Report to

Garnaut Climate Change Review

Modelling Policies to Address Market Failures in the Energy Sector

25 September 2008

McLennan Magasanik Associates

Ref: J1614 Report V4

Project Team

Walter Gerardi

Melbourne Office
242 Ferrars Street
South Melbourne Vic 3205
Tel: +61 3 9699 3977
Fax: +61 3 9690 9881

Brisbane Office
GPO Box 2421
Brisbane Qld 4001
Tel: +61 7 3100 8064
Fax: +61 7 3100 8067

Email: mma@mmassociates.com.au
Website: www.mmassociates.com.au

TABLE OF CONTENTS

1 INTRODUCTION 2

2 MARKET FAILURES IN THE ENERGY MARKET 3

2.1 Market failures and climate change 3

2.2 Effects of an emission trading scheme 4

2.3 Supply side 5

2.4 Demand side 7

2.5 Materiality of market failures 10

3 IMPACT OF MARKET FAILURES AFFECTING ENERGY SUPPLY 12

3.1 Review of the literature 12

3.2 Factor affecting technological development 16

4 IMPACT OF MARKET FAILURES AFFECTING ENERGY DEMAND 18

4.1 Review of literature 18

4.2 Factors affecting modelling of energy efficiency 19

5 MODELLING IMPACTS ON TECHNOLOGY DEPLOYMENT 22

5.1 Modelling objectives 22

5.2 Effectiveness of policy instruments 24

5.3 Appraisal 25

5.4 Issues of modelling induced technical change in Australia 29

5.5 Modelling issues 29

1 INTRODUCTION

The Garnaut Climate Change Review (herein denoted "The Garnaut Review") is investigating a range of issues regarding Australia's response to climate change arising from emissions of greenhouse gases. Amongst other objectives, the Garnaut Review has been asked to "recommend medium to long-term policy options for Australia, and the time path for their implementation which, taking the costs and benefits of domestic and international policies on climate change into account, will produce the best possible outcomes for Australia".

The Garnaut Review has taken the strategy that an effective response to climate change would necessarily include a review of the potential market failures that may reduce the effectiveness of broad based policy measures aimed at reducing greenhouse gas emissions. As part of this effort, MMA has been asked to report on market failures in the energy sector, how to model policies that overcome such market failures and the likely impact of these policies on uptake of low emission technologies.

The objectives of this project were to:

- Undertake a meta analysis of the Australian and international literature with regards to market failures in both the demand and supply sides of the energy sector and the corresponding effect of Government policies on the rate of technological deployment and uptake.
- Based on the meta analysis, assess the suitability of the methods used to incorporate the accelerated rate of technological deployment and uptake into economic frameworks in the Australian context and provide preliminary options (with advantages and disadvantages for each option) on how these market failures and corresponding policy measures could be incorporated into the Review's economic modelling.

The key modelling task for the Review is to determine the impact of the market failures affecting the energy sector under an emission trading regime, with and without policies directed at overcoming those market failures. Whilst it is easy to identify potential market failures in the literature, it is far more difficult to determine the magnitude of the impact of market failures. Estimates of the impacts may be unreliable as it is often difficult to specify correctly the market failures in empirical analysis.

2 MARKET FAILURES IN THE ENERGY MARKET

Good government policy aims to maximise the net economic welfare of the community. Properly functioning competitive markets maximise economic welfare, except where market failures exist. Market failure occurs when the marginal cost to society from undertaking an activity does not equate to the marginal benefit to society from that activity. Where this occurs, the level of the activity will be not be optimal from society's point of view. Therefore, a rationale for government policy intervention is to overcome market failures.

There are four classes of market failure:

- Public goods – where consumption or access to a good or service does not prevent others from consuming or having access to that good or service. Public parks are an example of a public good as one person consuming the services of the park does not prevent others from consuming the services. Because the owner of a public good cannot exclude consumers from using the good, they cannot earn the full return from providing the good and hence will have the incentive to under provide the good.

- Externalities – where the full cost or benefit from undertaking an activity is not fully borne by the producer of that activity. Air and water pollution are classic examples of an externality as the costs to the community of the pollution are not borne by the polluter. Because the cost of the pollution is not being borne, the polluter will tend to undertake more of that polluting activity than is optimal from society's point of view.

- Monopoly – where a firm dominates a market and can use its market power to increase prices and reduce the provision of the good in order to maximise its profits. This typically leads to less of that good being provided than is optimal from society's point of view.

- Incomplete markets over time and space. This occurs where a market does not exist for some good or service. Financial markets are typically incomplete (for example, markets for 50 year bonds do not exist). Incomplete markets occur because of incomplete information (uncertainty) over consumers' requirements and producers' costs.

Although the presence of market failures provides a rationale for government intervention, this intervention will have a cost. Therefore, a criterion for good policy intervention is that the benefits to society of overcoming market failure should exceed the costs to society of that intervention.

2.1 Market failures and climate change

In responding to climate change, there are a number of apparent market failures. The obvious market failure is the externality associated with greenhouse gas emissions, which is un-priced in any market. Although this will be dealt with by implementing the preferred policy option of the Garnaut Review – namely an emission trading scheme - there is considerable uncertainty as to what future carbon price will apply, deriving from uncertainty about the scale of optimal caps on emissions in the future, from uncertainty as to the form and timing of a global agreement to curb emissions and from uncertainty over costs of abatement options.

Because of this uncertainty, market participants face uncertainties as to what low emission technologies are likely to be economic in the future. This makes effective decision making on research, development and commercialisation more difficult, particularly for long lived technologies. With long time horizons and uncertainty over policy responses, firms are not encouraged to undertake large scale, long term investments required to drive rapid diffusion of low carbon technologies[1].

There are other market failures in relation to research, development and innovation[2]:

- Positive spillovers from the public good aspects of knowledge accumulation, the value of which cannot be captured by innovators. Many investments produce spillovers but have sufficient private returns for firms to invest without that support. Policy should be crafted to elicit private investments that would not otherwise have been made, but for which the collective private and spillover returns are still positive.
- The uncertainty relating to future market developments. This could lead to sub-optimal decision-making by public and private agents about investments in assets with long lives. The danger is that agents may misjudge future developments. This may then lead to more costly provision of the economic services provided by that infrastructure over its lifetime and to lock in of existing technology options.

2.2 Effects of an emission trading scheme

Greenhouse gas emissions and their impact on the global climate constitute a classic case of a market failure warranting government intervention. The negative environmental impacts – or costs – of these emissions have historically not been reflected in the price of energy. This failure gives rise to what is known as a negative externality and leads to an over-supply of emissions producing activities and/or the use of technologies with inefficiently high emissions[3].

The Australian government has committed to introducing an emissions trading scheme as main policy mechanism for abating greenhouse gas emissions. Emissions trading will set a cap on greenhouse gas emissions that cannot be exceeded and therefore encourage the adoption of low emission technologies in order to not exceed the cap.

---

[1] M. Grubb (2005), “Technology innovation and climate change policy: an overview of issues and options”, *Keio Econmic Studies*, 41(2), pp 103 to 132.

[2] Insight Economics (2007), *Innovation pathways for greenhouse gas reduction – scoping study*, (unpublished) prepared for the NSW Government, June.

[3] Insight Economics (2007), ibid.

Nonetheless, there remains a role for complementary policy measures as part of Australia's response to climate change. As noted in the PM Task Group on Emissions Trading Report, "there is evidence that households and firms do not always take up opportunities for seemingly cost effective improvements in energy efficiency".[4] Studies by Stern and others have pointed to other market failures that inhibit the adoption of low emission technologies[5]. The focus for policy makers is to develop cost effective complementary policies.

