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).

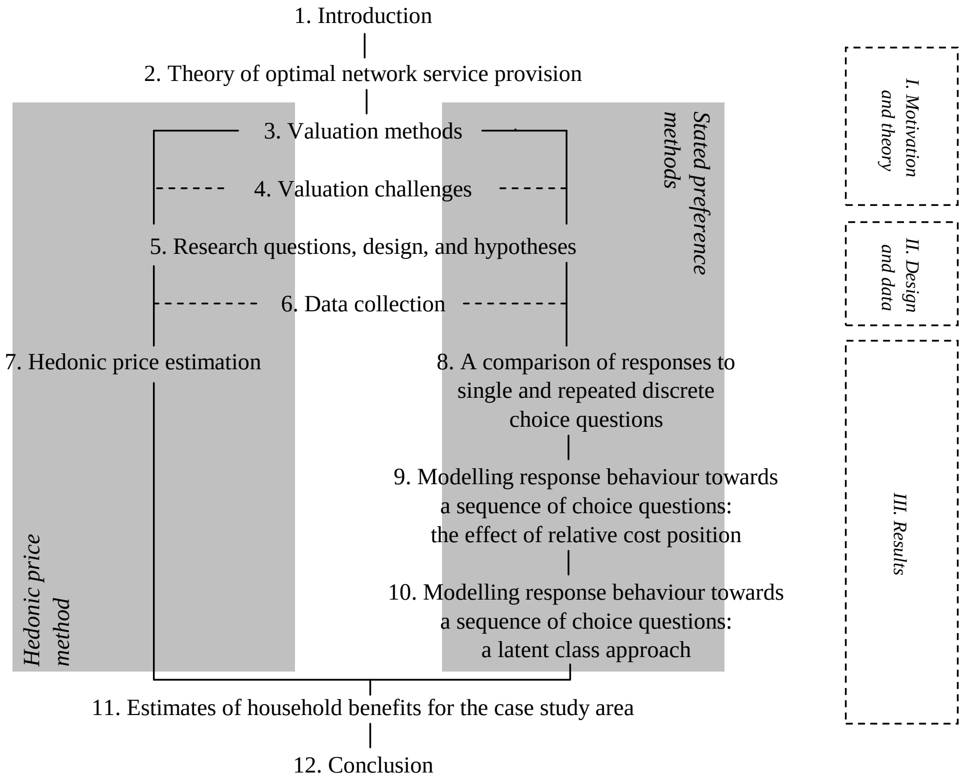

Figure 1.1: Structure of the thesis

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

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[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.

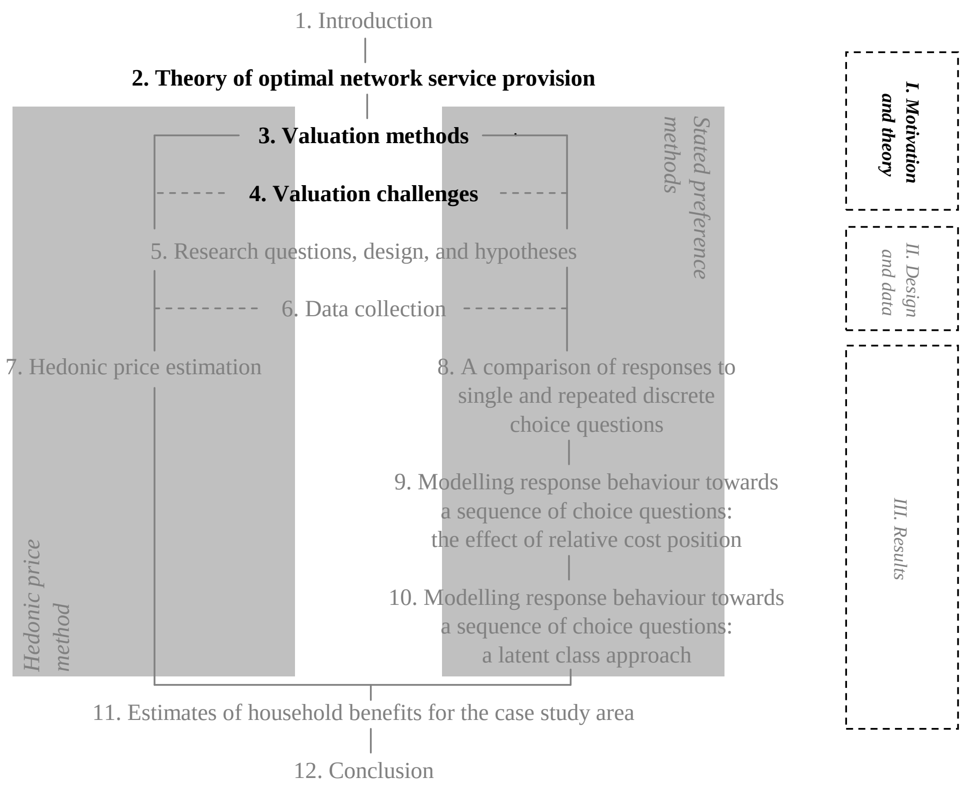
[4] The findings of Chapter 10 were reported in an article that has been revised for resubmission to *Environmental and Resource Economics* (McNair *et al.*, 2011c). This author conducted all analysis and took the primary role in writing the article, with David Hensher providing input at the modelling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

PART ONE:

Research motivation and theoretical framework



2 Theory of optimal network service provision

2.1 Introduction

In the introductory chapter, a broad research question was established with respect to the net economic benefits of undergrounding low-voltage electricity and telecommunications networks. The purpose of this chapter is to formalise a framework for defining the situation where net economic benefits are maximised (the *social optimum*) and to highlight the role that household benefit estimates play in working towards that optimum. Although this chapter does not deal with the primary focus of the thesis, which is the *estimation* of benefits, it nevertheless plays a vital role in the thesis by setting out the *motivation* for the estimation of benefits. In subsequent chapters, the focus shifts to the methods typically used to inform estimates of household benefits. Chapters 3 and 4 examine certain challenges associated with these methods. The remainder of the thesis uses a case study to address research questions related to these challenges and to provide benefit estimates for undergrounding where little or no information was previously available.

In Section 2.2, the *natural monopoly* characteristics of network infrastructure service provision are discussed and, in Section 2.3, the governance structures typically associated with natural monopoly markets are introduced. After a formal economic model is set out in Section 2.4, the implications for net economic benefits are examined under three types of governance structure; namely the unregulated private monopolist (Section 2.5), the public monopolist (Section 2.6), and the regulated private monopolist (Section 2.7). In particular, the focus is on the marginal effect of service quality on social welfare, recognising that undergrounding is a project that enhances the quality of network services. The mechanisms used to achieve net economic benefits under the latter two governance structures are discussed: namely, *cost-benefit analysis* by the public service provider and *quality-adjusted price cap* regulation of the private service provider. The important role of household benefit estimates in implementing each mechanism is highlighted.

2.2 Electricity networks and natural monopoly

2.2.1 Introduction

Before developing an economic model for characterising the amount of undergrounding that would maximise net economic benefits, it is necessary to establish the nature of the market in which electricity network services are provided and consumed. In particular, it is important to recognise that electricity network services are provided in a *natural monopoly* setting.

2.2.2 Electricity networks

Four distinct stages are involved in the provision of electricity to consumers. First, the electricity is generated. Second, it is transported along high-voltage transmission (generally inter-city) networks to substations. Third, it is transported along lower-voltage distribution (generally intra-city) networks to consumers. Fourth, and finally, retail services, such as billing and customer support are provided. Many governments around the world have vertically disintegrated electricity businesses into separate entities dedicated to each of these stages in order to facilitate competition in the generation and retail sectors. The focus of this research is on the third stage: *distribution networks*. Distribution network businesses (or network service providers) operate and maintain the lower-voltage, intra-city networks that transport electricity from substations to consumers. These businesses do not supply electricity *per se*, but rather they provide a transportation service that enables retailers to purchase electricity from generators and sell it on to consumers.

The quality of this service varies on several dimensions. For example, faults in network equipment can cause the supply of electricity to be interrupted or the voltage of electricity supplied to fluctuate. Of particular interest in this research is a dimension that is often overlooked in discussions relating to network service quality – the impact on consumers of the network infrastructure itself. Overhead networks, in particular, may affect consumers by:

1) polluting the aesthetics on and around consumers' properties;
2) imposing a risk of electrocution (particularly when infrastructure is damaged by strong winds or storms);
3) requiring trees to be trimmed away from wires;
4) reducing the amount of yard space available for certain developments (for example, swimming pools or garages); and
5) increasing the risk and severity of car accidents.

It is important to recognise that undergrounding is a project that enhances the quality of network services, where quality is broadly defined to include the dimensions outlined above. It is not the *process* of undergrounding that benefits consumers, but the improvement in network quality that results from that process.[6] In general, there are other means by which improvements in quality can be achieved, though undergrounding may be the only project that achieves significant improvements in particular aspects of quality, such as the impact of the network on neighbourhood aesthetics. The focus in the remainder of this chapter is therefore broadened to one of network service quality. Economic models are used to define the optimal level of network service quality. The optimal amount of undergrounding will be the amount present in the set of projects that achieves that level of quality at lowest cost.

2.2.3 Natural monopoly

The large, fixed costs associated with constructing an electricity distribution network mean that it is less costly for one provider to supply the service for a given urban area than for multiple providers to do so. The single provider in this setting is referred to as a *natural monopolist*. In general, a natural monopoly exists where costs exhibit *sub-additivity* over the relevant range of demand in a market. Costs are sub-additive at a given level of one or more outputs if those outputs can be supplied by a single firm at lower cost than can be supplied by multiple firms. Formally, a cost function, c, is sub-additive at output level Σx_i if $c(\Sigma x_i) < \Sigma c(x_i)$ (Ajodhia, 2006).

[6] In fact, the process of undergrounding may impose some inconvenience cost on households while the capital works take place.

Sub-additivity typically arises from *economies of scale* and/or *economies of scope*.[7] The latter applies only when multiple goods (and/or services) are being produced, so the focus here is on the former. Economies of scale exist where average total costs are decreasing over output. Sub-additivity of costs, and hence natural monopoly, exists if economies of scale apply over a sufficient range of output relative to demand. To illustrate what is meant by "sufficient range", consider the market described by Figure 2.1, where X is the demand for connection to the network, and q is the quality of the network service ($X_q > 0$). The market is a natural monopoly since the total cost of a single provider supplying X_1 is less than the total cost of two firms supplying any pairing of amounts that sum to X_1 (Train, 1991). For example, the figure shows that if the market is split equally between two firms, then the average cost of producing X_1 is $AC_2 > AC_1$. Natural monopoly exists even though economies of scale do not apply over the full range of output, X_1.

Electricity networks, and other utility services, are a classic example of natural monopoly markets. The initial infrastructure investment, which does not vary with output, is considerable relative to variable costs. Duplicating the network would clearly add to total costs. The physical infrastructure is durable and specific to the market. Substitute services, such as private petrol-fuelled generation, are relatively costly. The implications of these market characteristics are considered in detail in the remainder of this chapter.

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[7] Another driver, which is of less relevance here, is economies of density. Developed in the context of airline competition, it is a short-run construct that holds the network fixed but recognises the nature of usage (Brueckner and Spiller, 1994).

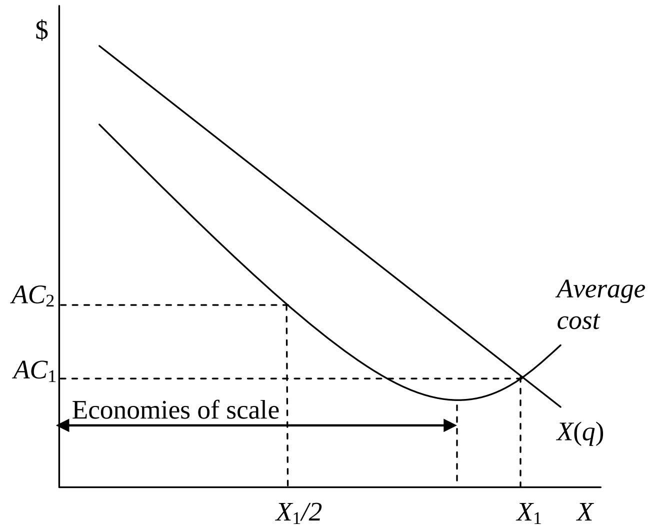

Figure 2.1: Natural monopoly

2.3 Governance structures

Natural monopoly markets are almost universally subject to some form of government intervention. However, the nature of that intervention varies over nations and has varied over time. The mechanisms used to achieve optimal quality outcomes depend on the governance structure that is in place. In this section, the governance structures of interest are introduced. In subsequent sections, these structures and their related mechanisms are discussed in detail.

The economic theory of governance structures for natural monopolies has changed considerably over time. Prior to the 1960s, the "market failure" literature characterised governments as omniscient, benevolent institutions whose role was to intervene in "failed" markets, of which a natural monopoly market is an example. In the 1960s, it was recognised that governments, like all organisations, are flawed. The focus shifted to the economics of property rights, epitomised by Coase's (1959) argument that once property rights in resources have been created, markets allocate resources to their highest value uses and the only role for government is to maintain a legal system that defines property rights and arbitrates disputes. In the 1970s, it was recognised that defining and enforcing property rights is costly, particularly for certain transactions. In recent decades, there has been growing acceptance of the "transaction cost" economics literature (Williamson, 1979), reflected in the awarding of the Nobel Prize to its creator, Oliver Williamson, in 2009. This literature argues that there is a role for a range of governance structures depending on the extent of contractual hazards involved in a given type of transaction.

The choice of governance structure is characterised in Figure 2.2, which is based on similar diagrams presented in Williamson (2000) and Crocker and Masten (1996). In "unassisted market" transactions (Node A in Figure 2.2), parties are free to bargain as they please and there are few ongoing obligations once a transaction has taken place. However, establishing an electricity network requires large, durable investments in infrastructure that is specific to the market. Because this infrastructure has a relatively low value in its next best use, the parties (the network service provider and consumers represented by the government) are essentially locked into a bilateral trading relationship. Difficulties associated with switching to substitute goods or redeploying assets mean there are substantial transactional surpluses on offer. Transaction costs are likely to be lower where contracts are employed as a means of avoiding ongoing haggling and opportunistic behaviour with respect to the division of those surpluses. This theory offers an alternative explanation and justification for government intervention in electricity network services: that governance structures other than the unassisted market evolved because they resulted in lower transaction costs.

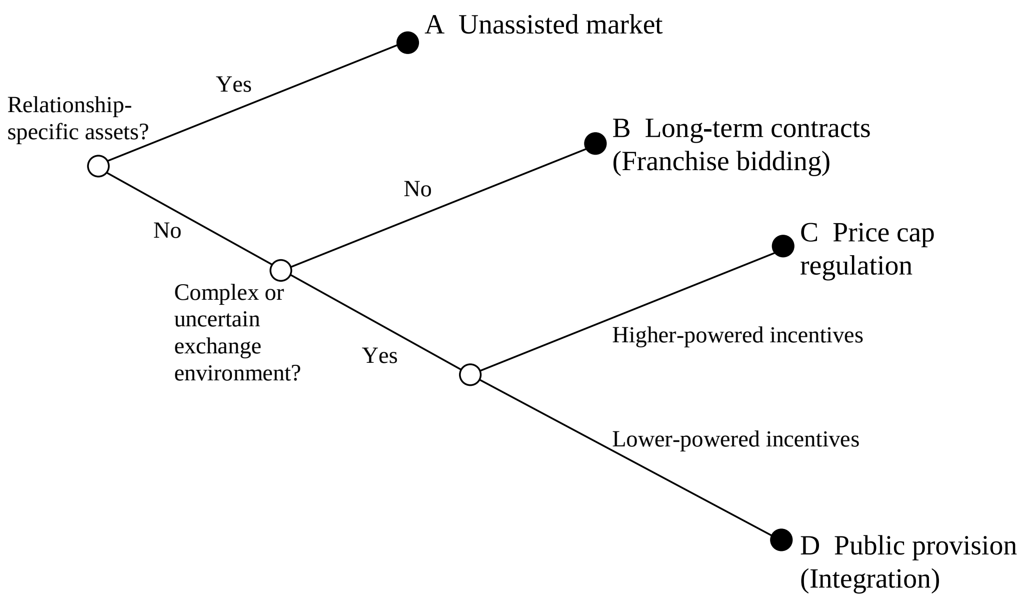

Figure 2.2: Governance structures

An example of a long-term contract is monopoly *franchise bidding* (Demsetz, 1968), which achieves competition *for* the market even though competition *in* the market is not possible (Node B). Complete contracts are not possible due to costs of composition and enforcement and the inability to precisely define obligations under unforeseen changes in circumstances. The more severe the conditions leading to contract incompleteness, the more the parties will rely on relational aspects of the contract and/or reduce the duration of the contract to minimise transaction costs. An explanation for the absence of franchise bidding structures for electricity network services in practice is that uncertain cost and demand conditions mean that transaction costs are lower under regulation (Node C) based on short-term incomplete contracts. If uncertainties are sufficiently severe or if the good is sufficiently complex, then transaction costs may be lower still under "vertical integration"; that is, where the government undertakes to provide the network service itself (Node D). This governance structure avoids the costs of haggling and opportunistic behaviour with respect to terms of trade and facilitates beneficial sharing of information. However, these advantages come at the cost of bureaucratic inefficiencies (Crocker and Masten, 1996). Williamson (2000) argued that this structure should be seen as a last resort. Moving from left to right in Figure 2.2, costs of haggling and opportunistic behaviour are mitigated, but bureaucratic costs are increased. The most efficient structure for a given transaction exists where the total of these two types of cost is minimised.

Historically, public provision has been the dominant governance structure in the electricity networks market, but in the past several decades there has been a worldwide trend towards the more decentralised governance structure of regulation via short-term, incomplete contracts. There is a spectrum of possible regulatory regimes with incentives becoming more high-powered as structures shift from Node D towards Node C. The focus of regulation was initially on addressing socially costly monopoly rents using structures with lower-powered incentives such as *cost-of-service* or *rate-of-return regulation*. Over time, regulation in some jurisdictions has incorporated higher-powered incentives to minimise costs (*price cap regulation*) and, more recently, incentives to achieve optimal quality (*quality-adjusted price cap regulation*).

In the following section, a formal economic framework is developed to define conditions for optimal network service provision. In subsequent sections, three governance structures of interest are characterised using the formal model, with particular focus on the role of the social value of quality in each. The three structures to be examined are the unregulated private monopoly (Node A), price cap regulation of a private monopoly (Node C) and the fully-integrated public monopoly (Node D). An intermediate (between Nodes C and D) structure commonly observed in the utilities sector is the regulation of a government-owned corporation by a government-appointed regulator. The profit-maximising objective of these corporations is often conflicted with other objectives that are imposed, either transparently or otherwise, by their major shareholder – the government. This complicates the translation of the corporation's behaviour to a formal model. Therefore, the analysis in the following sections focuses on the extreme cases – fully-integrated public provision and price cap regulation of a private firm – as a means of demonstrating the various mechanisms used to achieve optimal service quality and the role of the social value of quality in those mechanisms.

2.4 A formal economic framework

2.4.1 Introduction

In this section, a formal economic framework is developed. The intention is not to develop a framework for comparing the merits of the various governance structures. Rather, it is to understand the mechanisms used to achieve improved quality outcomes under different structures, and the role of estimates of the social valuation of quality in those mechanisms. To achieve this objective, it is necessary to analyse the behaviour of market participants within a common framework. Although the behaviour of these participants is a complex phenomenon, the intention is to translate the primary elements of that behaviour to a mathematical framework. As argued by Simon (1957, p. 89), "mathematical translation… permits clear and rigorous reasoning about phenomena too complex to be handled in words." However, it is acknowledged that it is unwise to rely on the mathematical translation alone. Simon (1957, p. 90) also pointed out that the "poverty of mathematics is an honest poverty that does not parade imaginary riches before the world”. In recognition of this “honest poverty”, assumptions are emphasised and, as the chapter progresses, consideration is given to features that may have been omitted or obscured in the mathematical translation.

Central to the approach is the notion of *social welfare*. Social welfare is a function of the welfare (or utility) of the individuals that comprise society. It is a measure by which outcomes can be compared, where a higher level of social welfare represents a more desirable outcome for society. The optimal amount of undergrounding is defined as the amount that maximises social welfare. In practice, the costs of gathering information may mean that it is not efficient to exactly achieve the optimum as it is characterised here, but it is useful as a concept because it defines the goal of policy.

The framework is developed in two stages. First, a *general equilibrium* model adapted from models in Jones (2005) is presented to show how the condition for optimal network service provision is derived from the basic problem of consumers’ constrained maximisation of utility. The assumptions required to simplify the condition to include only the *primary* costs and benefits are emphasised. In a second stage, these main costs and benefits are carried over to a *partial equilibrium* model adapted from Laffont and Tirole (1993) that introduces two additional features that it is not possible to include in the general equilibrium model: *endogenous productivity* and *asymmetric information* between agents. It is this partial equilibrium model that is used in subsequent sections to define the conditions for optimal service provision under the various governance structures of interest. Criticisms of the assumptions underlying the model are acknowledged following the analysis.

2.4.2 General equilibrium foundations of optimal provision

Consider an economy comprising *I* consumers who derive utility, *U*, from electricity, *X*, network quality, *Q*, and a composite of all other goods, *Y* (which is numeraire).[8] For simplicity, assume that network quality is a composite of the various dimensions of quality and that it cannot be differentiated between consumers. Each consumer is endowed with an equal share of a composite resource, which is allocated as an input, N_j, in production of good *j* (where *j = X, Q or Y*).[9] The price of this composite resource is *c*. Each consumer receives an equal share of profits from private production. These simplifying assumptions of equal endowment and shareholding across consumers allow the model to focus on the efficiency of provision rather than on distributional effects, which can be isolated through pricing (or taxation) decisions. Consumers choose the allocation of their resources except with regard to production of network service quality, which is an exogenous policy variable.[10] Production of network quality is funded by a fixed charge (*A*) and/or a consumption charge (a specific tax, *t*, on electricity). All markets other than that for *Q* are competitive, including the market for electricity.[11]

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[8] U'>0, U"<0 and there is heterogeneity in preferences across consumers.

[9] $dj/dN_j>0$, $d^2j/dN_j^2<0$ and productivity is held constant.

[10] *Q* is *non-rivalrous*, so $dQ_i/dX = 0$, and the level of *X* has no bearing on the cost of providing *Q* (*Q* has zero marginal cost in *X*).

[11] This is consistent with the institutional arrangements for electricity markets in many Western nations, where generation and retail markets are privatised and competitive, but the networks used to distribute the electricity are regulated natural monopolies.

The full expression for changes in social welfare in this economy (and the derivation thereof) is presented in Appendix A. Here, the focus is on a simplified expression comprising the *primary* social costs and benefits of network service provision. The primary benefit is value placed by consumers on the quality improvement and the primary cost is the resource cost of providing that improvement. Formally, changes in social welfare are defined as:

$$\sum_i \frac{dW^i}{\lambda^i} = \sum_i \frac{U_Q^i}{\lambda^i} dQ - cdN_Q$$

where λ^i is the marginal utility of income for consumer *i*.

The resulting condition for welfare maximising provision of network service quality is:[12]

$$\frac{dW}{dN_Q}\frac{1}{\lambda} = \frac{U_Q}{\lambda}\frac{dQ}{dN_Q} - c = 0$$

This condition is equivalent to the classic Samuelson (1956) condition for optimal provision of a pure public good. It simply states that marginal quality improvements should be undertaken up to the point at which the additional benefit to consumers no longer exceeds the additional resource cost (as illustrated in Figure 2.3).

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[12] It is assumed that a benevolent social planner chooses N_Q and that Q is a known function of N_Q. The *Hatta Decomposition* (Hatta, 1982) shows how, for individual consumers, dollars are a reliable proxy for utility, whenever policy changes are incrementally small. This decomposition finds that income effects are a scaling coefficient on the efficiency effects from marginal policy changes that play no role in single consumer economies.

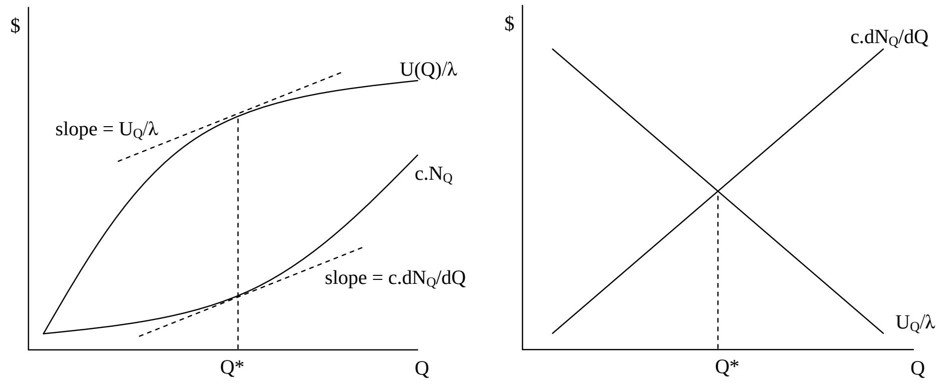

Figure 2.3: The primary costs and benefits of service quality provision

The detailed workings in Appendix A make explicit the two main assumptions that are required to obtain the simplified optimisation condition above. First, the social welfare function is assumed to be an *unweighted* sum of individual welfare. This allows the condition for optimal provision to exclude the welfare effects of changes in market prices by assuming that they simply transfer welfare from one consumer to another (sometimes referred to as the "dollar is a dollar" assumption). In other words, distributional effects are ignored, so that the model focuses solely on efficiency considerations. Second, all electricity and network service provision costs are assumed to be recovered via fixed charges ("lump-sum transfers").[13] This assumption of a non-distorted electricity market allows effects of network quality changes on that related market to be ignored.

2.4.3 A model of optimal provision with endogenous productivity and incomplete information

Two substantial limitations of the general equilibrium framework in the natural monopoly setting are the assumptions of exogenous productivity and a benevolent

[13] It is assumed that these fixed charges would not exclude any consumers from the market.

social planner with full information. Rationales for the governance structures typically associated with monopoly provision have revolved around *endogenous* productivity and the *incompleteness* of information available to social planners. Having established the assumptions implicit in the social welfare function comprising the primary social costs and benefits, the general equilibrium framework is now abandoned in favour of a partial equilibrium framework that retains the primary costs and benefits, but relaxes the assumptions of exogenous productivity and a benevolent social planner with full information. Following Baron and Myerson's (1982) seminal article, this "agency" framework came to dominate economic analysis of monopoly markets. However, as discussed later in the chapter, some authors have criticised its limited applicability in practice (for example, Crew and Kleindorfer, 2002) and its over-simplified assumptions regarding *ex post* governance (Williamson, 2000). Transaction cost economics (Williamson, 2000) may represent a more realistic view of the world, however, it is less conducive to translation to a formal mathematical framework. Moreover, accommodating further complexity in the framework would not further the objective of this section (and subsequent sections), which is to understand the role of estimates of the social value of service quality in mechanisms used to achieve optimal quality under different governance structures. This chapter therefore proceeds with the agency framework and highlights the implications of alternative theories following the formal analysis.

Following Laffont and Tirole (1993), the model presented here assumes three drivers of social welfare – the quality of the service provided, the resource cost of producing the service, and the magnitude of any profit earned by the service provider. Optimal provision of the network service is defined as the simultaneously determined levels of quality, cost and profit that maximise social welfare subject to any constraints.

Consider a provider of network services for a fixed number of consumers with fixed electricity consumption. Service quality, q, is variable and verifiable by all agents. Total cost, which was defined as cN_Q in the general equilibrium model, is now:

$$C = (\beta - e).q + \alpha$$

Fixed cost, α, is assumed to be known and normalised to zero for simplicity. Average cost is a function of the technology available to the firm, β, and the level of cost-reducing effort, e. Disutility of effort, $\Psi(e)$, increases with effort ($\Psi'(e)>0$) at an increasing rate ($\Psi''(e)>0$) and is zero when effort is zero ($\Psi(0)=0$). Different assumptions about institutional arrangements will call for different revenue arrangements for the service provider. In general, the excess of revenue over total cost is referred to as a transfer, t. The service provider's utility is:

$$U = t - \Psi(e)$$

It is assumed that leaving a rent (positive utility) to the service provider is socially costly. There are two reasons why rent extraction may be socially beneficial. First, where revenue is collected using distorting prices or funded by distorted taxes, it imposes a social cost by reducing market activity. Second, leaving a rent to the service provider is likely to be considered socially costly due to distributional concerns (if the provider is privately owned). Following Laffont and Tirole (1993), and based on the former reason, this model includes a shadow cost of public funds, δ, which is broadly interpreted as the social cost of leaving a rent to the firm.[14] The notation for the social value of quality, which was $\Sigma[U_i(Q)/\lambda_i]$ in the general equilibrium model, is simplified to $S(q)$, where $S'(q)>0$ and $S''(q)<0$. Social welfare is:

$$W = S(q) - (1 + \delta)\,(C + t) + U$$

$$= S(q) - (1 + \delta)\,[C + \Psi(e)] - \lambda.U$$

This leads to three conditions for optimal network service provision:

No rent is left to the service provider: $U = 0$

Total cost, $C + \Psi(e)$, is minimised (for given q): $\Psi'(e) = q$

Optimal provision of quality (for given e): $S'(q) = (1 + \delta)\,(\beta - e)$

The third condition is equivalent to the condition derived from the general equilibrium model. It implies that marginal quality improvements should be undertaken until the social value of the improvement no longer exceeds the marginal cost (after accounting for the shadow cost of public funds).

