, but this information does not include the age of the building rated, limiting the utility of this data for analysing *new* building performance.

very little change and therefore learning or innovation[3]. Our past analysis of the BCA2010 increment suggests it was somewhat more stringent, with a benefit cost ratio around 2:1, which still represents a low level of stringency.[4] As the literature notes, learning rates are likely to be low when the degree of change implied in the performance requirements is low.

Also it must be considered that buildings that had already received development approval prior to the introduction of the May 2010 standards would (most likely) have continued through to construction at the previous performance standard. Then a 'grace period' of one year was offered to industry, meaning that only new buildings developed after May 2011 (and therefore commissioned some 12 – 18 months later) are certain to be built to BCA2010. Therefore data from 2012 onwards should be used for analytical purposes. The Northern Territory appears to have been the only jurisdiction not to adopt BCA2010 for commercial buildings, effectively from May 2011 onwards, and therefore data from the NT should be excluded from consideration.

Finally we note that under-compliance with an energy performance requirement could lead to quantitative analyses under-estimating the true incremental cost of Code compliance. There was extensive but colloquial evidence of under-compliance offered to the *National Energy Efficiency Buildings Project*, undertaken in 2013 – 14 (**pitt&sherry** & Swinburne University). However, we are unaware of careful compliance audits having been undertaken to verify the extent and nature of any such under-compliance. For the time being, and pending such compliance auditing, this factor may have to be ignored.

Against this background, we have identified two potential methodologies for quantifying commercial building energy performance learning rates in Australia. These are described, and their relative strengths and weaknesses assessed below.

3.2 Quantity Surveyor Elemental Cost Method

The most direct method for establishing commercial building energy performance learning rates would be to work with a range of quantity surveyors, and potentially other building professionals such as designers and construction companies, and request (or pay) them to search back through their records of actual buildings constructed to identify costs associated with elements of construction (in $/sqm) that in their opinion are directly related to meeting energy performance requirements and not to other factors (cosmetics aspects of design, unrelated changes in unit costs due to changing factor prices, for example). This documentary evidence could establish how these cost elements changed immediately after the introduction of BCA2010. The professionals would then be requested to document from their records how the costs of the same elements varied in subsequent years in at least broadly similar buildings. This information would need to be accompanied by the NABERS star rating of each building, or evidence of the reference and as-designed energy intensity, to ascertain whether the buildings under- or over-complied with NCC requirements. Cost data could be normalised in this case.

The advantages of this approach are that such data should be available to quantity surveyors and building designers, and it represents a consistent trace of professional assessments of incremental costs attributable (in their and the reviewer's professional opinion) to the Code changes. A further advantage of this approach is that it could be applied to any building type, noting that adding more building types to the study will multiply the costs of the study.

[3] *Final Regulation Impact Statement for Decision (RIS 2009-07): proposal to review the energy efficiency requirements in the building code of Australia for commercial buildings classes 3 and 5 to 9*, Centre for International Economics, December 2009, p. 14.

[4] Considerably lower than for residential buildings, for example, where BCA2010 proceeded with an expected BCR of 0.8.

A disadvantage of this approach is that it does not take into account the performance of the whole building, as designed or as constructed, and therefore may miss key elements contributing to energy performance. A further risk is that quantity surveyors may tend to overstate actual costs, as they tend to take a conservative approach. That said, the methodology would identify *differences* in estimated cost, so any bias in the absolute values would be minimised. As noted, the data would represent cost estimates, rather than actual costs. We consider it unlikely that construction companies would reveal their actual costs associated with specific buildings, as they would consider this information commercial in confidence. There is also a risk that quantity surveyors may need to seek permission to reveal cost data, although there would not be a need for buildings to be identified, and this may reduce their concerns. More generally, the methodology is subject to recruiting willing quantity surveyors, and also to the accuracy and reliability of their records. The methodology could be exposed to 'strategic bias' (where results are influenced by the views of the firms, rather than the actual data), but this is not considered a significant risk and in any case could be managed by recruiting a number of firms across a number of markets and building types. A reasonable sample of building types and sizes, and also markets/climate zones (including some outside CBDs in regional/rural settings), as well as cross-section of QS firms, would be required.

Given the specific nature of the research, data compilation would require expert researchers to conduct personal interviews or even in-situ research. Given the potential for the information sought to be considered sensitive by the industry, a personal approach would be essential to achieving a reasonable response rate.

Overall, we note from previous experience that recruiting willing participants for a study of this type, and working with them to achieve permission to share data, will be time-consuming. At least three months should be allowed for this research phase. Some professionals that offer to participate in good faith will fail to achieve owner permissions to share data, while others will run into record-keeping limitations. We note that the method will impose search and reporting costs on those participating in the study, and the Department will need to anticipate a mechanism to compensate them for these costs. A payment per complete record would be appropriate, as it would be linked to both the search costs and the public good value of the information. Costs could be capped by limiting the number of data records sought from any one firm, and also in total across Australia. For statistical validity and coverage reasons, it will be necessary to recruit a range of firms with a presence in different geographic markets and commercial building segments.

3.3 NABERS/Green Star Rating Premiums Method

Another methodology would be to work with building designers/energy assessors/construction companies practicing in NABERS or Green Star (energy) assessments, and ask them to document – again from their records – cost estimates for at least 4, 4.5, 5, 5.5 and 6 star offices (and potentially shopping centres), either expressed as absolute costs or as cost premiums over a Code-compliant building, or both – and to document how these costs/premiums varied through time. As with the first method, the precise nature of the information sought would demand expert researchers to conduct personal interviews or even in-situ research. Given the potential for the information sought to be considered sensitive by the industry, a personal approach would be essential to achieving a reasonable response rate.

This methodology has been proposed to **pitt&sherry** by two design firms independently as something that they would consider viable and valid. They noted that it is 'common knowledge' that quoted premiums for a given performance level (eg, 5 star) have declined through time. Cost premium data could be correlated with construction volumes of the building types by star band to construct a learning curve – noting that NABERS ratings do not include the age of the building and therefore the NABERS ratings of *new* buildings would have to be estimated using stock turnover models.

The advantages of this approach include that NABERS has been operating since 2003 and therefore there is a large sample of (office and, to a lesser degree, retail) buildings to which this methodology could be applied.

There have been some studies regarding the additional costs associated with NABERS star ratings[5], the main source of such data would be private costs assessments made by quantity surveyors commissioned by new building owners/developers. As such, this data would be considered commercial-in-confidence and is generally not published. However, by working with the industry, and seeking only de-identified data, it should be possible to develop algorithms that relate cost premiums by star rating with time. It may be possible to access data anytime from 2003 onwards, as NABERS commenced operating in that year. NABERS ratings (energy, no Green Power), or Green Star as-built ratings, reflect the verified energy performance of actual, as-built buildings. If cost data can be identified for these buildings, then this can be correlated with actual energy performance with greater confidence than is the case for the previous method, as the rated performance of the designs used in the first method is unlikely to be available for all buildings. For example, there are no ratings tools for some commercial building types.