The concept of cost-effectiveness is complex. Abatement options may be privately cost effective or socially cost-effective. Privately cost-effective measures are those that have a net benefit to the individual or firm taking the measure. Socially cost effective measures are those that have a net benefit for society as a whole if they are taken, although the individual or firm taking them may not individually be better off. Any measure that reduces the overall cost of achieving the emissions abatement target set under the proposed emissions trading scheme will be socially cost effective. In a broader context that includes other non-greenhouse related benefits (co-benefits), determining whether a measure is socially cost effective becomes more difficult and tends to favour stronger interventions.

Increases in the price of energy resulting from the emissions trading scheme will lead to some of the socially cost effective energy efficiency opportunities and low emission technologies being adopted. However, there are also a range of significant non-price market failures and other barriers to the development and uptake of socially cost effective energy efficiency opportunities and low emission generation technologies. The role for complementary policies alongside emissions trading is to address these market failures and other barriers.

2.3 Supply side

On the supply side, market failures may be present that hinder the optimal uptake of new low emission generation technologies. These market failures either affects the decision to invest in new low emission technologies (that is, mute the incentives for the development and deployment of new technologies) or may favour conventional technologies over low emission technologies.

The market failures that affect technology diffusion can be summarised as follows[6]:

- *Knowledge spillovers*. A firm adopting technologies creates benefits for other firms while incurring most of the costs of adoption. This is because an adopting firm cannot typically keep other firms from also exploiting some of the knowledge gained from adoption, even where a patent or other protection exists. Firms therefore do not have

---

[4] Australian Government (2007), *Task Group on Emission Trading Report*, Canberra, pp 134

[5] See N. Stern (2007), *The Stern Review: The Economics of Climate Change*, HM Treasury, London, Chapter 16

[6] A. B. Jaffe, R. G. Newell and R. N. Stavins, (2001), "Technological change and the environment", *Discussion paper 00-47 REV*, Resources for the Future, Washington DC.

the incentive to increase those benefits by investing in technological development and diffusion.

- *Adoption externalities*. The cost of a new technology to a user may depend on the number of other people who adopt the technology. Further, the initial adopters of a new technology typically aid the diffusion process by making available to other parties information on the new technology. Early adopters generate knowledge on the existence, characteristics and applicability of the new technology. This knowledge is likely to become available to other firms who can use this knowledge even though they did not incur the cost of its generation.
- *Learning by doing*. Uptake of new technologies typically involves the adopter learning by doing. That is, an early adopter itself improves the characteristics and operation of the technology through learning by doing. The benefits of this learning by doing may be passed onto other later adopters, even though they did not compensate the early adopter for the costs incurred during the learning by doing process.
- *Network externalities*. These externalities occur where costs of a technology may reduce or its benefits increase, as adoption becomes more widespread.
- *Incomplete information*. There is a great deal of uncertainty around the potential outcomes of adopting new technologies. Further information about these prospects is typically asymmetric, in that developers of technologies have better information about these prospects than other investors who may wish to invest through adoption. Early investors may be sceptical about the prospects of a technology and demand a premium on return in order to cover the risks of the investment.

The result of these market failures is that investment in and deployment of low and zero emission energy supply technologies may be at a lower level than is optimal from society's point of view.

Adoption externalities and spillovers can exist for all forms of new technologies, not just low emission energy supply technologies. Justifying support for low emission energy supply technologies requires some prospect that the potential for knowledge spillovers and learning by doing is greater with low emission technologies than for other technologies[7].

Institutional arrangements affecting energy markets are generally designed to enhance competition in energy supply, with a key principle being technological neutrality. However, because of the complexity of the structure of energy markets, some market failures may arise particularly where network externalities arise in electricity and gas transmission. This is discussed further in another MMA report to The Garnaut Review.

---

[7] Newell, R.G. (2004), "Energy Efficient Challenges and Policies", in workshop proceedings of Pew Center on Global Climate Change (2004), *The 10-50 Solution: Technologies and Policies for a Low Carbon Future*, March 25-26, Washington D.C.

2.4 Demand side

Below is a summary of the market failures impact on the demand side of energy markets. As the focus is on modelling methods, only a brief discussion of the market failures is provided[8].

2.4.1 Information failures

In making decisions regarding the energy efficiency characteristics of goods and services purchased or of production and distribution systems, market participants have to obtain and process a large amount of information. In this respect energy efficiency is in principle not different to other areas of the economy – whole professions exist to search out, package and interpret information for consumers and producers. Difficulties in obtaining and interpreting information are related to the existence of many of the market failures and barriers to the development and implementation of cost-effective energy efficiency opportunities discussed below including transactions costs, incentive misalignments, the public good nature of information and a host of limitations facing decision makers such as bounded rationality, and other relevant behavioural barriers.

Another form of information failure arises when information about the optimal course of action is in itself missing. This type of failure is most likely to arise in the context of non-product specific information which offers little opportunity for cost-recovery. In the energy efficiency context this includes information on energy saving techniques or practices (such as solar passive design principles). While firms may provide some of this information as an adjunct to related product specific information, there is a risk that such information will be undersupplied in the market.

2.4.2 Transactions costs

Transactions costs include the costs of obtaining and interpreting information as well as any costs associated with implementing energy efficiency opportunities including the costs of negotiating, implementing and enforcing contracts. In the context of energy efficiency, the costs of obtaining and interpreting information can be particularly problematic where energy is a small part of the overall budget and items are purchased for attributes other than their energy characteristics. For example, when purchasing a TV consumers may be more interested in the quality and size of the picture and the look and features of the appliance than in the standby power consumption.

It may be rational for consumers to act in this way in the sense that the costs to individual consumers of obtaining and interpreting energy consumption information about an appliance can be too high relative to the gains from ending up with an energy efficient appliance. However, this leaves the door open for economic efficiency improving policy interventions. For example, finding the energy consumption characteristics of washing

---

[8] There is a large literature on market failures relating to energy efficiency. See MMA (2008), *Defining an National Energy Efficiency Strategy – Part I*, report to The Climate Institute, for more details on the market failures.

machines may be prohibitive for an individual consumer but may be cost effective if done once for each appliance and published in the form of an energy label.

Transaction costs are less likely to prevent cost-effective decision makings in sectors where energy costs form a large or major part of the overall budget, such as in power generation or energy intensive manufacturing as in such cases investing in obtaining and interpreting information can lead to large savings. The different impact of transaction costs on different types of energy users suggests that measures that seek to address information failures in a differentiated and targeted way are much more likely to deliver low abatement costs than measures that apply equally to all energy users.

Implementing energy efficiency solutions also include such 'hidden' transactions costs as time taken to arrange and supervise work, disruptions while work is occurring and so on. Such costs are easily ignored in analyses of the benefits from energy efficiency improvements and can lead to an exaggeration of the expected net benefits from implementing energy efficiency opportunities. On the other side of the ledger, indirect benefits in the form of reduced exposure to price volatility, enhanced supply security and 'feel good' or reputational benefits can easily be ignored too and may lead to underestimates of the benefits from implementing energy efficiency opportunities.

2.4.3 Incentive misalignments

Because information is costly to obtain and interpret one party can have more information than another (asymmetric information) and seek to protect any information they can exploit to their advantage even if it is to the detriment of other parties (and indeed more to the detriment of other parties than to their own benefit). Where transactions costs in obtaining information lead to asymmetric information and this is combined with incentive misalignments (the adjustment of which can be costly to negotiate) market failures resulting can occur.