2.5 The unregulated private monopoly

Having established formal conditions for socially optimal network service provision, it is now possible to examine social welfare outcomes under various governance structures. This section examines the situation in which network services are provided by a private monopolist in the absence of government intervention. This arrangement rarely occurs in practice for the reasons discussed in Section 2.3. The model confirms that this arrangement tends to result in sub-

[14] Where transfers from the Government are ruled out, this cost of funds becomes the shadow cost of funds in the electricity market.

optimal social welfare outcomes; however, rather than appealing to transaction costs, the model points to the fact that a private firm's profit-maximising objectives do not align with the conditions for social welfare maximisation. An unregulated firm maximises its utility, $U = t - \Psi(e)$. It does so by choosing network quality, q, cost-reducing effort, e, and, effectively, the transfer, t. Consider the case where revenue is generated by a charge, A, on each of N consumers, so that $t = NA - C$. Let us assume that the firm selects the level of the charge, but if the charge exceeds the average value placed on service quality by consumers, $S(q)/N$, then all N consumers exit the market (by substituting to the next best alternative source of electricity; for example, private petrol-fuelled generators).

The utility function to be maximised is then equivalent to the social welfare function with no social cost of leaving a rent to the firm, $\delta = 0$:

$$\begin{aligned} U &= S(q) - (\beta - e)\, q - \Psi(e) \\ &= S(q) - [C + \Psi(e)] \end{aligned}$$

The firm chooses cost-reducing effort, e, service quality, q, and the charge, A, in accordance with the consumer rationality constraint and the first-order conditions for effort and quality:

$$A = S(q)/N$$

$$\Psi'(e) = q$$

$$S'(q) = \beta - e$$

Because the firm does not take into account the social cost of earning a rent, it extracts all consumer surplus from the market. If lump-sum transfers were possible and if distributional concerns were set aside, then this outcome would be socially optimal. However, if leaving a rent to the firm is socially costly ($\delta > 0$), then the first condition for optimal provision is not met since $U > 0$.

This model assumes electricity consumption is fixed. The case in which quality affects consumption of electricity (or monopoly consumption goods generally) was examined in detail by Spence (1975) and Sheshinski (1976). They found that quality is unlikely to be set at the social optimum by an unregulated monopolist. Quality may be over- or under-provided depending on the relative quality valuations of the marginal and average consumers in the market.

2.6 The integrated public monopoly

The unregulated monopoly structure discussed above is rarely observed in practice. Governments the world over have intervened in monopoly markets for the reasons discussed in Section 2.3. This section examines a governance structure in which the government fully integrates network service provision within the public sector. In the context of the model, the main social benefit of the intervention is the elimination of the socially-costly rent earned by the unregulated private service provider. However, there are also social costs arising from the intervention. One such cost that can be incorporated in the model is the reduced incentive to expend cost-reducing effort under the government's "soft" budget constraint. There are other reasons why the objectives of a government may not coincide with the social objective function. Indeed, there is a large literature on *political economy* examining such issues (for example, Persson and Tabellini, 2000). The model presented here abstracts from these issues and focuses solely on the lack of cost-minimisation incentives.

Consider the case where the observed costs, C, are covered by government revenue, but the budget is balanced so there is no transfer, $t = 0$. Only the managers of the network observe the components of cost, namely technology, β, and cost-reducing effort, e. Governments generally do not link employee remuneration to performance with respect to innovation and cost minimisation. Managers on a fixed salary maximise their own utility, $U = -\Psi(e)$, by expending no cost-reducing effort, $e = 0$. The model predicts that the managers have no preference regarding the level of service quality since they bear neither the costs nor the benefits of the decision. In practice, the government is likely to target a particular service standard. Suppose this target is set at q^*, the socially optimal level conditional on the observed marginal cost, $c = \beta$, such that:

$$S'(q^*) = (1 + \delta)\, c$$

Only two of the three conditions for socially optimal service provision are met. The first condition is met since there is no socially costly rent, $U = 0$. The second condition is not met since cost-reducing effort is zero and hence total (observed plus unobserved) cost is not minimised. The third condition is met since the government has set quality at the optimal level, q^*, conditional on the *zero* level of cost-reducing effort. However, q^* is below the optimum determined simultaneously with *optimal* cost-reducing effort. If cost-reducing effort were expended, marginal cost would fall and a marginal increase in quality would become economically viable.

2.6.1 Cost-benefit analysis

Under the public provision governance structure, the mechanism for achieving optimal quality is direct *cost-benefit analysis*. This involves an assessment of the impact of marginal quality changes on social welfare:

$$W_q = S'(q) - (1 + \delta)\, c$$

where $c = \beta - e$

The government can improve social welfare by increasing service standards where $W_q > 0$; that is, where the marginal social value of the increase, $S'(q)$, exceeds the marginal social cost, $(1 + \delta)\, c$.[15] Clearly, the estimate of the marginal social value of quality plays a crucial role in this mechanism. Inaccurate estimation of this value would lead to lower social welfare outcomes because quality changes resulting in a net social cost may be implemented and, conversely, quality changes resulting in a net social *benefit* may *not* be implemented.

Similarly, the marginal cost used in the evaluation is important. A disadvantage of this governance structure is that its inherent low-powered incentives cause marginal cost to be above the optimal level (since cost-reducing effort, *e*, is sub-optimal). As a result, certain quality improvements may be rejected even though the benefits exceed the *efficient* marginal cost.

[15] To achieve the optimal quality level, cost-benefit analysis would need to be undertaken for all possible combinations of investments. A more realistic optimum would be characterised by the trade-off between the costs involved in undertaking the analysis and the surpluses to be gained from it.

Turning to the quality-enhancing project of interest, cost-benefit analysis of undergrounding in a given area would involve a comparison of the estimated social value of the expected quality improvement and the estimated cost of delivering the project (net of ongoing cost savings). In principle, a network could be divided into many areas and cost-benefit analyses conducted for each, providing information on the amount of network undergrounding that would be socially optimal (conditional on the estimated cost, which may be above the efficient level).

2.7 Incentive regulation of a private monopoly

The third and final type of governance structure examined here is high-powered incentive regulation of a private network service provider (the firm). Following Laffont and Tirole (1993), total cost, C, is assumed to be paid by the government and a transfer, t, is paid to the firm. The firm's objective is to maximise its utility, $U = t - \Psi(e)$. The model abstracts from theories of *regulatory capture* (Stigler, 1971) and assumes the regulator's objective is to maximise social welfare subject to information constraints. The information constraint in this model is that the regulator does not observe the components of cost; namely, technology, β, and cost-reducing effort, e. The firm's disutility from cost-reducing effort is an additional cost of production that is not observed by the regulator. The firm would not be compensated for this disutility in a regulatory regime that allowed recovery only of observable, tangible costs.

2.7.1 Quality-adjusted price cap regulation

Decentralised contracts

The mechanism by which the optimal social welfare outcome is achieved in this setting is a *quality-adjusted price cap* regulatory regime. This mechanism is the culmination of work by several authors in the 1970s and 1980s. Seminal work by Spence (1975) introduced the use of decentralised regulatory contracts in which firms are compensated according to the social surplus resulting from their quality performance. Loeb and Magat (1979) showed that a firm will deliver the welfare maximising level of output if its revenues (or prices) reflect the consumer surplus generated by its output.[16] More recently, DeFraja and Iozzi (2004) and Currier (2007) have set out dynamic decentralised regulatory mechanisms that would, according to their models, lead to welfare maximisation in the long run. These decentralised contracts induce optimal provision of quality by internalising the social cost-benefit optimisation within the firm's profit maximisation problem. Quality-adjusted price cap regulation integrates these quality incentives with incentives for efficient cost-reducing effort by making the firm residual claimant with respect to its costs. The mechanism can be represented by the following transfer function:

$$t = \Psi(e^*) - (C - C^*) + S(q) - S(q^*)$$

where C^* and q^* are cost and quality performance targets, respectively.

---

[16] Distributional concerns associated with this mechanism were addressed by transferring some surplus to consumers through the application of a quality target that is unrelated to the firm's own quality performance.

Under this contract, the firm's utility is:

$$U = \Psi(e^*) - (C - C^*) + S(q) - S(q^*) - \Psi(e)$$

A utility-maximising firm will select socially optimal effort and quality levels for any C^* and q^* that are unrelated to the firm's own performance (C and q) as demonstrated by the first-order conditions:

$$\partial U/\partial q = -(\beta - e) + S'(q) = 0$$

$$\partial U/\partial e = q - \Psi'(e) = 0$$

The information constraint

In order for this form of regulation to satisfy all three conditions for socially optimal provision, it also needs to ensure rent extraction ($U = 0$), which occurs via the setting of C^* (and q^*). However, this task is hampered by the regulator's incomplete information about the firm's cost function. Consider the case where the regulator knows that β could take one of two values, β_L or $\beta_H > \beta_L$. Quality is assumed to be constant, $q = q^*$, and the regulator needs to offer a transfer function that satisfies the firm's rationality constraint, $U \geq 0$. If the regulator knew the type (β) of the firm, it would choose the constant parameters, $\Psi(e^*)$ and C^*, so that the transfer function, $t = \Psi(e^*) - (C - C^*)$, passed through Point A (see Figure 2.4) for a low-cost firm or point B for a high-cost firm. However, the regulator does not know the type of the firm, which means that only the latter transfer function, $t = \Psi(e^*) - (C - C_1^*)$, ensures the firm's rationality constraint is met regardless of type. The outcome is socially optimal if the firm is high-cost, but if the firm is low-cost, it would receive a positive rent and expend below-optimal cost-reducing effort (Point D). Expected social welfare can be improved if the regulator offers a transfer function in which the firm is only *partial* residual claimant with respect to costs. Figure 2.4 illustrates a transfer function, $t = \Psi(e^*) - \gamma\ (C - C_2^*)$, where $0 < \gamma < 1$ and $C_2^* < C_1^*$. If offered this transfer function, low- and high-cost firms would choose Point E and Point F, respectively. This limits the rent of a low-cost firm at the cost of inducing sub-optimal effort from a high-cost firm. This reflects the classic result from the Laffont and Tirole (1993) principal-agent model: the regulator's two objectives – improving productivity and limiting firm profits – are in conflict. There is a trade-off between rent extraction and effort inducement.

Yardstick competition

The information constraint described above means that the regulator cannot induce the firm to achieve the socially optimal outcome. A potential means of overcoming this problem is *yardstick competition*, or relative performance evaluation, which allows a regulator to gain information on β by comparing a firm's performance to that of other firms (Shleifer, 1985). To the extent that firms' technological environments are the same, yardstick competition can result in the optimal outcome through a price cap contract (Laffont and Tirole, 1993). If C^* and q^* are set at the median performance across firms, then the firm with median performance will have $U = 0$ (assuming the transfer, t, also includes an adequate compensation for disutility of optimal cost-reducing effort). Firms with above-median performance will earn a rent, while firms with below-median performance will have negative utility. Frontier Economics (2003) note that the number of firms experiencing negative utility could be reduced by setting C^* and q^* as the average performance of the two worst performing firms.

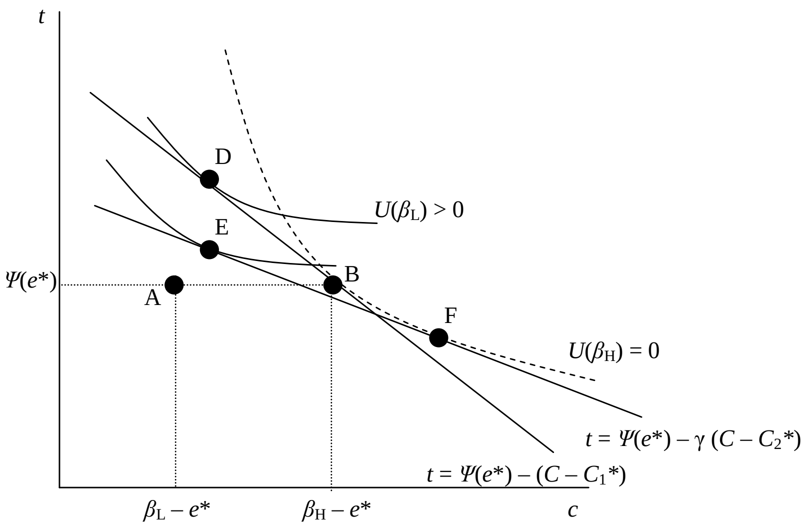

Figure 2.4: Regulation under asymmetric information

In practice, it is difficult to use methods that simply average cost and quality performance across firms due to differences in size and operating environments. A more general cost function than that assumed in the simple model above is presented in Figure 2.5 (where *Z* represents the size of the network).

In a dynamic model, regulators observe in each period the optimal quality and total cost levels chosen by the firm for given technology, β, and firm size, *Z*. Technology (and hence optimal cost and quality) varies over time and firm size varies across firms. Regulators require some measure of productivity that is comparable across firms and across time. Various measures have been proposed based on benchmarking methods such as *data envelopment analysis* and *stochastic frontier analysis*. For further detail on these methods, readers are referred to Coelli *et al.* (2005). Implementing measures of productivity across heterogeneous firms remains a challenge for regulators the world over.

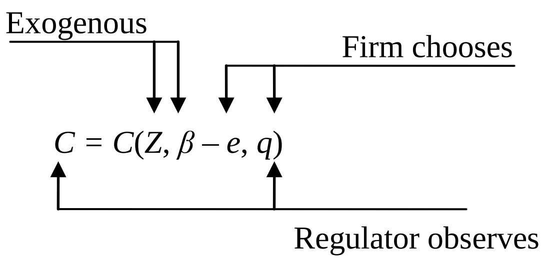

Figure 2.5: Regulation and the cost function

The quality-adjusted price cap mechanism

In practice, the quality-adjusted price cap form of regulation is represented by the following rule for changes in the weighted average price cap formula over time, *t*:

$$\frac{\sum_{i=1}^{n} p_{i,t+1}.x_{i,t}}{\sum_{i=1}^{n} p_{i,t}.x_{i,t}} \leq 1 + CPI_t - X + Q$$

where

p are prices, *x* are quantities, *CPI* is the change in prices across the economy, and $Q = (q_t - q^*)\, S'(q^*)$

Once the form of regulation has been established, there are two main regulatory parameters to be set periodically by the regulator. The first is *X*, which has commonly been referred to as the “X-factor” following the RPI-X regulatory approach developed by Stephen Littlechild (Beesley and Littlechild, 1989) and applied to British Telecom. It represents the *per period* reduction in prices for a given quality level. It is calculated to extract rent by reflecting changes (or forecast changes) in some measure of industry-wide productivity.

The second is $S'(q^*)$, which is often referred to as the "quality incentive rate". This is the mechanism by which optimal quality is achieved in the price cap governance structure. This incentive rate is the means by which the social cost-benefit analysis is internalised in the firm's profit maximising condition. It determines the magnitude of the financial reward or penalty for exceeding or falling short of the target level of quality performance. Setting the incentive rate at the estimate of the marginal social value of quality means that the financial rewards and penalties provide an ongoing incentive to move towards the socially optimal quality level. In contrast to the case of fully integrated public provision, the marginal cost upon which the cost-benefit analysis is based is the efficient level (as a result of the high-powered incentives to minimise cost).

Just as in the case of public provision, accurate estimation of consumers' marginal value of quality is crucial to achieving the social welfare optimum under this type of government intervention. A challenge in practice is to reflect in the quality incentive rate all of the aspects of quality that affect consumers' utility. For example, schemes implemented to date have stopped short of accommodating the time of day that supply interruptions occur.

Turning to the quality-enhancing project of interest, estimates of the social value of quality improvements resulting from undergrounding could, in principle, be included in incentive rates. Ideally, separate rates, or components of a quality index, would apply to supply reliability and a composite of other benefits derived from undergrounding (for example, aesthetics and perceived safety). The rates could potentially vary from one area to another to reflect differences in the marginal value of the benefits of undergrounding. The goal is a situation in which the firm weighs up the additional revenue it would gain from undergrounding a given area (including from ongoing improved reliability) against the cost (net of ongoing savings in maintenance and energy losses). There would be many challenges involved in implementing such a regime. For example, undergrounding would need to be incorporated within the yardstick competition framework to prevent the firm from earning large rents from extracting all consumer surplus via the financial rewards linked to undergrounding.

2.8 Limitations of model assumptions

The analysis employing the mathematical framework in the preceding sections favours high-powered incentive regulation as a governance structure. All models make simplifying assumptions that depart from reality in one way or another, but some authors have argued that the assumptions underlying the type of model presented above may lead to infeasibilities in practice. For example, proponents of transaction cost economics argue that the model is based on complete contracts that are not feasible because quality is a complex good and future costs and demand are uncertain. Possibly as a result of these infeasibilities, the quality-adjusted price cap form of regulation has been implemented in very few countries to date; namely Norway (Langset *et al.*, 2001) and the Netherlands (Netherlands Competition Authority, 2006). Three other considerations that could hamper the effectiveness or feasibility of certain forms of regulation are described below. They are included here as acknowledgement of the debate that surrounds governance structures in monopoly markets.

2.8.1 The commitment problem

Crew and Kleindorfer (2002), and proponents of transaction cost economics generally (Grossman and Hart, 1986; Williamson, 1979; 1983; 2000), have criticised the assumption that the regulator can credibly commit to certain contracts. The incentive for efficient cost-reducing effort under price cap regulation will not hold if the regulator cannot credibly commit to allowing efficient firms to continually earn *observed* (excluding disutility of effort) profits (or to allowing inefficient firms to earn losses). The commitment may not be credible if firms are aware that regulators face considerable political pressure to limit *observed* monopoly profits and that there is a risk of expropriation. A firm knows that once it reveals information through the *ex ante* optimal contract the regulator will have an incentive to change the contract. If the firm anticipates this risk of expropriation, then it no longer has an incentive to minimise costs and the outcomes described in Section 2.7 are not feasible.

2.8.2 Administrative burden and rent-seeking

To this point it has been assumed that regulation is a costless exercise. As recognised by transaction cost economics (Williamson, 1979), this is certainly not the case in practice, though the costs of regulation vary depending upon the type of regulatory regime. In general, considerable resources are expended by both the regulator and the firm in the process of periodically setting the regulatory parameters. Where yardstick competition is impractical or infeasible, regulators can become quite intrusive in an effort to gain information about the cost function or to control outcomes – even dictating firms' policies. In some cases, firms may appeal regulatory decisions, leading to further expenditure of resources on legal and expert advice by both parties. Of course, the public provision governance structure also leads to some additional administrative costs and some waste of resources through rent-seeking behaviour as interest groups lobby to obtain a share of the redistribution of monopoly profits. The administrative and rent-seeking costs incurred under regulation are arguably higher even than those under the integrated public monopoly governance structure.

2.8.3 Regulatory capture

In the model employed in this chapter, it is assumed that the regulator's objective is to maximise social welfare. Stigler (1971) and others since (for example, Peltzman, 1989) have argued that regulation does not maximise social welfare, but rather, that it is captured by the industry and designed to protect the interests of firms. They argue that this *regulatory capture* arises because compact, well organised groups such as producers can apply more pressure to regulators than broad, diffuse groups such as consumers. Regulators may give favourable decisions in order to maintain relationships at firms where they anticipate future managerial positions. At the extreme, regulators might accept bribes from firms.

2.9 Summary and conclusions

This chapter has defined conditions for socially optimal network service provision under various monopoly governance structures using a specific economic model. The social value of network service quality is a crucial element in these conditions. The importance of accurate estimation of this value is highlighted by the model since inaccurate estimation would lead to a loss of social welfare.

Consistent with observed governance structures and arguments in the wider literature, the model predicts that the social optimum will not be achieved by a monopoly firm in the absence of government intervention. An integrated public monopoly governance structure eliminates the socially costly monopoly rent, but at the cost of reduced incentives for cost minimisation. It utilises direct cost-benefit analysis of projects to move towards optimal levels of service quality. The key components of the cost-benefit analysis are the marginal social value of quality and the marginal cost of quality provision. As a result of the low-powered incentives inherent in the governance structure, the marginal cost used in the analysis will be above the efficient level and, consequently, quality changes that could potentially result in a net social benefit may not be implemented.

Another form of governance structure, regulation by quality-adjusted price cap, uses financial penalties and rewards for quality performance to provide an ongoing incentive for the firm to adjust quality to the socially optimal level. Again, the marginal social value of service quality is crucial as it determines the magnitude of the rewards and penalties required to internalise social costs and benefits in the firm's profit-maximisation problem. In contrast to the integrated public monopoly governance structure, the marginal cost used by the firm in the cost-benefit analysis will, based on model assumptions, be at the efficient level. However, violations of model assumptions regarding regulatory commitment, regulatory capture and administrative burden would prevent the social optimum from being achieved in practice.

The main conclusion to be drawn from this chapter is that, regardless of governance structure, the marginal social value of network service quality is a crucial element in identifying social welfare enhancing investments in quality. If firms, governments and regulators rely on inaccurate estimates of this social valuation, then quality-enhancing network projects resulting in a net social cost may be implemented and, conversely, projects that would result in a net social benefit may *not* be implemented.

Turning to the quality-enhancing project of interest in this research, the net social benefits of undergrounding in a given residential area depend on the value placed by households on the quality improvements resulting from the project. Accurate estimates of the household benefits of undergrounding are required to ensure that undergrounding takes place in, and only in, areas where the social benefits exceed the social costs.

The next two chapters describe methods for estimating the social value of network service quality and discuss in detail certain challenges associated with those methods.

3 Valuation methods

3.1 Introduction

Chapter 2 established the role of the social value of service quality in understanding whether undergrounding electricity networks in a given area would result in a net economic benefit. This chapter describes two types of method used to gather information on the value placed by households on network service quality – the hedonic price method (in Section 3.2) and stated preference (SP) methods (in Section 3.3). The discussion is tailored to focus on the methods as they would be applied when the objective is to understand household preferences for undergrounding. The outputs from the methods are related to the formal economic framework developed in Chapter 2.

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. SP methods attempt to elicit households' preferences for potential network service options by asking questions in a survey context. As will become clear, there are relative advantages and disadvantages associated with each method. In some cases, the data collected using the two methods can be pooled (Louviere *et al.*, 2000); however, this is not the case in this research. Both methods are studied here because either may be preferred by analysts depending on the time and financial resources available when considering the merits of undergrounding in a given area. Value estimates would be more robust and defensible if consistent results could be obtained across the two methods.

In the following chapter, certain challenges associated with the methods are discussed in detail. Then, in the remainder of the thesis, research questions related to those challenges are addressed using a case study, which also provides benefit estimates for undergrounding where little information was previously available in the literature.

3.2 The hedonic price method

3.2.1 Introduction

Lancaster (1966) and Rosen (1974), among others, have argued that many goods and services can be characterised as a bundle of attributes. Differing levels of those attributes lead to the availability of many different *versions* of a good. The hedonic pricing method uses observed market prices for a good and observed attribute levels to estimate the implicit effect of each of the attributes on the overall price. These effects are termed *implicit prices*. They give an indication of the value that consumers place on each attribute as revealed through their chosen purchases from the available versions of the good.

The method has been applied to all manner of goods, including automobiles and computers (Berndt, 1990), plastic bags (Anstine, 2000), and breakfast cereals (Stanley and Tschirhart, 1991). However, the good to which the hedonic price method has been most widely applied is real estate. Studies have used the hedonic pricing technique 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 this research, the real estate attribute of interest is the presence of underground (as opposed to overhead) low-voltage electricity distribution networks – an attribute that has not been valued in previous published studies.[17] As will become clear, the implicit price of this attribute conveys limited information about the social value of the network service quality improvement that results from undergrounding. Henceforth, the discussion relates to the application of the hedonic price method in this context.

3.2.2 Theory of hedonic price estimation

The theoretical framework for the estimation of implicit prices is as follows. The market price for a piece of real estate (referred to henceforth as a property) is $p = p(UG, Z)$, where UG indicates whether the property is serviced by underground wires and $Z = z_1, z_2, \ldots, z_n$ is a vector of the amounts of n other property attributes (for example, number of bedrooms, block size, distance to central business district). Households spend their income, y, on housing (real estate) and a composite good, x, whose price is normalised to unity. Households maximise their utility, $U = U(x, UG, Z)$, by choosing x, UG, and Z subject to their budget constraint, $y = x + p(UG, Z)$. The first order conditions of this constrained optimisation are $\partial p/\partial UG = U_{UG}/U_x$ and $\partial p/\partial Z_i = U_{Zi}/U_x$ for $i = 1, \ldots, n$. For attributes with continuous levels, these conditions mean that households purchase the quantity of each attribute up to the point at which their value (or, equivalently,

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[17] Some studies have valued the impact of proximity to high-voltage transmission networks (Colwell, 1990; Des Rosiers, 2002; Gregory and von Winterfeldt, 1996; Hamilton and Schwann, 1995; Sims and Dent, 2005), but this infrastructure has quite different impacts on households.

their willingness to pay (WTP)), U_{Zi}/U_x, for an additional unit of the attribute is just equal to the implicit price, $\partial p/\partial Z_i$, of the attribute.

However, the main attribute of interest in this research, *UG*, is a discrete binary attribute. Consequently, a household's WTP for underground wires, U_{UG}/U_x, is not necessarily equal to the implicit price for underground wires, $\partial p/\partial UG$ (denoted henceforth as P_{UG}). Figure 3.1 illustrates the optimal discrete choice in the *x*-*UG* plane cut at Z^*. In order to purchase a house serviced by underground wires, a household must forgo $P_{UG}(Z^*)$ units of *x*. This is the implicit price of underground wires for house type Z^*. Two households are shown, both with income Y^*. One has a utility function U_A and the other U_B. The indifference curves for the optimal utility levels of each household, U_A^* and U_B^*, are shown in the diagram.[18] The household with utility function U_B chooses a house serviced by underground wires but the other household does not.

3.2.3 Second stage of hedonic estimation

Rosen (1974) suggested a second stage in the hedonic estimation process in which the estimated implicit prices are combined with data on the characteristics of individual suppliers and demanders to estimate supply and demand functions simultaneously. It has since been recognised that this second stage is more complex than Rosen had envisaged (Palmquist and Smith, 2002). Identification of the demand function requires data sufficient to distinguish the behavioural functions of households (in terms of their preferences for property attributes) from both the hedonic price equation and the supply functions for those attributes.

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[18] These functions are undefined for $0<UG<1$, but lines are shown for illustrative purposes.

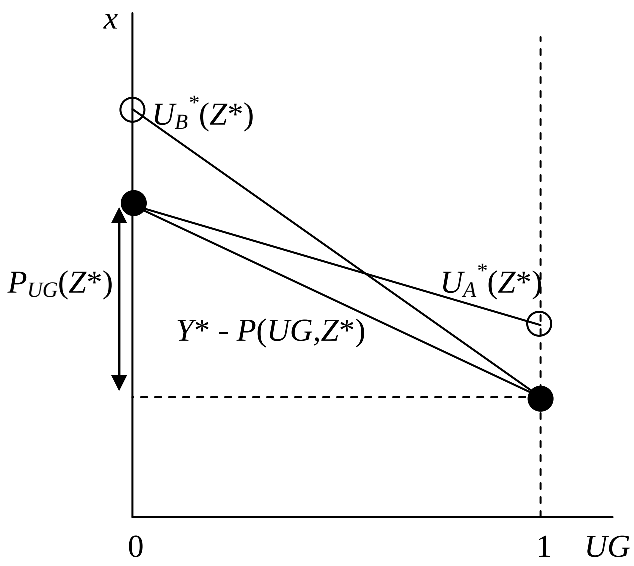

Figure 3.1 Household consumption decision

This identification has been achieved in a few cases by pooling data from multiple independent markets (Palmquist, 1984) or by assuming that household preferences follow a specific function form with non-linear restrictions on the attributes (Epple, 1987; Mendelsohn, 1985). However, the vast majority of empirical hedonic price studies do not proceed to this second stage due to the cost of these data requirements or other problems achieving identification (Palmquist and Smith, 2002). In this research, the focus is on the more common form of hedonic price study involving only the first stage of hedonic estimation – the estimation of implicit prices.

3.2.4 Relating implicit prices to the social valuation

The implicit price, $P_{UG}(Z^*)$, derived from the (first stage) hedonic price estimation is related in a specific way to the marginal social value of quality, $S'(q)$, discussed in Chapter 2. Returning to the notation used in the general equilibrium model, $S'(q)$ is equal to $\Sigma U_Q^i/\lambda^i\ dQ$; that is, the sum of individual households' marginal values of quality (utility in dollar terms) or, using an equivalent term, households' marginal WTP for quality. Assuming the change in quality from undergrounding is ΔQ, then an approximation of the social value of undergrounding is $\Sigma U_Q^i/\lambda^i \, \Delta Q$. The first stage of the hedonic price method does not estimate this value directly, but certain information about households' WTP is revealed. An individual household's WTP for underground wires is less than the implicit price, $P_{UG}(Z^*)$, if the household purchases a house serviced by *overhead* wires. It is equal to or more than the implicit price if the household purchases a house serviced by *underground* wires. Assuming a continuous distribution of WTP across households, the implicit price represents the WTP of the marginal purchaser of the underground wires attribute.