This methodology shares with the first the need to recruit a number of building professionals willing to participate in the research. Second the method, as with the first, is dependent on the quality and accuracy of records kept by building professionals. Third, there would again be some opportunity for 'strategic bias' to influence the findings, and again the best risk management method would be to seek a large and diverse data sample. Fourth, this method could only be used for a limited range of building types for which ratings tools have been in place at least from 2011 onwards. The data will be weighted heavily towards offices, with smaller numbers of retail and hotel buildings.

We note that the applicability of data resulting from this methodology to the specific context of new mandatory energy performance requirements in the NCC could be questioned. NABERS has, for most of its life, been a voluntary program, and it is reasonable to assume that those who aspired to higher star ratings did so because of a business case that would have involved both additional costs (for higher star ratings) *and additional revenues*. This is not an exact analogy for a Code change, both because of the (likely) reduction in additional revenue, but also because of learning and scale effects reducing the observed cost premiums.
Data from the *Commercial Building Disclosure* program may also be able to be used in this method, albeit that it shares with NABERS the absence of a 'building age' field that would enable the analyst to know whether the data relates to a new building or not. If this data were able to be bifurcated in new/existing, then the new building data would have the additional value, when compared with NABERS or Green Star, that the buildings built new post the mandatory application of this program may provide a stronger analogy for Code compliance, in that both involve mandatory incentives, albeit of different kinds.

'New build' status data *is* available to the Green Star program – albeit that it is not published – but it may be that the Government could work with the Green Building Council to access relevant data. For example, if a list of Green Star rated new buildings could be compiled by star rating and date of construction (imputed from the year of rating for which the building was classified as a 'new build'), this meta-data could be used to target research into the incremental costs of these buildings, or to facilitate a targeted survey of building owners.

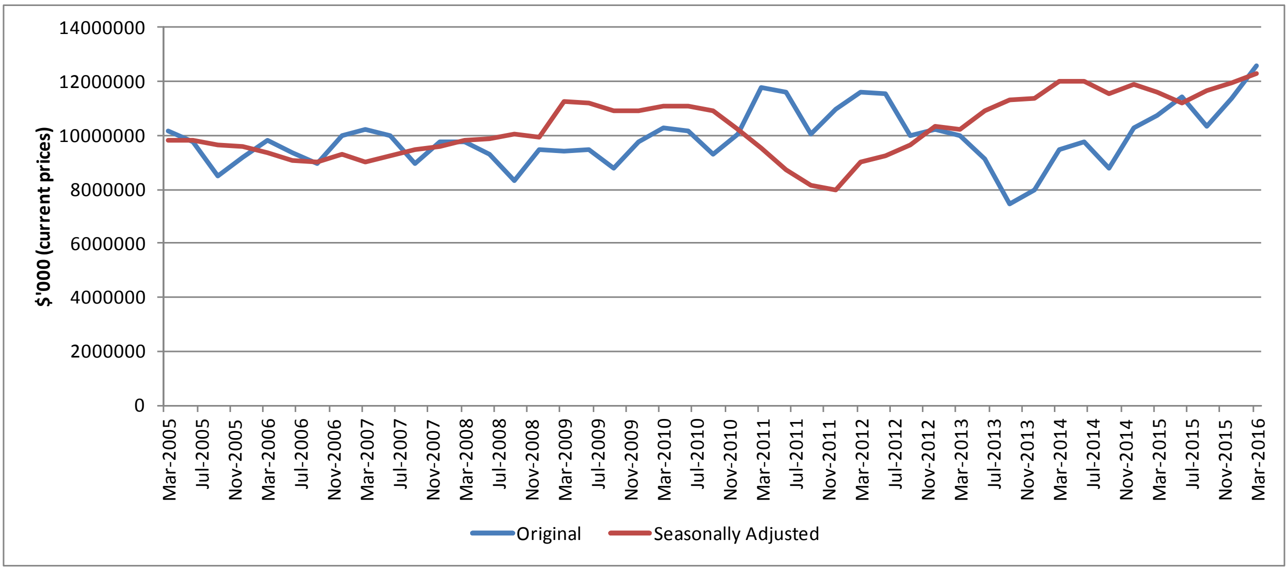
Overall, we believe this is likely to be a relatively productive methodology. It would require significantly less time per building than the QS method, as the professional would only need to find records/observations of incremental cost and star ratings. Under the QS approach, the professional would also need to locate and examine drawings and specification, analyse and determine key 'elements' impacting on incremental cost and energy performance, and this for each design examined. A further key advantage of this approach is the potential for data over a longer period of time (potentially from 2003 onwards, rather than only 2012). This should mean that it would be possible to correlate the data collected with at least one or both NCC changes impacting on commercial buildings, to determine whether these points mark trajectory changes in the data. A limitation is that the data will be derived primarily from offices, but potentially also for shopping centres – although we understand the number of shopping centre ratings in early years was very limited.

[5] See for example ARUP, *City of Sydney NABERS Energy Cost Analysis*, March 2009.

3.4 Building Value Method

A possible third method would be take a top-down, statistical approach, examining historical trends in the value of new construction work done, normalised for a range of factors, and correlated with the volume of new buildings constructed, to show trends in actual costs incurred per unit of building work done. The aim would be to identify if there is any evidence that, after other factors are accounted for, average construction costs in fact rose (or deviated from trend) after the introduction of BCA2010 and, if so, by how much and for how long. Possible data sources would include the Australian Bureau of Statistics *8755.0 Construction Work Done, Australia, Preliminary* (Figure 7) and/or property value data held by property/real estate firms such as Jones Lang Lasalle, BIS Shrapnel or others such as the Property Council of Australia.

Figure 7: Value of Non-Residential Construction Work Done, Australia



Source: Australian Bureau of Statistics *8755.0 Construction Work Done, Australia, Preliminary*

The potential advantages of this approach include, firstly, that it could be undertaken as a desktop study and would not require recourse to building professionals. This means that it could be done more quickly and at lower cost. Second, the analysis would cover all new construction work done (non-residential) in Australia, giving a much larger sample size than would be available for the previous methods. Third, the data is available (from ABS) quarterly from 1974 onwards, in original, seasonally-adjusted and trend terms, and by state and territory, allowing for long-term and regionally-differentiated analysis. This means that both the 2006 and 2010 Code changes could be examined. Use of private data sources (JLL, etc) might enable more refined analysis again (eg, by building type), but such data would need to be purchased.

The potential disadvantages of this method include, firstly, that the signal to noise ratio would be low. That is, the raw data will be affected by a wide range of factors, including inflation, building market cycles, regional building market differences, changes in underlying factor costs (labour, concrete, steel, etc), changes in construction volume, seasonal factors and others. That said, data exists with which to normalise for all these factors. Construction volume (such as square meters of new building work done) is regrettably not tracked by the ABS, therefore another data source would be needed to correlate value with volume of work done. This will be a key step, as major variations in the economy and building cycle will affect both value and volume; thus, by expressing value per unit of new construction work done, this key 'noise' element would be removed from the data. Detailed stock turnover models do exist – such as that created by **pitt&sherry** and BIS Shrapnel for the Commercial Building Baseline model and study – that could be updated and used for this purpose.

