Estimating the household benefits of undergrounding electricity distribution networks

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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. To my knowledge, it contains no material previously published or written by another person, except where duly acknowledged in the text.

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Abstract

Underground low-voltage electricity networks have several advantages over overhead networks including reliability of supply, safety and improved visual amenity. The economic viability of replacing existing overhead networks with new underground networks depends on the value of these benefits to households, but no complete value estimates are available. In this thesis, the focus is on benefit valuation, with two methods used to gather information regarding the benefits of undergrounding in a case study area – the hedonic price method, in which household preferences are revealed through purchases in the real estate market; and, the stated choice method, in which preferences are elicited using a survey. The empirical data were collected in Canberra, Australia.

Evidence from the stated choice survey suggests the value of benefits to households would be at least A$6,838 per household on average, with a 95 per cent confidence interval of A$5,444 to A$8,253. The demand function underlying this estimate is broadly consistent with evidence from the hedonic price study, which measures the benefits to a *marginal* purchaser in the real estate market. Some 31 per cent of households in the study areas chose to pay an estimated price premium of 2.9 per cent (between 0.4 and 5.3 per cent with 95 per cent confidence) to purchase a property serviced by underground networks (holding constant other property characteristics).

In addition to estimating values for policy use, the thesis focuses on one challenge associated with applying each method. The hedonic price method can be difficult to apply in cities where retrofit undergrounding has yet to take place, since the type of network infrastructure tends to be highly correlated with other property characteristics, such as building age and distance to the central business district. In this thesis, it is shown that this problem can be overcome by analysing data from areas with a mix of underground and overhead infrastructure where properties are otherwise relatively homogeneous.

Turning to the stated choice method, this thesis supports a growing body of literature finding violations of the assumptions typically made when analysing responses to a sequence of choice tasks; in particular, the assumptions of truthful, independent response and stable preferences. Preferences stated in the first of a sequence of binary choice tasks were not significantly different from those stated in an incentive compatible single binary choice task, but, in subsequent choice tasks, willingness to pay for undergrounding was lower and responses were influenced by cost levels observed in past questions.

An understanding of the decision processes (or heuristics) underlying this influence is required to ensure value estimates are not biased. The response patterns identified by novel econometric analysis in this thesis are consistent with certain types of heuristics involving strategic misrepresentation and/or value learning. The results suggest practitioners should test whether the standard assumptions are violated, and, if they are, account for the violations either by econometric techniques, such as the models presented in this thesis, or by simple sample selection approaches, such as focusing on responses to the first question presented to each respondent.

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List of acronyms

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AIC	Akaike information criterion
AVC	Asymptotic variance-covariance
CAPI	Computer-assisted personal interview
CBD	Central business district
CE	Choice experiment
CS	Compensating surplus
DCCV	Dichotomous choice contingent valuation
ECLC	Equality-constrained latent class
FOC	First-order condition
GML	Generalised mixed logit
ML	Mixed logit
MN	Multinomial
MNL	Multinomial logit
MWTP	Marginal willingness to pay
NBN	National Broadband Network
NOAA	National Oceanic and Atmospheric Administration
RB	Repeated binary
SB	Single binary

SP	Stated preference
WTP	Willingness to pay

1 Introduction

1.1 Undergrounding electricity and telecommunications wires

In recent decades, it has become standard practice in Western nations for low-voltage electricity distribution and telecommunications networks to be installed underground in new housing developments. Prior to that, these networks were typically installed as overhead wires on poles in lower-density residential areas. As a result, many suburban areas in cities around the world are still serviced by overhead networks. A number of cities have implemented or are considering programs to replace these overhead networks with new underground infrastructure.

This network conversion process, which is referred to as *undergrounding*, involves several steps. Typically, the first step is to install new electricity and telecommunications wires under the verge in each street using either open trenching or underground horizontal drilling.[1] A similar process is then used to install new wires from connection pillars (typically positioned near the front corner of every second property) to the meter box at each house. The new underground wires are then connected to the existing meter box and telecommunications connection box within each residence and disturbed work areas are re-instated and repaired. After supply is changed over from the overhead to the underground network, existing poles and overhead wires are removed.