To demonstrate this, consider the value function $\theta(UG, Z; y, u)$ described by Rosen (1974) where $u = U(y - \theta, UG, Z)$. The WTP for underground wires, holding all other house attributes constant at Z^*, is $\theta_{UG}(Z^*; u^*, y)$ where u^* is the optimum quantity given Z^*. A demand function for underground wires in the market for houses of type Z^* can be constructed by arranging these WTP amounts in descending order across households. The social value of underground wires is equal to the area underneath this demand function. Figure 3.2 demonstrates that the implicit price of underground wires is determined by the equilibrium of this demand function and the supply of houses serviced by underground wires, S, for each given type of house as characterised by Z. Over the relatively short periods of time used for cross-sectional hedonic price studies, the supply of houses serviced by underground wires in the real estate market is perfectly inelastic (in cities where no retro-fit undergrounding has taken place).

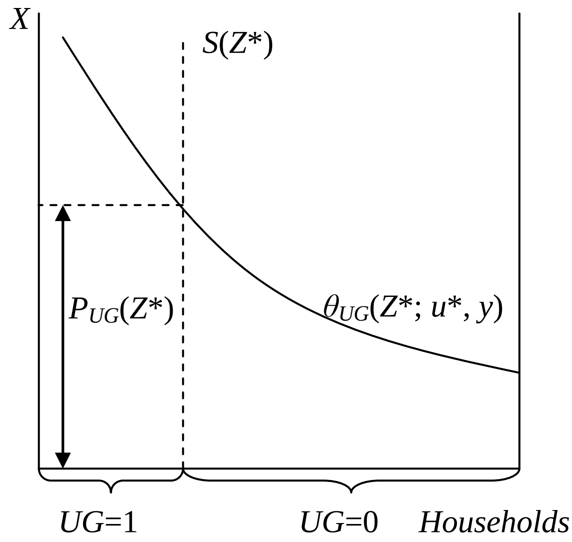

Figure 3.2 Implicit price and willingness to pay

The fact that implicit price estimation provides only limited information about the value of interest, households' mean WTP for undergrounding, is a drawback of the method. The hedonic price method is nevertheless an appealing approach to gathering some, albeit limited, information about households' WTP due to the relatively inexpensive data requirements and the revealed, "real market" nature of the data used. In certain cases, it may reveal to the analyst whether the *median* WTP is considerably above or below the cost of undergrounding. Consider an example where the cost of undergrounding is estimated at \$15,000 per property, a hedonic price study reveals that 20 per cent of households paid an estimated implicit price of \$5,000 for the underground networks attribute, and other benefits, such as those to network service providers, are estimated at \$2,000 per property. Given that median household WTP for undergrounding is less than \$5,000 (as revealed through the real estate market), it seems unlikely that the benefits of undergrounding would exceed the costs. On the other hand, if the hedonic price study showed that 80 per cent of households paid an estimated implicit price of \$20,000, then it would be likely, though not certain, that net benefits would be positive. However, in many cases, the likely outcome of a cost-benefit analysis would be unclear.

3.2.5 Estimating the hedonic price function

Once the analyst has specified a functional form for $p = p(UG, Z)$, what remains is to estimate the hedonic regression model and interpret the implicit prices. The economic theory discussed above does not dictate a particular functional form since the price function represents a locus of market equilibria. Three commonly used functional forms are the log-log, semi-log and linear forms.[19] In the semi-log functional form, a logarithmic transformation is applied to the dependent variable, but not to the explanatory variables. A standard semi-log regression model incorporating time trend and area fixed effects is:

$$\ln p_{ijt} = \alpha + \beta\, UG_{ij} + \gamma\, Z_{ijt} + \delta\, A_j + \lambda\, T_t + \varepsilon_{ijt}$$

where

$\ln p_{ijt}$ is the log of real price of house i in area j at time t;

UG_{ij} is a dummy variable for indicating that house i is serviced by underground wires;

Z_{ijt} is a vector of other house attributes;

T_t is a vector of time indicator variables and;

A_j is a vector of area indicator variables.

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[19] Where the marginal effects of attributes are not constant, other, flexible specifications, such as Box-Cox transformations, are preferred. Such specifications may be necessary in second stage hedonic estimation.

The parameters to be estimated are α, β and the parameter vectors γ, δ and λ. The parameter of particular interest is β, which represents the implicit price of underground networks. In this model form, β is the proportionate increase in price, p, for a change from overhead to underground wires holding all other variables constant.

An equivalent log-log model would be:

$$\ln p_{ijt} = \alpha + \beta \ln UG_{ij} + \gamma \ln Z_{ijt} + \delta \ln A_j + \lambda \ln T_t + \varepsilon_{ijt}$$

A disadvantage of the log-log model is that it does not allow any of the explanatory variables to take the value zero (or values less than zero), since the natural logarithm of numbers less than or equal to zero is not defined. This is problematic in the case of indicator variables such as the variable of interest, *UG*, which indicates the presence of underground networks.

An equivalent linear model would be:

$$p_{ijt} = \alpha + \beta\, UG_{ij} + \gamma\, Z_{ijt} + \delta\, A_j + \lambda\, T_t + \varepsilon_{ijt}$$

Although many examples of this type of model can be found in the literature, it is inconsistent with the linear homogeneity properties implied by microeconomic theory and should be avoided on *a priori* grounds (Diewert, 2003).

3.3 Stated preference methods

3.3.1 Introduction

In contrast to the hedonic price approach in which households' preferences are *revealed* by choices made in real markets, SP methods discover households' preferences through choices made in a survey context. The natural monopoly nature of the electricity network and indivisibilities in the service mean that consumers are rarely able to choose their preferred version of the service. Consumers are only offered one version of the service for a given property. The exception, as discussed in Section 3.2, is the household that is active in the real estate market. They choose between multiple versions of the service to the extent that the service differs across properties. However, this group represents only a small proportion of the population. In general, it is not possible to observe households trading off price against network quality in a real market; but, these trade-offs can be observed in the context of an SP survey.

This highlights one of the primary advantages of SP methods relative to the hedonic price method – the ability to observe choices relating to alternatives and attribute levels that are not observable in an actual market. This ability is valuable when information is being sought about an alternative not currently available in the market or when attribute levels associated with an existing alternative are invariant or highly correlated, as is often the case (Hensher *et al.*, 2005). It is claimed that the primary disadvantage of SP methods is that they simulate a market that is, in a sense, hypothetical, and therefore may not replicate the financial constraints confronted by consumers in real markets. However, the extent of this disadvantage depends largely on the nature of the survey mechanism. Financial constraints may be absent if a respondent believes that their response will have no influence on the agency's actions or if they believe the agency would not be able to enforce payment. However, if a respondent believes that their response may (up to some non-zero probability) influence the agency's actions and that the agency could enforce a policy outcome (including payment) based on their response, then the survey becomes a real market transaction of sorts and financial constraints are present.

A number of studies have focused on *hypothetical bias* by comparing results from hypothetical choice experiments with those from choice experiments with immediate and certain implementation (Alfnes and Steine, 2005; Carlsson and Martinsson, 2001; Hensher, 2010; Lusk and Schroeder, 2004). It is important to make a distinction here between *inconsequential* hypothetical surveys (where a respondent believes there is zero per cent chance of implementation) and *consequential* hypothetical surveys (where a respondent believes their responses will influence up to some non-zero probability the likelihood of an alternative being implemented by the agency) (Carson and Groves, 2007). Economic theory predicts that responses to a consequential *hypothetical* survey and a survey with immediate and certain implementation will be equivalent. Consistent with this theory, Carson *et al.* (2006) found a difference between responses to *inconsequential* hypothetical questions and questions involving 100 per cent probability of actual payment, but, importantly, found equivalence in responses to all questions involving a non-zero (20 per cent, 50 per cent, 80 per cent and 100 per cent) probability of actual payment.

3.3.2 Background

SP methods have been applied in various forms across a range of disciplines, including marketing, and transport, health, and environmental economics. To date, the SP approach applied in the monopoly service quality context has drawn most heavily, though not exclusively, on the approaches applied by environmental economists. The techniques used to estimate households' values for specific attributes of public environmental goods translate well to the context of valuing specific attributes of network service quality. Similarly, the techniques used to value the environmental improvements resulting from specific public projects translate well to the context of valuing the network quality improvements resulting from specific infrastructure projects.

The SP methods applied in the environmental economics discipline, and hence those applied in the monopoly service quality context, have changed considerably as a substantial literature has emerged over the past three decades. One of the earliest SP methods to be applied was an *open-ended contingent valuation* survey in which respondents were simply asked to state their maximum WTP for a changed policy scenario. Certain biases introduced by this preference elicitation format were recognised from an early stage; in particular, strategic "shading" of bids similar to that observed in first-price sealed-bid auctions and clustering of bids around certain prominent numbers such as zero, $50 or $100 (Arrow *et al.*, 1993; Carson and Mitchell, 1989). These shortcomings led to this approach largely being abandoned in favour of the *dichotomous choice contingent valuation* (DCCV) survey format in which a changed policy scenario is offered at a certain price and respondents indicate whether they accept the offered scenario or retain the status quo. This referendum-type format became widely accepted following its recommendation by the National Oceanic and Atmospheric Administration (NOAA) Blue Ribbon Panel in 1993 (Arrow *et al.*, 1993). It potentially holds the appealing property of *incentive compatibility*, which, as will become clear later in this chapter, means that truthful revelation of preferences is the dominant strategy for all respondents regardless of their perceptions about how others will respond. However, it was recognised that asking a single question to each respondent is relatively inefficient in statistical terms. This inefficiency gave rise to expanded survey formats, such as the double-bounded DCCV survey in which a follow-up question is asked in an attempt to narrow the identified interval within which the respondent’s WTP value is known to lie.

These contingent valuation survey formats typically involve the valuation of a single, specific policy change. In many instances, policy makers are interested in the contribution of specific attributes of a good to the overall valuation of the change; for example, the contribution of the reduction in the frequency of unannounced power cuts to the overall valuation of undergrounding. Estimates of these contributions would inform the valuation of a range of possible policy scenarios based on the various combinations of the attributes. A broader class of stated choice surveys, termed *choice experiments* (CE), originally developed in the transport economics (Hensher and Truong, 1985) and marketing (Hensher and Louviere, 1983) disciplines, was adapted to fulfil this purpose in the contexts of environmental goods (Bennett and Blamey, 2001) and monopoly service quality (for example, Beenstock *et al.*, 1998). In order to identify the role of specific attributes in respondents’ choices, these surveys typically involve multiple choice questions, where each offers multiple policy scenarios described by a set of relevant attributes.

Before proceeding further, it is helpful to place these DCCV and CE survey formats in the context of a more general framework by recognising that a survey mechanism can be considered as two parts: the *elicitation format*, and the *social choice function*. The latter is the process by which survey responses are translated into a policy decision. As will become clear in the next chapter, this process, if it is known to respondents (or, if it is not known, the perceptions of the process) may influence responses to the survey itself. The former part, the elicitation format, refers to the nature of the question or questions that generate the survey responses. DCCV and CE are terms that describe the elicitation format. Both are examples of *stated choice* elicitation formats, which are the focus here since they are the most commonly used format in SP studies today. Stated choice formats vary on several dimensions, including the number of choice tasks per respondent, the number of alternatives in each choice task (and whether the status quo is represented as an alternative), the number of attributes in each alternative and the number of different levels each attribute can take.

The DCCV elicitation format is a specific form of stated choice survey featuring a single choice task per respondent, two alternatives per choice task (where one of those alternatives represents the status quo) and a fixed set of attributes characterising the relevant policy scenario. Typically these attributes are not described in the DCCV question itself, but they are generally detailed in background information in an earlier part of the questionnaire. The term CE loosely refers to a broader class of stated choice survey that typically, though not without exception, features multiple questions per respondent, multiple alternatives per choice task, multiple attributes describing each alternative and multiple levels taken by each attribute over choice tasks.

The critical elements of stated choice methods are the theoretical framework, its econometric representation, and the experimental design of the choices that comprise the survey. Each of these elements is discussed in turn below.

3.3.3 Random utility theory

The most common theoretical framework underpinning stated choice methods is *random utility theory* (McFadden, 1980).[20] It is broadly consistent with the economic theory of consumer behaviour discussed in earlier chapters of this thesis. The choices made by survey respondents are assumed to be determined by a process of utility maximisation where utility is a function of respondents' preferences. However, analysts have incomplete information with respect to respondents' utility functions and can therefore only explain stated choices up to a probability.

More formally, random utility theory is built on the assumption that the utility, U, derived by a respondent from an alternative is a function of the attributes of the alternative (typically including cost or price), choice invariant characteristics (such as the characteristics of the respondent or the choice task) and a random, unobserved element, ε. In any given choice task, respondents choose the alternative that yields the highest utility. The outcome is an index of the observed choice, y. The utility that respondent i derives from alternative j in choice task t is assumed to be:

$$U_{ijt} = \alpha_{ij} + \beta_i'\mathbf{x}_{itj} + \delta_{it}'\mathbf{z}_{it} + \varepsilon_{itj}$$

Parameter vectors β_i and δ_{it} capture the contributions to marginal (dis)utility from observed variables, $\mathbf{x}_{itj}$, and choice-invariant characteristics, $\mathbf{z}_{itj}$, respectively. The coefficient on the alternative-specific constant, α_{ij}, captures the mean of the residual effect of other influences on marginal (dis)utility. The random element, ε,

[20] An example of an alternative theory is *random regret minimisation* (Hensher *et al.*, 2010).

is assumed to be independently and identically distributed across choices and individuals according to the extreme value type I function. This allows the econometric representation of the theory to take the form of a logit model of choice probability.

3.3.4 Discrete choice models

The econometric representation of the random utility framework has become more advanced and general in its assumptions, particularly over the past two decades as improvements in computer technology have facilitated the use of simulation techniques such as simulated maximum likelihood estimation. Dozens of different models have now been proposed. The discussion here is limited to a few models that relate to those employed in the empirical part of this thesis. The *generalised mixed logit* (GML) model (Fiebig *et al.*, 2009; Hensher and Greene, 2009), which is arguably the current state-of-the-art, is specified first. Other model forms, including the commonly-used *multinomial logit* (MNL) and *mixed logit* (ML) models (Hensher and Greene, 2003), are defined as specific cases of this more general model, where the primary differences in the models relate to the accommodation or otherwise of heterogeneity in taste and/or scale across individuals. The GML choice probability function is:

$$\pi_{itj} = \text{Prob}(y_{it} = j \mid \mathbf{x}_{itj}, \mathbf{z}_{itj}, \mathbf{v}_i) = \frac{\exp\left(V_{itj}\right)}{\sum_{j=1}^{J} \exp\left(V_{itj}\right)}$$

where

$$V_{itj} = \alpha_{ij} + \beta_i{}'\mathbf{x}_{itj}$$

$$\beta_i = \sigma_i\beta + [\gamma + \sigma_i(1 - \gamma)]\Gamma\mathbf{v}_i$$

$$\sigma_i = \exp(-\tau^2/2 + \tau w_i)$$

The term $\mathbf{v}_i$ represents a vector of zero-mean random variables that provide the stochastic element in the taste intensities, and Γ is a lower triangular Cholesky matrix (containing rows of zeros where parameters are non-random) providing the standard deviations and covariances for the taste intensities over the population of respondents. A weighting parameter, γ, governs the relationship between scale and residual taste heterogeneity. Unobserved scale heterogeneity, w_i, is distributed standard normal, with coefficient τ. The parameters to be estimated are τ, α, the coefficient vectors β and δ, and the non-zero elements of Γ.

Choice invariant variables can be incorporated in the same way as observed variables:

$$V_{itj} \quad = \alpha_{ij} + \beta_i'\mathbf{x}_{itj} + \delta_i'\mathbf{z}_{it}$$

where

$$\delta_i \quad = \sigma_i\delta + [\gamma + \sigma_i(1 - \gamma)]\Gamma\mathbf{v}_i$$

Alternatively, they can be used to explain heterogeneity in the means of the parameter distributions on the observed coefficients:

$$\beta_i \quad = \sigma_i\beta + \delta'\mathbf{z}_{it} + [\gamma + \sigma_i(1 - \gamma)]\Gamma\mathbf{v}_i$$

The ML model, which accommodates taste heterogeneity but not scale heterogeneity, is the special case where $\gamma = 0$ and $\tau = 0$. The MNL model, which accommodates neither taste nor scale heterogeneity, features an additional restriction, $\Gamma = 0$, so that $\sigma_i = \sigma = 1$ and $\beta_i = \beta$.

In GML and ML models, choice data are typically treated as *panel* data (multiple observations per respondent). The resulting log-likelihood function to be maximised is the sum over individuals of the log of the joint probability of the sequence of T choices:

$$\ln L = \sum_i \ln \prod_t \prod_j \pi_{itj}{}^{y_{itj}}$$

In the MNL model, data are treated as *cross-sectional*, as though all observations were sourced from a representative decision maker. In that case, the log-likelihood function to be maximised is the log of the sum of choice probabilities over all tasks:

$$\ln L = \sum_i \sum_t \sum_j y_{itj} \ln \pi_{itj}$$

Another model, the *latent class model*, accounts for heterogeneity in a discrete, rather than continuous, manner. Following Hensher and Greene (2010), the latent class logit choice probability function for the discrete choice from J alternatives can be written:

Prob[choice j by individual i in choice task t | class q] = $\pi_{it|q} = \dfrac{\exp\left(V_{itjq}\right)}{\sum_{j=1}^{J} \exp\left(V_{itjq}\right)}$

where

$V_{itjq} \quad = \alpha_{qj} + \beta_q{}'\mathbf{x}_{itj} + \delta_{qt}\mathbf{z}_{itj}$

The probability that individual i belongs to class q of Q is:

$$G_{iq} = \frac{\exp\left(\theta_q\right)}{\sum_{q=1}^{Q} \exp\left(\theta_q\right)}\ ,\ \theta_Q=0$$

The log-likelihood function to be maximised is the sum over individuals of the log of the expectation over classes of the joint probability of the sequence of T choices:

$$\ln L = \sum_{i=1}^{N} \ln \pi_i = \sum_{i=1}^{N} \ln \left[\sum_{q=1}^{Q} G_{iq} \prod_{t=1}^{T} \pi_{it|q} \right]$$

3.3.5 Relating choice models to social values

If at least one of the attributes in the vector, $\mathbf{x}_{itj}$, represents the financial cost of the alternative to the respondent, the estimated utility function, V_{itj}, can be used to estimate the marginal social value of service quality, $S'(q)$, discussed in Chapter 2. To this point, quality, q, has been broadly defined to incorporate all of the various attributes of network service quality. In discrete choice models, the contribution to utility of each of the various attributes of service quality can be captured. It is therefore possible to consider respondents' marginal values for specific attributes of service quality as well as their marginal values for changed policy scenarios potentially affecting multiple attributes.

Turning first to marginal valuations of specific attributes of service quality, recall from Chapter 2 that the marginal social value of quality is $\Sigma U_Q^i/\lambda^i\, dQ$; that is, the sum of individual households' marginal values for quality multiplied by the change in quality. In the case where quality is an exogenous policy variable (so that each consumer is unable to choose their own consumption level), this measure is the compensating surplus illustrated in Figure 3.3 as the interval BC (where the change in quality is from Q_0 to Q_1 and Y is numeraire).

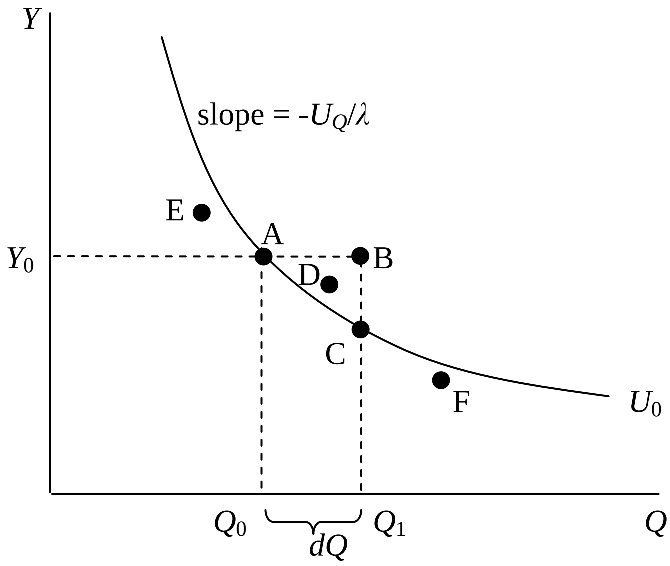

Figure 3.3: The value of a marginal change in quality

Discrete choice models estimate the utility function based on observed choices. Using the consumer represented by Figure 3.3 as an example, observed choices could include the choice of Point D from the set of alternatives A, C, and D; or, the choice of Point A from the set of alternatives A, E, and F. In simple, linear discrete choice models, the marginal effect of a quality attribute on utility, U_Q^i, is estimated by the coefficient in the vector $\boldsymbol{\beta}_i$ that corresponds to the relevant quality attribute in the vector **x**. The marginal utility of income, λ^i, is estimated by the negative of the coefficient in the vector $\boldsymbol{\beta}_i$ that corresponds to the cost attribute in the vector **x**. The value of a unit change in quality, U_Q^i/λ^i, is therefore the ratio of these two coefficients. In summary, the relationship between the notations used in the general equilibrium welfare model in Chapter 2 and the linear econometric choice model is:

$$U_Q^i/\lambda^i = -\beta_\iota^{quality}/\beta_\iota^{cost}$$

This measure is often referred to as the marginal willingness to pay (MWTP) for the relevant quality attribute. The social value of a unit change in quality, $\Sigma U_Q^i/\lambda^i$, is the sum of individuals' MWTP across the population.

To obtain an estimate of the *social* value from a discrete choice model, it is necessary to infer a value for the full population from the results from the surveyed *sample* of the population. If a sample comprising proportion ρ is representative, then the social value of a unit change in quality is $1/\rho\ \Sigma U_Q^i/\lambda^i$ where the sum is across survey respondents. If the sample is not representative, then the sum can be weighted towards types of households or consumers that are under-represented and *vice versa*. Typically, some individuals will reject the opportunity to complete a survey (either at the recruitment or questionnaire stage). A topic of ongoing debate relates to the treatment of these non-respondents when extrapolating the results. For example, a conservative assumption is to include these individuals in the surveyed sample and assume that they place no value on the good in question.

Turning now to the valuation of a changed policy scenario affecting multiple attributes, Small and Rosen's (1981) classic paper details the link between discrete choice models and valuations generally. Based on earlier work by Ben-Akiva and Lerman (1978), they set out the explicit evaluation of the value (compensating surplus, *CS*) of a changed scenario when using a logit model (where superscript 0 and 1 denote before and after the change) is:

$$CS_i = -\frac{1}{\beta_i^{\text{cost}}}\left[\ln\sum_j \exp\left(V_{ij}^1\right) - \ln\sum_j \exp\left(V_{ij}^0\right)\right]$$

In the case of a single good where a specific quality attribute is changed with all other attributes held constant, this equation collapses to the simple ratio of coefficients described above. In the case where multiple attributes change simultaneously, a more complex calculation will apply, but its calculation using the indirect utility function, V, estimated in the discrete choice model is generally straightforward.

However, in some cases, it is not possible to use the explicit evaluation. An example is the case commonly present in DCCV studies in which a logarithm transformation is applied to the monetary attribute resulting in an estimate of the marginal utility of income that is not constant over prices. In these cases, analysts typically rely on a computational approximation of Small and Rosen's (1981) more general equation for compensating surplus (Equation 5.5 in their paper). In certain cases, analysts are able to utilise the fact that the choice probability curve, π, for a specific policy scenario represents a demand curve for that scenario (Hanemann, 1984; McConnell, 1995). An example of such a case can be found where the elicitation format is a binary choice between the status quo and a changed policy scenario, where no allowance is made for panel data in the model (as is the case in the standard MNL model). The area under this curve represents the expected WTP of the representative respondent for the relevant policy scenario:[21]

$$E(WTP)_j = \int \pi_j dx^{\cos t} = \int \frac{\exp(V_j)}{\sum_j \exp(V_j)} dx^{\cos t}$$

[21] To calculate expected WTP using this approach, the analyst needs to fix the levels of attributes (other than the cost attribute) to represent a specific scenario.

This expression, which, like the Small and Rosen (1981) expression, represents a Hicksian compensating measure of welfare change, is commonly used when data are collected using a DCCV elicitation format where a specific policy scenario is of interest (Hanemann, 1984; Seller *et al.*, 1985). However, it can also be applied to MNL model results derived from data collected using binary CE formats. In some cases, this can be evaluated explicitly. In others, such as the case where a logarithm transformation has been applied to the monetary attribute, it may be necessary to approximate the integral. Often it will be necessary to make an assumption about the upper tail of the curve. A common assumption involves truncating the integral at the maximum cost level used in the survey, giving the *improper expectation*:

$$E*(WTP)_j = \int_{-\infty}^{\max cost} \pi_j dx^{cost} = \int_{-\infty}^{\max cost} \frac{\exp(V_j)}{\sum_j \exp(V_j)} dx^{cost}$$

This assumption accords with standard statistical practice of not extrapolating beyond the range of the data, and has desirable properties including consistency with theoretical constraints, statistical efficiency, and ability to be aggregated (Duffield and Patterson, 1991).

Just as in the case of MWTP estimates, values calculated at an individual level need to be aggregated across respondents and extrapolated to the full population in order to estimate the social value of the policy change. Similar challenges to those discussed earlier apply.

3.3.6 Experimental design

Recall that, according to random utility theory, the utility that respondent *i* derives from alternative *j* in choice task *t* is assumed to be:

$$U_{ijt} = \alpha_{ij} + \beta_i'\mathbf{x}_{itj} + \delta_{it}\mathbf{z}_{itj} + \varepsilon_{itj}$$

Up to this point, this section has focused on the estimation of β_i and δ_{it}, the contributions to marginal (dis)utility from the observed variables, $\mathbf{x}_{itj}$, and choice invariant characteristics, $\mathbf{z}_{itj}$. Here, the focus turns to the observation of the variables themselves. The quality of preference information derived from a stated choice survey depends on the nature of the choices observed. The aim is to design choices that induce trade-offs between scenario attributes in a way that reveals the relative importance of each attribute to the respondent. Where a cost attribute is present, the choices reveal the willingness to trade money for each of the non-monetary attributes. The term *experimental design* refers to the design of the choices, and the inherent attribute trade-offs, that appear in a survey. There is a fast-growing literature on the experimental design of stated choice experiments. A brief summary of some recent developments is provided here and readers are referred to Rose *et al.* (2010) for further detail.

Once the problem being studied has been understood and refined, the first steps in designing a stated choice experiment involve identifying the alternatives to appear in the choice tasks and the attributes that will be used to describe those alternatives. Alternatives may be labelled (for example, underground network and overhead network) or unlabelled (for example, Option A and Option B). Where alternatives are labelled, some attributes may be specific to particular alternatives. Analysts typically assume that a larger number of attributes increases the complexity of a choice task (Arentze *et al.*, 2003; Swait and Adamowicz, 2001).[22] However, it is also important to consider the *relevance* of attributes. If attributes considered material by a respondent are omitted from the alternative descriptions, then the choice task may be more confusing as the respondent may attempt to make inferences about the level of the omitted attribute (Hensher, 2008).

To generate an experimental design, the analyst must decide on the levels that each attribute can take and the number of choice tasks to be presented to each respondent. A wide range of attribute levels is desirable from a statistical perspective, but it is important that the levels are credible and meaningful to respondents. It is also desirable to maintain attribute level balance, meaning that each attribute level appears an equal number of times for each attribute in the design. The final step in the experimental design process is to use the available attribute levels to create the various scenarios that comprise the choice tasks ultimately presented to respondents.

Different types of designs may be preferred depending on the available information and the analyst's preferences with respect to statistical properties and the size of the design. A *full factorial* design is one in which all possible choice tasks are enumerated. While these designs are *orthogonal* (zero correlation between attributes) and balanced, they are often impractically large. *Fractional factorial* designs overcome this problem by using only a subset of tasks from the full factorial design. Different subsets lead to different types of fractional factorial

[22] Swait and Adamowicz (2001) quantify task complexity using the measure of *entropy*, which is a function of the similarity of choice probabilities across alternatives, as well as the number of attributes and the degree of attribute correlation.

designs. An orthogonal subset has been a common design choice, but, if prior information about preferences is available, then the design can be altered to extract more information per choice task. For example, orthogonal designs for binary choice tasks frequently include tasks containing a dominant scenario; that is, a scenario in which all attributes are at more desirable levels than in the other scenarios in the choice task. These choice tasks generate very little new information since no trade-offs are induced. The analyst is likely to have enough prior information to identify the expected sign of the parameters, so, at the very least, choices between low-quality-high-price and high-quality-low-price goods can be avoided. If prior parameters, or a (Bayesian) probability density function for the parameters, are assumed, then a design can be generated to maximise the amount of information derived from each choice task. These types of designs are known as *efficient designs*.