3.5 Summary and Comparison of Methods

In summary, it is worth recalling that the key challenge facing any methodology is that the information required is not directly observable and is considered commercially sensitive. The first two methods require the co-operation of a large number of parties and could potentially be influenced by any strategic bias on the part of research participants. In both cases, working with a large number of independent parties will be the best way to manage this risk, but this will also have consequences for the cost and timeline associated with these methods. Method 3 overcomes these limitations but could be criticised for being too 'statistical' in nature and potentially influenced by factors that are not able to be fully normalised. Nevertheless, it would drawn on real and valid data.

The strengths and weakness of the three methodologies are summarised in Table 1 below. Research briefs for all three are set out in Appendix A.

Table 1: Comparison of Potential Methodology Designs

Method	Length of time	Cost [ex GST]	Accuracy of output	Size of survey needed [consultations]	Pros	Cons	Overall
Method 1. Quantity Surveyor Method	6-8 months. Time for each building is expected to be much longer to assess than NABERS (greater detail)	$120,000+ for research and ~$15,000 for data purchases (50 * $300)	Expected to have high elemental precision, but results may be limited by sample size and diversity by region, building type.	Data capture on ~50 Australian commercial buildings; covering major commercial types/classes, across different Australian jurisdictions with energy patterns and climate zones.	Direct access to professional cost estimates on a consistent basis over time. Data would relate directly to last Code change.	Quantity Surveyor cost estimates have the reputation of being excessive – this could lead to stakeholder scepticism regarding the results. A focus on components rather than performance of the whole building. More time required for research into each building using QS Method compared to Method 2 or 3.	• Extra cost may be justified by the direct coverage of the BCA2010 change.

Method	Length of time	Cost [ex GST]	Accuracy of output	Size of survey needed [consultations]	Pros	Cons	Overall
Method 2. NABERS/ Green Star Ratings Method.	4-6 months.	$80,000+ for research and ~$15,000 for data purchases (50 * $300)	Data expected to be factual and historically valid; however, the data relates to voluntary uptake of higher than mandated performance requirements, which is not an exact analogy for future Code changes.	Data capture on ~50 Australian commercial buildings; covering major commercial types/classes, across different Australian jurisdictions with energy patterns and climate zones.	Since measurement is post-build as a whole, the cost/premium data be more reliable, though more averaged than QS estimates. NABERS has been in the market for longer than a decade – familiarity with stakeholders. Access to NABERS data is expected to be straightforward. May get more buildings through Method 2 than Method 1. for	Limited to those building types covered by NABERS or Green Star ratings tools. Not an exact analogy for Code changes.	• Well supported by stakeholders but may be less valid as a proxy for Code-induced costs.

Method	Length of time	Cost [ex GST]	Accuracy of output	Size of survey needed [consultations]	Pros	Cons	Overall
					these buildings would		
Method 3. **Building Cost Method.**	~3 months	~$40,000 assuming no data purchases, and up to ~$10,000 for data purchases (may not be necessary)	Accuracy enhanced by very large sample size, but data will require multiple normalisations.	Large sample; only possible partners would be data owners such as BIS Shrapnel, JLL, etc.	Cheaper, more reliable (not contingent on co-operation from third parties), more rapid.	Stakeholders may question (or find it hard to understand) the statistical normalisation routines used.	• Relatively straightforward and low cost. • Large sample size and robust underlying data.

3.6 Stakeholder Consultations – Responses to Methodologies

To test the practicality of the first two methods (Method 3 was developed after consultations were undertaken), and also to assess likely stakeholder perceptions of the validity of each, we undertook a limited process of stakeholder consultation. This enabled us to gauge:

- Overall attitudes and strength of feeling about the issue of industry learning;
- Specific views about the relative merits of the different methodologies;
- Alternative methodologies that may be identified by stakeholders;
- Specific offers of support or assistance in rolling out one or more methodologies.

We engaged with the major industry associations – eg, Westfield (Scentre), MBA, HIA, ICANZ, AIRAH, GBCA, ASBEC, BBP, and others –and researchers (QUT, UNSW, UniSA). We issued a brief letter of introduction, with background to the project with an explanation of key points attached for context (key definitions, etc), followed up with personalised phone interviews to a set script of questions.

Firstly, ***pitt&sherry*** wishes to thank all the industry associations and academics for their time and feedback in relation to assessing the methodologies presented above. In addition, some groups offered to work with ***pitt&sherry*** with modelling in providing data to measure market impacts associated with increased star ratings.

As this study will have direct affect on industry practitioners, we sought to interview a higher proportion of stakeholders from industry compared to those of an academic perspective. The industry to building scientist/engineer academics ratio was 80:20. We interviewed Directors, CEOs, General Managers of building industry associations; product manufacturer associations/council; a General Manager of an engineer's association; a General Manager in one of Australia's largest commercial and retail property developer firms; a building energy efficiency consultancy firm; a Professor of building science/civil engineer and a Doctor and Research Fellow with 18 years experience in building engineering.

The consultation was undertaken on the basis that comments would be de-identified. Therefore we include quotes to illustrate the kinds of comments made, but these quotes are not attributable to any specific party. The generic terms 'industry stakeholder' and 'research stakeholder' are used.

The stakeholder responses to the methodologies are presented below.

3.6.1 Stakeholders with a preference for Method 1 (QS)

An industry stakeholder conditionally preferred Method 1:

> *Method 2 appears to be dependent on referencing against Green Star or NABERS compliance, and not all projects that have been undertaken by our organisation have consistently adopted these tools as standards. As such, adopting this method may not yield a comprehensive understanding of the comparison with the regulatory impact. In addition, with Green Star, the assessment occurs as a one-off, but for our assets, the owners are driven by long term on-going costs and the monitoring of the built systems. If Method 2 were adopted then NABERS is preferred because it is at least based on managing water and energy costs over time. We voluntarily monitor our assets using NABERS despite this not being mandatory. We are not just driven by compliance but have an objective to be sustainable in a practical and pragmatic way. This organisation undertakes internal modelling for sustainability and practises life cycle costing analysis in its decision making processes.*

A research stakeholder preferred Method 1 (Quantity Surveyor Method). The key arguments were that quantity surveyors have access to direct cost impacts. However, the researcher considered the procurement method must be factored in to the results. Traditionally, contracts for design and construction are commissioned separately. This misses efficiencies that integrated teams are able to obtain. Architects are not specialised trained in energy efficiency, so results can be sub-optimal. The researcher pointed to a case study in Brisbane - the Joint Communications Centre (Dandirri). This project was designed by the Public Architect and was a

> *project of innovative approach and remarkable result – it was an experiment, running 70 analyses on energy efficiency and scoring 94 out of a possible 106 under Green Star.*

This provides a good case study of cost, investment and innovation. However, the operational performance of this building was reported to have been negatively affected by poor air-tightness. The key point being made was that an integrated design and construction process could have led to lower incremental construction costs and higher benefits. 'Better integrated teams leverage greater advantages.'

The researcher also noted that an important issue was

> *Isolating the upfront capital investment and separating this from the long term operational costs*

We note that a conventional benefit cost analysis methodology will take into account and value operational cost savings over time, albeit that there is greater uncertainty as to these future values than there is with short term observations of incremental construction costs, and also that discounting has a greater (negative) impact on the present value of future savings of operational costs than it does on incremental construction costs, again because the latter occur upfront in the buildings life, while the former may persist over decades.