[1] The use of underground drilling is more expensive than open trenching, but it limits the areas disturbed and reduces the impact on local residents during underground installation works.

Undergrounding is taking place through systematic, ongoing programs in a number of locations in the United States of America, including in several Californian cities and in a few cities in Florida, Maryland and Virginia. The New Zealand cities of Auckland and Wellington have also implemented undergrounding programs. In the United Kingdom, programs are focused on undergrounding network infrastructure in national parks and areas of outstanding natural beauty.

In Australia, only the cities of Perth and Darwin have implemented formal undergrounding programs, but interest in more widespread undergrounding has been renewed by the recent commencement of the roll-out of the National Broadband Network (NBN) (Bester, 2010; Economic Regulation Authority, 2010; Energy Networks Association Limited, 2010). Most of the households to be connected as part of the first phase of the NBN roll-out in the State of Tasmania are to be serviced by overhead cables installed on existing poles. As the roll-out proceeds, consideration needs to be given to whether a better long-term outcome could be achieved by installing NBN cables underground and relocating low-voltage electricity networks at the same time.

1.2 The net economic benefits of undergrounding

Undergrounding is an expensive exercise, with major civil works required to install the new wires and remove the existing infrastructure. This expense must be justified by the mixed bundle of benefits conferred by undergrounding, which includes reduced ongoing network maintenance costs, improved aesthetics, better safety during storms and fires, and improved supply reliability. It is important that policymakers evaluate economic viability before proceeding with an undergrounding program. That is, it is important they consider whether the benefits of undergrounding would exceed the costs, or, equivalently, whether the net benefits of undergrounding would be positive.

1.2.1 The costs of undergrounding

The primary cost of undergrounding is the initial capital cost. This includes the cost of new assets, such as wires and substations, and the cost of the civil works, including trenching and/or drilling, installing new wires, reconnection work within each residence, and removal of existing overhead infrastructure. This cost varies by location depending on several factors, including the soil conditions and whether existing telecommunications wires are reticulated on poles. In Perth, soils are typically sandy, existing telecommunications wires are already underground, and civil works contractors can be offered certainty of work as part of Western Australia's ongoing underground power program. The capital cost of undergrounding in Perth is approximately A$10,000 per property (Office of Energy, 2008). In other areas, where conditions are less favourable, the capital costs can be much higher. For example, in South Australia, these costs exceed A$20,000 per property (ETSA Utilities, 2009). In a few small undergrounding projects in Florida, capital costs have ranged from US$489 to US$4,609 per customer (Infrasource Technology, 2007b). These costs are lower than those experienced in Australia, due, at least in part, to the fact that some of the project areas are dominated by multi-dwelling units.

1.2.2 The benefits of undergrounding

Undergrounding confers a mixed bundle of benefits on network service providers, households and the wider community. Network service providers benefit from lower ongoing maintenance costs. In particular, the costs of periodic pole inspections, reinstatements, and replacements are avoided once undergrounding has taken place. Undergrounding also leads to some energy savings due to the lower energy losses from the heavier cables that can be used in the lower-temperature underground environment.

Households situated in areas where undergrounding takes place benefit in several ways. First, the appearance of residential areas is improved by the removal of visible poles and wires. Trees are allowed to grow to a more natural shape and, in some instances, views from residential properties may become less polluted. In some areas, households are responsible for keeping trees clear of power lines on their property. When wires are placed underground, households save on fees paid to tree surgeons and time and safety costs associated with undertaking trimming themselves. Where vegetation management is a responsibility of local government, these benefits flow to the government (and the community it represents).

Underground networks are less exposed to risks of damage from fires, strong winds, storms and other severe weather events. This leads to safety benefits from reduced risks of electrocution from fallen wires and supply reliability benefits from reduced frequency of electricity and telecommunications outages.

Households in areas with overhead wires are typically connected to the network by an overhead service line from a nearby pole. As a result, some restrictions are imposed on the use of yard space beneath these service lines. In some instances, the positioning of service lines prevents the installation of swimming pools or garden sheds. Undergrounding leads to the removal of these restrictions.