In situations where goods have a short life span, consumers can quickly discover hidden attributes of goods on the market and sample goods from different providers, discarding those with negative attributes the seller is trying to hide. Thus, situations of ‘repeat purchasing’ make it harder for producers to exploit information asymmetries. However, many purchases to which energy efficiency is relevant are large and infrequent (domestic appliances, houses, industrial equipment), meaning that new and updated information must be obtained for each purchase and trying different providers to learn about different implementations and hidden characteristics is available to a much more limited extent.

2.4.4 Public good aspects of RD&D

Research, development and diffusion of new energy efficiency technologies and practices can be both risky and costly and the results of such research have a significant public good aspect. However, once useful information is created from this effort, it can be hard to extract payment for its use (that is information can be spread through channels that are extremely low cost compared to the value of the information provided). This creates a barrier to private firms undertaking socially beneficially research and development.

This is a problem common to research and development in all areas and the Australian government has attempted to address this barrier through a range of general measures including intellectual property laws, the direct funding of government research and development activities (e.g. through CSIRO and Universities), and tax incentives, competitive grants and concessional loans to encourage private sector research and development. Additional targeted energy efficiency RD&D measures may be warranted, especially in areas where RD&D relates to a better understanding of thermal and other physical principles or involves design concepts rather than technological breakthroughs that can be protected more easily.

Even when new energy efficiency technologies and practices are available there is often some lag to their adoption resulting from a reluctance of firms to take the risk of being the first movers, with consequent 'teething' costs, when this will facilitate competitors adopting the measure subsequently at lower cost. Government interventions that demonstrate the benefits of new energy efficiency technologies and practices can help to overcome this deployment lag.

2.4.5 Behavioural and organisational barriers

As noted in the Stern Review,[9] individuals and firms are not always able to make effective decisions involving complex and uncertain outcomes. Indeed, when faced with complexity, uncertainty or risk, the full understanding of which would require significant investments of time and energy, individuals and firms may adopt simple decision rules that lead to *satisficing* rather than *optimising* behaviour.[10]

In the context of energy efficiency opportunities such complexity, uncertainty or risk may appear to arise from factors such as difficulties in calculating the long-run value of energy savings, determining appropriate responses to the risks and uncertainties around future energy costs or a lack of understanding of new energy efficiency technologies.

The adoption of simple decision rules or rules of thumb is obviously most likely in situations where a reasonable outcome is sufficient or the difference between a reasonable outcome and an optimal outcome is not large (e.g. individuals purchasing household appliances where energy efficiency is only amongst a number of relevant factors) as compared to situations where energy efficiency is a primary consideration to the profitability of an enterprise (e.g. energy generation companies). However, the use of simple decision rules that lead to non-efficient outcomes has been documented even in the commercial sector.[11]

---

[9] N. Stern (2007), ibid, pp 380-381.

[10] Productivity Commission (2005), *The Private Cost Effectiveness of Improving Energy Efficiency* , Canberra, pp 55

[11] Produtivity Commission (2005), ibid, pp 56.

The decision rules adopted by individuals and firms will often be strongly influenced by social and institutional norms. That is, there is a tendency for individuals and firms to continue to take decisions in the same way they have taken such decisions in the past despite changed circumstances.[12] Social and institutional norms are not static, and will change over time. Without some form of awareness raising, particularly in the transitional period, there will often be a lag between changed circumstances and changing social and institutional norms.

Some commentators have also noted that within firm principle agent problems (organisational barriers) may prevent the adoption of cost-effective energy efficiency measures by firms. Managers may choose not to adopt a potentially cost-effective energy efficiency measure because they perceive it to be risky and the personal consequences of failure are more costly than the pay-off from success, or because the performance is assessed on a shorter time frame that the energy efficiency measure will take to pay off. Coordination problems within firms may also lead to a failure to realise cost-effective energy efficiency measures.[13]

2.5 Materiality of market failures

A range of market failures have been identified. In the following sections, we review the literature on the importance of these market failures with an emphasis on their impacts on uptake of new low emission technologies. The majority of the literature on this subject is sourced from overseas, as there is only a limited number of studies in Australia on the impact of market failures in the energy sector on the uptake of technological development.

Recent studies have shown that long term productivity improvements flow from improvements in the stock of knowledge[14]. This stock of knowledge can be enhanced by investments in research and development or by learning by doing from investing in new technologies. As such, these processes are subject to barriers and impediments, which may be amenable to policy intervention.

The current level of understanding on the impact of market failures on technological adoption processes is imperfect.[15] There is strong evidence for the existence of positive spillovers from knowledge accumulation, such that technical change is often characterized by increasing returns and imperfect competition (particularly in the energy supply sector). The experience curve literature, however, shows a wide variation in the empirical evidence of rates of cost reduction with experience. There is even more variation in the evidence on the impact on economy wide growth rates from the spillover effects of technology development and diffusion. These uncertainties lead to the conclusion that technical change is fundamental to determining the social costs of policies to abate

---

[12] N. Stern (2007), ibid, pp 381.

[13] Productivity Commission (2005), ibid, pp 58-59.

[14] Source: Insight Economics (2007), *ibid*.

[15] J. Kohler, M. Grubb, P. Popp and O. Edenhofer (2006), “The Transition to Endogenous Technical Change in Climate-Economy Models: A Technical Overview to the Innovation Modeling Comparison Project”, *The Energy Journal*, *Special Issue: Endogenous Technological Change and the Economics of Atmospheric Stabilisation*, pp 35.

greenhouse emissions, but the mechanisms by which social costs are affected and the strengths of the effects are not yet clear[16].

The literature on technological change highlights the importance of a number of market failures influencing technical change[17]. Innovation is characterized by uncertainty in new discoveries, the need to consider new markets and the partly non-rival and non-excludable nature of knowledge about technologies. Increasing returns mean that there will be imperfect competition in technical change. These increasing returns can cause path dependency, with the possibility of lock in to sub-optimal technologies. The uncertain returns may also result in socially sub-optimal expenditures on research and development. Imperfect information and search costs of available knowledge may also impede technological diffusion.

Although these factors are acknowledged in the literature as important and should be considered in any modelling of the benefits and costs of carbon abatement policies, estimates on the magnitude of the impacts from these factors vary widely and are subject to considerable contentious debate. There is strong support for further research and development of new technologies[18]. Not only is this due to the market failures that impact on research and development directly, but other market failures affecting energy demand and supply reduce the demand for new technologies, which is a major driver for research and development of emerging technologies. There is also growing support for measure to assist in the deployment of newly commercialised technologies, where significant cost reductions through learning by doing can occur[19].

---

[16] Source: Insight Economics (2007), *ibid*.

[17] Source: Insight Economics (2007), *ibid*.

[18] R. Doombosch and S. Upton (2006), Do we have the right R&D priorities and programmes to support the energy technologies of the future, *Round Table for Sustainable Development*, OECD, Paris, June

[19] IEA/OECD (2003), *Creating Market for Energy Technologies*, Paris; V. Norbergy-Bohm. (2000), Creating Incentives for Environmentally Enhancing Technological Change: Lessons from30 Years of US Energy Technology Policy, *Technology Forecasting and Social Change*, Volume 65, pp 125-148.

3 IMPACT OF MARKET FAILURES AFFECTING ENERGY SUPPLY

Energy markets may be exposed to a number of potential market failures. Energy is considered an essential good with significant social and environmental externalities. The supply is generally concentrated in a small number of large providers using capital intensive and long lived assets. These characteristics can lead to lock in of conventional, high emitting technologies and make it more difficult for new low emission technologies to enter the market[20].