3.6.2 Stakeholders with a preference for Method 2 (NABERS/Green Star)

An industry stakeholder perceived the rate of change and rate of learning within the building sector/ component sector to be very rapid. From the methods presented the 2nd was preferred due to availability/access of data, because NABERS will share its data. The key issues perceived by this stakeholder were:

1. Technology is rapidly evolving and this is accelerating the rate of change in industry;
2. There is a lack of thinking time [time poor culture] – which translates to a lack of planning and design and engineering judgment; which means learning is not optimised as it could be; and
3. Components that are star rated that contribute to energy efficiency in the building envelope cannot be disaggregated from the whole overall star rating.

One industry stakeholder had a strong preference for Method 2. They considered that the main flaws with Method 1 were, "it's a blunt approach"; that costs are often exaggerated with quantity surveyors; and that the QS industry uses average costs so that the high cost and the low cost options are "dumbed down". In short, they doubted whether the QS method would deliver accurate indications of the specialised mix of technologies that are required to achieve high building performance at low cost.

Another limitation they perceived with Method 1 was that taking a building-by-building approach would underestimate the impact of institutional learning – that is, the effects of learning and innovation that spread from one project to another over time and lead to reduced compliance costs through time.

> *With technology costs - for example insulation - scale of production and volume and demand reduce costs. In Europe, double glazed windows are cheaper than single glazed, due to this effect. The learning curve in Europe in building energy efficiency has borne fruit. The European Union Energy Performance Certificate scheme drives consumer demand, and reduced costs due to increased volume and scale of production. Equipment costs present a negligible barrier to increased energy efficiency due to the effect of regulation. In Europe, the supply chain is aligned in the right direction. Using the example of insulation manufacturing, the industry is gearing up for a better product (due to regulation) which increases demand and reduces cost. In the 1970's double glazing was mandated - the industry changed; scale or production increased; costs reduced – industry adapts, and regulations are powerful in driving adaptation. The regulation sets the framework so that everyone is moving in*

the same direction. Regulations are not viewed by all as burdensome – however, regulations do provide signals. Generally, after the adoption of the 6 star regulation, even small-scale builders were happy to accommodate changes such as changes to window area on request, and cost increases do not enter the conversation once the builder adapted to the changes.

This stakeholder made an analogy with MEPS (Mandatory Energy Performance Standard) standards in the appliance sector noting:

Improving Australian MEPs has negligible cost impact, considering the volumes produced and that most products are imported, including from countries with higher standards. Australia is in a global market, and should be benchmarking against global standards. Benchmarking against international standards should be a regular occurrence rather than only an economic assessment (BCR) approach.

Another industry stakeholder preferred the second methodology, partly due to quantity surveyors being known to over-estimate and deliver being unreliable cost estimates. A key observation noted by this stakeholder was that, in their view, no learning is in fact required to meet higher performance standards, as the required knowledge is already available and deployed in the market today.

This stakeholder also noted that when a new performance requirement shifts the default solution from one level to another, the new level becomes the industry standard and scale effects drive out incremental costs. They gave as a hypothetical example:

In the insulation industry, if R3 is the current standard, and if R6 were to be the new standard, the R3 product is currently available at scale, but R6 is not currently available at scale. But this would change and mass production of R6 would solve the challenge of higher energy efficiency and reduced cost. In summary, the scale of mass production and increased demand pushes reduced incremental cost impacts while meeting increased code stringency.

Another example was:

In the commercial sector, using an example of a multi-story office block, if the regulations changed in the quoting stage, then re-design would occur and the company would stick to the quote. This demonstrates a forced innovation and compliance at cost-effectiveness – this is learning.

The same stakeholder noted that poor compliance with current standards could lead to an over-estimation of the incremental costs of moving to new standards. They noted:

What is known throughout the industry is that, under Section J, if the standard is 10, then average compliance is at about an 8. Therefore, if incremental costs are measured against a new standard that is set at a 12, then the jump in compliance costs from current actual practices can seem high and not cost-effective'.

It is known in industry that systemic non-compliance exists in terms of meeting energy efficiency minimum standards. There is no penalty, and no checks or inspections or consequences for non-compliance, so there is a systemic issue as there is no penalty or 'name and shame' in providing exposure to the public for businesses that operate purely opportunistically and have no intention of complying with the regulations.

The same stakeholder also noted that past RISs have under-estimated actual energy prices increases and therefore under-estimated the cost effectiveness of energy savings. Also, they were concerned that the benefit cost analyses did not appropriately value community-wide benefits, even if these are not monetised.

A further insight was:

From a big picture point of view, and learning rates, it is unhelpful to be distracted by the slow adapters. The approach could be to look at the middle of the pack - look to the trends in the middle, *and the pace at which that middle ground moves. There will always be those that drag their heels, the slow adapters, in every industry, but the whole sector shouldn't be beholden to the slowest adaptors. For example, although NABERS has been in place since the 1990's, there are still some that say they haven't had long enough adapt to performance requirements*

Another industry stakeholder said that both methodologies are feasible and plausible, with a slight preference for Methodology 2 on a conditional basis. The concern with Method 1 was that it may not pay sufficient regard to the overall performance of the building envelope. Method 2 should look at specific case studies from a whole-of-building perspective. A second point was that

Technologies may evolve in quantum leaps [rather than incremental improvements]; if this is the case, then the study could look at the individual component effects/contribution' [that is, how 'leaps' with certain elements contribute to a change in overall costs].

This stakeholder queried an aspect of both methodologies, and that was that any method needed to examine the separate contributions of the 'supply market' [building products, materials and technologies] and the 'design market' [how designers integrate elements into overall solutions at least cost] in determining the overall learning rate.

A researcher and also an industry stakeholder both stressed the need to take into account the impact of under/over compliance from a systemic perspective:

where there is no auditing / policing at the lowest levels (non-compliance) then it detracts from overall performance, but where all components comply, the actual star rating may exceed standards due to positive feedback'. The industry stakeholder asked how might 'transfer of learning in industry be accelerated to increase compliance? What methods could be used to speed industry learning – for example how to transfer high compliance at the big commercial building sector (which has high energy performance as business as usual) to the mid-tier which is lagging in Australia?

Another industry stakeholder preferred Method 2:

Method 2 offers a recognised framework which ensures consistent data and assessment. A framework or checklist that contains standards and criteria that clearly defines what information the user needs to provided and can also result in a true benchmark for future reviews. The Method 2 ratings method framework provides a set of criteria; data consistency, and prescribes how data is collected and what it is referenced to - it reduces the spread of uncertainty, so that the results are statistically significant and reliable. Without a systematic approach, such as Method 2, individual interpretation could undermine the level of data reliability.