Where overhead networks are reticulated along the street verge, there are benefits from reduced incidence and severity of motor vehicle accidents. If, on the other hand, overhead networks are reticulated along the back spine of properties, undergrounding removes the need for network operators to access residential properties to conduct inspections or maintenance on the network. This access can be inconvenient for households; for example, where arrangements need to be made with regard to pets kept in back yards.

1.3 Valuing the benefits of undergrounding

The benefits described above are not as easily quantified as the capital costs of undergrounding. The savings to electricity and telecommunications businesses in terms of lower energy purchases and network maintenance costs can readily be estimated, but these benefits are usually only a small percentage of the cost of undergrounding. The expense of undergrounding must be justified primarily by the benefits to households. The estimated value of household benefits is therefore a key component in the economic evaluation of undergrounding programs.

Here lies a major problem. There appears to be no complete estimate of the benefits to households available in the literature. Supply reliability improvements have been valued using contingent valuation (Carlsson and Martinsson, 2007; Layton and Moeltner, 2005) and choice experiments (Accent, 2008; Beenstock *et al.*, 1998; Carlsson and Martinsson, 2008a), but it seems no studies have attempted to value the overall household benefit from undergrounding, including amenity and safety benefits. Several studies have examined household disutility from proximity to *high-voltage transmission* infrastructure (Colwell, 1990; Des Rosiers, 2002; Gregory and von Winterfeldt, 1996; Hamilton and Schwann, 1995;

Ignelzi and Priestley, 1991; Kinnard and Dickey, 1995; Sims and Dent, 2005), but this type of infrastructure affects households quite differently from low-voltage distribution infrastructure. The infrastructure is larger and, in contrast to low-voltage network infrastructure, is rarely situated on residential property in urban areas. Perhaps the most significant difference is the perceived health risks associated with electromagnetic fields generated by high-voltage wires.

As a result of the absence of complete benefit estimates, the 1998 Australian Government investigation into the costs and benefits of undergrounding distribution networks (Commonwealth Department of Communications Information Technology and the Arts, 1998) and the subsequent investigation by the New South Wales economic regulator (Independent Pricing and Regulatory Tribunal, 2002) categorised most household benefits as unquantifiable. This led to the conclusion in both reports that widespread undergrounding is not justified on the basis of *quantifiable* costs and benefits. A similar situation has occurred in studies conducted in the United States (InfraSource Technology, 2007a).

The absence of household benefit estimates in the literature is not for want of available techniques. Indeed, environmental economists have been estimating household values for the removal of urban disamenities for many years. Most studies have employed either the *hedonic property price* approach or *stated preference* techniques.

The hedonic price method uses data from the real estate market to gather information on households' preferences for underground networks as *revealed* through their purchase decisions. Its purpose is to isolate the contribution of specific property attributes to the overall sale price of a property. These contributions are termed *implicit prices*. The method has been used to estimate implicit prices for real estate and associated environmental attributes such as energy efficiency (Dinan and Miranowski, 1989), noise (Nelson, 1982), air quality (Brookshire *et al.*, 1982; Freeman, 1979), quality of schools (Black, 1999), agricultural sedimentation (Bejranonda *et al.*, 1999) and proximity to urban wetlands (Mahan *et al.*, 2000) and landfill (Hite *et al.*, 2001).

In contrast, stated preference methods attempt to elicit households' preferences by asking questions in a survey context. This approach has become increasingly popular over recent decades due to its ability to elicit preferences with respect to goods that are not observable in an actual market. In particular, the stated choice approach, in which survey respondents are asked to indicate their preference between designed scenarios, has become a common technique for valuing environmental benefits.

The literature makes a distinction between two types of stated choice survey. The earliest environmental valuation studies employed the *contingent valuation* technique (Carson and Mitchell, 1989), in which respondents are presented with a choice between the status quo and a single policy scenario at specified cost. Over the past decade, this technique has come to be complemented by a broader class of stated choice survey, termed the *choice experiment* or *choice modelling* (Bennett and Blamey, 2001), which was originally developed in the transport economics (Hensher and Truong, 1985) and marketing (Hensher and Louviere, 1983) disciplines. Choice experiments typically involve presenting multiple choice tasks, where each task offers multiple policy scenarios described by a set of relevant attributes.