3.1 Review of the literature

Whilst there have been a number of studies conducted in Australia on the impact of greenhouse gas mitigation, few of them explicitly consider the impact of mitigation measures on technological change or the impact of targeted policies to lead to cost reductions in the long term. What studies there are tend to focus on the benefits and costs of research and development in general, not on the benefits and costs of demonstration and deployment of new technologies

Three reasons are provided for the dearth of research in this area. First, there is very little data on the impact past mitigation policies have had on technological change. There are no empirical estimates of the potential impact on technology development available from the current suite of mitigation policies. Second, there is an assumption that the bulk of development of mitigation technologies would likely occur overseas and that the small size of the Australian market means that innovation policy in Australia would have little influence on reducing costs of low emission technologies. Third, there has been little need for this type of evaluation and, hence, modelling tools to assess technological change have not been developed. Most studies do not consider the impact other market failures may have on the effectiveness of emission trading on developing energy supply options, and instead assume no impact.

Some Australian based studies include:

- The Australian Business and Climate Group[21] published a study undertaking a theoretical analysis of the impact of market failures. They argued for the need for active measures to support research, development and demonstration of new technologies as well as for a need for support of first of a kind of commercialised technologies. They also argued for additional measure to support early stage deployment of new technologies to overcome early mover cost and risk barriers. However, they did not undertake empirical estimation of the costs and benefits of

---

[20] T. J. Foxon (2002), "Technological and institutional lock in as a barrier to sustainable development", *ICCEPT Working Paper*, London, November

[21] Australian Business and Climate Group (2007), *Stepping Up – Accelerating the Deployment of Low Emission Technology in Australia*, August

such measures, with their analysis restricted to small number of case studies. They have indicated that for solar PV installations, where Australia has some comparative advantage, installations costs have reduced at approximately 5% per annum on the back of Government support policies. They estimate that costs will fall by 20% for every doubling of capacity.

- The Bureau of Transport and Regional Economics undertook a study of the response of urban freight patterns to greenhouse gas abatement scenarios[22]. They employed a bottom up model of the Sydney urban road network to model responses to greenhouse abatement strategies. Candidate responses ranged from vehicle technology measures, vehicle movement measures and infrastructure planning measure. Technology development was not explicitly modelled, rather shifts in technology use patterns were modelled using a range of price elasticities, whereby technology response and vehicle usage patterns were a function of changes to fuel prices. The analysis indicated that the greatest response came from adoption of more fuel efficient technologies, suggesting the importance of modelling changes to technologies as a function of mitigation policies, although this was not explicitly modelled.
- A study by ABARE[23] found that policies to develop and diffuse low emissions technologies followed by late action to curb emissions led to significantly lower costs than early action to curb emissions. This is because early action would lock in existing low emission technologies and would result in early shutdown of energy intensive assets. They recommend action by governments to deploy technology push policies, such as research and development. Their analysis assumed a global learning by doing rate for carbon capture and storage technologies of 10% per doubling of capacity but only after 5 Mt of carbon dioxide had been captured by this new technology. There is no indication that market failures to the adoption of new technologies (apart from the greenhouse externalities) were explicitly modelled. Rather market pull was assumed to lead to early commercialisation of new low emission abatement technologies.
- A study by the CSIRO[24] comparing mitigation costs with benefits from curbing damages from climate change used conservative assumptions on the impact of market failures on technology adoption and cost reductions for new technologies. Uptake of new technologies as a function of their relative price and other key economic variables were determined from statistical analysis of historical relationships. However, it appears that the modelling did not explicitly consider the impact of other market failures on technology adoption and diffusion. Rather it appears that technology shares were assessed on the basis of relative costs subject to constraints such as

---

[22] BTRE (2004), “Modelling respones of urban freight patterns to greenhouse gas abatement scenarios”, *BTRE Working Paper No 62*, Canberra.

[23] H. Ahammad, A. Matysek, B.S. Fisher, R. Curtotti, A. Gurney, G. Jakeman, E. Heyhoe and D. Gunesekera (2006), “Economic Impact of Climate Change Policy: Role of Technology and Economic Instruments”, *ABARE Research Report 06.7*, Canberra

[24] R.N. Jones and B.L. Preston (2006), *Climate Change Impacts, Risk and the Benefits of Mitigation*, report to the CSIRO Energy Futures Forum, December. See also CSIRO and ABARE (2006), *Modelling Energy Futures Forum Scenarios*, report to the CSIRO Energy Futures Forum, December.

turnover of capital stocks, existing or new policies such as subsidies or taxes, and market constraints. Rates of technological change were obtained from ABARE's GTEM model of the international economy, which does not explicitly model rates of technological change as a function of the presence of market failures. As rates of technology change are highly uncertain, the study also relies on a scenario based approach, whereby rates of technology may vary as part of the scenario parameters.

- A report prepared for REGA[25] assessed the benefits and costs of adopting a deployment measure such as a portfolio standard for low emission energy generation. In this study, market failures to the adoption of low emission technologies were discussed and benefits were assessed from learning by doing arising from early adoption of these technologies. It was assumed that the portfolio standard would overcome the key market failures to deployment. Learning by doing was modelled as simple progress ratios for the Australian component for each low emission technology (whereby the Australian component varied from 30% for wind to 60% for hot dry rocks geothermal and carbon capture and storage). Positive benefits were found for modest targets under the portfolio standards and as long as a wide range of low emission technologies were eligible. Too high a target led to a net cost due to the crowding out effect and restricting the target to renewable energy options led to net costs as the learning by doing benefits from carbon capture and storage were not captured. A report by the Productivity Commission[26] criticized this study on the grounds that they felt that market failures in deployment were weak, that the modelling did not address fully the crowding out issue and that the learning by doing rates were, in their view, overestimated.

No other study was available in the Australian literature that modelled the response of technological change of policies to address market failures.

There are, however, many overseas studies on market failure and technology adoption rates. These studies focus on three themes. First, there are many studies on the theoretical considerations on the need to include endogenous technological change from overcoming market failures. The general conclusion from these studies is that emission trading will provide a price signal for technological development but not necessarily at an optimal rate due to other market failures[27]. Second, there are a small number of studies focussing on the modelling of the impact of market failures, typically through case studies or econometric analysis. Third, there are studies attempting to compare policies to overcome market failures, using simplified benefit costs techniques.

The majority of the empirical work relies on case studies.

---

[25] McLennan Magasanik Associates (2007), *Increasing Australia's Low Emission Electricity Generation – An Analysis of Emission Trading and a Complementary Measure*, report to the Renewable Energy Generators Association, October

[26] Productivity Commission (2008), *What Role for Policies to Supplement and Emissions Trading Scheme*, subsmission to The Garnaut Review, June

[27] M. Grubb, C. Carraro and J. Schellnhuber (2006), "Technological change for atmospheric stabilisation: introductory overview to the innovation modelling comparison project", *The Energy Journal*, Special Issue.

Overseas studies have typically stressed three important components[28]:

- To consider the impact of market failures along the chain of technology development: invention, innovation, demonstration and commercial deployment[29]. This would require different approaches to model each parts of the chain.
- The importance of developing niche markets for new technologies to allow for learning by doing. There is a general consensus that both technology push and demand pull policies are required.
- To separate out learning from further technological developments and learning from institutional knowledge development. The latter arises from firms developing new techniques and organising business to manage new technologies (e.g. distributed generation technologies versus centrally dispatched generation technologies).

The reliance on case studies to provide insights does not allow for the easy translation of results into top down modelling approaches, such as employed in general equilibrium modelling of the Australian economy. Top down modelling approaches typically rely on econometric estimates to derive substitution rates and/or elasticity estimates for substitution between inputs, which are affected by long term historical rates of technology development. Whilst the case studies provide anecdotal evidence for particular technologies, the results are not easily translatable to broader modelling approaches. The case studies tend to concentrate on technologies that have been successfully developed, whereas not all technologies supported by government policies will go on to be commercially successful. There is also a wide variation in the improvement wrought by different technologies, which is difficult to average into the aggregated technology share variables typically employed in computable general equilibrium models.