The NABERS Method 2 approach was given support by a stakeholder who provided the following detailed explanation:

Although there will be pros and cons with any methodology, working within a consistent system will minimise negative impacts – for either methodology you would expect to identify the megatrends, and from there a deep dive into case studies if it is required. We and our members favour NABERS as a tool. Our members are familiar and have a broad level of acceptance and understanding of the NABERS rating system, which provides a consistent approach, as well as offering a large building stock that has gone through a NABERS undertaking – the data exists. I would favour the NABERS methodology because there are no additional requirements to set up this methodology system – there is no duplication of effort or cost – there is no reduction of productivity as a whole with this methodology. NABERS already exists, it provides better value and a consistent approach.

3.6.3 Stakeholders with no preference for the methodologies presented

An industry stakeholder noted that their organisation had conducted research in the past that suggested higher standards would not be cost effective, and opposed either methodology on the basis that they considered the case closed.

Another industry stakeholder did not support either methodology because of the perceived difficulty in defining a reference case and the different questions the methodologies seem to pose in their view. The stakeholder asked,

> *What is the 'base case'? Is the 'base case' a building which is non-compliant relative to existing requirements under the building code, or a building which was built before the current requirements under the Building Code were introduced (but compliant at the time of development)? This isn't clear from the information provided. Presumably clarity on this point will be essential to underpinning a project moving forward as they are different starting points.'*

Second, this industry stakeholder noted,

> *The two methodologies outlined are, in my view, asking different questions. The first dwells specifically on the Building Code (which is what I understand the National Energy Productivity Plan is focussing on at #31), the second on 'rated' buildings. I don't think these are comparable starting points and I see risks in the project (which is meant to be focussing on the Building Code) using what are voluntary tools as a 'base case'.*

We note that this is, in effect, a direct criticism of Method 2 but not Method 1.

Another industry stakeholder did not preference either methodology; however, they provided insight on how to use either methodology.

> *Industry leaders at the cutting edge in this space invest in builds that initially are more expensive, due to experimentation and prototype style of investment at the design phase. These industry leaders invest in learning, and this investment helps initiate a form of traction within industry. For general industry practitioners, where change occurs through force, i.e. regulation, they also have a learning phase to interpret and adopt practices which may not be the most cost effective in the short term, but occur due to short lead times and lower resources. The traction point for all practitioners occurs where subsequent builds then gain from the industry leader learning, so then meeting increased stringency becomes procedural or business-as-usual (over time).*

As above, this stakeholder suggested that there would be a need to consider how design changes in response to new performance requirements would change the incremental costs, and expressed concern that a quantity surveyor might miss this element. This stakeholder also noted that the two methods ''mixed up apples and oranges": Method 1 would illustrate how the BCA leads industry to change, while Method 2 would show how NABERS has led consumers (or the market) to change. They noted that it would be useful and transparent to align the stars of the BCA and NABERS (for example) so that comparisons could be made within the sector about the impact of changes through both mechanisms which have applied to commercial building design.

It was also suggested that the New South Wales energy and water efficiency scheme BASIX would make an appropriate case-study to understand learning or innovation rates because it was introduced with minimal 'lead time' with a fully operational tool and has since remained static for over a decade in terms of energy efficiency standards, therefore trends could be observed more easily against this stable backdrop of how industry process and design has adapted. We note, however, that this tool only applies to residential buildings.

4. Overall Conclusions

We conclude that while it is uncontroversial that building energy performance and related costs change over time, there is little agreement – in the literature or between stakeholders – about the magnitude and causes of these changes. Noting that the extent and persistence of incremental costs associated with higher energy performance requirements would be a key determinant of what is judged to be cost effective performance standards, a lack of quantitative evidence about this factor could lead to poor policy outcomes.

As reported, we encountered a wide spread of stakeholder views, from those strongly supportive of this research proceeding to those strongly opposed. In our view this reinforces the need for objective but also transparent data analysis to be the basis of any future RIS. To this end, we suggest that any research is undertaken in close consultation with a broad range of stakeholders (industry, research community and policy stakeholders) with a view to increasing their understanding and acceptance of the research findings.

In the first phase of the project, findings from the international literature review were that learning or innovation (whereby costs are reduced over time with cumulative production or output) is recognised across jurisdictions, technology and sector types and through time, from when the relationship was first documented in the aircraft industry in 1936. Although research has been conducted with components such as solar panels, and in the construction industry, and also the residential building sector to a limited extent, we can find no evidence of quantitative research having been undertaken to establish learning rates in the commercial building sector in Australia or overseas.

With respect to the measurement methodologies, the majority of respondents preferred Method 2, the NABERS/Green Star Method. In some instances it was a slight preference for Method 2; or a preference for Method 2 with caveats or conditions attached, and two respondents having neither preference and finding both methods plausible. Two out of the ten interviewed clearly preferred Method 1, with another providing implicit support. In general the feedback was that quantity surveyor cost data may be considered too conservative. That said, some stakeholders noted that the different contributions of design and other building elements need to be teased out, and this would require professional judgement, including from but not limited to quantity surveyors. In short, stakeholder perspectives on methodologies were divided. In some cases, there was explicit evidence of 'strategic bias', or views being based on preferred or non-preferred outcomes of a future RIS process rather than the inherent merits of the methods. Method 3 was developed after consultations and therefore not tested with stakeholders.

Despite a general preference for Method 2, many noted an important qualification with the validity of this approach – which we also highlighted in Section 3.3 – that the voluntary nature of NABERS and Green Star may not provide strong analogy for a future mandatory requirement under the NCC. This method is more likely to over-estimate than to under-estimate the incremental costs associated with higher performance, as the examples of higher performance are all 'above-Code' and may well have been commissioned to meet specific niche requirements where cost-minimisation was not primary driver. By contrast, Method 1 would examine actual responses to at least one past Code change, but we note that that change occurred almost a decade before the one in question in a RIS will take effect, raising questions about whether learning rates are likely to have remained constant or to have changed over such a time period. Method 3 has the key merit of large sample size, along with the practical benefits of not being contingent on recruiting large numbers of participants, leading to a shorter timeframe and significantly lower cost.

Overall, noting the critical importance of learning rates on observations of future cost effective energy performance requirements, and also noting the paucity of existing research in this field, we encourage the Department to pursue all three methods if time and funding allows. This would ensure that there is a range of quantitative observations that could inform future RIS processes, including a central value (potentially an average of the research results) and also sensitivity values for 'low' and 'high' sensitivity analysis. It would ensure that stakeholder preferences are taken on board by government, thereby not disenfranchising any particular stakeholder groups.

If time and/or funds are strictly limited, we suggest that Method 3 be prioritised, due to its lower cost, shorter timeline but also its large sample size. We would identify Method 1 as the second priority, notwithstanding its higher cost and longer timeframe, given its direct relevance to the key research question. Method 2 would also provide valuable insights, and is well supported by stakeholders, and should be undertaken if possible.

5. References

Australian Government (COAG Energy Council), (2015). 'National Energy Productivity Plan 2015-2030'. December 2015, Published by the Department of Industry, Innovation and Science, Canberra. https://scer.govspace.gov.au/files/2015/12/National-Energy-Productivity-Plan-release-version-FINAL.pdf

Australian Building Code Board (ABCB) (RIS2009), 'Final Regulation Impact Statement for Decision (RIS 2009-07): Proposal to revise the Energy Efficiency requirements in the Building Code of Australia for Commercial Buildings – Classes 3 and 5 and 9. December 209. Prepared by the *Centre for International Economics Canberra & Sydney.*

Bazen, E., (2016). *pers comms*, Principal Policy Officer, Building Commission, Department of Commerce, Western Australia.