Different measures of the amount of information generated by the choice tasks lead to different types of efficient design. Several noteworthy designs base the measure on the asymptotic variance-covariance (AVC) matrix of the parameters, which can be calculated analytically or by simulation using the prior parameter estimates. The AVC matrix is:

$$\Omega(\beta \mid x, y) = -I^{-1}(\beta \mid x, y)$$

where

$I(\beta \mid x, y) = \dfrac{\partial^2 \ln L(\beta \mid x, y)}{\partial\beta\partial\beta'}$ is the second derivative of the log-likelihood function.

D-efficient designs minimise the d-error (= det(Ω)$^{1/K}$) of the AVC matrix and *A-efficient* designs minimise the a-error (= tr(Ω)/K) of the AVC matrix. The latter is calculated solely on the diagonal variance elements of the matrix, while the d-error is a function of the variance and covariance elements of the matrix. *S-efficient* designs maximise a chosen function of the asymptotic t-ratios of the parameter estimates, where the standard deviation is the square root of the relevant diagonal element in the AVC matrix. A type of design that is particularly relevant when estimation of marginal WTP is the objective of the survey is the *C-efficient* design (Scarpa and Rose, 2008). This design maximises a chosen function of the t-ratios of the estimates of marginal WTP for the non-monetary (or non-price) attributes, where the t-ratio is:

$$t(WTP) = (-\beta_1 / \beta_P) / se(WTP)$$

where

β_P is the parameter on the price attribute;

β_1 is the parameter on the relevant non-price attribute; and

$$se(WTP) = \sqrt{\frac{Var(\beta_1) - 2\dfrac{\beta_1}{\beta_P}Cov(\beta_1, \beta_P) + \left(\dfrac{\beta_1}{\beta_P}\right)^2 Var(\beta_P)}{\beta_P^2}}$$

The design can be generated to maximise the average (or a weighted average) of the t-ratios of the non-price attributes, or to maximise the minimum t-ratio across the non-price attributes.

Efficient designs are typically computer generated by estimating the criterion measure for a large number of different designs, with the “best” design updated after each iteration. Various algorithms have been proposed as a means of selecting the designs as part of this iterative process, utilising random selection from a candidate set of choice tasks (Cook and Nachtsheim, 1980) or re-labelling, swapping and cycling (Huber and Zwerina, 1996).

3.4 Summary and conclusions

This chapter has described two methods for estimating the marginal social value of network service quality – the hedonic price methods and SP methods.

The theoretical framework for hedonic price estimation has been established, focusing on the first stage of the hedonic estimation process in which the implicit effects of attributes of a good on the overall price of the good are estimated. In the case of a binary attribute, such as the type of network infrastructure (underground or overhead) the implicit price is equal to the marginal value (or WTP) for the marginal purchaser of the attribute in the market. A drawback of the hedonic price method is the limited information conveyed by the implicit price about the value of interest; namely, the mean WTP for underground networks across households. On the other hand, the data required for the method tend to be relatively inexpensive to collect and they reveal households' preferences via choices made in a real market setting. Moreover, in some cases, the method may reveal whether the *median* WTP across households is considerably greater than or less than the *per property* cost of undergrounding. As a result, the hedonic price method can be an appealing approach to gathering some information on the social valuation of the network quality improvement resulting from underground wires.

The second approach, which allows estimation of the mean WTP across households, is the SP approach. This chapter has described the different survey mechanisms that have been developed over recent decades as SP methods have grown in popularity, focusing on a broad type of SP survey – the stated choice survey. A number of econometric models based on random utility theory have been introduced herein, focusing on the state-of-the-art and on models that have been widely used in recent decades. These models can be applied to data from stated choice surveys to estimate the value of interest developed in Chapter 2 – the marginal social value of quality. The primary advantage of stated choice surveys is that they allow the analyst to observe choices that are not made in the market. This makes the technique extremely valuable in the monopoly service quality setting in which household choices are rarely observed.

In the next chapter, certain challenges associated with applying the hedonic price and SP methods are examined in detail. The subsequent chapter outlines research questions formed on the basis of those challenges. These questions are addressed in the remainder of the thesis.

4 Valuation challenges

4.1 Introduction

Chapter 2 established the importance of accurate estimation of the social value of network service quality in understanding where undergrounding would result in a net economic benefit. Two methods used to inform estimates of this social value – the hedonic price method and stated preference (SP) methods – were introduced in Chapter 3. The objective in this chapter is to detail certain challenges associated with applying those methods. The intention is not to outline all of the valuation challenges being dealt with in the literature, but rather to focus on one particular challenge associated with each method. In subsequent chapters, research questions formed on the basis of these challenges will be addressed using a case study.

The chapter is set out as follows. Section 4.2 discusses the difficulties associated with applying the hedonic price method when explanatory variables are highly correlated. This *multicollinearity* problem is particularly common when estimating the implicit price of underground networks in cities where retro-fit undergrounding is yet to take place. Section 4.3 turns to challenges associated with SP methods, focusing in particular on the implications of *task dependence*; that is, the situation in which respondents' decision processes are influenced by information observed in the course of completing the choice tasks. Section 4.4 concludes the chapter.

4.2 Multicollinearity and the hedonic price method

A statistically appealing approach to estimating the implicit price of underground wires is the *difference-in-difference* approach. In essence, this approach would involve a comparison of the increase in property prices before and after undergrounding relative to the increase over the same period for some control group of properties that had not been subject to undergrounding. This approach is less appealing in practice since it can only be applied where some retro-fit undergrounding has already taken place. In most circumstances, information on the benefits of undergrounding is sought by policy makers *prior* to any program proceeding. A more useful approach would be applicable in towns and cities where undergrounding has yet to take place. However, the nature of the data when using such an approach presents a challenge. Generally, houses in these towns and cities can be broadly categorised in two groups – inner-city, older houses serviced by overhead wires, and outer-city, newer houses serviced by underground wires. Disentangling the effect of underground wires from the effects of other property attributes on property prices can be difficult in this setting.

Recall that the hedonic price function to be estimated is $p(UG, Z)$, where UG indicates whether the property is serviced by underground wires and $Z = z_1, z_2, \ldots, z_n$ is a vector of the amounts of n other property attributes. In a city-wide sample, the presence of underground wires, UG, is likely to be highly correlated with certain other important property attributes in Z. In many cities, installation of underground wires has been a standard development requirement in new, greenfields housing developments for several decades. Prior to that requirement, underground wires tended only to be installed in commercial or high-density developments. As a result, houses serviced by underground wires tend to be those built in recent decades on the suburban fringe. The presence of underground wires is therefore highly correlated with building age and distance to the central business district (CBD). This multicollinearity in the explanatory variables is potentially problematic.

The implicit price of interest is the impact of underground wires on property prices with all other variables held constant. In the presence of multicollinearity, this estimate is imprecise because there are few observations in which the type of network infrastructure changes independently of the variables to be held constant, which include building age and distance to CBD. In loose terms, if observations with underground wires tend to feature newer buildings, then the model has difficulty determining whether price effects are due to the type of network infrastructure or the age of the buildings. This difficulty is manifest in two ways. First, standard errors on the coefficient estimates are large for the affected explanatory variables. Second, the estimates are not robust in the sense that minor changes in the model can cause them to vary dramatically. Moreover, other biases, such as omitted variables bias, can be amplified by multicollinearity.

4.3 Task dependence and stated preference methods

4.3.1 Introduction

There has been a rapid rise in the popularity of stated choice methods as a non-market valuation tool in recent decades. As a result of the relatively recent development of the techniques, there is ongoing research and debate with respect to many challenges associated with applying the methods. For example, a current line of investigation concerns the way in which econometric models account for heterogeneity over respondents (and/or alternatives) in the extent to which responses are deterministic as reflected in the scale parameter (Fiebig *et al.*, 2009; Hensher and Greene, 2009). Another line of investigation deals with the way in which models account for heterogeneity in taste over respondents. Recently developed models allow assumptions about the shape of the distribution of taste to be applied directly to estimates of marginal willingness to pay (WTP) rather than to the parameter estimates that are components in a function used to evaluate WTP (Hensher and Greene, 2009; Scarpa *et al.*, 2008; Train and Weeks, 2005). Another line of investigation concerns the way in which econometric models account for the decision processes applied by respondents when completing choice tasks. Certain models have been proposed that account for simplifying heuristics (decision processes) such as attribute non-attendance (Scarpa *et al.*, 2009) and aggregation of common-metric attributes (Hensher and Greene, 2010; Hensher and Layton, 2010; Hess and Hensher, 2010; Layton and Hensher, 2010). Other models have been developed to understand the role of choice complexity and cumulative cognitive burden in the adoption of simplifying heuristics (Swait and Adamowicz, 2001).

In this research, the focus is on accounting for *task dependence*. Broadly, this term is used to refer to the situation in which respondents' decision processes are influenced by information observed in the course of completing the choice tasks.[23] Such decision processes lead to a violation of certain assumptions that are typically made when analysing responses to stated choice surveys. These standard assumptions are that:

1) respondents truthfully answer the question being asked; and

[23] The term *task dependence* is not used here to refer to the correlation that exists between multiple responses by a given respondent.

2) respondents’ true preferences are stable throughout the decision process and over the course of a sequence of choice tasks.

Several studies have found evidence of violations of these standard assumptions (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; Herriges and Shogren, 1996; Holmes and Boyle, 2005; Ladenburg and Olsen, 2008; McFadden and Leonard, 1995; Racevskis and Lupi, 2008; Swait and Adamowicz, 2001). This growing body of literature suggests that an alternative set of assumptions is required to derive WTP estimates from stated choice data. The appropriate set of alternative assumptions depends on the nature of respondents’ underlying decision processes (or heuristics).

In this section, the heuristics that have been proposed in the literature as a means of explaining task dependence are described. They are grouped into two broad categories – those that involve a violation of the first standard assumption, and those that involve a violation of the second. A discussion of the empirical evidence with respect to those heuristics follows.

Violations of the standard assumptions tend to be more obvious when similar goods are offered at very different prices over the course of a sequence of choice questions (Carson and Groves, 2007). Such surveys arise in non-market valuation settings where significant heterogeneity is expected in the distribution of WTP for a public project over the population, but the set of credible project options is viewed as similar. The valuation of the network quality benefits resulting from undergrounding is an example of such a setting. This type of survey is therefore the focus in this thesis. A consequence of offering similar goods at different prices is that utility differences across alternatives tend to be driven mainly by the monetary (or cost) attribute. As a result, task dependence is manifest primarily as a relationship between stated choices and the cost levels observed in previous choice tasks.[24] In surveys where cost plays a less dominant role, the previously observed levels of other attributes may also become important, but, in this research, the focus is on the role of the cost attribute.

4.3.2 Strategic misrepresentation heuristics

Decision processes that violate the first standard assumption are broadly classified here as *strategic misrepresentation* heuristics. Such heuristics arise from the fact that respondents anticipate a social choice function; that is, the process by which responses will be used by the agency to arrive at a policy decision. Respondents' decision processes could be affected in several ways, depending on the anticipated social choice function. In order to influence the outcome in their favour, respondents might answer a different question from that being asked, for example by considering alternatives accepted in previous choice tasks.

Carson and Groves (2007) use established *mechanism design* theory (Hurwicz, 1972; Mirrlees, 1971) to highlight two specific types of survey mechanism that do not induce such heuristics:

[24] It is assumed throughout that backward navigation through choice tasks is prevented, as is often the case in internet and CAPI surveys. A mail-out paper survey would require a different analysis of heuristics.

1) one in which the elicitation format is a single binary choice (between the status quo and one alternative) and the social choice function is based on majority rule (Farquharson, 1969); and
2) one in which the elicitation format is a sequence of binary choices and the social choice function is based on majority rule applied to a single, randomly selected question from the sequence.

These mechanisms are said to be *incentive compatible* if the agency can credibly claim to be able to force any of the alternatives on any given respondent. It is not necessary for the survey to be binding (Carson *et al.*, 1997) or a full public vote (Green and Laffont, 1978). Incentive compatibility implies that truthful response to each question being asked is the *dominant strategy* for all respondents. That is, truthful response is the utility-maximising strategy for all respondents regardless of perceptions about others' responses.

The first mechanism has successfully been applied in the dichotomous choice contingent valuation (DCCV) survey context, particularly following its recommendation by the National Oceanic and Atmospheric Administration (NOAA) blue ribbon panel in 1993 (Arrow *et al.*, 1993). However, where the objective is the estimation of WTP for multiple attributes, the presentation of multiple choice tasks per respondent is preferred, and in some cases necessary. It greatly increases the statistical efficiency of estimation through opportunities for learning how to evaluate choice tasks (Braga and Starmer, 2005) as well as the much higher number of choice observations. It allows estimation of individual-specific taste intensities and heterogeneity in taste intensities across a population, which may be problematic when using a single observation per respondent (Rose *et al.*, 2009). The second mechanism may be possible in a laboratory environment

(Boyle *et al.*, 2004), but in field surveys the "random draw" social choice function lacks credibility. Respondents are unlikely to believe that the agency would discard the majority of the data that they expended resources collecting (Carson and Groves, 2007). As a result, elicitation formats with multiple questions per respondent will continue to play an important role in value estimation. It is therefore important to understand the decision processes that are induced by these survey mechanisms so that WTP estimates are not biased by inappropriate modelling assumptions.

It has long been recognised in neo-classical economic theory that consumers may conceal their true preferences if it enables them to obtain a public good at a lower cost (Samuelson, 1954). More recently, Carson and Groves (2007) highlighted the predictions of this theory in relation to stated choice surveys comprising a sequence of binary choices where similar goods are offered at different prices over the course of the sequence. One of the predicted patterns of response behaviour is the rejection of an alternative that is preferred to the status quo when a similar good was offered at a lower cost in a previous choice task. This rejection increases the likelihood that the respondent's most preferred option observed in the sequence of choice tasks to that point is implemented. For example, consider the social choice function where any option receiving majority support in a binary choice goes on to be considered for implementation by the agency and the respondent assumes that options proceeding to that stage have equal likelihood of implementation. Under certain assumptions about respondents' perceptions of others' preferences, a respondent may have an incentive to withhold support for all but their most preferred option.

Bateman *et al.* (2008b) differentiate between *strong cost minimisation*, in which respondents always reject a (sufficiently similar) good if it was offered at a lower cost in a previous choice task, and *weak cost minimisation*, in which respondents weigh up the rejection against the perceived risk of the good not being provided at the lower cost. The latter reflects a perceived social choice function in which the likelihood of implementation by the agency increases with consumers' stated WTP (as is often the case when stated choice surveys are used as input to project cost-benefit analyses). The prediction in both cases is that, on average, the WTP estimate implied by the first question in a sequence will exceed the WTP estimates implied by subsequent questions (assuming backward navigation through choice tasks is prevented). This prediction has been found to hold empirically in several studies (Bateman *et al.*, 2008b; Carson *et al.*, 2009; DeShazo, 2002; Racevskis and Lupi, 2008; Scheufele and Bennett, 2010a; Scheufele and Bennett, 2010b).

DeShazo (2002) also argued that respondents evaluate choice questions in terms of deviations from reference points based on previously accepted alternatives. He argued that respondents' value functions shift when a "non status quo" option is chosen because the choice is viewed as a transaction up to a probability and this causes a revision of the reference point around which the asymmetric value function predicted by prospect theory is centred (Kahneman and Tversky, 1979). Despite the difference in underlying theory, this model shares the two main predictions of the *weak cost minimisation* heuristic; first, that respondents compare presented alternatives with alternatives accepted in previous choice tasks, and, second, that respondents consider *expected* utility based on the probability of provision. It also shares the prediction that the WTP estimate implied by the first question in a sequence will exceed the WTP estimates implied by subsequent questions.

An entirely different prediction arises if respondents find some questions implausible and answer as though cost or attributes of the good are at levels considered more realistic or more likely (Carson and Groves, 2007). For example, Bateman *et al.* (2008b) describe a *cost averaging strategy* in which respondents believe that the cost that would be charged if the good were provided would lie somewhere in the middle of the range of costs presented in a sequence. Under such a strategy, the prediction is that alternatives with cost levels from the low (high) end of the range observed by the respondent will be accepted less (more) frequently than in a truthful response. There is little empirical evidence of respondents employing this heuristic. In fact, Bateman *et al.* (2008b), when investigating the possibility of this heuristic, found that it was contrary to the response patterns in the data.

4.3.3 Value learning heuristics

Decision processes that violate the second standard assumption are broadly classified here as *value learning* heuristics. Value learning heuristics revolve around the idea that preferences are initially poorly-formed and are discovered in the process of completing choice tasks (Plott, 1996). They generally predict that discovered preferences are positively influenced by the cost levels presented in choice tasks.

The literature identifies a second type of learning, *institutional learning*. This type of learning relates to the process of learning how to evaluate and complete a choice task (Braga and Starmer, 2005). Institutional learning and its converse, fatigue, have been shown to influence "noise" in the data, manifest as changes in the variance of the random error component (or, equivalently, scale)[25] (Bradley and Daly, 1994; Caussade *et al.*, 2005; Holmes and Boyle, 2005), but there is no implied relationship with WTP. Given the focus here on the effect of decision processes on WTP, the notions of institutional learning and fatigue are not central to the discussion that follows.

In the context of DCCV surveys with multiple questions per respondent, the outcome of value learning decision processes has been termed *starting-point* or *anchoring* bias. Some of the earliest DCCV surveys used a bidding game format. In this format, if a respondent rejected the policy scenario at an initial cost level (or bid), follow-up questions would be asked with successively decreasing bids until the respondent accepted the policy scenario. If the respondent accepted the initial policy scenario, a succession of increasing bids would be offered until the policy scenario was rejected. WTP estimates derived from this approach have been found to be influenced by the level of the initial bid (Boyle *et al.*, 1985; Carson and Mitchell, 1989). Survey formats with limits on the number of follow-up questions have been found to suffer from the same phenomenon. In the double-bounded format, which is limited to a single follow-up question either above or below the initial bid depending on the response to the initial question, the WTP distributions implied by the initial and follow-up questions have been found to differ (Hanemann *et al.*, 1991; Herriges and Shogren, 1996; McFadden and Leonard, 1995).

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[25] In the multinomial logit model, the scale parameter, λ, is an inverse function of the variance of the unobserved effects, $\sigma^2=\pi^2/6\lambda^2$.

Ariely *et al.* (2003) used a series of experiments to show that initial valuations are heavily influenced by anchors (even if those anchors are known by respondents to be arbitrary), but subsequent valuations are coherent in terms of improvements or decrements in the good. They emphasise that this *coherent arbitrariness* has implications not only for SP methods, but for the revelation of preferences in real markets. In the first experiment detailed in their paper, participants were asked two questions with respect to a range of ordinary consumer goods. In the first question, they were asked whether they would be willing to purchase a good for a price equal to the last two numbers in their social security number.[26] In the second, they were asked a simple open-ended maximum-WTP question. Subsequently, a random device determined whether the good would be sold on the basis of the first or second question. The authors found that responses to the second question were strongly influenced by the arbitrary bid value used in the first question.

While it has been suggested that some of these outcomes could be explained by yea-saying or fatigue, the most commonly held view is that the cost levels observed in the choice tasks provide a focal point (or anchor) for the uncertain respondent. For example, Herriges and Shogren (1996) model the decision process as though respondents form a *posterior* WTP distribution equal to a weighted average of the cost level observed in the given choice task and an initially held *prior* distribution of WTP. The motivation for this decision process remains unclear. While some authors have speculated that respondents might infer that the cost level reflects some expert opinion of the value of the good (Herriges

[26] The average retail price of the goods was around US$70.

and Shogren, 1996), the coherent arbitrariness result (Ariely *et al.*, 2003) suggests otherwise since the phenomenon remains even when respondents are aware that the cost level is entirely arbitrary.

With respect to the longer sequences of questions typically employed in choice experiments, some authors have maintained the focus on the effect of the first choice task (Ladenburg and Olsen, 2008), while others have suggested that the effect may extend beyond the first task, potentially for the duration of the sequence of questions. Although Herriges and Shogren (1996) employed a short, two-question elicitation format in their study, they speculated that preference revision could take place throughout longer sequences of questions. Bateman *et al.* (2008b) characterised this type of decision process as a "good deal / bad deal" heuristic in which an alternative is more (less) likely to be chosen if its cost level is low (high) relative to the levels presented in previous choice tasks. Day *et al.* (2009) used the term *reference pricing* to describe this phenomenon. They found evidence to suggest that respondents consider the prices presented in previous choice tasks, with more weight placed on recently completed tasks. In contrast, Ariely *et al.* (2003) found that, as a sequence of questions progresses, the initial anchor continues to have a greater influence on stated preferences than information presented more recently.

It remains somewhat unclear how this type of decision process should be accounted for when estimating WTP given that it clearly implies a relationship between WTP estimated under the standard assumptions and the cost levels used in the choice survey (Carlsson and Martinsson, 2008b). Herriges and Shogren (1996) argue that the analyst should be interested in the prior distribution of WTP, uncertain as it may be, rather than the posterior distribution influenced by the experimental design. However, other authors have argued that the value learning decision process represents a respondent's *discovery* of his/her preferences and hence greater weight should be placed on responses to questions presented later in a sequence (Braga and Starmer, 2005). Bateman *et al.* (2008a) highlight the more fundamental problem that a decision process in which prices influence values is incompatible with standard microeconomic theory.

4.3.4 Empirical evidence on heuristics as competing hypotheses

While a number of studies have found evidence of response patterns associated with a single heuristic, whether it be a strategic misrepresentation type of heuristic (Carson *et al.*, 2009; Carson *et al.*, 2006; Hensher and Collins, 2010) or a value learning type of heuristic (Ariely *et al.*, 2003; Carlsson and Martinsson, 2008b; Herriges and Shogren, 1996; Holmes and Boyle, 2005; Ladenburg and Olsen, 2008), only a few have tested the heuristics discussed above as competing hypotheses to ascertain which best explains responses in a given data set. Two of those studies, DeShazo (2002) and Bateman *et al.* (2008b), found evidence that supports the strategic misrepresentation type of heuristic in which consideration is given to alternatives accepted in previous choice tasks and to the perceived probability of provision. In contrast, the weight of evidence found by Day and Pinto (2010) supports a value learning heuristic, although the study found that no proposed heuristic unambiguously explained the "ordering anomalies" in the data.

It appears that no study has investigated the possibility of heterogeneity in response behaviour across respondents; that is, the possibility that each of the proposed heuristics explains the response behaviour of a sub-group of respondents in the survey.

4.4 Summary and conclusions

In this chapter, certain challenges associated with estimating the implicit price of, and the WTP for, undergrounding have been discussed. Rather than attempting to outline all of the valuation challenges being dealt with in the literature, this chapter has focused on one particular challenge associated with each of the two methods discussed in Chapter 3.

Turning first to the hedonic price method, a challenge that must be overcome when estimating the implicit price of underground wires in a city in which retro-fit undergrounding is yet to take place is multicollinearity in the explanatory variables of price function. This multicollinearity arises because installation of underground wires in new housing developments has only become widespread in recent decades and, as a result, the presence of underground wires is typically highly correlated with building age, the distance to the CBD and, potentially, other important explanatory variables. Disentangling the separate effects of these variables becomes difficult when they are highly correlated. The difficulties are manifest in the statistical models as large standard errors on the coefficients of the relevant variables and a lack of robustness to small changes in model specification.

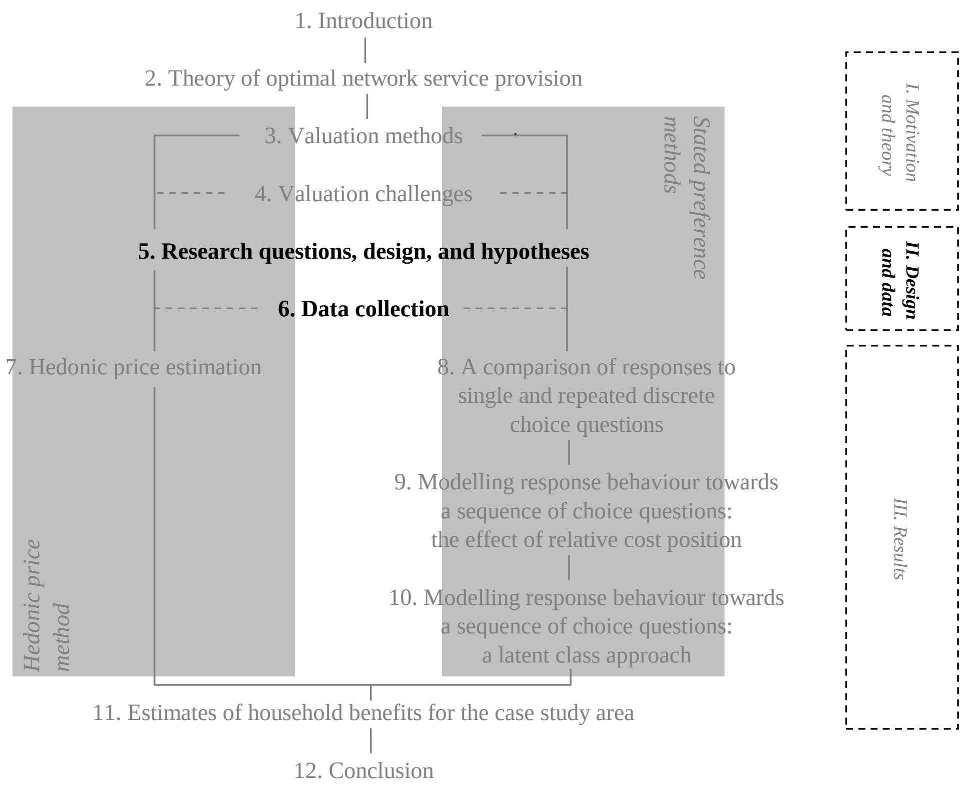
Although there are many challenges associated with applying SP methods, the focus here is on accounting for respondent decision processes that lead to task dependence. A growing body of evidence is showing that respondents’ decision processes are influenced by information observed in the course of completing choice tasks. Analysing the choice data on the basis of the standard assumptions of truthful, independent response and stable underlying preferences is likely to lead to biased estimates of WTP. Specific decision processes raised in the literature have been discussed in this chapter in two broad categories – strategic misrepresentation and value learning. Strategic misrepresentation involves answering a different question from that being asked as a means of influencing the policy outcome. Value learning, on the other hand, involves the revision of underlying preferences based on information (and, in particular, the cost levels) observed in choice tasks.

The two types of heuristics have important, but quite different, implications for the application of stated choice methods. Where strategic misrepresentation is prevalent, it seems greater weight should be placed on the response to the first question in a sequence, and econometric techniques could be adapted to account for the effects of the decision process in subsequent questions. Where value learning is prevalent, a more fundamental question is raised about the underlying microeconomic theory. In particular, it raises the possibility that values are determined, at least in part, by prices. This is at odds with the strict *vice versa* relationship assumed in neo-classical economic theory. It is therefore vital to understand the extent to which each of these decision processes may be affecting the data generated by a given stated choice survey.

In the next chapter, research questions are formed on the basis of the valuation challenges discussed in this chapter. These research questions will then be addressed in the remainder of the thesis using a case study.

PART TWO:

Research design and data



5 Research questions, design, and hypotheses

5.1 Introduction

The broad research question outlined in the introductory chapter related to the evaluation of net economic benefits from undergrounding electricity networks in residential areas. Chapter 2 showed that the marginal social value of network service quality is a crucial element in this evaluation, regardless of governance structure in the industry. Inaccurate estimation of the values could lead to investments with a net economic cost being undertaken and, conversely, investments with a net economic benefit *not* being undertaken. Considerable reliance is therefore placed on two methods for gathering information on the social value of the network quality improvement resulting from undergrounding – the hedonic price method and stated preference (SP) methods. In Chapter 4, the focus was narrowed to two specific challenges associated with applying the methods – *multicollinearity* in the hedonic price method and *task dependence* in stated preference methods. In this chapter, research questions are formed on the basis of those challenges. A research design is developed to address the questions in a case study and, where possible, the hypotheses to be tested are specified.

5.2 Research questions

The intention is to form questions and related hypotheses that, once addressed, would lead to improvements in the application of the methods or, at least, improved understanding of the nature of the challenges and avenues for future research. Consistent with the objectives outlined in the introductory chapter, the research questions addressed in the case study are as follows:

Q1. Can the hedonic price method be adapted to overcome the multicollinearity problems generally present in cities where retro-fit undergrounding is yet to take place?

Q2. Do respondents to stated choice surveys employ strategic misrepresentation heuristics?

Q3. Do respondents to stated choice surveys employ value learning heuristics?

Q4. Does elicitation format, in terms of the number of choice tasks per respondent and the number of alternatives per choice task, influence the extent to which respondents employ strategic misrepresentation or value learning heuristics?

Q5. What is the social value of the network quality improvement that would result from undergrounding in the case study area?