One recent study also examined the implications of market risks faced by investors[30]. Although market risk of itself is strictly not a market failure, the study pointed to the fact that investors base their decision on the choice of plant to invest in on a range of market risks. Models of energy markets often treat risk in a very simple fashion, basing decisions on new investments on simple mean values for key assumptions. According to this study, empirical analysis needs to consider directly the risks faced by investors, and need to directly model where risk eventuates and the interaction policy has with those risks. Policies can affect risks differently and this difference needs to be taken into account when assessing emissions trading and complementary measures. For example, a feed-in-tariff passes risks onto consumers (since prices are fixed), whilst a renewable portfolio standard such as MRET will pass the risks onto investors in generation. This study also concluded that modelling should consider the option value of revealing information on new technologies early to the market.

---

[28] IEA/OECD (2003), *Creating Markets for Energy Technologies*, Paris

[29] T.J Foxon and P.J Peasron (2006), *Policy Process for Low Carbon Innovation in the UK: Successes, Failures and Lessons*, University of Cambridge Environmental Economic and Policy Research Discussion Paper Number 16.2006

[30] UK Energy Research Centre (2007), *Investment in Electricity Generation – The Role of Costs, Incentives and Risks*, London, May.

As previously stated, there is only limited empirical analysis to verify theoretical considerations. One study examined thirty years of technology development support by the US Government for 4 generation technologies (wind, photovoltaic, natural gas turbines and circulating fluidised bed technologies)[31]. Based on their empirical analysis, they concluded that both supply push and demand pull policies are required for successful deployment. Governments must also create markets in which these technologies can successfully develop (in the case of the fossil fuel technologies considered, both the need to reduce oil consumption and the need to reduce emissions of harmful pollutants created an incentive for government to impose rules for more efficient technologies). In terms of demand pull policies, they found that Governments must be careful to design policies to provide the right amount of market incentives to create niche markets (addressing the need to develop niche markets but also not crowd out existing low emission technologies). Incentives must be long lived to allow for long term development and to prevent start stop approaches to technology development, where there is a risk of all the learning being lost if support stops too soon (as has happened with renewable energy support policies). Design of policies should also guard against technology lock in by supporting a range of technologies and allowing flexibility to alter support as circumstances change. These factors may also need to be considered in the modelling of technology support measures.

One factor not assessed in the literature is the impact that small nations (such as Australia) can have only technology development.

3.2 Factor affecting technological development

Factors affecting the effectiveness of technological development and diffusion of supply side technologies include:

- *Industry structure*: energy market structures can tend to favour large scale technological options over small scale and dispersed technological options.
- *Financing capability*. Many small scale technologies have been developed by small firms, who do not have the financial clout to expand adoption of these technologies. This can limit deployment of these technologies. Large scale technologies tend to be developed by large firms with adequate in-house financial resources for ongoing development.
- *Lock in of conventional technologies* (prevalent in energy markets), which may prevent faster adoption of new technologies.
- *Sources of innovation.* Some innovations in the energy sector come from developments of complementary technologies in other sectors. The classic example is the development of the gas turbine arising out of research and development in jet engines.

---

[31] V. Norberg-Bohm (2000), “Creating Incentives for Environmentally Enhanced Technological Change: Lessons from Thirty Years of US Energy Technology Policy”, *Technological Forecasting and Social Change*, 65, pp 125-148

The spillover activity is continuing. Fluidised bed technologies are also being developed for the chemical industry as well as the electricity generation sector.

- *Rate of public R&D* for further development of technologies. The rate tends to be higher for conventional technologies due either to political clout or the fact that a large source of R&D funding comes from conventional energy sources (e.g. coal royalties in Australia).
- *Extent of private niche markets*, which are large for conventional technologies and small for small scale renewable technologies.

4 IMPACT OF MARKET FAILURES AFFECTING ENERGY DEMAND

It is widely accepted that there are significant untapped energy efficiency opportunities in a range of sectors including the building, residential, commercial and power generation sectors.[32] Indeed, the IEA estimates that unexploited energy efficiency potential offers the single largest opportunity for emissions reductions and believes that accelerating progress in energy efficiency is therefore indispensable. In 2006, the IEA published a range of scenarios (accelerated technology scenarios) showing how energy-related CO_2 emissions could be returned to current levels by 2050 using technologies that already exist or are under development. In the scenarios, which did not employ any technologies with an incremental cost of more than US$25 per tonne of avoided CO_2 emissions, improved energy efficiency in the buildings, industry and transport sectors lead to between 17% and 33% lower energy use than in the business as usual scenario. [33]

The IEA found that there was still significant scope for adopting more efficient technologies in buildings, industry and transport. This is particularly the case in developing countries, but opportunities remain in developed countries such as Australia as well.

There is, however, significant evidence that energy efficiency opportunities that are cost-effective in the sense of reducing the overall cost of greenhouse gas emission abatement (socially cost-effective measures) are not currently undertaken because of a range of market failures and other barriers to the development and adoption of energy efficiency opportunities. These market failures and barriers include information failures, transaction costs, incentive misalignments, public good aspects of information and RD&D, capital constraints and behavioural and organisational barriers. This section deals with the issue of how market failures in energy efficiency affect technology adoption and how these issues should be modelled.

4.1 Review of literature

There is an extensive literature extensive on the impact of market failures on the demand side and benefits and costs of overcoming those market failures[34]. However, the empirical analysis employed to determine the extent of market failures is generally basic. The basis of the model is based on simple engineering cost models of appliance use. The analysis proceeds by calculating the private benefits of adopting energy efficiency option, then

---

[32] See Stern Review Report on the Economics of Climate Change p 398; IEA Energy Efficiency Policy Recommendations to the G8 2007 Summit, Heilingdamm

[33] International Energy Agency, Energy Technology Perspectives, 2006, Paris: OECD/IEA.

[34] See The Allen Consulting Group (2004), *The Energy Efficiency Gap: Market Failure and Policy Options*, report prepared for the Business Council of Sustainable Energy, The Australasian Energy Performance ContractingAssociation and the Insulation Council of Australia and New Zealand. See also MMA (2008), *Defining a National Energy Efficiency Strategy – Part 1*, report to The Climate Institute.

assuming that options that meet a payback rule are adopted under an energy efficiency policy.

The steps in the analysis are typically as follows:

- For each appliance, identify the energy use intensity of the most efficient model and the standard model. Compute the difference in energy use. The value of foregone energy use (foregone energy use multiplied by the energy price) represents the key benefit modelled.
- Calculate the capital and ongoing costs of adopting more efficient appliance. This represents the cost of adoption of the new appliance.
- Calculate the payback period or present value of adopting the options.
- Options with net benefits within a defined payback period are then considered as those that would be taken up under an energy efficiency program. Take-up over time of these options and the associated energy savings are then modelled assuming constraints on take-up rates (typically following a sigmoid or S shaped build up of adoption over time).
- In bottom up models, the energy savings are then input in simulation models of energy markets to estimate downstream benefits and costs. These are estimated by calculating the overall reduction in demand for energy as a result of adoption of energy efficient appliances
- In top down models, the energy savings are typically translated into an accelerated improvement in autonomous technological change in end use activities.

In essence, energy efficiency programs are largely geared to encouraging consumers to adopt new technologies. In the literature, there is little in the way of historical analysis to explore the relationship between various policy measures and the rate of technological development and deployment. In benefit cost studies, uptake of new technologies is often assumed to occur over time following an S shaped pattern (slow initial uptake, following by an accelerated uptake as the appliance becomes accepted before the rate plateaus out at some level less than 100%). The parameters of this uptake relationship are often assumed, not estimated based on statistical analysis of historical uptake rates.