Belusko, M., & O'Leary, T. (2010). Cost analyses of measures to improve residential energy ratings to 6 stars-playford North Development, South Australia. *Construction Economics and Building*,*10*(1-2), 36-47.

Centre for International Economics, (CIE), (2009), 'Draft Indicative Elemental Estimate'. Published by CIE, preprared by BMT & asocc Quantity Surveyors, Sydney.

Centre for International Economics (CIE), (2010). 'Energy-efficiency: building code star-ratings: what's optimal, what's not'. Prepared for Masters Builders Australia, Canberra & Sydney. http://www.masterbuilders.com.au/informationsheets/energy-efficiency-building-code-star-ratings

Centre for International Economics (CIE), (2012). 'Benefits of building regulation reform: From fragmentation to harmonisation.' http://www.thecie.com.au/?page_id=379

Couto, J. P., and Texiera, J. C., (2005) Using linear model for learning curve effect on highrise floor construction. Constuction. Management Economics, 23.4, (2005), 355–364.

Craig, N. (2008). 'Six-star energy rating adds $10,000 to cost of new house: MBA'. The Age newspaper, November 21, 2008. http://www.theage.com.au/business/sixstar-energy-rating-adds-10000-to-cost-of-new-house-mba-20081120-6cv8.html

CSR Limited, (2014). 'Star ratings & the cost of improved ratings'. CSR Limited website http://www.csr.com.au/building-knowledge/research/star-ratings-and-the-cost-of-improved-ratings

Department of Climate Change and Energy Efficiency (DCCEE) (2010), 'National Building Energy Standard-Setting, Assessment and Rating Framework'. Part of the National Strategy on Energy Efficiency, Building Framework Discussion Paper, published by the Commonwealth of Australia, Canberra.

Department of Climate Change and Energy Efficiency (DCCEE) (2012a). 'Identifying Cost Savings through Building Redesign for Achieving Residential Building Energy Efficiency Standards'. Published by the Department of Climate Change and Energy Efficiency Commonwealth of Australia; prepared by Sustainability House. http://industry.gov.au/Energy/Energy-information/Documents/identifyingcostsavingsbuildingredesignachievingenergyefficiencystandards.pdf

Department of Climate Change and Energy Efficiency (DCCEE) (2012b). 'Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis**'.** Published by the Department of Climate Change and Energy Efficiency Commonwealth of Australia; prepared by Pitt&Sherry. http://www.industry.gov.au/Energy/Energy-information/Documents/pathwayto2020newbuildingenergyefficiencystandards.pdf

Department for Communities and Local Government, UK (2006). 'Building A Greener Future: Towards Zero Carbon Development'. Consultation paper. Crown copyright, London. http://webarchive.nationalarchives.gov.uk/20120919132719/http:/www.communities.gov.uk/documents/planningandbuilding/pdf/153125.pdf

Dutton, J. M., & Thomas, A. (1984). 'Treating Progress Functions as a Managerial Opportunity.' *Academy Of Management Review*, *9*(2), 235-247. doi:10.5465/AMR.1984.4277639

ECOFYS, (2007). 'U-Values for better energy performance of buildings' ECOFYS for EURIMA, Cologne, Germany.
http://www.ecofys.com/files/files/ecofys_2007_uvaluesenergyperformancebuildings.pdf.

European Commission (2016). 'Energy' website, accessed 22 June 2016.
https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

Everett, G. and Farghal, H., 'Learning Curve Predictors for Construction Field Operations.' *Journal of Construction Engineering and Management*. vol 120. (1994), pp603-616.

Gottlieb, S. C., & Haugbølle, K. (2010). 'The repetition effect in building and construction works: A literature review'. Hørsholm: SBI forlag
http://vbn.aau.dk/ws/files/19224303/SBi_2010-03.pdf

Government of Western Australia, Department of Commerce, (2014). 'Building a risk-based regulatory environment' Media release. 15-April-2016 [Accessed 16-May-2016].
https://www.commerce.wa.gov.au/announcements/building-risk-based-regulatory-environment

Government of Western Australia, Department of Housing and works, (2004). 'Office Accommodation Polices: A guide to Procurement and Management of Western Australian Government Office Accommodation'. [Policy 14: Sustainability and Government Accommodation – Energy and Water]. Perth.
http://www.health.wa.gov.au/infrastructure/docs/POLICY_Office_Accommodation.pdf

Green Building Council of Australia (GBCA) (2013a). 'The Value of a Green Star – a Decade of Environmental Benefits'

Green Building Council of Australia (GBCA) (2013b). 'Making the Case for Green Star Certification'. [accessed 19-May-2016]
https://www.gbca.org.au/uploads/63/34623/Evolution_2013_The_Case_for_Green_Star_Certification.pdf.

Green Building Council of Australia (GBCA) (2015)'What is Green Star? Green Star is an internationally recognised sustainability rating system.' [Website accessed 16-May-2016]
https://www.gbca.org.au/green-star/green-star-overview/

Green Building Council of Australia (GBCA) (2016). 'Case Studies' . Case studies from New South Wales (The Ponds) and South Australia (dsquared); [website accessed 30 May 2016] See
http://www.gbca.org.au/green-star/green-star-projects/green-building-case-studies/the-ponds-shopping-centre/

http://www.gbca.org.au/green-star/green-star-projects/green-building-case-studies/dsquared-office-fitout/

Greenlivingpedia (2011), '5 star rated houses in Victoria, Australia'. Greenlivingpedia website: for a sustainable future. [Website accessed 18 May 2016]
http://www.greenlivingpedia.org/5_star_rated_houses_in_Victoria,_Australia

Green Start Consulting, (2012). ‘the introduction of 6 star in Western Australia’. Published online through Green Start Consulting and citing the Building Commission. Accessed on 16-May-2016 http://www.greenstartconsulting.com.au/introduction-of-6-star

Green Star Project Directory, A green star rating tool https://www.gbca.org.au/project-directory.asp#365

Hall, P, (1993). ‘Policy Paradigms, Social Learning and the State: The Case of Economic Policy Making in Britain.’ Comparative Politics, City University of New York. http://www.jstor.org/stable/422246

Hax, A, and Majluf, N. (1982). ‘Competitive Cost Dynamics: The Experience Curve’. Interfaces 12: (5) October 1982: pp.50-61 file:///C:/Users/verya/Desktop/Competitive%20cost%20dynamics%20The%20Experience%20Curve.pdf

Hemmersbaugh P, and Farber D, (1993). ‘The Shadow of the Future: Discount Rates, Later Generations, and the Environment’ 46 *Vand. L. Rev.* 267 (1993), available at http://scholarship.law.berkeley.edu/facpubs/1052

Horne, R, Hayles, C, Hes, D, Jensen, C, Opray, L, Wakefield, R and Wasiluk, K. (2005). ‘International comparison of building energy performance standards’. Prepared by RMIT University and SBE Architects for the Australian Greenhouse Office, Dept. of Environment and Heritage.