These research questions are addressed using a series of studies based on two data sources – real estate sales data and stated choice survey data. As discussed in the next chapter, both data sources were collected for a case study area as part of this research. The data collection was designed in a specific way to facilitate analysis that would generate evidence relating to the research questions. The remainder of this chapter describes that design and the hypotheses tested as part of the analysis.

5.3 Research design and hypotheses

5.3.1 Hedonic price estimation: research design

The primary objective of collecting real estate sales data was to facilitate analysis that would provide evidence to address the first of the research questions outlined above – *Q1*. This question relates to whether the hedonic price method can be adapted to overcome the multicollinearity problems generally present in cities where retro-fit undergrounding is yet to take place. The data can also be used to provide limited evidence with respect to the fifth research question, *Q5*, which relates to the estimation of the social value of undergrounding in the case study area.

Turning to the first question, one possible means of overcoming the problems posed by multicollinearity is to limit the sample to areas where the correlation between underground networks and other explanatory variables is lower. An example of such an approach is the *boundary discontinuity* approach that has been applied in studies estimating the implicit price of school quality (Black, 1999; Davidoff and Leigh, 2008; Gibbons and Machin, 2003). This approach is a special case of the regression discontinuity approach (Hahn *et al.*, 2001). 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 would involve 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 well as minimising correlations, this approach also controls for unobserved neighbourhood characteristics by allowing comparison of prices for houses with similar access to features such as shopping centres, recreational areas and transport facilities, but different types of network service.

Not all boundaries between overhead and underground network areas would be useful for this purpose. Often, they coincide with suburb boundaries. Using data from these boundaries does not fully overcome the collinearity problem since it is difficult to disentangle the price effects of the type of network infrastructure from those of the unobserved suburb effects (that may be captured in the area fixed effects indicator variables). Ideally, the sample would be based around intra-suburb network boundaries within the case study area.

To see the importance of the sample selection approach, consider an expansion of the sample. Almost all of the introduced data would fall into one of two categories: sales of older houses in inner suburbs serviced by overhead wires; and, sales of newer houses in outer suburbs serviced by underground wires. These data would be of little value since they would hamper efforts to disentangle the price effect of underground networks from those of building age and distance to the central business district.

The disadvantage of the intra-suburb boundary approach is that the selective sample may not be representative of the wider population. If this were the case, then the data would be less useful for gathering evidence with respect to the research question relating to the social value of undergrounding in the case study area as a whole. Therefore, the representativeness of the sample needs to be assessed; for instance, by testing for equivalence in socio-demographic characteristics of the two area populations.

5.3.2 Study #1: Identification and robustness of the implicit property price of underground networks

The first study presented in this thesis, in Chapter 7, analyses data from suburbs in the case study area meeting the criteria described above. The intention is to estimate the implicit price of underground networks. The main equation estimated is a semi-log hedonic price function:

$$\ln P_{ijt} = \alpha + \beta.UG_{ij} + \gamma.Z_{ijt} + \delta_j + \lambda.T_t + \varepsilon_{ijt}$$

where

$\ln P_{ijt}$ is the log of real price of house *i* in area *j* at time *t*;

UG_{ij} is a dummy variable for indicating that house *i* is serviced by underground wires;

Z_{ijt} is a vector of other house attributes;

T_t is a vector of time trend variables; and,

δ_j are area fixed effects.

The focus of the study is β, the parameter used to establish the implicit price of underground wires. Other house attributes are included where they are likely to be significant or correlated with type of infrastructure in the sample areas. The null hypothesis to be tested is that the coefficient, β, on the underground networks indicator variable, *UG*, in the hedonic price function is zero.

There are two problems posed by mulitcollinearity. The first is that multicollinearity leads to large standard errors. If the standard error on the coefficient is sufficiently low that the coefficient estimate is statistically different from zero, then this problem will have been overcome. The other problem is that the coefficient estimate is highly sensitive to changes in model specification. To assess whether this problem has been overcome, statistical significance is tested for several variants on the main model specification. If the coefficient is significant for each variant, then this problem will also have been overcome.

Hypothesis #1 $H_0^1: \beta = 0$

$$H_A^1: \beta \neq 0$$

With respect to *Q5*, this study provides limited evidence relating to the social value of the network quality improvement that would result from undergrounding in the case study area. As described in detail in Chapter 3, the implicit price of underground wires, β, represents the value placed on undergrounding by the *marginal* purchaser of that attribute in the real estate market. To estimate the social value of undergrounding, the analyst requires an estimate of the average or total value placed on undergrounding across all households. The coefficient, β, provides an estimate of one point on the demand curve for undergrounding, but this is not sufficient to calculate the social value of undergrounding, which equals the area under the entire demand curve. It does, however, provide an indication of where the demand curve lies.

5.3.3 Stated choice survey: research design

Turning now to the design of the stated choice data collection, there are four research questions to be addressed by the data. The first two, *Q2* and *Q3*, relate to ascertaining whether respondents are employing strategic misrepresentation or value learning heuristics. The third, *Q4*, relates to the influence of elicitation format (in terms of the number of choice tasks per respondent and the number of alternatives per choice task) on the extent to which those heuristics are employed by respondents. The fourth, *Q5*, relates to the social value of undergrounding in the case study area.

One way of assessing whether strategic misrepresentation heuristics are being employed in a multiple question elicitation format is to compare responses to a control group that is free from strategic misrepresentation. To achieve this, a split-sample treatment of elicitation format was used. One group of respondents received an incentive compatible survey mechanism comprising a single binary choice between the status quo (the current overhead network service) and an undergrounding option with a suburb-based majority-rule social choice function (the single binary, *SB*, format).[27] A second group responded to an expanded elicitation format comprising a sequence of four binary choice tasks (the repeated binary, *RB*, format).[28]

Data from the *RB* format can also be used to assess whether value learning heuristics are being employed by respondents. To ensure this is possible, the order in which choice tasks were presented to respondents was cycled through all possible orderings. This allows analysis of the influence of cost levels observed in previous choice tasks. For example, it is possible to compare whether a $4,000 undergrounding option offered in the third choice task is more likely to be accepted if the options presented in the previous choice tasks cost $2,000 and $12,000 as opposed to $2,000 and $6,000.

Turning to the question relating to the influence of elicitation format on the adoption of both types of heuristic, the influence of expanding the number of choice tasks per respondent can be assessed by comparing responses to the *SB* and *RB* formats. However, to examine the influence of expanding the number of alternatives per choice task, a third elicitation format in the sample was required. This third group responded to a further expanded elicitation format comprising a

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[27] It is also necessary for the agency to credibly claim to be able to force any alternative on a given household. It is a maintained assumption that this condition held in the stated choice survey in this thesis. It is expected that the presence of ActewAGL, the local electricity network service provider, as a partner in the research (reflected in the branding on the questionnaire) would have assisted in this regard.

[28] All non status quo alternatives involve new underground infrastructure. This ensures that every alternative in the design is meaningful as an *SB* choice, while allowing the same set of alternatives to be used in all elicitation formats.

sequence of four choice tasks each made up of the status quo and *two* undergrounding options (the multinomial, *MN*, format). The effect of this expansion of the number of alternatives is assessed by comparing evidence on the adoption of heuristics in data from the *RB* and *MN* formats.

To ensure approximately equal representation of elicitation formats across choice observations, four in six respondents were assigned to the *SB* format, and one in six were assigned to each of the *RB* and *MN* formats. In both the *RB* and *MN* formats, the order in which choice tasks were presented to respondents was cycled through all possible orderings to ensure that the role of cost level ordering in the strategic misrepresentation and value learning heuristics can be determined. A summary of the split-sample treatment of elicitation format is presented in Figure 5.1.

The alternatives used in the choice tasks in each format were drawn from the same design to ensure that the effects of elicitation format can be isolated from other design-driven effects. An example of the translation of a design comprising eight undergrounding options to the split-sample treatment of elicitation formats is presented in Figure 5.2. The figure represents a cycle of 12 respondents. Eight respondents are assigned to the *SB* format. Each receives one of the eight undergrounding options. Two respondents are assigned to the *MN* sample-split. Both are offered all eight undergrounding options over the course of four choice tasks. Two respondents are assigned to the *RB* format. Each receives half of the eight undergrounding options over the course of four binary choice tasks. One of those respondents receives the four undergrounding options presented in the column on the far right-hand side of the choice tasks in the *MN* format. The other respondent receives the remaining four undergrounding options.

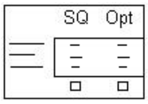
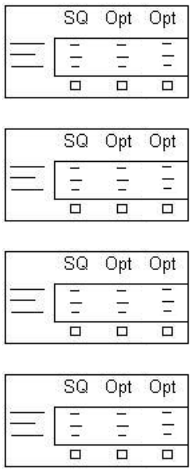
Sample split	Single binary (*SB*)	Repeated binary (*RB*)	Multinomial (*MN*)
Stylised representation of elicitation format			
Social choice function	The agency will proceed with further investigation of the undergrounding option in your suburb if it is preferred to the current service by more than 50% of survey respondents in your suburb.	The agency will proceed with further investigation of an undergrounding option in your suburb if it is preferred to the current service by more than 50% of survey respondents in your suburb.	
Proportion of full sample of respondents, *N*	4/6	1/6	1/6

Figure 5.1: The split sample survey mechanism

Finally, by recruiting survey respondents from the case study area, the data can also be used to estimate the social value of the network quality improvement resulting from undergrounding in that area.

This thesis presents four studies that analyse the data generated by the stated choice survey. Each tests a hypothesis or series of hypotheses that address the research questions. These hypotheses are detailed in the following sections.

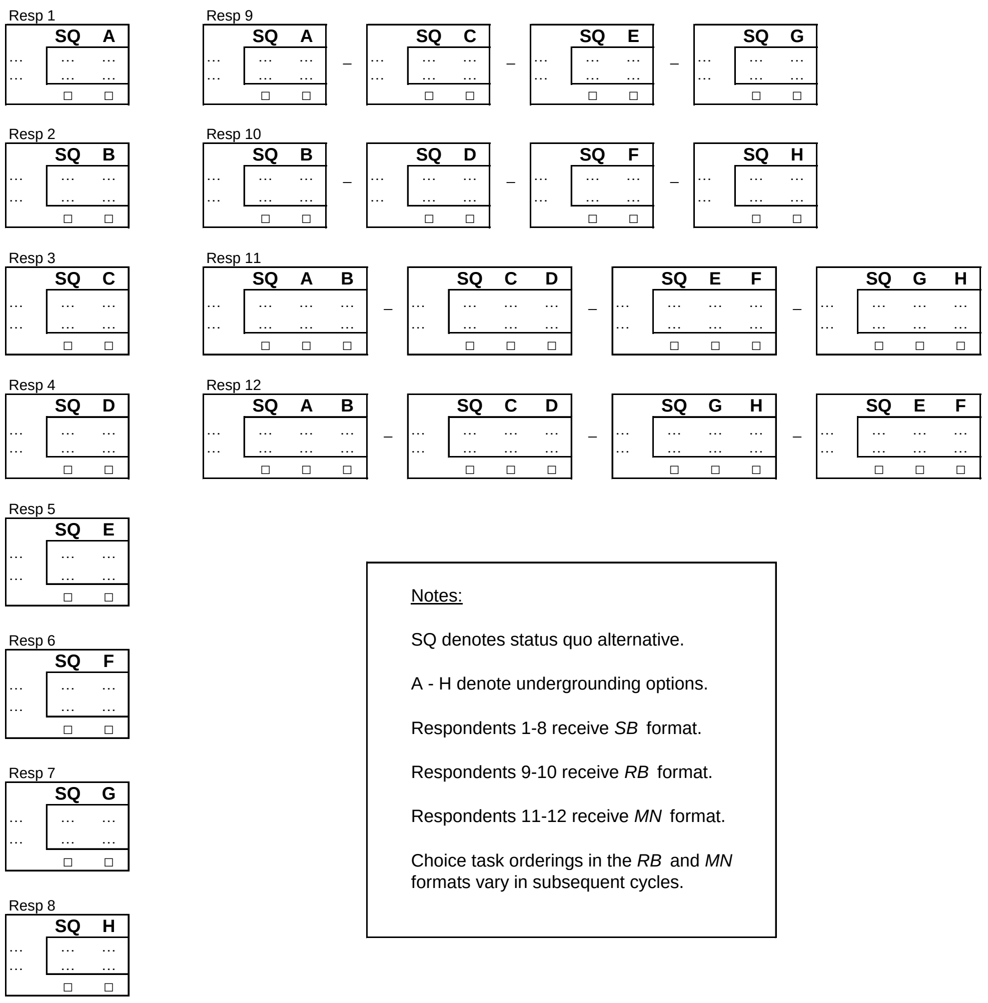


Figure 5.2: Linking the design to the split-sample treatment of elicitation format

5.3.4 Study #2: A comparison of responses to single and repeated discrete choice questions

As discussed in Chapter 4, the prediction of neo-classical economic theory is that strategic misrepresentation heuristics will be employed in the *RB* format, but not in the *SB* format. The expected pattern of response behaviour in the *RB* format is the rejection of some undergrounding options that would have been accepted had they been presented as a single choice task. As a result, the prediction is that estimated willingness to pay (WTP) for undergrounding would be lower in the *RB* format than in the *SB* format. This prediction is tested by comparing expected

WTP for the mean undergrounding scenario from a multinomial logit (MNL) model estimated on data from the *SB* format with the equivalent estimate from a MNL model estimated on data from the *RB* format.

The author is aware of just one existing study (Racevskis and Lupi, 2008) and one concurrent study (Scheufele and Bennett, 2010a) employing this type of split-sample treatment of elicitation format. As yet, there is no body of evidence to support or counter Racevskis and Lupi's (2008) finding of a significant difference between models fitted to data from the *SB* and *RB* elicitation formats. This thesis represents a contribution towards addressing this research gap.

The (one-tailed) hypothesis to be tested is based on the prediction of theory. Rejection of the null hypothesis would be consistent with the prediction of the strategic misrepresentation heuristic.

Hypothesis #2 H_0^2: E(WTP)$_{SB}$ = E(WTP)$_{RB}$

H_A^2: E(WTP)$_{SB}$ > E(WTP)$_{RB}$

where $E(WTP)_j = \int \pi_j dx^{\cos t} = \int \frac{\exp(V_j)}{\sum_j \exp(V_j)} dx^{\cos t}$ as described in Chapter 3.

The MNL model is utilised for this test because models estimating heterogeneity in taste (the mixed logit (ML) model), scale (the scaled MNL model) or both (the generalised mixed logit model) across individuals are problematic when estimated on data with a single choice observation per respondent. Although ML models may be able to disentangle the Gumbel error distribution and the random parameter distributions when estimated on repeated choice data (Fosgerau and Nielsen, 2006), further work is required to establish whether this is true of models estimated on single binary choice data. Rose *et al.* (2009) found random parameter estimates to be statistically insignificant where data were single choice observations per respondent in their study of the impact of the number of choice tasks per respondent.

Economic theory also predicts that responses to the *SB* format may differ from responses to the *first* question presented to each respondent in the *RB* format. The first question presented in the *RB* format does not hold the “take it or leave it” property required for incentive compatibility. The consequence of this is that, in theory, respondents may reject an alternative in anticipation of receiving a better offer later in the sequence. The question as to whether this prediction is realised in practice is an important one, since, if it is not, the *RB* format would be preferred to the *SB* format due to the additional information it generates at little or no additional cost.

To test whether stated preferences in the first of a sequence of choice tasks are affected by advance knowledge that multiple choice tasks will be presented, the MNL model on the *RB* data used to test Hypothesis #2 is altered to include interactions between the cost variable and indicator variables for the order in which choice tasks were presented. For example, an indicator variable, *q1,* would take the value one when a choice task is the first presented to a respondent (and zero or minus one otherwise depending on the coding approach).[29] Again, the test involves a one-tailed comparison of WTP for the mean undergrounding scenario from MNL models on the two response formats, but, in this test, WTP is evaluated at the first question in the sequence in the model on the *RB* data.

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[29] The effects coding approach used in the study is detailed in Chapter 8.

Hypothesis #3 H_0^3: E(WTP)^{SB} = E(WTP)$^{RB \mid q1 = 1}$

H_A^3: E(WTP)^{SB} > E(WTP)$^{RB \mid q1 = 1}$

Although rejection of H_0^3 would be consistent with the prediction of the cost minimisation heuristics, the same result would follow from a value learning heuristic that is asymmetric in the way in which cost levels influence underlying preferences. If lower cost levels have a greater impact on preference revision, then, over the course of a sequence, average underlying WTP will fall. Further testing would be required to understand which heuristic is best supported by the data and whether there is heterogeneity in heuristics across respondents; that is, whether sub-groups of respondents are employing different heuristics giving a mixed overall outcome. Two approaches are taken to gathering this evidence. The first examines the effect of "relative cost position", which, as will become clear, provides evidence on which heuristics best explain the data pooled across all respondents. In the second approach, an *equality-constrained latent class* (ECLC) model is used to estimate the proportions of respondents behaving in accordance with the different heuristics. This approach also allows examination of whether the number of alternatives per choice task influences the heuristics employed by respondents.

5.3.5 Study #3: The effect of relative cost position on response behaviour towards a sequence of choice questions

Turning to the "relative cost position" approach, the intention is to understand which heuristics may be most prevalent in the data. While it may not be possible to identify whether an heuristic has been employed by observing the responses of a single respondent, over a sufficiently large sample, it is possible to identify the response patterns predicted by a given heuristic in terms of relationships between responses and cost levels observed by respondents in previous choice tasks. The means of achieving this are to incorporate, in ML and MNL models on the *RB* data, variables indicating the four possible “relative positions” for the cost level presented in a choice task. In any given choice task, the cost level presented must be one of the following four “relative positions”:

a) both the minimum and the maximum level presented in the sequence to that point (*m11*);[30]

b) the minimum, but not the maximum level presented in the sequence to that point (*m10*);

c) the maximum, but not the minimum level presented in the sequence to that point (*m01*); or

d) neither the minimum nor the maximum level presented in the sequence to that point (*m00*).

In this study, the *m11*, *m10* and *m01* indicator variables are interacted with the cost variable to allow estimation of the relationship between cost sensitivity and the positioning of the cost level relative to the levels presented to the respondent in previous choice tasks. For example, if the parameter estimate for the *m00* interaction is significantly higher than that for the *m01* interaction, this indicates that cost sensitivity is lower (and WTP is higher) when the cost level is within the range of levels presented in previous choice tasks relative to when it is the highest

[30] A necessary and sufficient condition for the *m11* relative position is that the question is the first in the sequence.

level presented in the sequence to that point (with all other variables, including cost, held constant). This would imply, for example, that an alternative with a cost level of $4,000 is more likely to be chosen if previously presented cost levels were $2,000 and $6,000 than if they were $2,000 and $1,000.

The relationships between the relative cost position interaction coefficients implied by the various heuristics are presented in Table 5.1. *Strong cost minimisation* predicts an increase in cost sensitivity when the cost level is not the minimum presented in the sequence to that point. Alternatives are rejected whether cost is the highest level observed by the respondent or within the range observed. Under *weak cost minimisation* the relationship between these two relative positions is uncertain since likelihood of acceptance depends on the maximum level of cost *accepted* in the sequence to that point. The parameter relationships implied by *reference point revision* are the same as those implied by *weak cost minimisation*, with likelihood of acceptance decreasing where a lower-cost alternative has been presented in an earlier choice task. *Value learning* implies that cost sensitivity is increased when cost is the highest level observed by the respondent and decreased when cost is the lowest level observed by the respondent relative to the first question or to questions in which cost lies within the range observed by the respondent. *Cost averaging* implies the opposite set of effects. Finally, the standard assumptions imply that relative cost position has no influence.

Table 5.1: Parameter relationships implied by heuristics

Heuristic	Implied parameter relationships
Strong cost minimisation	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}=\beta_{m00*cost}$
Weak cost minimisation	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}$ and
Reference point revision	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m00*cost}$
Value learning	$\beta_{m10*cost}>\beta_{m11*cost}>\beta_{m01*cost}$ and $\beta_{m10*cost}>\beta_{m00*cost}>\beta_{m01*cost}$
Cost averaging	$\beta_{m10*cost}<\beta_{m11*cost}<\beta_{m01*cost}$ and $\beta_{m10*cost}<\beta_{m00*cost}<\beta_{m01*cost}$
Standard assumptions	$\beta_{m10*cost}=\beta_{m11*cost}=\beta_{m00*cost}=\beta_{m01*cost}=0$

The parameter estimates from the models are compared to these implied relationships to determine which heuristics are consistent with, or counter to, the data. Identification of a single overriding theory may not be possible, but some discrimination is possible and allows a narrowing of the range of potential explanations for the response behaviour observed in the *RB* sample.

A null hypothesis of truthful response with stable preferences is tested against the alternative hypothesis of task dependence. If the null is rejected, behavioural explanations for the task dependence are sought by comparing the interaction coefficient relationships to those implied by the heuristics.

Hypothesis #4

$$H_0^4 : \beta_{m11*cost} = 0 \text{ and } \beta_{m10*cost} = 0 \text{ and } \beta_{m00*cost} = 0 \text{ and } \beta_{m01*cost} = 0$$

$$H_A^4 : \beta_{m11*cost} \neq 0 \text{ or } \beta_{m10*cost} \neq 0 \text{ or } \beta_{m00*cost} \neq 0 \text{ or } \beta_{m01*cost} \neq 0$$

The ML model uses the relative cost position indicator variables to explain heterogeneity in the mean and variance (heteroscedasticity) of the distribution of cost sensitivity over respondents. The results will provide preliminary insights into any heterogeneity in the way in which respondents behave in the presence of a particular relative cost position. This will deepen the understanding of the nature of the heuristic or heuristics being employed by respondents in this survey.

5.3.6 Study #4: A latent class approach to estimating heterogeneity in response behaviour towards a sequence of choice questions

While the study into the effect of relative cost position identifies the heuristics that best explain the response patterns in the data, it is not well-suited to estimating the extent of any heterogeneity in response behaviour across respondents. The possibility of heterogeneity in the use of heuristics is investigated separately in this study. An ECLC model is used to estimate the latent (or unknown) proportions of respondents behaving in accordance with three heuristics based on the three broad types of decision process discussed in Chapter 4:

1) the standard assumptions (truthful, independent response with stable preferences);
2) value learning; and
3) strategic misrepresentation.[31]

[31] It is not possible to elicit this information simply by asking respondents to reveal their behaviour. The responses would be of little value since those behaving in accordance with the

The model is applied to data from both the *RB* and *MN* formats.

Recall from Chapter 3 that the latent class logit choice probability function for the discrete choice from J alternatives is:

Prob[choice j by individual i in choice task t | class q] = $P_{it|q}$ = $\dfrac{\exp\left(\mathbf{x}'_{itj}\beta_{jq}\right)}{\sum_{j=1}^{J}\exp\left(\mathbf{x}'_{itj}\beta_{jq}\right)}$

The probability that individual i belongs to class q of Q is:

$$G_{iq}=\frac{\exp\left(\theta_q\right)}{\sum_{q=1}^{Q}\exp\left(\theta_q\right)}\text{ , }\theta_Q=0$$

The log-likelihood function to be maximised is the sum over individuals of the log of the expectation over classes of the joint probability of the sequence of T choices.

$$\ln L=\sum_{i=1}^{N}\ln P_i=\sum_{i=1}^{N}\ln\left[\sum_{q=1}^{Q}G_{iq}\prod_{t=1}^{T}P_{it|q}\right]$$

The standard attributes, **x**, are defined so that they take the value zero in the status quo utility function. To achieve this, the attributes are defined in terms of changes relative to the status quo. The reason for this redefinition becomes clearer in the discussion to follow.

The Q classes are defined by separate parameter vectors, $\boldsymbol{\beta}_{jq}$. Parameters are constrained to take the value zero in certain classes, but the non-zero parameters to be estimated will be constrained to take the same value across classes (that is, they will be assumed to be generic). These Q vectors effectively translate to Q sets

strategic misrepresentation heuristic would indicate that they responded to each choice task independently and truthfully.

of utility functions to which respondents are assigned up to a probability to maximise the log-likelihood function.

In this study, Q=3 sets of utility functions are specified to capture the response patterns associated with each of the three types of decision process. Given that the literature contains variants on each hypothesis, there is likely to be some argument about how the utility functions should be specified for each class. While it is not claimed that the functions specified here represent a definitive set of utility functions, they are considered the most suitable for this study based on the weight of evidence in the literature and model fit testing. They are tailored to analyse responses to stated choice surveys in which similar goods are offered at very different prices over the course of a sequence.[32] The consequence is that value learning and strategic behaviour tend to be driven mainly by the cost attribute. These utility functions are specified accordingly, however, the approach could be expanded to incorporate the effects of other attributes.

Standard assumptions (Class 1)

The utility functions specified for the latent class of respondents behaving in accordance with the standard assumptions are the conventional sum-product of the k attributes as they appear in the choice task being answered and their associated taste intensities:

[32] This type of survey is required here since significant heterogeneity is expected in the distribution of WTP for undergrounding over the population, but credible project options are viewed as similar.

$$U_{it,\mathrm{SQ,class1}} = \beta_1 x_{1,it,\mathrm{SQ}} + \ldots + \beta_k x_{k,it,\mathrm{SQ}}$$

$$U_{it,\mathrm{ALT,class1}} = \beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}}$$

Value learning (Class 2)

The second latent class represents those responding in accordance with a value learning heuristic. The focus here is on the role of cost levels in value learning. Cost levels are generally considered to be the main influence in the value learning process in stated choice surveys in which similar goods are offered at very different prices over the course of a sequence. The utility function is specified to capture the response patterns of this group by allowing the alternative-specific preference to vary with the average of cost levels observed in the sequence up to and including the current choice task.[33] The cost level in the current choice task is included in the average to accommodate the prediction of coherent arbitrariness (Ariely *et al.*, 2003), anchoring, and starting-point bias (Herriges and Shogren, 1996) that the cost level observed in the first choice task will influence preferences prior to response. The utility functions are as follows:

$$U_{it,\mathrm{SQ,class2}} = \beta_1 x_{1,it,\mathrm{SQ}} + \ldots + \beta_k x_{k,it,\mathrm{SQ}}$$

$$U_{it,\mathrm{ALT,class2}} = \beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}} + \beta_{k+1} z_{it,\mathrm{ALT}}$$

---

[33] In longer sequences of choice tasks, perfect recall is less likely and a weighted specification (for example Day *et al.*, 2009) may be preferred to the equal-weight average applied here. In this study, it was not possible to estimate separate classes for different lengths of choice tasks over which the learning occurs. The class is defined in such a way that learning occurs over the duration of the full sequence of four choice tasks, but value revision is based on changes in average observed cost, which become smaller on average over the course of a sequence.

where

z_{itj} $= z^{o}_{itj} - \check{z}_{j}$

z^{o}_{itj} = the average of cost levels observed up to and including the current choice task

$\check{z}_{j}$ = the average of cost levels in the sample (across all respondents and all choice tasks)

The purpose of $\check{z}_{j}$ is econometric rather than behavioural. It simply "normalises" the average observed cost variable by ensuring its sample mean is approximately zero. This prevents the latent class model from using the coefficient, β_{k+1}, to infer heterogeneity in taste across classes, thus ensuring the model estimates only heterogeneity in response behaviour towards the sequence of questions.

The average observed cost variable is calculated using only on the cost levels observed in undergrounding alternatives and it is included only in the utility function for undergrounding alternatives. Cost levels observed in the status quo alternative, which are zero in every case, are not included in the calculation and the status quo utility function is unchanged from Class 1.

A positive coefficient on the average observed cost variable would indicate, for example, that respondents are more likely to accept a $6,000 undergrounding alternative in the second question of a sequence if the first question contained an undergrounding alternative costing $4,000 rather than $2,000.

Strategic misrepresentation (Class 3)

In a third class of response behaviour, utility functions are specified to capture the response patterns predicted by a strategic misrepresentation heuristic. The heuristic is modelled on the *weak cost minimisation* and *reference point revision* heuristics in that it has two features.[34] The first is that respondents compare alternatives to those accepted in previous choice tasks. In particular, they choose the status quo option not only when the status quo is preferred to the alternatives, but, potentially, also when a previously accepted alternative is preferred to the alternatives currently on offer. It is assumed that respondents effectively replace the status quo with a reference alternative once they have expressed a preference for an alternative over the status quo. The reference alternative is defined as the highest-cost alternative previously accepted in the sequence. Over the range of cost and WTP levels that matter, this reference alternative yields the highest *expected* utility (based on the provision probabilities discussed below) of all previously accepted alternatives.[35]

The second feature of this heuristic is that respondents consider the probability of provision. When a similar good is offered at very different cost levels over the course of a sequence of choice tasks, respondents may assume that higher-cost goods are more likely to be provided because the agency is more likely to proceed with the project the higher the respondents' stated WTP. It is assumed that the perceived probability of project provision is equal to the ratio of the maximum

---

[34] These are shown in Study #3 (Chapter 9) to be the most prevalent strategic misrepresentation heuristics in the data.