4.2 Factors affecting modelling of energy efficiency

The bulk of the Australian and overseas studies on energy efficiency are confined to benefit costs analysis of proposed policy developments (MEPS, mandatory labelling, etc). These studies are typically bottom up studies using cost analysis to determine the potential energy savings, then calculating the benefits using partial models of the energy markets.

There are a small number of studies looking at benefits and costs of energy efficiency per se, but there are no studies that explore how such policies could lead to technological developments in energy efficiency. One study used an analytical approach to assess the impact of allocation rules under the proposed EU Emission Trading System on the uptake of energy efficiency and technology innovation. The study found that the overgenerous allocation rules provided only a modest incentive for energy efficiency or technological innovation, as the rules led to low allowance prices (price induced innovation was likely to be too weak), the auction share too small to have any innovation affect, and because closure rules and uncertainty over future allocation procedures provide little incentive to innovate over time[35]. Another study used an integrated model of the US economy (similar in concept to the CoPS MMRF model) to simulate the impact of policies that provided incentives for technological innovations[36]. The model they employed has over 200 sectors modelled in some detail including technological production functions (based on constant elasticity of substitution aggregator functions) and a household sector that produces a number of services. Energy services where modelled as a function of energy input and energy saving capital. They found positive benefits to the deployment of policies to develop new technologies for energy efficiency, although the savings from these policies were found not to be large enough to meet US targets under the Kyoto Protocol.

From the review of the literature, it is apparent that the level of energy efficiency uptake and technological development of energy efficiency options are both affected by a number of factors including:

- The type of abatement program.
- The portion of total costs for the firm spent on energy.
- The underlying technological possibilities for substituting energy for other inputs.
- Income level of consumers targeted by the abatement program.
- Stage of development of the economy.
- Time lines to account for adoption and reaction to abatement programs.
- The cost of the programs and the means of funding these costs.

The literature also identifies a number of issues that make it difficult to estimate the benefits and costs of policies to encourage energy efficiency. First, non pecuniary factors may hinder the uptake of energy efficient appliances. Some energy efficient technologies are not adopted because of other factors such as poor ascetics. The classic example is fluorescent light bulbs, which have not been adopted on a large scale despite their energy saving benefits as they are seen to be ugly, cannot be fitted readily in some light fittings and can give a poor glow. Second, there is a large risk of errors in technical estimates of the potential improvements from adopting technologies. Most studies of energy

---

[35] J. Schleich and R. Betz (2005), "Incentives for energy efficiency and innovation in the EU emission trading system", presented at the *ECEEE Summer Study – What Works and Who Delivers?*

[36] D. Hanson and J. A. Laitner (2004), "An integrated analysis of policies that increase investments in advanced energy efficient/low carbon technologies", Energy Economics, 26, pp 739-755.

efficiency savings are based on simple engineering cost models that compute energy savings based on assumed usage patterns and energy intensity of the appliance, typically determined under test conditions. Usage patterns can vary widely from those under test conditions, which can lead to overestimates of the potential energy savings.

Third, a rebound in energy use can occur as energy services become cheaper as a result of an energy efficiency program. The savings in energy costs can be spent on obtaining more of that service or spent on other goods with embodied energy. Estimates of the rebound effect vary widely, but more recent studies indicate that rebound is likely to be less than +/- 20% for most end-use applications and program types. The largest rebound occurs with improvements in energy efficiency in end-use applications in energy intensive industries because of the higher energy demand elasticity applying.

Double counting of energy savings should also be avoided. This can occur because some programs will improve energy efficiency, reducing the energy saving benefit of subsequent programs. For example, improved insulation would improve internal air conditioning, reducing the benefit from tighter standards for air conditioners under a mandatory energy efficiency program.

As a result of the issues discussed above, modellers need to be careful in interpreting energy efficiency options with estimated net private benefits. Does the lack of adoption of options with estimated net private benefits arise due to a market failure, or because the estimation of the benefits did not account for transaction and search cost (which are a true economic cost) or other non pecuniary costs?

5 MODELLING IMPACTS ON TECHNOLOGY DEPLOYMENT

5.1 Modelling objectives

The objectives of any modelling of policies in a carbon constrained world are to identify policies, which minimise the cost to the economy of constraining carbon emissions, and drive uptake of innovations and technology.

Modelling of carbon abatement policies needs to be able to quantify the implications for the Australian economy of a carbon constrained future. Modelling tools capable of achieving this will need to be able to capture the global impacts of carbon constraints — which will influence Australia's terms of trade — as well as economic outcomes in Australia itself. The modelling will also need to capture potential feedbacks caused by mitigation policies, both on a global and domestic scale. For example, models that do not include the impact of rising food costs from increased bio-sequestration (as agricultural land is locked up into forest plantations) may underestimate the costs of carbon abatement.

The modelling framework also should be able to quantify the costs and benefits of adoption of specific technologies to abate emissions in Australia. Without this, the results will lack sufficient detail to translate to actual outcomes on the ground. Furthermore, they will not provide accurate insights about the costs of mitigation and may lead to options that are not optimal. Not only does this require sophisticated models of sectoral impacts, but also robust and rigorous data. There is reasonable data on the cost of mitigation options for some sectors of the economy such as stationary energy, fugitive emissions and transport. But there is very little reliable data on the potential for reducing emissions from the agricultural sector and for the cost of sequestration as the amount of land locked up for plantations increases.

The modelling framework should have some avenue to capture returns to research and development and 'learning by doing', as these elements are key indicators of innovation. Returns to research, development and deployment result in productivity enhancements, which can lead to reduced emissions per unit of economic activity, and associated reduced costs to meet abatement targets. However, a major issue with top down models is their poor treatment of technological change. Understanding the drivers and effects of such technical change has been poorly understood in the past. Most top down economic models have incorporated an assumed (exogenous) technical change component to explain productivity improvements. However, recent insights from the economic growth literature, combined with insights from the innovation literature and advances in quantitative techniques, have started to shed light on this topic, allowing endogenous technical change to be included in models.

Allowing for endogenous technological change is important, because it raises the potential to estimate explicitly the impacts of induced technical change arising from policy prescriptions. The limited empirical studies undertaken to date suggests that inclusion of endogenous technological change in model frameworks tends to lead to lower estimates of the costs of responding to climate change.

Ideally, assessment of potential abatement pathways and policy options requires a three step process. The three steps are:

- Economic analysis of the options for abatement in each sector. This analysis is confined to engineering-economic tools to determine the ranking of costs of abatement options in each sector. This analysis can also provide a guide of abatement costs for more detailed modelling. It can be used to screen options for further modelling to those options that are most likely to be least cost. Techniques include levelised cost analysis and cost effectiveness analysis.

- Sector wide modelling, which determines outcomes for the sector as a whole, by extending the analysis to include interactions between economic agents within the sector and to account for how historical outcomes may affect future developments[37]. Sector wide modelling can also provide detailed information on the impact of abatement actions on key indicators of performance in the sector (e.g. industry profitability, price impacts to customers) as well as provide more accurate assessments of the uptake and affect of abatement options. This approach is also more robust where there are multiple benefits to adopting a technology (other benefits not just greenhouse benefits). Approaches range from simple spreadsheet models with exogenously imposed behavioural responses (e.g. price elasticity of demand) to complex optimisation models which employ sophisticated mathematical techniques to optimise behaviour to meet some common goal (maximise firm or industry profits, minimise costs to consumers) subject to range of regulatory and economic constraints.

- Economy wide modelling, which allow for interactions across sectors and second round effects on the economy from adoption of abatement policies within a sector. This modelling can either use inbuilt behavioural assumptions for determining outcomes within a sector or can use the outputs from engineering-economic models or sectoral models as inputs into the modelling process. Techniques range from simple input-output type models to sophisticated computable general equilibrium models of the Australian economy.