In principle, both the hedonic property price approach and stated choice methods could be used to quantify the benefits households would derive from undergrounding. However, there are many challenges associated with applying these methods. The hedonic price approach can be difficult to apply when property characteristics are highly correlated. This *multicollinearity* problem is common when estimating the implicit price of underground networks in cities where retro-fit undergrounding is yet to take place. As a result, it can be difficult to disentangle the price effect of underground wires from the effects of other property characteristics, such as building age and proximity to the central business district. Even when this implicit price *can* be estimated, available data are rarely sufficient to identify the demand function required to estimate the benefits of undergrounding across all households.

One of the challenges associated with stated choice methods is that of understanding the implications of *task dependence* in the choice data. Task dependence refers to the situation in which responses are influenced by information observed in the course of completing the choice tasks. Several studies have found task dependence in choice data by identifying violations of one or both of the standard assumptions of truthful response and stable preferences (for example, Ariely *et al.*, 2003; Bateman *et al.*, 2008b; Boyle *et al.*, 1985; Cameron and Quiggin, 1994; Carson *et al.*, 2009; Day *et al.*, 2009; Day and Pinto, 2010; DeShazo, 2002; Hanemann *et al.*, 1991; Hensher and Collins, 2010; Herriges and Shogren, 1996; Holmes and Boyle, 2005; Ladenburg and Olsen, 2008; McFadden and Leonard, 1995; Swait and Adamowicz, 2001). Some of these studies have speculated as to the respondent *decision processes* (or *heuristics*) that lead to task dependence, such as *strategic misrepresentation* (Carson and Groves, 2007), and *value learning* (Plott, 1996). Only a few have investigated which of the various heuristics raised in the literature best explains the response patterns in a given data source (Bateman *et al.*, 2008b; Day and Pinto, 2010; DeShazo, 2002). It seems that none has investigated the possibility of heterogeneity in response behaviour over the population; that is, the possibility that each of the heuristics explains the response behaviour of a sub-group of the population.

1.4 Research objectives

The objective of this thesis is to make a contribution towards addressing the research gaps identified in the preceding discussion. In particular, the intention is to:

1) estimate the value of benefits to households from undergrounding low-voltage electricity and telecommunications networks in a specific case study area;

2) investigate whether the hedonic price approach can be adapted to overcome the multicollinearity problems generally present in cities where retro-fit undergrounding is yet to take place; and

3) develop the understanding of the respondent decision processes that lead to task dependence in stated choice data by:

    a) investigating whether *elicitation format*, in terms of the number of choice tasks per respondent and the number of alternatives per choice task, influences the extent to which respondents employ heuristics that lead to task dependence; and

b) investigating whether sub-groups of the population respond in accordance with different heuristics.

1.5 Research approach

These objectives were addressed by the collection and analysis of data from two sources – real estate sales data, and stated choice survey data. Both data sources were collected in the city of Canberra, Australia. Electricity networks in Canberra have been installed underground in new housing developments since the late 1980s, but approximately 70 per cent of Canberra households (about 100,000 households) are situated in older suburbs serviced by overhead networks.

The real estate sales data are used to estimate the implicit price of underground wires (as opposed to overhead wires) in Canberra, holding constant other property characteristics. Since very little retro-fit undergrounding has taken place in Canberra, the data are also used to investigate whether a selective sampling approach can be used to overcome the problems caused by multicollinearity in the explanatory variables in the price function. The selective sampling approach to be investigated is similar to the boundary discontinuity approach used to value school quality (Black, 1999; Davidoff and Leigh, 2008; Gibbons and Machin, 2003). It can be applied where property attributes change continuously over space, but the attribute of interest changes discretely at a boundary. In this case, it involves comparison of the prices of properties that are broadly similar to each other, but on opposite sides of boundaries between adjacent areas serviced by underground and overhead wires. As will become clear, the implicit price estimated using this approach provides limited information about the benefits to households from undergrounding. It represents the value placed on underground wires by the *marginal* purchaser of that attribute in the real estate market. The correct measure of benefits is the average (or total) value placed on underground wires across all households. In principle, this can be estimated directly using the second data source – the stated choice survey data.