[35] A spreadsheet simulation showed that, if the good being offered is sufficiently similar across tasks, the highest-cost alternative previously accepted yields higher expected utility (as a reference alternative) than all other previously accepted alternatives for all combinations of WTP and cost (in the present task) in which the present alternative yields expected utility higher than at least one previously accepted alternative.

cost level *accepted* and the maximum cost level *observed*.[36] Consider the case where a project option priced at $4,000 is accepted in the first of a sequence of binary choice tasks. If a project option priced at $8,000 is presented in the second task, then the perceived probability of project provision is revised to 50 per cent. The respondent is faced with a trade-off. The perceived probability of provision can be increased to 100 per cent, but at the cost of accepting the more expensive ($8,000) alternative. If the alternative is accepted, it becomes the reference alternative in the next choice task. Alternatively, if a project option priced at $2,000 is presented in the second choice task, then the choice does not influence the probability of project provision (and the respondent will accept the $2,000 alternative assuming the goods are sufficiently similar).

The utility equations represent the expected utilities from the reference and current alternatives:[37]

$$U_{it,\mathrm{SQ,class3}} = p_{it,\mathrm{SQ}}(\beta_0 + \beta_1 x^{a}_{1,it} + \ldots + \beta_k x^{a}_{k,it})$$

$$U_{it,\mathrm{ALT,class3}} = p_{it,\mathrm{ALT}}(\beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}})$$

where

[36] The perceived probability of provision is unlikely to ever be 100 per cent due to uncertainty about others' preferences and the advisory nature of most surveys. However, it is the relative probabilities, rather than the absolute probabilities, that are important in determining the choice probabilities.

[37] The "1-p" terms are not required since utility from the status quo is zero.

$\mathbf{x}^{a}_{it}$ = the levels of attributes in the highest-cost alternative accepted in previous choice tasks ($x^{a}_{1,it}$ is the maximum cost level accepted in previous choice tasks)

$p_{it,SQ} = x^{a}_{1,it}/x^{o}_{1,it}$

$x^{o}_{1,it}$ = the maximum cost level observed up to and including the current choice task

$p_{it,ALT} = max[p_{it,SQ}\ , x_{1,it,ALT}/x^{o}_{1,it}]$

The importance of defining the standard attributes in terms of changes relative to the status quo now becomes clear. If a respondent has chosen the status quo in all choice tasks to a given point, then $x^{a}_{1,it}$=0, $p_{it,SQ}$=0 and $U_{it,SQ,class3}$= $U_{it,SQ,class1}$= $U_{it,SQ,class2}$=0. In the first question in a sequence, the Class 3 utility functions are identical to those in Class 1 since $p_{it,SQ}$=0 and $p_{it,ALT}$=1. Once a respondent has chosen an alternative over the status quo, that alternative replaces the status quo as the reference point and $U_{it,SQ,class3}$>0. Alternatives presented in subsequent choice tasks are accepted if the expected utility from choosing the alternative exceeds the expected utility from choosing the reference alternative.

Class structure in the equality-constrained latent class model

The three sets of utility functions are operationalised in the latent class model by three separate sets of restrictions on a ‘master’ utility function. Certain parameters are restricted to be zero and certain parameters are restricted to be equal both within and across classes, as shown in Table 5.2. The alternative-specific constants and the standard attributes, **x,** are divided into two parts – one multiplied by $p_{it,ALT}$ and another by 1- $p_{it,ALT}$. In Classes 1 and 2, coefficients on attributes multiplied by $p_{it,ALT}$ and 1- $p_{it,ALT}$ are assumed to be equal so that they represent the marginal utility of the standard attribute without consideration of the probability of provision. In Class 3, the coefficients on attributes multiplied by 1-$p_{it,\mathrm{ALT}}$ are set to zero so that utility *does* depend on the probability of provision. A set of reference alternative variables are restricted to hold zero value in Classes 1 and 2 (in which previously accepted alternatives are ignored), but in Class 3, they are assumed to have the same taste intensities as the equivalent variables in the "non status quo" alternatives in the current choice task. All non-zero attributes are assumed to take the same value across classes.

Table 5.2: Class structure

Variable	Alternative	Parameters[a]		
		Class 1 (Standard)	Class 2 (Learning)	Class 3 (Strategic)
$p_{it,\mathrm{SQ}}$	Status quo	0	0	β_0
$\mathbf{x}^{a}_{it}p_{it,\mathrm{SQ}}$	Status quo	0	0	$\boldsymbol{\beta}$
$p_{it,\mathrm{ALT}}$	Underground alternative	β_0	β_0	β_0
$\mathbf{x}_{it}p_{it,\mathrm{ALT}}$	Underground alternative	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$
$1-p_{it,\mathrm{ALT}}$	Underground alternative	β_0	β_0	0
$\mathbf{x}_{it}(1-p_{it,\mathrm{ALT}})$	Underground alternative	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$	0
$z_{it,\mathrm{ALT}}$	Underground alternative	0	β_{k+1}	0

[a] $\boldsymbol{\beta}$ refers to a coefficient vector, $\beta_1, \beta_2, \ldots, \beta_k$, associated with $x_1, \ldots, x_k$.

Two sets of hypotheses are tested. The first set tests whether each heuristic explains the behaviour of a positive proportion of respondents. Recall that G_q is the estimated proportion of respondents behaving in accordance with heuristic q of Q.

Hypothesis #5 $\quad H_0^5 : G_1^{RB} = 0$

$$H_A^5 : G_1^{RB} \neq 0$$

Hypothesis #6 $H_0^6 : G_2^{RB} = 0$

$H_A^6 : G_2^{RB} \neq 0$

Hypothesis #7 $H_0^7 : G_3^{RB} = 0$

$H_A^7 : G_3^{RB} \neq 0$

Hypothesis #8 $H_0^8 : G_1^{MN} = 0$

$H_A^8 : G_1^{MN} \neq 0$

Hypothesis #9 $H_0^9 : G_2^{MN} = 0$

$H_A^9 : G_2^{MN} \neq 0$

Hypothesis #10 $H_0^{10} : G_3^{MN} = 0$

$H_A^{10} : G_3^{MN} \neq 0$

The second set of hypotheses tests whether the proportions differ between data from the *RB* and *MN* formats.

Hypothesis #11 $H_0^{11} : G_1^{RB} - G_1^{MN} = 0$

$H_A^{11} : G_1^{RB} - G_1^{MN} \neq 0$

Hypothesis #12 $H_0^{12} : G_2^{RB} - G_2^{MN} = 0$

$H_A^{12} : G_2^{RB} - G_2^{MN} \neq 0$

Hypothesis #13 $H_0^{13} : G_3^{RB} - G_3^{MN} = 0$

$H_A^{13} : G_3^{RB} - G_3^{MN} \neq 0$

5.3.7 Study #5: Estimates of household benefits for the case study area

The method for estimating the household benefits from undergrounding in the case study area is informed by the results of the preceding studies. Therefore, the approach to accounting for the decision processes of respondents is described in Chapter 11. The key measure of household benefits to be estimated is the mean WTP for undergrounding across survey respondents. From a policy perspective, there is also interest in the heterogeneity in WTP across respondents and whether this heterogeneity can be related to the specific benefits of undergrounding valued most by respondents or to the socio-economic characteristics of respondents. This would assist policy makers in identifying which residential areas would benefit most from undergrounding. To enable this type of analysis, the questionnaire included the question: “What would be the two most significant benefits to your household from undergrounding?

1) improved appearance and unobstructed views;
2) fewer power cuts;
3) better safety, particularly during storms and bushfires;
4) reduced tree trimming requirements and associated costs;
5) fewer restrictions on use of yard space (for example, for construction of a garage or swimming pool);
6) less need for ActewAGL to access your backyard; or
7) other (please specify below).”

The questionnaire also included questions about the socio-demographic characteristics of the respondent and their household. In particular, questions relate to the age, gender and education of the respondent, the number of persons in the household, the suburb location of the household and annual household income.

The answers to these questions can then be incorporated as respondent characteristics, $\mathbf{z}_{it}$, in the indirect utility function described in Chapter 3:

$$V_{itj} = \alpha_{ij} + \beta_i'\mathbf{x}_{itj} + \delta_i'\mathbf{z}_{it}$$

In the case of data from the binary elicitation formats, they can then be related to the household benefits from undergrounding by examining their effect on the measure of expected WTP:

$$E(WTP)_j = \int \pi_j dx^{\cos t} = \int \frac{\exp(V_j)}{\sum_j \exp(V_j)} dx^{\cos t}$$

5.4 Summary and conclusions

This chapter has established a structure for the research presented in the remainder of this thesis. It has outlined questions relating to the conceptual and practical challenges discussed in Chapter 4 that, once addressed, will lead to improvements in the application of the methods or, at least, improved understanding of the nature of the challenges and avenues for future research. A series of studies has been designed to address these research questions using two data sources – real estate sales data and a stated choice survey. Approaches to data collection have been designed in a specific way to facilitate analysis that generates evidence relating to the research questions. Where possible, the hypotheses to be tested in the studies have been specified.

The next chapter details the two data collection processes. Then, results from the four studies examining valuation challenges are set out in Chapters 7 through 10. Chapter 11 provides estimates of the household benefits of undergrounding for policy use and Chapter 12 discusses the study outcomes and concludes the thesis.

6 Data collection

6.1 Introduction

In the preceding chapters, it was established that the marginal social value of network service quality is a crucial element in defining the conditions under which undergrounding electricity networks would result in a net economic benefit. Two methods for estimating this value were introduced and certain challenges associated with applying those methods were discussed. In Chapter 5, research questions were posed on the basis of those challenges and the structure for the studies conducted to address those questions was established. Approaches to collecting data from two sources for the purpose of facilitating those studies were described. This chapter details the data collection that took place. The chapter begins with an introduction to the case study area – the city of Canberra, Australia. Then, the collection of real estate sales data and stated choice survey data are detailed in Sections 6.3 and 6.4, respectively. Section 6.5 concludes the chapter.

6.2 The case study area: Canberra, Australia

The case study area for the studies presented in this thesis is the city of Canberra, Australia. Canberra is the capital city of Australia and had a population of approximately 351,000 at the time of the data collection in mid-2009.[38] Electricity

[38] The population of the wider "Australian Capital Region", including Canberra and areas in surrounding New South Wales, was approximately 575,000 (Source: Australian Bureau of Statistics Cat No. 1308.8).

networks in Canberra have been placed underground in the majority of high-density residential and commercial areas. The only lower-density residential areas to be serviced by underground networks are those developed since underground installation became a standard condition in land development deeds in the late 1980s. The suburbs serviced entirely by underground networks are shown by the shaded areas in Figure 6.1. Approximately 70 per cent of Canberra households (about 100,000 households) are situated in older suburbs serviced by overhead networks (represented by the unshaded areas in the figure). The networks in these suburbs are usually reticulated along the rear boundary of properties, reflecting Canberra's original town planning decision to limit the amount of overhead street verge reticulation. A few of those suburbs contain a mix of sections serviced by overhead and underground wires because they were developed during the period in the 1980s when underground installation was starting to become a standard condition in land development deeds. These suburbs are discussed in more detail in the following section.

The electricity distribution network service provider in Canberra, ActewAGL Distribution (ActewAGL), is considering the merits of replacing existing overhead infrastructure with new underground networks. The benefit estimates derived in this thesis are an input to ActewAGL's cost-benefit analysis of the potential project.

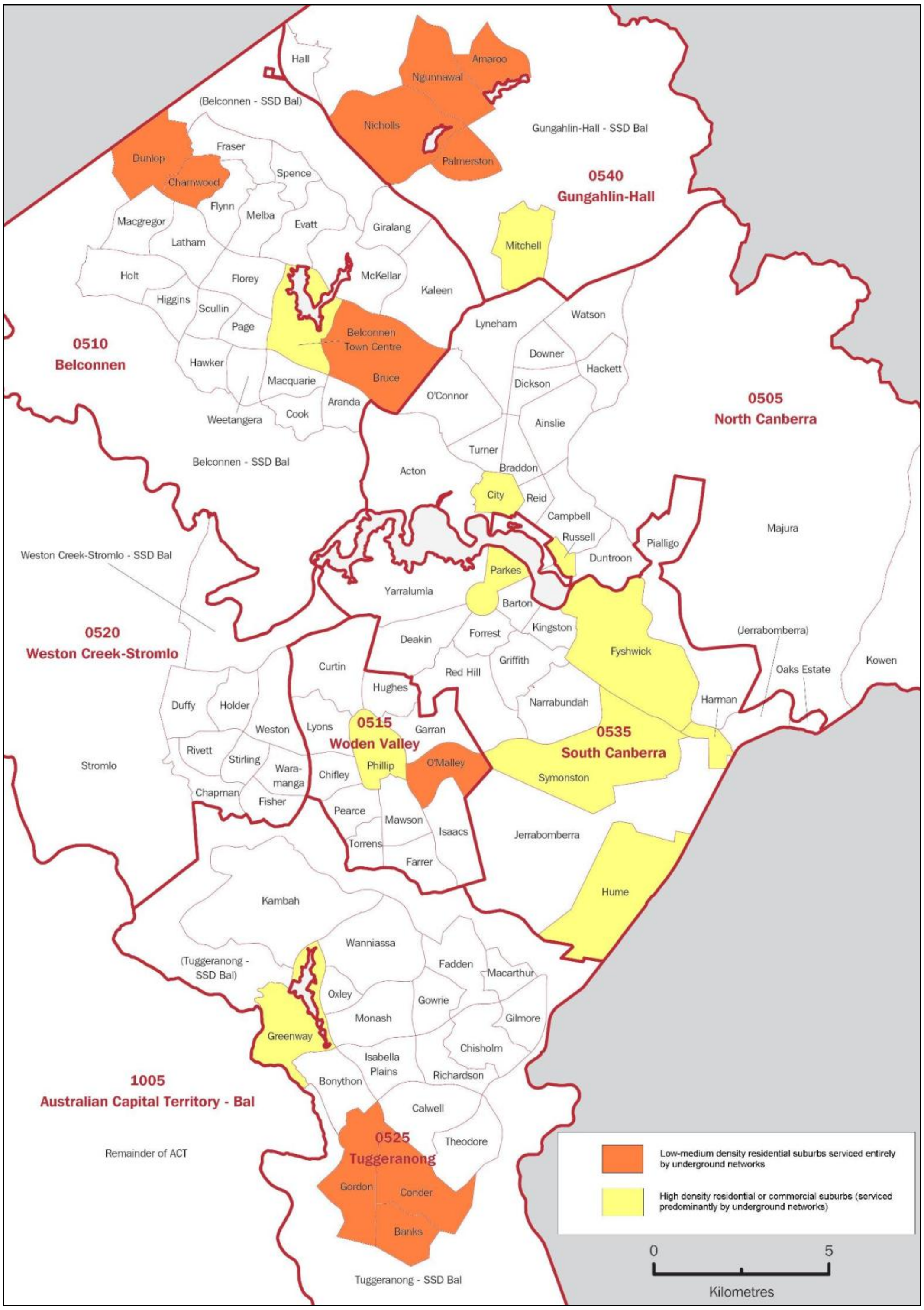

Figure 6.1: Map of Canberra suburbs by network type

Source: Australian Bureau of Statistics (ABS) and ActewAGL Distribution network maps

6.3 Property sales data

6.3.1 Selection of suburbs

The research design set out in Chapter 5 involved collection of real estate sales data from suburbs containing a mix of overhead and underground infrastructure. Several candidate suburbs in Canberra were identified. Most were developed during the period in the 1980s when underground installation was starting to become a standard condition in land development deeds. Following site visits and advice from valuers with extensive experience in the city (Egan National Valuers, Australian Capital Territory (ACT) Branch, and Frank Brodrick of CB Richard Ellis), three of these suburbs (Calwell, Florey and Macarthur) were selected for analysis due to the relative homogeneity of neighbourhoods and housing stock across sections with overhead and underground wires. The areas serviced by underground wires in each suburb are shown in Figure 6.2, Figure 6.3, and Figure 6.4.

As acknowledged in Chapter 5, the risk when using a selective sample is that the data are not representative of the broader population. Table 6.1 (p. 131) presents a comparison of the characteristics of individuals and households in the three sample suburbs and Canberra as a whole. Residents in the sample suburbs tend to be younger and household sizes tend to be larger; but, importantly, the sample suburbs are representative of Canberra in terms of unemployment and the distributions of household income and house size (measured as the number of bedrooms).

Figure 6.2: Underground networks in Florey

Figure 6.3: Underground networks in Calwell

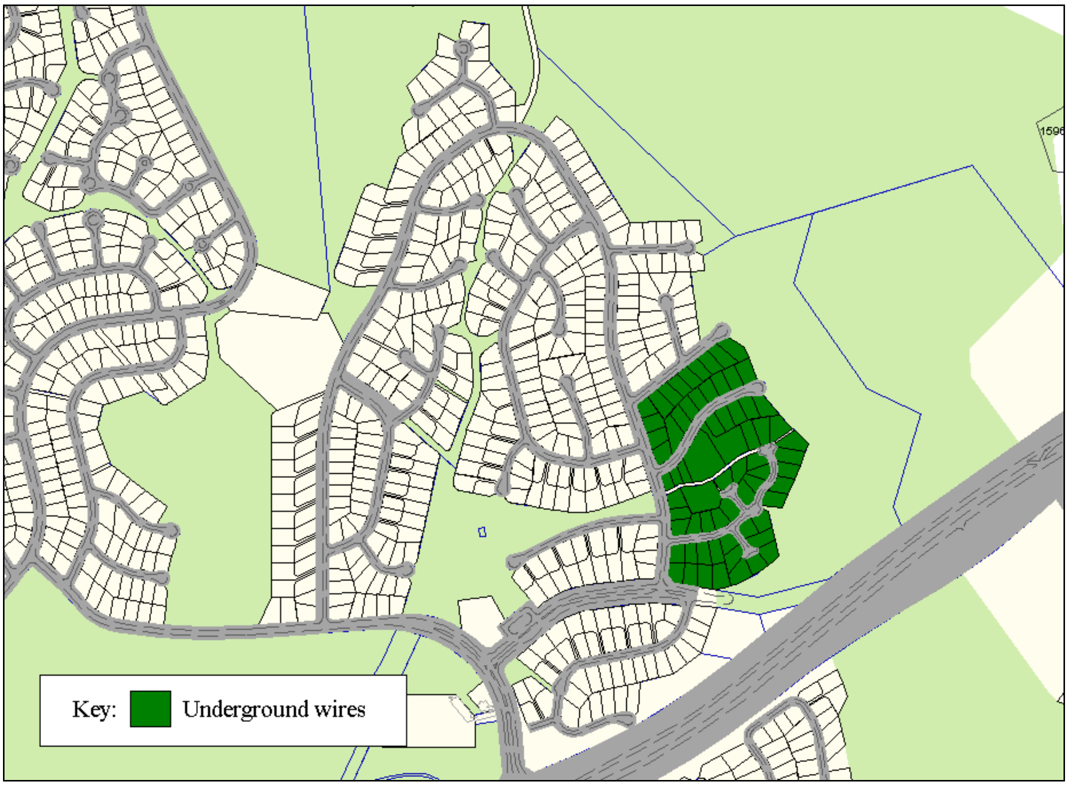

Figure 6.4: Underground networks in Macarthur

Table 6.1 Comparison of individual and household characteristics

	Sample suburbs (per cent)	Canberra (per cent)	χ^2 tests for differences (p-value)
Weekly household income:			
A$0 – A$1,699	49.9	50.9	0.20
A$2,500 or more	21.0	21.6	0.53
Unemployment rate	3.4	3.4	0.81
Age:			
0-14 years	22.6	19.1	0.00
65 years and older	5.3	9.7	0.00
Separate houses - household size:			
5 persons or more	16.4	14.0	0.00
Separate houses - building size:			
3 bedrooms	44.2	45.3	0.24
4 bedrooms	52.7	51.2	0.11

Source: ABS 2006 Census Data

6.3.2 Variables and data sources

Data were collected for sales of detached houses in these three suburbs between January 2004 and September 2008. The variables employed in the analysis and their sources are shown in Table 6.2. The variables were chosen based on a review of the literature (for example, Ball, 1973; Kain and Quigley, 1970) and discussions with experienced valuers. The housing attributes found to be most significant in recent house price studies in Canberra by Davidoff and Leigh (2008) and the Australian Bureau of Statistics (2008) were included. Quality of view was included because of its significance in several studies (for example Benson *et al.* (1998)).[39] Land characteristic data collected were: the size of the block, the distance to the central business district (CBD), a 3-point scale rating of the quality of views[40], and dummy variables for high road traffic and for servicing by underground wires.[41] Structure characteristics collected were: the number of bedrooms, the number of bathrooms and ensuites, and the number of car parking spaces in garages and carports. The quality of landscaping and the external condition of the house were rated jointly on a 3-point scale.[42] Data were not

[39] The selection of variables was further validated by the strength of the estimation results reported in Chapter 7.

[40] The rating of view quality was based on elevation and the amount of land visible from the property. The presence of overhead power lines was not a factor in the rating.

[41] By coding underground wires as a single dummy variable, it is assumed that wires do not impose externalities on adjacent properties without wires (and vice versa).

[42] It is expected that the measures of external quality would be strongly correlated with unobserved internal quality, effectively serving as a proxy. The estimate of the implicit price of external quality would then reflect the implicit prices of both external and internal quality.

collected for building age or other neighbourhood characteristics because, within each of the three suburbs, houses are of similar vintage and neighbourhoods are relatively homogeneous (for example, they have similar access to town centres and transport infrastructure).[43] These effects are captured using indicator variables for suburb. It was judged that this set of variables sufficiently captured the main property characteristics that could be correlated with undergrounding.[44]

Table 6.2 Data sources

Data from <http://www.allhomes.com.au>:	
	Sale price
	Date of sale
	Suburb
	Size of land
	Distance to CBD
	Number of bedrooms
	Number of bathrooms and ensuites
	Number of car parking spaces in garages and carports
Data from field visits to properties:	
	Quality of view (3-point scale)
	External condition of yard and building (3-point scale)
Data based on address of property:	
	High road traffic (dummy variable)
Data based on ActewAGL network maps:	
	Underground wires (dummy variable)

[43] There are very few knocked-down-rebuilt houses in these suburbs. Buildings in these suburbs are no older than 35 years, since all three were developed primarily in the 1980s.

[44] The estimated implicit price would be affected by *omitted variable bias* if any variable correlated with both undergrounding and the regression residuals is omitted from the regression.

Most of the data were obtained from <http://www.allhomes.com.au>, a website containing a database of all property sales in Canberra. Other data were collected during field work between November 2008 and January 2009. Any measurement error resulting from the time between the house sale and the field work is expected to be uncorrelated with type of network infrastructure. Data on the number of bedrooms, bathrooms and car accommodation were available from <http://www.allhomes.com.au> for 436 of the 863 sales of detached houses in the period of interest. Deleting eight "battle-axe" blocks that could not be inspected in the field and one price outlier, the final sample was 427 observations. Of these, 132 were serviced by underground wires, as described in Table 6.3. Summary statistics for the data are set out in Table 6.4.

Table 6.3 Final sample by suburb, year and type of network infrastructure

Period	Calwell	Macarthur	Florey	Total
2008 (to Sept.)	20 (5)	3 (1)	8 (2)	31 (8)
2007	56 (18)	13 (1)	31 (15)	100 (34)
2006	55 (15)	15 (3)	32 (16)	102 (34)
2005	51 (17)	20 (3)	31 (12)	102 (32)
2004	46 (10)	17 (0)	29 (14)	92 (24)
Total	228 (65)	68 (8)	131 (59)	427 (132)

Number of observations with underground wires are in parentheses

6.3.3 Multicollinearity

A regression explaining the indicator variable for underground wires (*UG*) in terms of the other explanatory variables from the main regression is presented in Table 6.5. The table shows that *UG* is unrelated at the 95 per cent confidence level to house sale date, the number of bedrooms and the presence of high-quality views, garages and ensuites. However, underground wires are negatively related to external condition, block size and the presence of high road traffic and average-quality views. An F-test shows the explanatory variables to be jointly significant at the 95 per cent confidence level indicating that housing characteristics differ between areas serviced by overhead and underground wires in the sample.

Table 6.4 Descriptive statistics

	Min.	Max.	Mean	S.D.
Continuous variables:				
Real sale price (2008 A$ '000s) (*PRICER*)	262	964	426.0	106.4
Number of days sale occurred after 11/01/2004 (*TIME*)	1	1696	791.6	448.4
Block area in m^2 (*SIZE*)	232	1561	813.8	223.8
Distance to Canberra General Post Office (*CBDDIST*)	8	19	14.7	4.0
Dummy coded variables:				
3 bedrooms (*BED3*)	0	1	0.47	
4 bedrooms (*BED4*)	0	1	0.43	
5 or more bedrooms (*BED5UP*)	0	1	0.07	
At least one garage (*GARAGE*)	0	1	0.71	
At least one ensuite (*ENSUITE*)	0	1	0.63	
Underground wires (*UG*)	0	1	0.31	
Situated on a distributor road (*TRAFFIC*)	0	1	0.15	
Some view (*VIEW2*)	0	1	0.38	
Spectacular view (*VIEW3*)	0	1	0.06	
Average external condition (*COND2*)	0	1	0.63	
Above average external condition (*COND3*)	0	1	0.11	
Suburb of Calwell (*CALWELL*)	0	1	0.53	
Suburb of Macarthur (*MACARTH*)	0	1	0.16	

Sample size, N=427.

This result means that the data cannot be treated as a randomised controlled trial. A simple comparison of average house sale prices across the two groups will not suffice. Rather, a hedonic regression is required to control for the differences between the groups. Importantly, the multicollinearity problem likely to have been present in a city-wide sample does not appear to be present here. The correlations between *UG* and the other explanatory variables are low. Assuming linear relationships between variables, the highest correlation is 0.27 and all but two are correlated at less than 0.2, suggesting that it is possible to disentangle the effect of underground wires on house price from the effects of the other variables. The full correlation matrix is presented in Appendix B.

Table 6.5: Regressing underground networks against other explanatory variables

Variable	Coefficient	t-stat
(Constant)	-13.344	-8.632
TIME	0.000	0.836
BED3	-0.155	-1.393
BED4	-0.146	-1.181
BED5UP	-0.007	-0.048
GARAGE	-0.007	-0.137
ENSUITE	0.094	1.683
TRAFFIC	-0.113	-1.980
VIEW2	-0.152	-3.066
VIEW3	-0.045	-0.482
COND2	-0.177	-3.591
COND3	-0.305	-3.848
DIST_LN	6.097	9.086
TIMESQ	-6.531 E-08	-0.613
SIZESQ	-2.058 E-07	-3.369
CALWELL	-3.917	-9.074
MACARTH	-2.623	-9.239
F	12.13	(p=0.000)
R^2	0.32	
N	427	
Dependent variable: *UG*		

6.4 Stated choice survey

Turning now to the collection of the stated choice survey data, there are several aspects of the data collection process to be described. These include selection of the medium for the survey instrument, pre-testing of the draft questionnaire, compiling the questionnaire, constructing the choice tasks, and recruiting the sample. Each is dealt with in turn in the discussion to follow.

6.4.1 Selecting the survey medium

The chosen medium for the survey instrument was the internet. The online survey was programmed and hosted by the Institute of Transport and Logistics Studies at the University of Sydney. This medium was preferred to paper-based survey approaches because it allowed the prevention of backward navigation through a sequence of choice tasks, which is crucial to the research design discussed in Chapter 5. It was preferred to computer-assisted personal interviews (CAPI) primarily due to cost constraints. The use of an elicitation format with a single choice observation per respondent meant that the required sample size (in terms of the number of respondents) was relatively large at around 1,500 respondents. The cost of collecting these data using CAPI exceeded the funds available for the research. One of the potential disadvantages of internet surveys relative to CAPI is that respondents are less likely to complete relatively long questionnaires. However, given the short sequences of choice tasks planned for this survey, this disadvantage is of little relevance. Internet surveys also have some advantages over CAPI such as the absence of any interviewer bias.

6.4.2 Pre-testing the questionnaire

The web-based questionnaire was developed in consultation with ActewAGL, the local electricity network business, and was refined based on *cognitive testing* with 11 participants. Cognitive testing refers to in-depth, semi-structured interviews with individuals or couples from the survey target group. The interviews were designed to identify how respondents understood and interpreted specific questions in the questionnaire and, for some questions, how they arrived at their answer. The interviews comprised two stages. In the first stage, the participant(s) completed the draft questionnaire and in the second stage an interviewer (a consultant from ORIMA Research) engaged the participant(s) in a conversation exploring the meaning of specific parts of the questionnaire and how the participant arrived at their answers. This process ensured that the questionnaire made sense to respondents and, as far as possible, successfully captured the information sought. It facilitated identification of questions that may have been misinterpreted by respondents and ways of improving those questions prior to fielding the survey. Second, it provided a richer understanding of the data collected in the survey.

6.4.3 Compiling the questionnaire

A summary of the questionnaire contents is provided here, focusing on components other than the choice tasks, which are discussed in detail later in this section. A complete example of the contents of the questionnaire is provided in Appendix C.