In terms of undertaking economic analysis, it is recommended that the engineering-economic approach is used to rank options identified in the sectoral studies. That is, using engineering-economic tools should be integral to the sectoral and general equilibrium studies for ranking options that are likely to abate emissions in each sector.

---

[37] Often referred to in the literature as path dependency.

5.2 Effectiveness of policy instruments

As stated previously, assessment of the impacts of various policy instruments on innovation are largely based on theoretical analysis of the issues. There are few studies based on an empirical analysis of the effectiveness of various instruments[38].

Based on published theoretical studies, the effectiveness on the degree of technological change of various policy instruments to abate emissions has been found to depend on a number of factors[39]:

- Type of technical development. The effectiveness of policy instruments in general is less clear for major technological developments than for minor ones. Both regulatory and price incentives are effective in inducing minor technical developments. In energy markets, it is likely that both major (e.g. carbon capture) and minor technological developments (e.g. improved turbine blade design) are available.
- Stage of development of particular innovations. Price incentives are likely to have fewer impacts on development of innovations that still require a lot of development.
- Underlying market structure. Both the rate and type of change may differ depending on whether the end use industry is competitive, oligopolistc or monopolistic. High levels of concentration tend to blunt the signal provided by higher prices for technological development. On the other hand, strategic imperatives may lead to competition for new technologies to allow a company to gain a strategic advantage over its competitors.
- Firms' ability to imitate innovations. This will impact on the rate of deployment of new technologies induced by policy instruments.
- Cost of innovations.
- Degree of leakage to other activities, with the higher the level of leakage the lower the level of effort (relative to the optimal amount) in technological development. This is not likely to be major issue for the energy industry as most of the technological developments are likely to be highly specific to that industry.

One of the key conclusions emerging from the literature on technological change is that it is important to distinguish between effective and optimal technological inducement. Whilst past studies have shown that both regulations and price incentives can be effective in inducing technological change, they can differ in the rate and direction of technical change and the optimality of that change. Regulations tend be narrowly focused and may lead to technical change in limited and high cost areas. Price or market based incentives

---

[38] A.B Jaffe, R.G. Newall and R.N. Stavins (2003), "Technical change and the environment", in *Handbook of Environmnetal Economic, Volume 1*, edited by K-G Maler and J.R Vincent, North Holland

[39] R.G.Newell, A.B. Jaffe and R.N. Stavins (2006), "The effects of economic and policy incentives on carbon mitigation technologies", *Energy Economics*, Volume 28 (5-6), pp 563-578; S. Rao, I keppo and K. Riahi (2006), Importance of technological change and spillovers in long term climate policy", The Energy Journal, Special Issue, pp123 – 140.

will typically lead to development of technologies with the greatest benefit to market as a whole[40].

A second conclusion is that the relative effectiveness of the policies tends to be sensitive to the nature of the costs of new technologies. Upfront subsidies can be more effective than prices signals with technologies with high upfront costs. This is likely to be the case with some of the new technologies in the energy industry (e.g. carbon capture and storage).

However, this does not preclude the use of price incentives to encourage technological development. Rather, a key conclusion emerging from many studies is that a raft of measures would be required to optimise technological development: increased R&D funding for novel technologies, upfront subsidies to demonstrate large scale technologies and price signals to reinforce learning by doing and the adoption of small scale technical development[41]. As stated in one study, a combination of subsidies and price incentives "allows significant carbon abatement over the near term (*due to price signals*) by diffusing existing technologies, while at the same preparing new technologies for the longer term".

5.3 Appraisal

A robust approach to modelling induced technological change has yet to be developed. Each approach has its advantages and disadvantages[42].

Methods of incorporating technical change in models include:

- *Exogenous input augmenting technological change* — this is the main technique used in most top down models. Technical change is assumed to occur at an exogenous constant rate through time. The rate of change is derived from historical estimates (say, for example, based on estimates of the historical rate of energy efficiency improvement).
- *Exogenous backstop technology* — employed in top down and bottom up models, this method assumes the appearance of some wholly new technology as a response to higher prices. The cost and characteristics of this new technology is assumed exogenously. Use of this approach has become more common.
- *Endogenous price induced input augmentation* — whereby the rate of input augmenting technical change various as a function of prices (usually formulated as a function of prior year prices). This technique is rarely used.
- *Endogenous learning by doing* — the cost of a new technology in a year is a function of the level of utilisation of the technology or rate of adoption (as defined by capacity installed) in prior years. This approach is also being used more often.

---

[40] S.Kerr and R. Newall (2004), "Policy induced technology adoption:evidence from US lead phasedown", Journal of Industrial Economics, Volume 51(3), pp 317-343

[41] K. Palmer and D. Burtraw (2005), "Cost effectiveness of renewable electricity policies", *Energy Economics*, Vol 27 (6), pp 873 - 894

[42] The arguments in this section are largely derived from I. Sue Wing (2006), *Energy Economics.*

The exogenous input augmenting technological change approach has the advantage of being grounded on historical data rather than subjective judgements, which will include the effects of various factors on technological change. A major disadvantage is that the rate of change in technology cost is predetermined and invariant to the effects of climate change. Therefore, substitution is the only method for abatement in these models under climate change policies. The approach also does not allow for radical technological change.

The backstop method allows for specific modelling of technological change by specifying a general new abatement technology. The parameters of this new technology are specified on engineering judgement, which can be highly subjective particularly for new technologies that may not be developed until far off into the future[43]. A second disadvantage is what is known as the "flip-flop" effect, whereby the choice of new technologies switches suddenly to only the backstop technology once the trigger price is reached. This is typically avoided by either imposing restrictions on the level of adoption of backstop technologies or for the modeller to apply other constraints to limit penetration of the back-stop technology[44].

The price induced input augmentation method is theoretically more robust, but is rarely used because of the difficulty of discerning the price function from historical data. Further it may not capture the full impact from learning by doing and the impact of spillovers on technological change.

The learning by doing approach is also grounded on real world experience. New energy technologies, such as renewable or low emission technologies, are still in a relatively early stage of market development. Therefore, costs of those new technologies are generally more expensive than the competing conventional energy technologies. Uptake of these new technologies typically experiences a dynamic trend in cost reduction over time due to learning by doing through market experience. This price experience relationship is typically presented as a so called progress ratio, which reflects the achieved percentage in cost reduction for every doubling of cumulative production volume. The learning rate is the inverse of the progress ratio.

Generally, learning by doing can be gained through improvements in various areas, such as:

- Technical learning.
- Manufacturing improvements.
- Large-scale production

---

[43] This is important in the context of modelling of the impacts of abatement policies on energy markets as the estimates of the impacts are typically affected by assumptions on the future cost of new low emission technologies such as carbon capture and storage and for potential cost reductions for existing low emission technologies such as renewable energy. One way to limit this disadvantage is to obtain a consensus from a range of experts on the key assumptions for these new technologies.

[44] A major criticism of past modelling efforts in the international literature is that it is often difficult to determine how the modellor arrived at these constraints and the parameters for the various technologies employed.

Energy systems experience learning by doing in various learning sub-systems, which are all interrelated. Hence, the potential for learning by doing must be carefully examined for each energy technology and country or region. A literature review on learning curves revealed that progress ratios can vary significantly between energy technologies and regions and over time.