The stated choice data analysed herein were collected using an internet survey of households serviced by overhead wires in Canberra. They are used to develop an understanding of the respondent decision processes underlying any task dependence. This understanding informs the approach used to estimate the benefits to households from undergrounding existing overhead networks in Canberra.

A split-sample treatment of elicitation format was employed in the survey to facilitate examination of the influence of elicitation format on the extent to which respondents employ heuristics that lead to task dependence. Three formats were used in the survey – a single *binary* choice between the status quo (the current overhead network service) and an undergrounding option, an expanded elicitation format comprising a sequence of four binary choice tasks, and a further expanded elicitation format comprising a sequence of four *multinomial* choice tasks each comprising the status quo and *two* undergrounding options.

Three studies are used to develop the understanding of the decision processes that lead to task dependence. In the first, estimates of household benefits derived from the single binary choice data are compared to those from the repeated binary choice data to examine whether the theoretical property of *incentive compatibility* is important in practice. A second study examines the effect on responses to the repeated binary choice survey of the cost of undergrounding options observed by respondents in earlier choice tasks. The nature of this effect provides some insight into the decision processes underlying the survey responses. The third study develops a novel approach to estimating, up to a probability, the proportion of respondents behaving in accordance with each of the broad types of decision process in both the repeated binary and multinomial choice formats.

In some cases, it is possible to pool data collected using revealed and stated preference methods (Louviere *et al.*, 2000); however, this is not true of the case studies presented in this thesis. Both methods are studied here because either may be preferred by policy makers depending on the time and financial resources available when considering the merits of undergrounding in a given area. Although the hedonic price is not a measure of average value across households, it can be checked for consistency with the demand function that is estimated in the stated choice study to derive the average value. Obtaining consistent results across the two methods would add robustness and defensibility to the benefit estimate from the stated choice study.

1.6 Outline of the thesis

The thesis is structured as shown in Figure 1.1. There are three parts to the thesis other than the introductory and concluding chapters. The first part outlines the motivation for the research and develops a theoretical framework (Chapter 2 to Chapter 4). The second part details the research design and the collection of data in accordance with that design (Chapter 5 and Chapter 6). The third part sets out the results of the analysis of the data (Chapter 7 to Chapter 11).