The questionnaire login page included a short letter explaining the survey topic and providing contact details for enquiries regarding technical problems, the content of the questionnaire and research ethics. It explained that respondents' identities would not be revealed to the research partners (ActewAGL, the Australian National University and the University of Sydney) and data would be used in a grouped format. The first page of the questionnaire (following login) provided background information on the context for the survey, including the reasons why undergrounding was being considered. Two photos taken in Canberra were presented alongside versions edited to simulate the visual changes that would result from undergrounding. A set of photos from East Victoria Park in Perth (Western Australia) before and after undergrounding was also presented. Further background information was provided in relation to the physical process of the undergrounding works and respondents were told to assume that all land-owners in an area to be undergrounded would be required to make a specific contribution towards the cost of undergrounding in their suburb.

The first set of questions in the survey related to the benefits and disadvantages of undergrounding. Respondents were asked to select two of the following specific benefits in response to the question: “What would be the two most significant benefits to your household from undergrounding?

1) improved appearance and unobstructed views;
2) fewer power cuts;
3) better safety, particularly during storms and bushfires;
4) reduced tree trimming requirements and associated costs;
5) fewer restrictions on use of yard space (for example, for construction of a garage or swimming pool);
6) less need for ActewAGL to access your backyard; or
7) other (please specify below).”

Respondents were then asked, “Other than cost, what would be the most significant disadvantage to your household?” The options provided were: “power cuts may be longer”, “inconvenience during undergrounding works”, “service pillar in front of property”, and “other (please specify below)”. Respondents were also asked whether they thought undergrounding was a good idea in principle, putting cost aside.

The purpose of the next section of the questionnaire was to establish the frequency and average duration of planned and unplanned power cuts associated with the respondent's current overhead service. This information would be used to describe the status quo option in the choice tasks (and, as described later in this section, to calculate the attribute levels in the undergrounding options). Pre-testing interviews had revealed that respondents preferred to be presented with a description of typical or average supply reliability levels and adjust them if necessary to align with their experience. Therefore, respondents were told that power cuts to be expected over a five-year period with an overhead service would be four power cuts without warning with average duration of one hour and three power cuts with written notice with average duration of three hours. Respondents were then asked whether this was representative of their current overhead service, or whether they would like to specify the number and duration of power cuts used to describe their current service.

The next section of the questionnaire gave instructions regarding the choice task(s). Respondents were told that there are a number of different options for undergrounding and that different types of wires, service connections and maintenance programs would affect cost and supply reliability outcomes. They were told that the survey was seeking their input on which option, if any, should be considered for their suburb. Respondents were told how many choice tasks they would be asked to complete and the number of alternatives that would be presented in each task. They were advised that decisions on undergrounding would generally be made at a suburb level. A decision rule (or social choice function) was given. Respondents were told, “ActewAGL will proceed with further investigation of the/an undergrounding option in your suburb if it is preferred to the current service by more than 50% of survey respondents in your suburb.” In the *SB* elicitation format, the word “the” was used, while, in the *RB* and *MN* formats, the word “an” was used. This social choice function was required to ensure that the survey mechanism was incentive compatible in the *SB* format.

Each choice task page included a reminder of the two most important benefits and the most important disadvantage of undergrounding selected by the respondent in earlier questions. Below each choice task, respondents were asked whether they would pay the specified land-owner contribution upfront with a discount or in instalments. Respondents were also asked, in relation to each attribute in the choice task, to indicate one of, “I did not consider this at all”, I considered this, but it did not influence my choice”, or “This did influence my choice.” The choice tasks themselves are described later in this section.

Once the choice tasks had been completed, a series of follow-up questions was asked. These related to attribute processing strategies used in the choice tasks (for example, aggregation of common-metric attributes and multiplication of frequency and duration attributes), the influence of earlier choice tasks, the influence of perceptions about others’ choices, the adequacy of the time and information available, and whether the respondent had seen or heard media stories on undergrounding in Canberra.[45]

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[45] The questionnaire did not include “cheap talk” scripts or reminders of substitute goods. Pre-testing interviews indicated high levels of consequentiality, with all participants indicating an

The final part of the questionnaire comprised questions about the socio-demographic characteristics of the respondent and their household. In particular, questions related to the age, gender and education of the respondent, the number of persons in the household, the suburb location of the household and annual household income.

6.4.4 Constructing the choice tasks

A split-sample treatment of elicitation format was applied to the choice task component of the questionnaire. Four in six respondents received a single binary choice between the status quo (the current overhead network service) and an undergrounding option (the single binary, *SB*, format). One in six respondents were presented with an expanded elicitation format comprising a sequence of four binary choice tasks (the repeated binary, *RB*, format). Finally, one in six respondents received a further expanded elicitation format comprising a sequence of four choice tasks each comprising the status quo and *two* undergrounding options (the multinomial, *MN*, format). The choice tasks used in these formats were constructed as follows.

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understanding that ActewAGL could decide to undertake undergrounding and pass on the cost in customer electricity bills. Most participants expected that the survey results would influence decisions on undergrounding. In other words, participants were considered “yea-sayers” since they understood that if they expressed a preference for a high-cost undergrounding alternative (over the status quo) in the survey this would increase the likelihood that undergrounding would take place and that they would be billed that amount.

Attributes and levels

The attributes used to describe the alternatives and the levels assigned to those attributes are presented in Table 6.6. Of the specific benefits of undergrounding, only supply reliability could be included as a variable in the choice tasks. It was judged that there was no credible way of including safety and amenity as attributes that vary independently of the type of infrastructure. These “non-reliability” benefits of undergrounding were effectively embodied in the alternative label. The purpose of the reminder of benefits and disadvantages of undergrounding included on the choice task pages was to ensure the prominence of supply reliability benefits in choice tasks did not cause a disproportionate focus on this benefit. The cost attribute took the form of a one-off undergrounding contribution that could be paid upfront with a small discount or by instalments for up to five years.

The cost attribute took the level zero in the current service (or status quo) alternative. In the undergrounding options, the level ranged from A$1,000 to A$16,000. It was expected, based on pre-testing responses and interviews, that acceptance of undergrounding options would be high (approximately nine in ten) at the low end of this cost range and low (approximately one in ten) at the high end of the range. It was expected that almost all respondents would accept undergrounding at zero cost.[46] Given the presence of ActewAGL as a partner in the research, it was expected that the claim to be able to enforce payment on all households in a suburb would be viewed as credible by respondents. The

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[46] In the main survey, 97 per cent of respondents agreed that undergrounding is a good idea in principle putting cost aside.

credibility of this claim is crucial to the incentive compatibility of the *SB* elicitation format.

Table 6.6: Attributes and levels

Attribute	Levels	
	Status quo (overhead) alternative	Undergrounding alternatives
Your one-off undergrounding contribution (2009 A$)	0	1,000, 1,100, 2,000, 2,100, 2,800, 3,000, 3,900, 4,000, 6,000, 6,200, 8,000, 8,200, 11,800, 12,000, 15,900, 16,000
Power cuts without warning:		
Number of power cuts each five years	Set by respondent	Proportions of status quo level: 0.25, 0.5, 0.75, 1 [a,b]
Average duration of power cuts	Set by respondent	Proportions of status quo level: 0.33, 0.66, 1.33, 1.66 [a]
Power cuts with written notice (occurring in normal business hours):		
Number of power cuts each five years	Set by respondent	Proportions of status quo level: 0.2, 0.4, 0.6, 0.8 [a,b]
Average duration of power cuts	Set by respondent	Proportions of status quo level: 0.33, 0.66, 1.33, 1.66 [a]

[a] Rounded to the nearest integer; [b] Absolute levels (0, 1 and 2) were assigned where respondents chose very low status quo levels (1 or less).

Supply reliability attribute levels for the status quo alternative were set by the respondent as described earlier in this section. The levels assigned to those attributes in the undergrounding options were calculated as proportions of the status quo levels (rounded to the nearest integer). The chosen levels were informed by a comparison of supply reliability in overhead and underground areas in Canberra and by advice from ActewAGL. They were set to maximise the range of levels subject to correlations and limitations inherent in the infrastructure. An example of the limitations on the range of credible attribute levels is the range of proportions applied to the power cut frequency attributes, which needed to lie between zero and one since one of the benefits of undergrounding is a reduction in the frequency of power cuts. A larger range of 0.33 to 1.66 was possible for the power cut duration attributes.

The experimental design

Two blocks of four choice tasks were constructed in the *MN* elicitation format to maximise the Bayesian C-efficiency of the design (Scarpa and Rose, 2008). The design was chosen to maximise the minimum of the t-ratios of the estimates of marginal willingness to pay (WTP) to avoid three attributes – the number of power cuts without warning, the total time off-supply due to power cuts without warning, and the total time off-supply due to power cuts with written notice – where the t-ratio is:

$t(WTP) = (-\beta_1 / \beta_P) / se(WTP)$

where

β_P is the parameter on the price attribute;

β_1 is the parameter on the relevant non-price attribute; and

$$se(WTP) = \sqrt{\frac{Var(\beta_1) - 2\frac{\beta_1}{\beta_P}Cov(\beta_1, \beta_P) + \left(\frac{\beta_1}{\beta_P}\right)^2 Var(\beta_P)}{\beta_P^2}}$$

The parameter estimates used to calculate the t-ratios were set at the mean of Bayesian prior distributions derived from pre-testing responses and from an earlier choice experiment conducted in Canberra by NERA and ACNielsen (2003). The variances and covariances used in the calculation were drawn from the asymptotic variance-covariance (AVC) matrix based on a Bayesian prior utility function. The AVC matrix is the inverse of the second derivative of the log-likelihood function:

$$\Omega(\beta \mid x, y) = -I^{-1}(\beta \mid x, y)$$

where

$$I(\beta \mid x, y) = \frac{\partial^2 \ln L(\beta \mid x, y)}{\partial\beta\partial\beta'}$$

The Bayesian prior utility function was the sum-product of the observed variables and their associated parameters described in Table 6.7.

Table 6.7: Bayesian prior utility function

Observed variable	Prior parameter mean	Prior parameter standard deviation (normal)
Type of infrastructure (1,-1)	5.200	1.7333
Number of power cuts without warning each five years$_a$	-0.850	0.2125
Total duration of power cuts without warning each five years$_a$	-0.220	0.0550
Number of power cuts with written notice each five years$_a$	-0.010	0.0025
Total duration of power cuts with written notice each five years$_a$	-0.490	0.1225
Your one-off undergrounding contribution (A$ 2009)	-0.002	0.0005

$_a$ Proportion of status quo level.

The *MN* design was used because it was expected that estimation of WTP for the supply reliability attributes, which were less statistically significant in the design than the alternative label and cost attribute, would rely heavily on data from that elicitation format.[47] The typical supply reliability levels for the status quo that

[47] The results in later chapters show that this reliance was the case. Coefficients on reliability variables tended to be statistically insignificant in models on data from the *SB* and *RB* formats, but were significant in models on data from the *MN* format (in which respondents discriminate between undergrounding options based on reliability attributes). The analysis in this thesis focuses on total WTP (for undergrounding scenarios) rather than marginal WTP for reliability and other

were presented in the questionnaire were assumed to apply. The cost levels assigned to the first undergrounding alternative in each choice task were drawn from A$1,000, A$2,000, A$3,000, A$4,000, A$6,000, A$8,000, A$12,000, and A$16,000. The cost levels for the second undergrounding option in each choice task were calculated as the sum of the level in the first option and a number drawn from -A$200, -A$100, A$100, or A$200. This ensured that the cost difference was sufficiently small to capture the trade-offs between cost and supply reliability improvements across the two undergrounding options. Candidate designs were generated by randomising the assignment of attribute levels across choice tasks. More than 50,000 iterations were computed in arriving at the final design, which maximised the minimum t-ratio of the WTP estimates across the attributes. The choice tasks in the final design were allocated to two blocks to minimise the maximum correlation between attribute levels and block assignment across all attributes.

The final design for the *MN* format is presented in Table 6.8. The *RB* design was created by splitting the two blocks of four *MN* format choice tasks into four blocks of four *binary* choice tasks. Each choice task in the *MN* format was used to create two binary choice tasks for the *RB* design; one comprising the status quo and the first undergrounding option presented in the *MN* choice task, and one comprising the status quo and the second undergrounding option presented in the

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attributes, which suggests that a contingent valuation approach may have been more appropriate than a choice experiment approach. However, the data collected on preferences for reliability attributes (via the *MN* format) are valuable to the industry partner, ActewAGL Distribution, and will be assessed in detail separately from this thesis.

MN choice task. The first block of *MN* choice tasks formed the basis of the first and third blocks of *RB* choice tasks, and the second block of *MN* choice tasks formed the basis of the second and fourth blocks of *RB* choice tasks as shown in Table 6.9. The *SB* design was an extreme blocking of the *RB* design, with each respondent in the *SB* sample split receiving one of the 16 choice tasks in the *RB* design.

Table 6.8: Experimental design for the *MN* elicitation format

Task ID	Alt	Type of network	Number of unplanned power cuts$_a$	Duration of unplanned power cuts$_a$	Number of planned power cuts$_a$	Duration of planned power cuts$_a$	Contribution
Block 1							
1	1	-1	1	1	1	1	0
1	2	1	0.5	1.33	0.6	1.33	12000
1	3	1	0.5	1.33	0.4	1.66	11800
5	1	-1	1	1	1	1	0
5	2	1	1	1.66	0.4	1.33	6000
5	3	1	0.25	0.66	0.2	0.33	6200
6	1	-1	1	1	1	1	0
6	2	1	0.5	0.33	0.4	0.66	3000
6	3	1	0.75	1.66	0.4	1.66	2800
8	1	-1	1	1	1	1	0
8	2	1	0.75	1.66	0.6	0.33	2000
8	3	1	1	0.33	0.6	0.66	2100
Block 2							
2	1	-1	1	1	1	1	0
2	2	1	0.75	0.66	0.2	1.66	4000
2	3	1	1	0.33	0.6	0.66	3900
3	1	-1	1	1	1	1	0
3	2	1	0.25	0.33	0.8	1.66	1000
3	3	1	0.5	1.66	0.8	0.33	1100
4	1	-1	1	1	1	1	0
4	2	1	1	1.33	0.2	0.33	16000
4	3	1	0.25	0.66	0.8	1.33	15900
7	1	-1	1	1	1	1	0
7	2	1	0.25	0.66	0.8	0.66	8000
7	3	1	0.75	1.33	0.2	1.33	8200

$_a$ Proportion of the status quo level set by respondent.

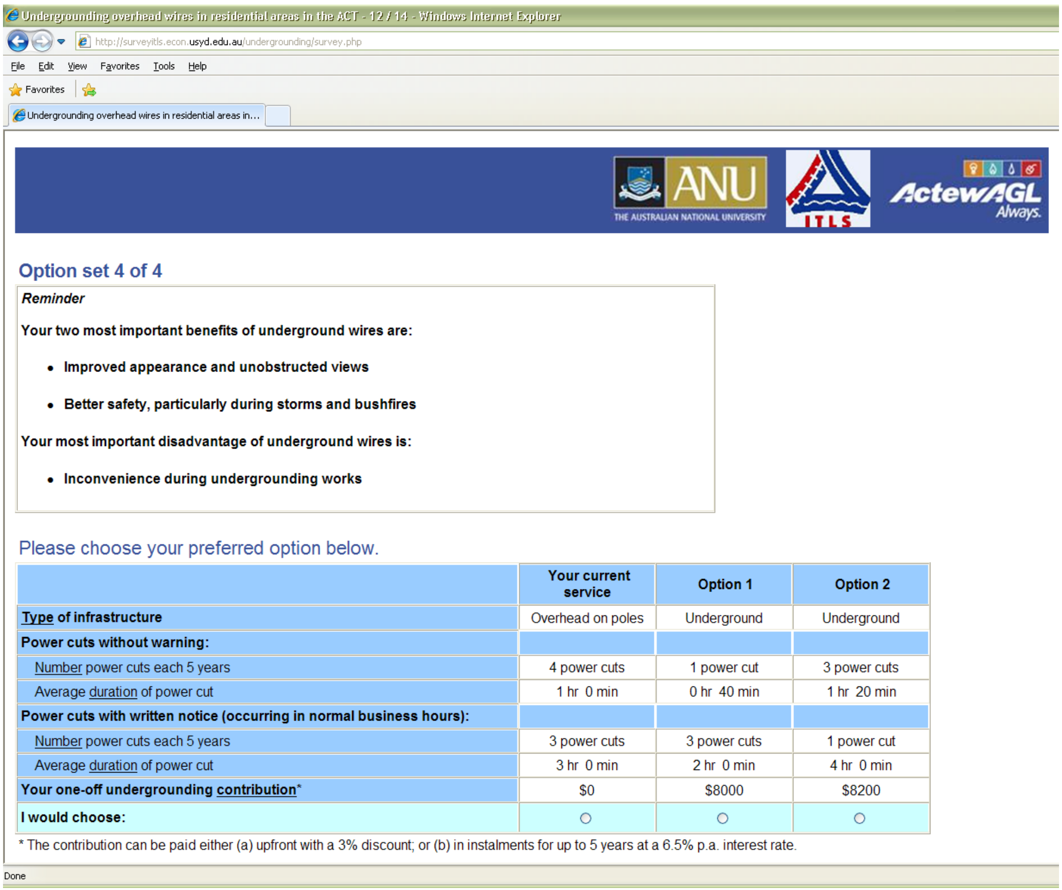
The survey was programmed to cycle through the various blocks, choice task orderings and elicitation format sample splits to ensure approximately equal representation across choice observations. Cycling through the choice task orderings ensured approximately equal observation of each of the "relative cost positions" introduced in Chapter 5. The full sample of *RB* data contained 289, 299, 297 and 271 choice observations for the *m11*, *m10*, *m01* and *m00* relative cost positions, respectively.

Table 6.9: Experimental design for *RB* elicitation format

MN format task ID	*MN* format alt	Alt	Type of network	Number of unplanned power cuts[a]	Duration of unplanned power cuts[a]	Number of planned power cuts[a]	Duration of planned power cuts[a]	Contribution
Block 1								
1	1	1	-1	1	1	1	1	0
1	2	2	1	0.5	1.33	0.6	1.33	12000
5	1	1	-1	1	1	1	1	0
5	2	2	1	1	1.66	0.4	1.33	6000
6	1	1	-1	1	1	1	1	0
6	2	2	1	0.5	0.33	0.4	0.66	3000
8	1	1	-1	1	1	1	1	0
8	2	2	1	0.75	1.66	0.6	0.33	2000
Block 2								
2	1	1	-1	1	1	1	1	0
2	2	2	1	0.75	0.66	0.2	1.66	4000
3	1	1	-1	1	1	1	1	0
3	2	2	1	0.25	0.33	0.8	1.66	1000
4	1	1	-1	1	1	1	1	0
4	2	2	1	1	1.33	0.2	0.33	16000
7	1	1	-1	1	1	1	1	0
7	2	2	1	0.25	0.66	0.8	0.66	8000
Block 3								
1	1	1	-1	1	1	1	1	0
1	3	2	1	0.5	1.33	0.4	1.66	11800
5	1	1	-1	1	1	1	1	0
5	3	2	1	0.25	0.66	0.2	0.33	6200
6	1	1	-1	1	1	1	1	0
6	3	2	1	0.75	1.66	0.4	1.66	2800
8	1	1	-1	1	1	1	1	0
8	3	2	1	1	0.33	0.6	0.66	2100
Block 4								
2	1	1	-1	1	1	1	1	0
2	3	2	1	1	0.33	0.6	0.66	3900
3	1	1	-1	1	1	1	1	0
3	3	2	1	0.5	1.66	0.8	0.33	1100
4	1	1	-1	1	1	1	1	0
4	3	2	1	0.25	0.66	0.8	1.33	15900
7	1	1	-1	1	1	1	1	0
7	3	2	1	0.75	1.33	0.2	1.33	8200

[a] Proportion of the status quo level set by respondent.

An example of a choice task screen (in the *MN* format) from the final web-based survey is presented in Figure 6.5.



Option set 4 of 4

Reminder

Your two most important benefits of underground wires are:

- Improved appearance and unobstructed views
- Better safety, particularly during storms and bushfires

Your most important disadvantage of underground wires is:

- Inconvenience during undergrounding works

Please choose your preferred option below.

	Your current service	Option 1	Option 2
Type of infrastructure	Overhead on poles	Underground	Underground
Power cuts without warning:			
Number power cuts each 5 years	4 power cuts	1 power cut	3 power cuts
Average duration of power cut	1 hr 0 min	0 hr 40 min	1 hr 20 min
Power cuts with written notice (occurring in normal business hours):			
Number power cuts each 5 years	3 power cuts	3 power cuts	1 power cut
Average duration of power cut	3 hr 0 min	2 hr 0 min	4 hr 0 min
Your one-off undergrounding contribution*	$0	$8000	$8200
I would choose:	○	○	○

* The contribution can be paid either (a) upfront with a 3% discount; or (b) in instalments for up to 5 years at a 6.5% p.a. interest rate.

Figure 6.5: Example of a choice task

6.4.5 Recruiting the sample

Based on the prior parameter estimates, 135 responses to the full *MN* design would be required to ensure the minimum t-ratio across the prior WTP estimates was at least 1.96 (the t-ratio associated with two-sided statistical significance at the five per cent level), where the t-ratio is calculated as:

$$t_n(WTP) = -\frac{\beta_1}{\beta_P} \Big/ \frac{se(WTP)}{\sqrt{n}}$$

where

β_P is the parameter on the price attribute;

β_1 is the parameter on the relevant non-price attribute;

$$se(WTP) = \sqrt{\frac{Var(\beta_1) - 2\frac{\beta_1}{\beta_P} Cov(\beta_1, \beta_P) + \left(\frac{\beta_1}{\beta_P}\right)^2 Var(\beta_P)}{\beta_P^2}}$$; and

n is the number of responses to the full design.

Since the design was split into two blocks, the number of respondents required in the *MN* sample split was 270. These calculations suggested that a full sample of at least 1,620 respondents (1,080 in the *SB* format and 270 in each of the *RB* and *MN* formats) would be required to ensure statistically significant estimates of WTP for supply reliability attributes in the *MN* format. Similar calculations for the *SB* or *RB* formats suggested the number of respondents required to achieve statistically significant estimates of WTP for supply reliability attributes in those formats would be much greater and would require funds in excess of those available for the research. Participating households would need to be owner-occupiers of stand-alone houses serviced by overhead wires, since these are the only households that would directly experience both the benefits of undergrounding and the land-owner contribution. A cash prize draw was offered as an incentive to participate, with A$1,500, A$1,000 and A$500 given to three randomly selected respondents completing the survey.[48] A completion rate of approximately 65 per cent was expected based on the anticipated effect of the prize draw incentive and

[48] The prize draw incentive did not compromise the incentive compatibility of the *SB* survey because it was not linked in any way to the survey responses. It was explained to respondents that the winners would be selected at random from those who completed the survey. The unique login code given to each respondent only allowed the questionnaire to be completed once.

experience in recent ActewAGL customer surveys. The aim, therefore, was to recruit approximately 2,500 households to participate.

Existing internet panels contained insufficient numbers of the target households. Consequently, households were recruited to the main survey by telephone using random sampling from directory listings for Canberra suburbs serviced by overhead wires. Screening questions were used to ensure that participating households were owner-occupiers of stand-alone houses serviced by overhead wires. Email invitations were sent to 2,485 households that agreed to participate. The invitation included information about the research, contact information for enquiries, terms and conditions for the prize draw, the URL link to the online questionnaire and a unique login code. The complete invitation is presented in Appendix D. Some 1,744 respondents completed the questionnaire; 1,163 in the *SB* sample split, 292 in the *RB* sample split and 290 in the *MN* sample split. The completion rate of approximately 70 per cent was higher than expected. The sample size of 290 for the *MN* sample split exceeded the 270 expected to be required to estimate WTP for supply reliability attributes that were statistically significant at the 95 per cent confidence level.

Table 6.10 shows that the number of responses collected for each choice task was approximately equal within each of the three experimental designs.

Table 6.10: Number of responses to each choice task

Multinomial (*MN*) design		Repeated binary (*RB*) design			Single binary (*SB*) design		
MN format task ID	Number of responses	*MN* format task ID	*MN* format alternatives	Number of responses	*MN* format task ID	*MN* format alternatives	Number of responses
1	143	1	1,2	73	1	1,2	72
2	146	2	1,2	74	2	1,2	72
3	146	3	1,2	74	3	1,2	72
4	146	4	1,2	74	4	1,2	73
5	143	5	1,2	73	5	1,2	73
6	143	6	1,2	73	6	1,2	73
7	146	7	1,2	74	7	1,2	73
8	143	8	1,2	73	8	1,2	72
		1	1,3	71	1	1,3	73
		2	1,3	73	2	1,3	73
		3	1,3	73	3	1,3	73
		4	1,3	73	4	1,3	73
		5	1,3	71	5	1,3	73
		6	1,3	71	6	1,3	72
		7	1,3	73	7	1,3	74
		8	1,3	71	8	1,3	72

6.4.6 Ex-post evaluation of the experimental design

Once the data have been collected it is possible to undertake an *ex post* assessment of the efficiency of the experimental design, which will be suboptimal (*ex post*) to the extent that the prior parameter estimates used to generate the design do not accurately reflect the preferences of the sample (Ferrini and Scarpa, 2007). That is, it is possible to determine the extent to which the design could have been improved had the preference information been known at the time of designing the choice experiment.

The criterion for design selection was *c-efficiency* (Scarpa and Rose, 2008); in particular, the minimum t-value for marginal WTP across supply reliability attributes.[49] When the prior parameter estimates were replaced with point (rather than Bayesian) parameter estimates from a multinomial logit model on the full sample of data collected using the *MN* elicitation format (reported in Table 6.11), the value of the criterion was 0.0607. When the design was optimised (over 20,000 randomisation iterations) based on the *ex post* parameter estimates, the value of the criterion was 0.0897, indicating that the implemented design was 32 per cent below optimal efficiency. This inefficiency does not substantially affect the analysis set out in this thesis, which focuses on *total* WTP for undergrounding scenarios, but it will directly affect the statistical significance of estimates of *marginal* WTP for supply reliability attributes (which may be analysed by ActewAGL as part of a separate piece of research).

6.5 Summary and conclusions

This chapter has introduced the case study area, namely the city of Canberra in Australia, and detailed the collection of data from two sources – property sales data and stated choice survey data. Data were collected in accordance with the design described in Chapter 5 to facilitate the studies required to address the research questions. Data relating to 427 property sales were collected for three suburbs containing adjacent areas serviced by overhead and underground networks that were otherwise relatively homogenous in terms of neighbourhoods and housing stock. This sampling approach is a potential means for overcoming the multicollinearity problems posed by a city-wide sample. The stated choice

[49] The t-value for marginal WTP for the undergrounding-specific constant was omitted from the criterion since the structure of alternatives in the design was fixed (each choice task comprised one status quo option and two undergrounding alternatives).

survey data were collected from 1,744 households across all Canberra suburbs serviced by overhead networks using an online survey. A split-sample treatment of elicitation format was used to facilitate analysis of task dependence in survey responses.

Table 6.11: Comparison of prior and *ex post* parameter estimates

Observed variable	Prior parameter mean	*Ex post* parameter estimates (MNL model on data from *MN* format)
Type of infrastructure (1,-1)	5.200	0.0260
Number of power cuts without warning each five years[a]	-0.850	-0.1623
Total duration of power cuts without warning each five years[a]	-0.220	-0.5881
Number of power cuts with written notice each five years[a]	-0.010	1.1650
Total duration of power cuts with written notice each five years[a]	-0.490	-0.7190
Your one-off undergrounding contribution (A$ 2009)	-0.002	-0.0001

[a] Proportion of status quo level.

Several lessons have been learned from the data collection process. The advice of valuers with extensive experience in the case study area proved an important step in identifying the study areas for hedonic price estimation. This advice enabled certain areas to be eliminated from consideration, based on differences in the original development and planning philosophies between areas serviced by overhead and underground wires. Site visits proved to be valuable in assessing the homogeneity of neighbourhoods and housing stocks in adjacent areas serviced by overhead and underground wires. Turning to the stated choice survey, pre-testing of the questionnaire proved to be an effective means of clarifying the questionnaire and avoiding large numbers of complaints and questions from respondents when undertaking the full survey. Some of the complaints and questions that *were* received could have been avoided by allowing more flexibility in the questionnaire; for example, by allowing respondents to skip questions and by asking more open-ended questions.