Not all the reduction in unit costs can be attributed to learning by doing effects. Other factors can also play a role. Firstly, continuing research and development can also reduce costs. This factor has been ignored in most studies attempting to estimate the learning by doing effect. Statistical analysis that omits the impact of research and development can lead to overestimates of the learning by doing effect. Secondly, econometric estimates of the learning by doing effect may not be able to distinguish between cause and effect as lower costs can also lead to higher uptake of the technology. A recent study has shown that these factors need to be accounted for in the specification of a model of learning by doing, otherwise the cost reductions through learning by doing can be overestimated for evolving and emerging energy technologies[45].

Distinguishing cost reductions through economies of scale and learning by doing may also be necessary. Estimates of learning by doing rates often include the impact on cost reductions of both learning by doing and improved economies of scale in production.[46] One study estimated that for wind generation, the most important factor leading to cost reductions has been economies of scale (increasing turbine size and wind farm size), which is estimated to contribute over half of the potential future cost reduction[47]. Separating out economies of scale would only be relevant in this study to the extent that Australia's contribution to overall production levels is modest or that economies of scale have already been achieved as a result of large scale uptake of renewable energy technologies internationally.

Other issues with the use of learning by doing rates include:

- Use of learning by doing can give rise to multiple equilibria and the resulting instability of the model solutions. This is typically handled by either examining in detail all equilibria to derive consistent insights or alternatively by imposing other decision rules to allow a choice amongst the equilibria.
- It can also lead to the flip flop effect again requiring subjective restrictions to prevent overdependence on uptake of technologies whose cost and availability are highly uncertain[48].

---

[45] T. Jamasb (2007), ibid.

[46] A. McDonald and L. Schrattenholzer (2001), "Learning rates for energy technologies", *Energy Policy*, Vol. 29, pages 255 -261

[47] IEA (2001), *Long-term Research and Development Needs for Wind Energy for the Time Frame of 2000 to 2020*, report by the Executive Committee of the International Energy Agency Implementing Agreement for Cooperation in the Research and Development of Wind Turbine Systems.

[48] As I Sue Wing (2006) states that "published runs typically do not exhibit such [flip flop] behaviour because additional constraints …. tuned to the modeler's sense of plausibility, are widely used to make the outputs appear more realistic. Like a sausage, the final product is evidently tasty, but the method of producing it is best left shrouded in mystery."

- Use of this method assumes that the cost reduction from learning by doing is a costless by-product of adoption, when in reality further costly research and development may be required.

To ensure broader economic impacts of uptake of new technology are understood, while allowing greater technological detail, there is an increasing tendency to link bottom up models with national and global economic models. This technique also is becoming prevalent in new modelling approaches that seek to endogenise technical change in climate change modelling. As noted by Kohler et al:[49]

> …technical change, progress and diffusion are driven by the development of knowledge capital and its particular economic characteristics of being partly non-rival and partly non-excludable. This leads to increasing returns from spillovers, with market failures due to oligopolistic competition and R&D expenditures less than the social optimum. There are two main formulations modellers use to capture this common idea: experience curves and knowledge capital. A two factor experience curve has cost reductions from R&D (learning by searching) and cost reductions from installed capacity (learning by doing). The knowledge capital formulations are equivalent to learning curves, because they describe productivity increases from R&D expenditures or capital investment. There is a tendency in the top-down models towards becoming hybrid models, because in order to incorporate endogenous technological change, they have to represent some detail in the relevant sectors, usually energy but also transport in some models.

Several attempts have been made at linking bottom up and top down models to provide more robust estimates of technological change and impacts from abatement policies. Options for integrating the modelling approaches include:

- Using a simple iteration approach, whereby demand side outputs from the top down model (incorporating behavioural responses) are incorporated in the bottom up model and the resulting supply side outputs from the bottom up model are then incorporated back into the top down model. The process may be repeated several times until stable results are achieved. This is the simplest approach and can work effectively where common inputs are used in both modelling approaches. This is the approach typically adopted in Australia.

- Hybrid modelling whereby an integrated economic energy model is built by "meshing the description of the economy in terms of specific technologies (as in bottom up models) with the reliance on real market data to explain behaviour (as in top down models)".[50] The simplest approach has been to use simple regression techniques to determine the behavioural parameters for use in bottom up models. More complex approaches include the incorporation of more detailed mathematical representations of the energy sector in top down models.

---

[49] Kohler J., Grubb M., Popp P. and Edenhofer O. 2006, The Transition to Endogenous Technical Change in Climate-Economy Models: A Technical Overview to the Innovation Modeling Comparison Project, *The Energy Journal*, Special Issue: Endogenous Technological Change and the Economics of Atmospheric Stabilisation,,pp 44.

[50] Rivers, N, and Jaccard, M. (2005), "Combining top-down and bottum-up approaches to energy-economy modelling using discrete choice models", *The Energy Journal*, Vol 26 (1), pp 83 - 106

- Agent based modelling approaches, whereby the behaviour of major players in the stationary energy markets are modelled explicitly in bottom up models. Thus behaviour is modified to include other objectives other than based solely on least cost outcomes. The range of behaviours is specified mathematically based on historical observation of behaviour of market participants.

True endogenous technological change has not been incorporated fully in any climate change modelling in Australia to date.

5.4 Issues of modelling induced technical change in Australia

A problem for modelling the impacts of a domestic emission trading scheme on technological development in Australia is that most of the studies are based on models for large scale economies like the United States or for the world economy as a whole. There are potential implications of this for the Australian context

First, would the scale of adoption in Australia lead to sufficient cost reduction through learning by doing to a similar extent as would occur under an international policy setting? Although there would be some learning by doing from international policy regime that would reduce costs of adoption in Australia, there are still likely to be some areas of learning by doing that would uniquely benefit the use of these technologies in Australia. For example, the development of carbon storage facilities taking into account Australia's geology. Thus, there is likely to be some potential for learning by doing arising from abatement or technology development policy in Australia, although the level of reduction may be smaller than indicated in overseas studies.

Second, could Australia essentially free-ride on such learning by doing in overseas countries and delay the introduction of any abatement policy until such time as costs of these technologies overseas are reduced? This may be possible, but it is likely that all developed countries would likely need to implement abatement policies in conjunction. There may also be some early mover advantage from early adoption of new technologies.

5.5 Modelling issues

Achieving comprehensive endogenous technical change in a top down Australian model is likely to be difficult to achieve in the near term, as there are substantial modelling and data challenges. Resolving these issues would likely consume too much time and cost to be of much use for the modelling undertaken for the Garnaut Review.

It will therefore be necessary to tailor the modelling tools to best fit the need, recognising that the results will never be comprehensive. In addition, modelling the benefits of specific policy to accelerate uptake of technology may need to resort to qualitative assessment. Judgment will always be required — informed by modelling.

A potential approach to incorporating the impact on technological change in the MMRF model framework is as follows:

- Develop learning by doing rates for the various technologies that are part of the technologies considered in the MMRF model (confined to key segments such as electricity generation and direct combustion activities). The learning by doing rates would be based on published studies of the learning by doing for each technology based on country wide rates of adoption. The rates would be adjusted for likely adoption levels in Australia. Empirical estimates of the learning rates should also be adjusted down to separate out the impacts of ongoing research and development and the potential impacts of economies of scale of production. Based on the small number of studies that have considered this issue, we suggest halving the learning by doing rates to account for these factors.

- Recognise that learning by doing involves the uses of resources during the learning process. This can be captured by assuming higher costs for the technologies (higher embodied labour and capital to represent resources expended in the learning process).

- Account for crowding out affects as resources expended on learning by doing and research and development in low emission technologies is not expended on other activities. To be conservative, assume either (1) that if additional research and development is carried out in Australia that it is at the expense of other research and development (applied as across the board reductions in research and development in each activity by proportion to total research and development), or (2) if the research and development is funded from revenue collected from permit auctions, then this should be modelled as a tax on private entities.