IEA, (2000), ‘Experience Curves for Energy Policy’. INTERNATIONAL ENERGY AGENCY**,** 75739 Paris, cedex 15, France, OECD/IEA

Jakob, M, Madlener R (2004). ‘Riding down the experience curve for energy efficienct building envelopes: The Swiss case for 1970-2020’. *International Journal of Energy technology and Policy.*

Jamasb T & Köhler J, (2007). ‘Learning Curves for Energy Technology: a Critical Assessment.’

Faculty of Economics, University of Cambridge

Johnstone, B. (2015). ‘Improvement Curves: An Early Production Methodology’. Published presentation by *Lockheed Martin Corporation*, 11 June 2015. [accessed 18th May 2016] http://www.iceaaonline.com/ready/wp-content/uploads/2015/06/PA03-Presentation-Johnstone-Improvment-Curves.pdf

Mályusz, L. and Pém, A., (2012). ‘Prediction of the Learning curve in Roof Insulation, Automatization in Construction’, (2012), DOI: 10.1016/j.autcon.2013.04.004

Malyusz, L., and Pem A. (2014). ‘Predicting future performance by learning curves’. Procedia - Social and Behavioral Sciences 119 (2014) 368 – 376. 27th IPMA World Congress. Budapest University of Technology and Economics, Budapest, Hungary

McDonald and Schrattenholzer (2001). ‘Learning rates for energy technologies’. *Energy Policy* Volume 29, Issue 4, March 2001, Pages 255–261. doi:10.1016/S0301-4215(00)00122-1

McLeod, P, (2016), *pers comms*. Sustainable Buildings economist; Phil McLeod PhD at **Pitt&Sherry** Engineering, Hobart.

McLeod, P; Fay, R. (2010). ‘Costs of improving the thermal performance of houses in a cool-temperate climate‘. *Architectural Science Review*. 53(3): 307-314.

Pellegrino, R, Costantino, N, Pietroforte, R, & Sancilio, S (2012). 'Construction of multi-storey concrete structures in Italy: patterns of productivity and learning curves', Construction Management & Economics, vol. 30, no. 2, pp. 103-115. Available from: 10.1080/01446193.2012.660776. [Accessed 18 May 2016].

pitt&sherry, 2012, *Pathway to 2020 for Increased Stringency in New Building Energy Efficiency Standards: Benefit Cost Analysis*

pitt&sherry and Swinburne University of Technology, 2014, *National Energy Efficient Building Project Phase 1 Report*

Reeves, M, Deimler, M, Stalk, G, and Pasini, F. (2012). 'BCG Classics Revisited: The Rule of Three and Four' Published in BGC Perspectives online. Based Henderson, B (1976). https://www.bcgperspectives.com/content/articles/business_unit_strategy_the_rule_of_three_and_four_bcg_classics_revisited/

Ritter, F. E., & Schooler, L. J. (2002). The Learning Curve. In International Encyclopedia Of The Social And Behavioral Sciences. 8602-8605. Amsterdam: Pergamon.

Rawlinsons Publishing, (2010). 'Rawlinsons Australian Construction: Handbook'. *Riverdale, WA*(2010).

Rubin, E, Azevedo, I, Jaramillo P, Yeh, S. (2015). 'A review of learning rates for electricity supply technologies'. Energy Policy 86 (2015) 198-218.

Stefan Christoffer Gottlieb, Kim Haugbølle: The repetition effect in building and construction works, A literature review, Danish Building Research Institute, Aalborg University · 2010

Sustainable Energy Association of Australia (2012), 'Your 6-Star Guide to operating an energy-efficient home save yourself money', http://www.esdaus.com.au/UserFiles/Six%20Star%20Guide.pdf

Schoots, K, Ferioli, F, Kramer, G and van der Zwaan, B, (2008). 'Learning Curve for Hydrogen Production Technology: an assessment of Observed Cost reductions'. *International Journal of Hydrogen Energy*, 33, 11, 2630-26440.

Stewart, R, D., Wyskida, R M., and Johannes, J, (1995). '*Cost Estimator's reference Manual (*2nd Edition) (Book, 717 p.) A *Wiley Inter-Science publication, New York.*

Thomas, H. P., Mathews, C. T., and Ward, J. G., (1986). 'Learning curve models of construction productivity. Journal of Construction Engineering and Management', 112. 2. (1986) 245–258

Thomas, PC, (2016). *Pers comms*. Director, *Team Catalyst*, Melbourne.

Urge-Vorsatz, D; Reith, A; Korytárová, K; Egyed, M; Dollenstein, J (2015): 'Monetary Benefits of Ambitious Building Energy Policies'. Research report prepared by ABUD (Advanced Building and Urban Design) for the Global Building Performance Network (GBPN).

Vorrath, S. (2012). 'Smart living: What is a 9-star house made of?' published online in reneweconomy 8 March 2012. http://reneweconomy.com.au/2012/smart-living-what-is-a-9-star-house-made-of-72694

Watson, P. (2016). *Pers comms*, Research Fellow, Housing and Community Research Unit (HACRU), School of Social Sciences, University of Tasmania, Hobart.

Wene, C, (2000). 'Experience Curves for Energy Technology Policy'. OECD/IEA

Wilkenfeld (2011). 'Review of Regulatory Impact Statement Methodology for Energy Efficiency Stringency Upgrades to the Building Code of Australia.' Prepared for the Department of Climate Change and Energy Efficiency, July 2011, *George Wilkenfeld and Associates*, Sydney, Australia.

World Green Building Council (WGBC) (2013). 'Business Case for Green Building'. Report published by the World Green Building Council
http://www.worldgbc.org/files/1513/6608/0674/Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf

Wright, T.P., Factors Affecting the Cost of Airplanes, *Journal of Aeronautical Sciences*, 3(4) (1936): 122-128.

6. Appendix A: Scope of Works

This section provides a more detailed description of the three possible research methods. Elements of the text below may be suitable for inclusion in requests for quote, for example.

6.1 Method 1 (Quantity Surveyor)

Objective:

- To identify actual, historical values for the additional or incremental costs associated with new commercial buildings achieving higher minimum energy performance requirements under the National Construction Code (specifically, those introduced in BCA2010), and how (and why) these values may have changed through time. The research should capture data on a reasonable diversity of building types and regions, and on not less than 50 actual buildings in total.

Key research questions:

- What documentary evidence is there regarding the additional or incremental costs (cost premiums) that were incurred on actual building projects to achieve BCA2010 energy performance requirements, as compared to the pre-existing (BCA 2006) standards? The premiums in question must be attributable to achieving the higher energy performance implied in higher star ratings and not to any other factor (location, fit-out, etc).
- Is there evidence that these incremental costs rose or fell over time? By how much?
- Do the results vary significantly by building type, region, construction company size/sophistication or any other factor?
- What factors appear to best explain the observed changes?
- How statistically significant are the results?