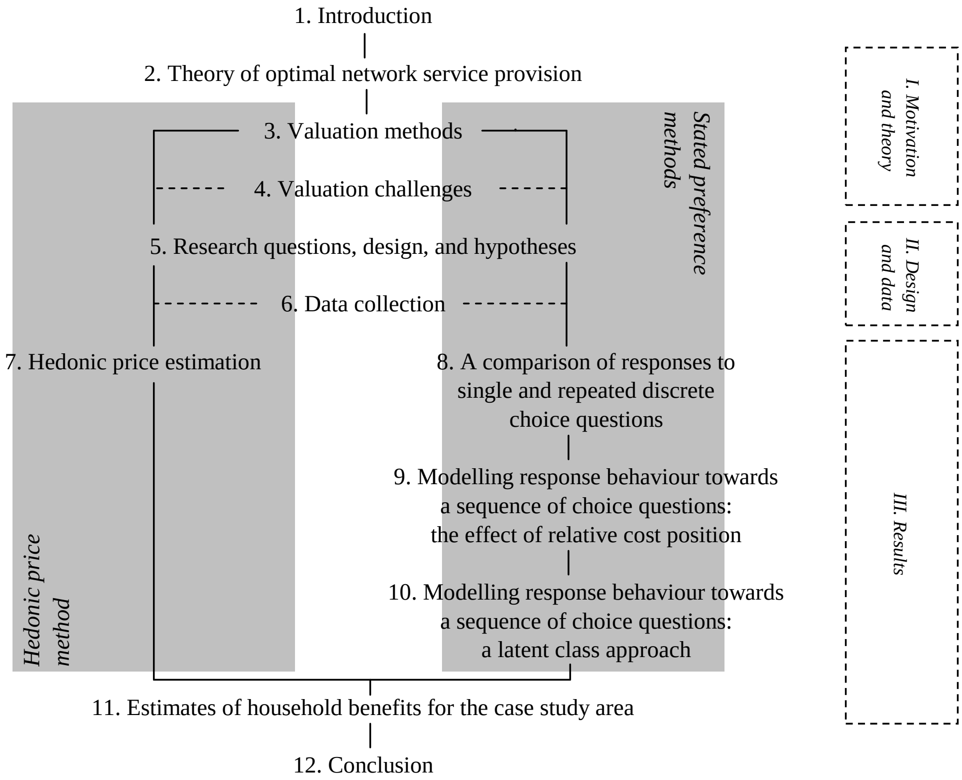

Figure 1.1: Structure of the thesis

Chapter 2 describes the natural monopoly characteristics of the electricity network service and discusses the governance structures typically associated with natural monopoly markets. Formal economic models are used to establish the role of the social value of network service quality in determining whether network infrastructure investments, such as undergrounding, would result in a net economic benefit.

Chapter 3 outlines two methods that can be used to gather information on household preferences for the network service quality improvement that would result from undergrounding – the hedonic price method and stated preference methods. The outputs from the methods are related to the social value of network service quality and the formal economic framework developed in Chapter 2.

Chapter 4 explores a challenge associated with applying each method. It describes the difficulties associated with applying the hedonic price method when property characteristics are highly correlated. It also discusses the implications of, and potential explanations for, task dependence in stated choice data.

In Chapter 5, research questions formed on the basis of the challenges explored in Chapter 4 are presented. A research design developed to address the questions in a case study is described and the hypotheses to be tested are specified.

Chapter 6 details the collection of data in the case study area (Canberra, Australia) based on the approaches developed in Chapter 5. Two data sources were collected – real estate sales data and responses to an internet stated choice survey.

Chapter 7 sets out an analysis of the real estate sales data using the hedonic price method. The implicit price of underground wires in Canberra is estimated and the ability of the sample selection approach to overcome the problems caused by multicollinearity is tested.[2]

Chapter 8 sets out a comparison of responses to two of the elicitation formats employed in the stated choice survey – the single binary choice format, and the repeated binary choice format – with a view to understanding the importance of the theoretical property of incentive compatibility in practice.

Chapter 9 uses data from the repeated binary choice survey to examine the influence on responses of the cost of undergrounding options observed by

[2] The findings of Chapter 7 were reported in an article published in *The Australian Economic Review* (McNair and Abelson, 2010). This author conducted all analysis and took the primary role in writing the article, with Peter Abelson providing helpful discussion at the research design stage and contributions during the writing of the article.

respondents in earlier choice tasks. The identified relationship provides insight into the decision processes underlying the survey responses.[3]

Chapter 10 demonstrates a novel approach to estimating, up to a probability, the proportion of respondents behaving in accordance with each of the broad types of decision process raised in the literature. The model is applied to data from the repeated binary and multinomial choice formats.[4]

In Chapter 11, the results of the preceding chapters are used to inform the specification of a model to estimate the benefits to households from undergrounding in Canberra. The value placed on undergrounding is related to the socio-economic characteristics of respondents and to the specific benefits from undergrounding viewed as most significant by respondents to provide an indication of the areas where undergrounding would yield the greatest benefits.[5]

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[3] The findings of Chapters 8 and 9 were reported in an article published in *Resource and Energy Economics* (McNair *et al.*, 2011a). This author conducted all analysis and took the primary role in writing the article, with Jeff Bennett and David Hensher providing input at the research design stage and contributions during the writing of the article.

[4] The findings of Chapter 10 were reported in an article that has been revised for resubmission to *Environmental and Resource Economics* (McNair *et al.*, 2011c). This author conducted all analysis and took the primary role in writing the article, with David Hensher providing input at the modelling stage and Jeff Bennett and David Hensher providing contributions during the writing of the article.

[5] The findings of Chapter 11 were reported in an article published in *Energy Policy* (McNair *et al.*, 2011b). This author conducted all analysis and took the primary role in writing the article, with Jeff Bennett, David Hensher, and John Rose providing input at the research design stage and contributions during the writing of the article.

Finally, Chapter 12 draws conclusions and identifies areas for future research.