Methodology/data sources

- This study will recruit quantity surveyors – or other building professionals with access to documented, accurate and unbiased cost information – to document for a total of at least 50 actual building projects, what design and/or specification changes were made to new commercial buildings after the introduction of the energy performance requirements in BCA2010 which, in their professional opinion were attributable exclusively (or primarily) to the 2010 energy performance requirements, relative to the earlier (2006) requirements, and not to any other factor.
- Note that buildings need only be identified with reference to the building type, size and region (eg postcode) and also by key dates (date of building/planning approval, date of the certificate of occupancy or equivalent). Address and ownership details are not required. Documentation should, however, refer as needed to relevant building plans and/or specifications to substantiate the relevant cost elements.
- For each building element considered relevant (the quantity surveyor is to indicate why and to what degree), identify what was documented at the time as the change in cost (in percentage terms) relative to the pre-BCA2010 element cost? Note that this may require the QS to compare actual cost estimates with ones from earlier, similar projects. What cost premium (or change in the total cost and cost per square meter for the whole building) did these elemental cost changes add up to?
- Similarly for each element, and with reference historically documented information relation to actual building projects, note how the incremental costs for those elements, attributable exclusively to the BCA2010 energy performance requirements, changed over time for similar building projects and locations? As a result, how did the overall building cost premium change over time?
- Building projects should be selected to cover as many NCC classes and climate zones or regions as possible. Also a range of building sizes should be covered, and the size of the primary construction firm/contractor noted. This data should be used to address the questions as to whether changes in these factors are correlated with differences in incremental costs and/or their path through time.
- Detail any limitations associated with the research methodology and offer recommendations, where required, to improve results in future.

Likely cost

- ~$120,000 for a research consultancy, plus an allowance of at least $15,000 for purchasing data, based on $300 per building and up to 50 buildings.

Expected timeframe

- 6 – 8 months, including 2 – 4 weeks for inception, planning, etc; 6 – 8 weeks for recruitment, 6 – 8 weeks for data capture and cleansing; 6 – 8 weeks for analysis; 4 weeks for final reporting.

6.2 Method 2 (NABERS/Green Star)

Objective:

- To identify actual, historical values for the additional or incremental costs associated with new commercial buildings achieving higher star ratings (for energy performance) at different points in time, and how (and why) these values may have changed through time. The research should capture data on a reasonable diversity of building types and regions, and on not less than 50 actual buildings in total.

Key research questions:

- What documentary evidence is there regarding the additional or incremental costs (cost premiums) that were associated with new commercial buildings achieving a range of star ratings (4 – 6 star range, in half-star increments, or equivalent) at specific points in time, from the mid-2000s to today? The premiums in question must be attributable to achieving the higher energy performance implied in higher star ratings and not to any other factor (location, fit-out, etc).
- Is there evidence that these incremental costs rose or fell over time? By how much?
- Do the results vary significantly by building type, region, construction company size/sophistication or any other factor?
- What factors appear to best explain the observed changes?
- How statistically significant are the results?

Methodology/data sources

- This study will recruit building professionals with access to documented, accurate and unbiased cost information regarding the premiums that were calculated to be associated with higher star ratings/energy performance for particular new buildings at particular times. A key requirement is to answer, with reference to suitable documentation, what was the cost premium for a new 4 star building, 4.5 star, 5 star, etc, in 2003? What were the cost premiums in 2005? In 2010? 2016? Data observations need not be annual but should aim to cover at least the decade up to 2016. The premiums identified must be attributable exclusively (or primarily) to the higher energy performance and not to any other factor (such as location, fit-out, etc). Documentation should draw on at least 50 actual building projects, preferably including a range of commercial building types and climate zones/locations.
- Note that specific buildings need only be identified with reference to the building type, size and region (eg postcode) and rating/construction year.
- Where possible, note what factors were identified as causing or contributing to a change in cost premiums over time.
- Building projects should be selected to cover as many NCC classes and climate zones or regions as possible. Also a range of building sizes should be covered, and the size of the primary construction firm/contractor noted. This data should be used to address the questions as to whether changes in these factors are correlated with differences in incremental costs and/or their path through time.
- Detail any limitations associated with the research methodology and offer recommendations, where required, to improve results in future.

Likely cost

- ~$80,000 for a research consultancy, plus an allowance of at least $15,000 for purchasing data, based on $300 per building and up to 50 buildings.

Expected timeframe

- 4 – 6 months, including 2 – 4 weeks for inception, planning, etc; 3 – 6 weeks for recruitment, 3 – 6 weeks for data capture and cleansing; 3 – 6 weeks for analysis; 4 weeks for final reporting.

6.3 Method 3 (Building Value)

Objective:

- To identify actual, historical values for the additional or incremental costs associated with new commercial buildings achieving higher minimum energy performance requirements under the National Construction Code (specifically, those introduced in BCA2010), and how (and why) these values may have changed through time.

Key research questions:

- What statistical evidence is there regarding the additional or incremental costs (cost premiums) that were incurred on actual (new) building projects to achieve BCA2010 energy performance requirements, as compared to the pre-existing (BCA 2006) standards?
- Is there evidence that these incremental costs rose or fell, or otherwise deviated from past trends, over time? By how much?
- Do the results vary significantly by building type, region, construction company size/sophistication or any other factor?
- What factors appear to best explain the observed changes?
- How statistically significant are the results?

Methodology/data sources

- This study will source statistical data, from the Australian Bureau of Statistics or other credible sources, on the value and volume (eg, floor area) of new commercial building construction work done over time (since at least 2005). That data should be normalised for a range of factors including (as required) inflation (specific factor costs should be considered including labour and key building materials), seasonal variations, building cycles and other relevant factors.
- Ideally data used would resolve individual building types, states/territories or NCC climate zones.
- The normalised data would be analysed to discern whether there is any evidence that the introduction of BCA2010 and BCA2006 energy performance requirements caused any deviation from trend unit construction costs and, if so, by how much and for how long.
- The analysis should detail and justify the normalisation processes used, and comment on the validity and statistical significance of the results. Do they vary by state/territory, climate zone, building type or any other factor?
- Detail any limitations associated with the research methodology and offer recommendations, where required, to improve results in future.

Likely cost

- ~$40,000 for a research consultancy. Where private data sources are used (eg, BIS Shrapnel, JLL, others) an additional data purchase cost may be incurred.

Expected timeframe

- ~3 months, including 1 – 2 weeks for inception, planning, etc; 6 – 8 weeks for data capture and analysis; 2 – 4 weeks for reporting.

Contact: Philip Harrington
Senior Principal – Carbon & Energy
pharrington@pittsh.com.au
(03) 6210 1489
0419 106 449

transport | community | mining | industrial | food & beverage | carbon & energy

Brisbane

Level 2

276 Edward Street

Brisbane QLD 4000

T: (07) 3221 0080

F: (07) 3221 0083

Canberra

LGF. Ethos House

Devonport

Level 1

35 Oldaker Street

PO Box 836

Devonport TAS 7310

T: (03) 6424 1641

F: (03) 6424 9215

Launceston

Level 4

113 Cimitiere Street

PO Box 1409

Launceston TAS 7250

T: (03) 6323 1900

F: (03) 6334 4651

Melbourne

E: info@pittsh.com.au

W: www.pittsh.com.au

incorporated as

Pitt & Sherry (Operations) Pty Ltd

CONSULT AUSTRALIA
Member Firm

pitt&sherry