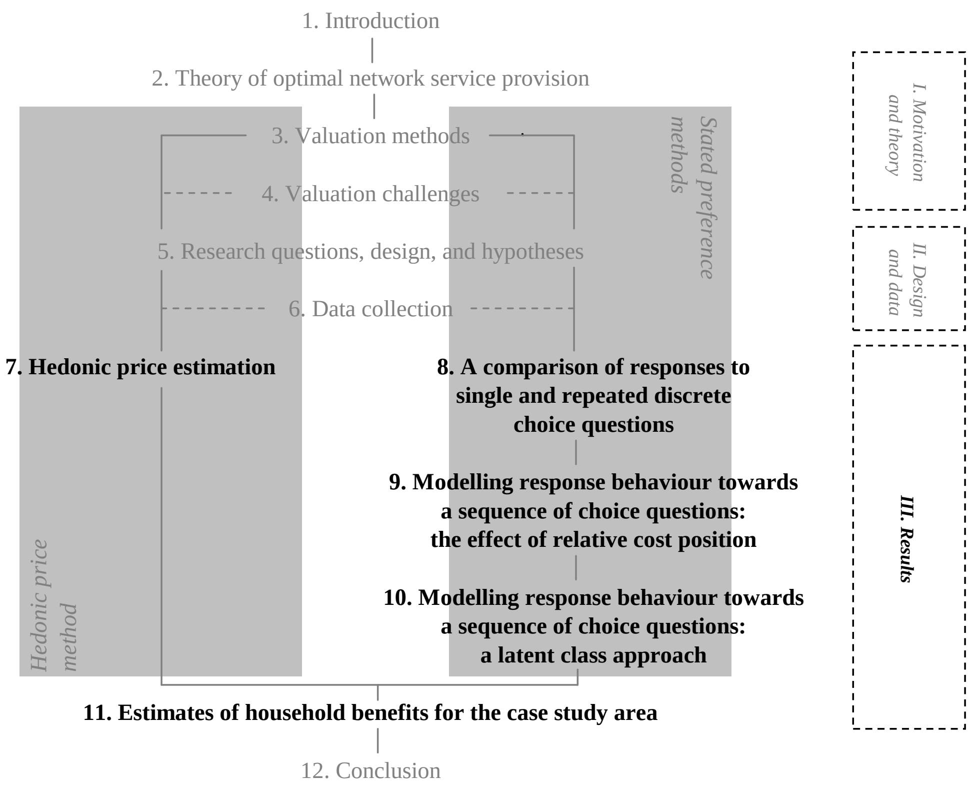
In hindsight, the maximum cost level used in the survey of A$16,000 could have been set higher, since, as will become clear in later chapters, a substantial proportion (approximately one-quarter) of respondents in the *SB* format were willing to pay this amount or more for the mean undergrounding scenario. On the other hand, some participants responded angrily to this amount and ActewAGL (and its 50 per cent shareholder, the ACT Government) were concerned about using cost levels that exceeded the expected cost of the project by a significant amount.[50] The decision on the maximum cost level used in the survey could have been better informed by a larger number of pre-testing interviews or a full pilot survey.

The following five chapters use the data described in this chapter to undertake the studies foreshadowed in Chapter 5.

[50] Participants in pre-testing interviews appeared to form a view on a maximum price that would be appropriate for households to pay even though they indicated they were unable to estimate, even approximately, the cost of the undergrounding civil works.

PART THREE:

Research results



7 Hedonic price estimation

The findings of this chapter 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.

7.1 Introduction

In Chapter 3, the hedonic price method was introduced as a means of gathering some, albeit limited, information about household preferences for the network quality improvement resulting from undergrounding electricity networks. Chapter 4 outlined a challenge associated with applying the method in cities where retro-fit undergrounding has yet to take place; namely, multicollinearity in the property characteristics. An approach to overcoming this challenge was developed in Chapter 5. The approach involves the use of a select sample from suburbs with a mix of overhead and underground networks and otherwise relatively homogenous neighbourhoods and housing stock. Chapter 6 introduced Canberra as the case study area, described the selection of sample suburbs in accordance with the approach developed in Chapter 5, and detailed the collection of data for the study. The objective of this chapter is to analyse those data and use the results to address certain research questions as foreshadowed in Chapter 5. In particular, the results will provide an indication of the demand for undergrounding in the case study area and evidence with respect to the effectiveness of the sample selection approach to overcoming the challenge of multicollinearity.

7.2 Summary of the method

As foreshadowed in Chapter 5, this study uses data from the selected suburbs in the case study area to estimate the implicit price of underground networks. The main equation to be estimated is a semi-log hedonic price function:

$$\ln P_{ijt} = \alpha + \beta.UG_{ij} + \gamma.Z_{ijt} + \delta_j + \lambda.T_t + \varepsilon_{ijt}$$

where

$\ln P_{ijt}$ is the log of real price of house i in area j at time t;

UG_{ij} is a dummy variable for indicating that house i is serviced by underground wires;

Z_{ijt} is a vector of other house attributes;

T_t is a vector of time trend variables; and,

δ_j are area fixed effects.

β is the parameter used to establish the implicit price of underground wires. It represents the proportional increase in price when a property is serviced by underground (as opposed to overhead) wires. The null hypothesis to be tested is that the coefficient, β, on the underground networks indicator variable, UG, in the hedonic price function is zero.

Hypothesis #1 $\quad H_0^1 : \beta = 0$

$$H_A^1 : \beta \neq 0$$

The statistical significance of β is not only an indication that the type of network infrastructure affects real estate prices. It also indicates that the problem of large standard errors that arises from multicollinearity has been overcome (since the standard error on the coefficient is sufficiently low that the coefficient estimate is statistically different from zero).

The other problem arising from multicollinearity is that the coefficient estimate is highly sensitive to changes in model specification. To assess whether this problem has been overcome, the hypothesis is tested for several variants of the main model specification. If the null hypothesis is rejected for each variant, then this problem has also been overcome.

7.3 Summary of the data

As detailed in Chapter 6, the study uses detached house sales data for three Canberra suburbs between January 2004 and September 2008. The three suburbs, Calwell, Florey and Macarthur, were developed during a period in the 1980s when underground installation was starting to become a standard condition in land development deeds. As a result, they contain a mix of sections serviced by overhead and underground wires. The neighbourhoods and housing stock in these suburbs are relatively homogenous across sections with overhead and underground wires. In Chapter 6, it was shown that these suburbs are representative of Canberra in terms of unemployment and the distributions of household income and house size (measured by the number of bedrooms).

The final sample comprised 427 house sale observations. Of these, 132 houses were serviced by underground wires. For further details of the sample and descriptive statistics, the reader is referred to Chapter 6.

The log of distance from the CBD (*DIST_LN*) and the square of block size (*SIZESQ*) were found to be the best-fitting transformations of the *CBDDIST* and *SIZE* variables, respectively, when estimating the main equation. Both *TIME* and

TIMESQ (equal to *TIME* squared) were included to account for a non-linear movement in average real prices over the period. Interactions between the indicator variable for underground wires and other house characteristics such as quality of views and road traffic were found to be statistically insignificant and were omitted from the final model.

7.4 Results

The results for the main regression (Model 1) of the study are presented in Table 7.1. The R^2 value of 0.83 indicates a model fit similar to recent house price studies in Canberra by Davidoff and Leigh (2008) and the Australian Bureau of Statistics (ABS) (2008). All coefficient estimates are significantly different from zero at the 95 per cent confidence level and with the expected sign. All but three of the coefficient estimates are highly significant with p-values less than 0.005.

The variable of interest, *UG*, has a coefficient of 0.029, indicating that the presence of underground wires increases house prices by 2.9 per cent when all other explanatory variables are held constant. The 95 per cent confidence interval around this estimated implicit price is relatively wide at 0.4 per cent to 5.3 per cent. While this study confirms there is a price premium paid for houses serviced by underground wires, a larger sample size would be required to estimate the implicit price with precision. Turning to Hypothesis #1, the null is rejected at the 95 per cent confidence level, which leads to the conclusion that the coefficient on *UG* is different from zero.

Table 7.1 Model results

Variable	Model 1		Model 2		Model 3		Model 4		Model 5	
	Coef.	t-stat.	Coef.	t-stat.	Coef.	t-stat.	Coef.	t-stat.	Coef.	t-stat.
(Constant)	6.937	16.24	6.908	13.83	5.978	14.33	6.953	16.40	7.169	6.33
UG	0.029	2.30	0.026	1.97	0.040	3.07	0.031	2.50	0.031	1.87
BED3	0.110	3.89	0.118	3.87	0.051	1.66	0.118	4.18	0.115	3.88
BED4	0.289	9.19	0.289	8.49	0.228	6.69	0.295	9.48	0.296	9.10
BED5UP	0.379	10.32	0.391	9.60	0.324	8.26	0.391	10.62	0.381	10.15
GARAGE	0.032	2.58	0.032	2.30	0.029	2.33	0.027	2.17	0.027	2.15
ENSUITE	0.067	4.69	0.066	4.20	0.066	4.55	0.065	4.62	0.064	4.48
TRAFFIC	-0.051	-3.50	-0.054	-2.83	-0.055	-3.75	-0.044	-3.05	-0.047	-3.03
VIEW2	0.040	3.18	0.051	3.39	0.039	3.02	0.041	3.26	0.046	3.37
VIEW3	0.163	6.90	0.164	6.11	0.183	7.77	0.159	6.79	0.163	6.67
COND2	0.058	4.58	0.059	4.14	0.050	3.79	0.063	4.97	0.058	4.38
COND3	0.177	8.62	0.176	7.39	0.163	7.87	0.181	8.74	0.169	8.06
TIME	$-0.259\ 10^{-3}$	-5.83	$-0.242\ 10^{-3}$	-4.85	$-0.263\ 10^{-3}$	-5.86			$-0.241\ 10^{-3}$	-5.27
TIMESQ	$0.202\ 10^{-6}$	7.45	$0.191\ 10^{-6}$	6.21	$0.205\ 10^{-6}$	7.50			$0.190\ 10^{-6}$	6.82
DIST_LN	$0.143\ 10^{-6}$	9.07	$0.144\ 10^{-6}$	8.01			$0.144\ 10^{-6}$	9.10	$0.132\ 10^{-6}$	7.70
SIZESQ	-0.553	-2.96	-0.545	-2.49	-0.610	-3.18	-0.560	-3.03	-0.534	-1.39
CALWELL	0.283	2.36	0.277	1.98	0.318	2.58	0.283	2.38		
MACARTH	0.186	2.34	0.183	2.00	0.212	2.61	0.180	2.29		
SIZELN					0.189	8.44				
Quarterly dummy var.	No		No		No		Yes		No	
Collection district dummy var.	No		No		No		No		Yes	
R^2	0.83		0.83		0.82		0.84		0.83	
N	427		342		427		427		427	

Dependent variable is *PRICERLN* (A$ 2008) in all models.

Four additional models were estimated to test the sensitivity of this result to various aspects of the estimation (see Table 7.1). In Model 2, the sample is reduced by removing observations located in three ABS collection districts (one in each of the three suburbs) that do not contain a mix of underground and overhead infrastructure. Thus, Model 2 tests the impact of excluding observations that are furthest from underground-overhead boundaries. In Model 3, the natural logarithm of block size is included rather than the *SIZESQ* variable used in Model 1. Testing sensitivity to specification of the block size variable is important because it is correlated (albeit weakly) with underground wires. In Model 4, the continuous time variables are replaced with quarterly dummy variables, and, in Model 5, the suburb dummy variables are replaced with ABS collection district dummy variables.

The estimated implicit price of undergrounding of 2.9 per cent of house value is robust across the model variations. The models estimate the implicit price at between 2.6 per cent and 4.0 per cent of house value, with 95 per cent confidence bounds ranging from -0.2 per cent to 6.5 per cent. The underground infrastructure variable is significant at the 95 per cent confidence level in all models except Models 2 and 5, in which its p-value is 0.06. The effects of underground wires have been disentangled from the effects of other property characteristics not only in the main regression, but also in a consistent manner across four models with alternative specifications. This result indicates that the lack of robustness that can arise due to multicollinearity has been avoided using the sample selection approach.

Turning to the relationship between the implicit price and the social value of undergrounding, the implicit price of underground wires, $P_{UG}(Z) \approx 0.029 \times P(Z)$, is the willingness to pay (WTP) of the *marginal* purchaser of the underground wires attribute in the market (as described in Chapter 3). Given that 31 per cent of houses in the sample are serviced by underground wires, it may be inferred that 31 per cent of households would be willing to pay at least 2.9 per cent of house price for this attribute. Figure 7.1 shows the relationship between the implicit price and WTP, θ_{UG}, of households that purchased houses with average attribute levels from the sample, Z^*. The mean real house price in the sample is A$426,000, so the implicit price of undergrounding for this house type is approximately A$12,350. If the sample is representative of the population and the distribution of sales prices is assumed to be relatively symmetrical, then approximately 31 per cent of households would be willing to pay A$12,350 or more for underground wires. If the supply of underground wires increases, the marginal valuation of A$12,350 is likely to fall.

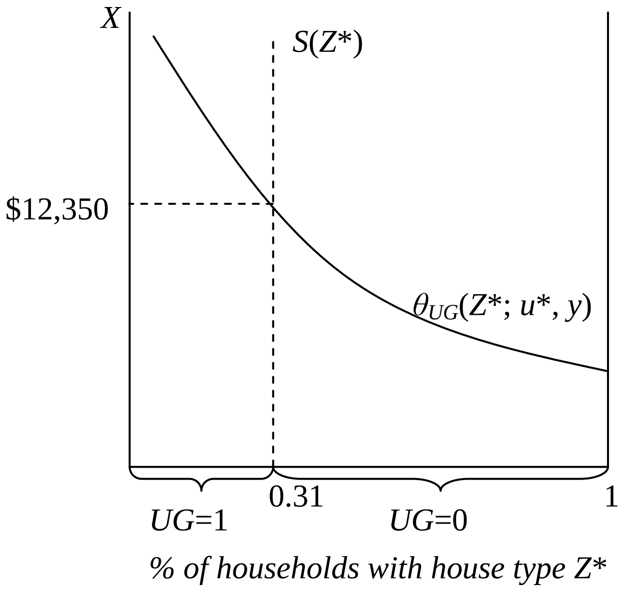


Figure 7.1 Estimated implicit price and willingness to pay

The 95 per cent confidence interval for the estimated implicit price evaluated at the mean house price in the sample is A$1,800 to A$22,770, reflecting the upper and lower bounds of 0.4 per cent and 5.3 per cent. This relatively large price range indicates that there is a fair degree of uncertainty around the implicit price estimate in this study. A larger sample size of real estate sales data would be required to narrow this interval.

The social value of undergrounding is equal to the area under the demand curve over all households. This measure cannot be calculated from the implicit price alone, but, by providing an estimated equilibrium point on the demand curve, the implicit price provides an indication of where the demand curve lies as demonstrated in Figure 7.1.

7.5 Summary and conclusions

In this chapter, real estate sales data were analysed with the intention of gathering evidence in relation to two research questions. The first research question relates to whether the sample selection approach developed in Chapters 5 and 6 can successfully overcome the problems caused by multicollinearity that tend to arise in a city-wide sample where retro-fit undergrounding has yet to take place. The two main problems caused by multicollinearity are large standard errors on the coefficient estimates for the affected variables, and a lack of robustness in those estimates to changes in model specification.

In Chapter 6, it was shown that the sample selection approach, which utilises house price data from areas with a mix of overhead and underground infrastructure where neighbourhoods and housing stock are relatively homogeneous, reduced the correlations between explanatory variables to relatively low levels. The results in this chapter confirm that the problems associated with multicollinearity have been successfully overcome by the sample selection approach in this case study. The coefficient on the indicator variable for underground wires is significantly different from zero at the 95 per cent confidence level in the main regression. The value and significance of the estimate are both robust against four alternative model specifications. The effect of underground networks on real estate prices has been successfully disentangled from the effects of other property characteristics when this was unlikely to have been possible when using a city-wide sample.

The second research question addressed, in part, by this study relates to the social value of the network quality improvement from undergrounding in the case study area. Undergrounding was found to increase house price on average by 2.9 per cent with other property characteristics held constant. There is a fair degree of uncertainty around this estimated implicit price with the 95 per cent confidence interval ranging from 0.4 per cent to 5.3 per cent. Regardless, a statistically significant relationship has been identified. The estimate lies within the range of 0 to 5 per cent of house prices predicted by the State Valuers-General of Australia (see Commonwealth Department of Communications Information Technology and the Arts, 1998). It is lower than the estimated property price impacts of proximity to high-voltage overhead transmission lines reported in the literature, which range from 5 to 17 per cent of property price (Colwell, 1990; Des Rosiers, 2002; Hamilton and Schwann, 1995; Ignelzi and Priestley, 1991; Sims and Dent, 2005).

At the mean real house price in the sample, the implicit price of underground networks equates to A$12,350 per property, with a 95 per cent confidence interval from A$1,800 to A$22,770. Some 31 per cent of households in our sample chose to pay the price premium for a house serviced by underground wires. Since the proportion of houses serviced by underground wires in Canberra as a whole is also around 30 per cent, the evidence from this study suggests that the median WTP for undergrounding in Canberra is likely to be less than A$12,350.

This study provides a single point on the demand curve for underground networks, but the social value placed on underground networks is equal to the area under this demand curve (in the selected suburbs, which are representative of Canberra in terms of unemployment and the distributions of household income and house size). This value depends on the extent to which the value placed on underground networks by those who purchased a house serviced by underground wires exceeds the implicit price, and on the extent to which the value placed on underground wires by those who purchased a house serviced by overhead wires falls short of the implicit price.

The stated choice data analysed in subsequent chapters allows estimation of the entire demand curve for underground networks, and, hence, facilitates estimation of the social value of the network quality improvement that would result from undergrounding in the case study area. The evidence from the stated choice analysis in relation to the demand curve is compared to the findings of this chapter in Chapter 11. This chapter has demonstrated a method that can provide an indication of the demand for underground networks that would be of some use to policy makers where no other information is available and where practical constraints necessitate a study that can be conducted quickly and inexpensively.

8 A comparison of responses to single and repeated discrete choice questions

The findings of this chapter and Chapter 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.

8.1 Introduction

In Chapter 3, stated preference (SP) methods were introduced as a means of estimating the social value placed on the network quality improvement resulting from undergrounding electricity networks. Chapter 4 outlined a challenge associated with applying these methods when the objective is to estimate values for multiple attributes; namely, the challenge of task dependence. The appropriate assumptions when estimating values for policy use depend on the decision processes (or heuristics) underlying respondents' stated choices. Task dependence is a phenomenon that can arise from several different heuristics. These heuristics were grouped into two broad categories: strategic misrepresentation, in which the perceived social choice function leads respondents to answer a different question from that being asked, and, value learning, in which respondents' underlying preferences are revised, based on information presented in choice tasks. Approaches to investigating these heuristics were described in Chapter 5. One of those approaches is to use data from a split-sample treatment of elicitation format to assess the effect on stated preferences of presenting multiple choice tasks per respondent as opposed to a single incentive compatible choice task. To implement this approach, data were collected for a case study area (Canberra, Australia) using a web-based survey (Chapter 6). The elicitation formats employed in the survey included a single binary (*SB*) choice task and a sequence of four binary choice tasks (the repeated binary, *RB*, format).

The objectives of this chapter are to use the data from these two elicitation formats to:

1) test whether stated preferences are affected by presenting four as opposed to one attribute-based choice task per respondent; and,

2) test whether stated preferences in the first choice task presented are affected by advance knowledge that four as opposed to one choice task will be presented.

The first objective seeks to develop an understanding of the importance of the property of incentive compatibility in practice. The second examines whether the first question in a sequence of choice tasks can be used as an unbiased comparator, thus saving the considerable expense of collecting a single choice observation per respondent.

Section 8.2 summarises the method foreshadowed in Chapter 5. Section 8.3 provides a summary of the data collection detailed in Chapter 6 and tests for differences in socio-economic characteristics of respondents in the two samples. Analysis of the data takes place in Section 8.4 and conclusions are drawn in Section 8.5.

8.2 Summary of the method

As discussed in Chapter 4, the prediction of neo-classical economic theory is that strategic misrepresentation heuristics will be employed in the *RB* format, but not in the incentive compatible *SB* format. The expected pattern of response behaviour in the *RB* format is the rejection of some undergrounding options that would have been accepted had they been presented as a single choice task. This rejection serves to maximise respondent utility in the *RB* format by increasing the likelihood of implementation of a more preferred alternative observed earlier in the sequence of choice tasks. As a result, the prediction is that estimated willingness to pay (WTP) for undergrounding would be lower in the *RB* format than in the *SB* format. This prediction is tested by comparing expected WTP for the mean undergrounding scenario from a multinomial logit (MNL) model estimated on data from the *SB* format with the equivalent estimate from an MNL model estimated on data from the *RB* format. A (one-tailed) hypothesis is tested is based on the prediction. Rejection of the null hypothesis implies that the prediction of the strategic misrepresentation heuristic is correct.

Hypothesis #2 H_0^2: E*(WTP)$_{SB}$ = E*(WTP)$_{RB}$

H_A^2: E*(WTP)$_{SB}$ > E*(WTP)$_{RB}$

Expected WTP is calculated as the area under the choice probability function truncated at the maximum cost level (A$16,000) with all non-cost variables set at their population means:[51]

[51] In the binary choice format, the choice probability curve represents the demand curve for the associated policy scenario (Hanemann, 1984; McConnell, 1995; Seller *et al.*, 1985). The use of the area under this curve as a welfare measure is consistent with the integral in Small and Rosen's (1981) Equation 5.5. The log transformation on cost in our models prevents the use of the alternative, explicit evaluation in Small and Rosen's Equation 5.9.

$$E^*(WTP) = \int_0^{A\$16,000} \pi_{it} dx^{\cos t} = \int_0^{A\$16,000} \frac{\exp(\overline{W}_{it})}{1+\exp(\overline{W}_{it})} dx^{\cos t}$$

where

$$\overline{W}_{it} = \alpha + \beta_{it}' \bar{x}_{it} + \beta_{it}^{\cos t} x_{it}^{\cos t}$$

$\bar{x}_{it}$ = a vector of the means of non-cost observed variables

The denominator of the choice probability function includes the number "one" in place of the exponent of the indirect utility from the status quo alternative, since, in this case, all choice tasks comprise two alternatives and all observed variables are defined in such a way that observed variables, $\mathbf{x}_{it}$, are equal to zero in the status quo alternative (j=1).

Turning to the second objective, economic theory also predicts that responses to the *SB* format may differ from responses to the *first question* presented to each respondent in the *RB* format.[52] The first question presented in the *RB* format does not hold the "take it or leave it" property required for incentive compatibility. The consequence of this is that, *in theory*, respondents may reject an alternative in anticipation of receiving a better offer later in the sequence.[53] The question as to whether this prediction is realised in practice is an important one since, if it is not,

[52] It is assumed here that backward navigation through the choice tasks is prevented as is common in internet and computer assisted personal interview surveys.

[53] In the reverse case, where the expectation is that worse offers will be offered later in the sequence, there is no incentive for respondents to misrepresent their preferences. Economic theory predicts that respondents might reject some preferred alternatives, but they would never accept a non-preferred alternative.

the *RB* format would be preferred to the *SB* format due to the additional information it generates at little additional cost.

To test whether preferences stated in the first of a sequence of choice tasks are affected by advance knowledge that multiple choice tasks will be presented, the MNL model on the *RB* data used to test Hypothesis #2 is altered to include interactions between the cost variable and effects-coded variables for the order in which choice tasks were presented (with variables indicating the first three order positions, *q1*, *q2* and *q3*, taking the value -1 in the fourth order position). Again, the test involves a one-tailed comparison of WTP for the mean undergrounding scenario from MNL models on the two response formats, but, in this test, WTP is evaluated at the first question in the sequence in the model on the *RB* data.

Hypothesis #3 H_0^3: $E^*(WTP)^{SB} = E^*(WTP)^{RB \mid q1 = 1}$

H_A^3: $E^*(WTP)^{SB} > E^*(WTP)^{RB \mid q1 = 1}$

8.3 Summary of the data

The analysis in this chapter uses data from two of the elicitation formats employed in the survey described in Chapter 6: the *SB* format and the *RB* format. In each binary choice task, respondents were presented with a description of their current (overhead) service and one undergrounding alternative.[54] The attributes used to describe the alternatives and the levels assigned to those attributes are detailed in Chapter 6. All of the benefits of undergrounding other than supply reliability

[54] All non-status-quo alternatives involved new underground infrastructure. This ensured that every alternative in the design was meaningful as an *SB* choice, while allowing the same set of alternatives to be used in all elicitation formats.

benefits are embodied in the alternative label, including the amenity and safety benefits that qualitative questions showed to be the major household benefits from undergrounding. As described in Chapter 6, the *SB* design is an extreme blocking of the *RB* design, with each respondent in the *SB* sample split receiving one of these 16 choice tasks.

The questionnaire advised respondents of the number of choice tasks that would be presented, the number of alternatives that would be presented in each task, and the attributes that would be used to describe each alternative. However, respondents were *not* given information about the range of levels that the attributes could take. The questionnaire outlined a suburb-based majority rule social choice function (often referred to as a “provision rule” or “decision rule” in the non-market valuation literature) that ensured incentive compatibility in the *SB* response format. In the *RB* format, the equivalent social choice function was that *any* undergrounding option that was preferred to the status quo by more than 50 per cent of respondents in a suburb would be considered for implementation in that suburb. The full questionnaire is presented in Appendix C.

Importantly, the survey instrument did not allow respondents to navigate back through the sequence of choice tasks. The survey was programmed to cycle through the various blocks, choice task orderings, and elicitation format sample splits to ensure approximately equal representation across choice observations. The number of responses to each choice task in the designs was approximately equal as shown in Table 6.10. Data were excluded from the analysis in this chapter where respondents took less than five minutes to complete the *SB* survey or less than six minutes to complete the *RB* survey. It was judged that these responses were given without consideration (possibly randomly) solely as a means of qualifying for the prize draw participation incentive.

Some 1,163 respondents completed the questionnaire in the *SB* sample split and 292 in the *RB* sample split. Table 8.1 shows there is no significant difference in the socio-economic composition of the two groups in terms of household size, gender, age, education, or income.

Table 8.1: Socio-demographic statistics by sample split

Variable	*SB* sample mean	*RB* sample mean	Test of difference in groups (p-value)[a]
Household size (persons)	2.94	3.06	0.402
Gender (% male)	51.9	53.1	0.703
Age:			
% under 40	18.8	19.7	0.733
% over 65	15.7	15.2	0.832
Highest level of education:			
% undergraduate degree	29.4	26.6	0.343
% postgraduate degree	31.2	34.1	0.333
Annual household income:			
% under A$52,000	11.3	10.0	0.533
% A$52,000 – A$103,999	30.6	32.4	0.545
% A$104,000 – A$181,999	29.3	30.3	0.723
% over A$182,000	9.9	8.6	0.439
% refused	18.2	17.6	0.816

[a] p-values calculated from χ^2-test of differences in proportions across groups, except p-value for household size, which is calculated from a two-sided t-test.

Indicator variables for the order in which choice tasks were presented were created for the analysis required to test Hypothesis #3. The variables were effects-coded as shown in Table 8.2.

Table 8.2: Effects-coding of question order variables

Variable	*q1*	*q2*	*q3*
Level when choice task is the *first* presented to a respondent	1	0	0
Level when choice task is the *second* presented to a respondent	0	1	0
Level when choice task is the *third* presented to a respondent	0	0	1
Level when choice task is the *fourth* presented to a respondent	-1	-1	-1

8.4 Estimates of willingness to pay from single and repeated formats

The model results are summarised in Table 8.3. The basic MNL models on the *SB* and *RB* formats (Models 1 and 2, respectively) include the natural log of the household contribution (cost), supply reliability attributes, and a constant to capture the value of the other benefits embodied in the alternative label. The log transformation of the cost variable is utilised because it results in a better model fit. The choice probability (or bid acceptance) curves derived from Models 1 and 2 with non-cost variables set at their population means are shown in Figure 8.1. Bid acceptance is significantly lower in the *RB* format relative to the incentive compatible *SB* format for all cost levels except those at the lower end of the range used in the design. Estimates of mean WTP for the mean undergrounding scenario derived from these models are presented in Table 8.4 along with confidence intervals derived from a bootstrapping procedure with 1000 random draws (calculated by drawing from normal distributions for all relevant parameters with moments set at their means and standard errors).[55] Point estimates for mean WTP are A$6,908 and A$5,369 in the MNL models on the *SB* and *RB* data,

[55] This procedure did not use the full covariance matrix through the Cholesky decomposition.

respectively. The one-tailed test based on random draws of 1000 paired differences has a p-value of 0.0775. At the 90 per cent confidence level the null is rejected, which leads to the conclusion that WTP is lower in the *RB* format than in the incentive compatible *SB* format.

Table 8.3: Summary of results from multinomial logit models

	Model 1	Model 2	Model 3
Response format	*SB*	*RB*	*RB*
Parameter estimates:			
Undergrounding-specific constant	.68486*** (.15256)	1.00020*** (.15343)	1.02303*** (.15466)
Log of household contribution (A$'000s)	-.66964*** (.08050)	-1.14726*** (.09017)	-1.17542*** (.09177)
Change in number of unplanned outages per 5 years	-.05588 (.05505)	-.04107 (.04210)	-.04281 (.04248)
Change in unplanned minutes off supply per 5 years	-.00060 (.00055)	-.00010 (.00046)	-.00011 (.00046)
Change in number of planned outages per 5 years	-.09450 (.08311)	-0.17447* (.08903)	-.18259** (.08992)
Change in planned minutes off supply per 5 years	-.00009 (.00029)	-.00031 (.00026)	-.00029 (.00027)
Interactions with log of household contribution:			
Order: question 1 (*q1*=1)			.22681*** (.06788)
Order: question 2 (*q2*=1)			-.08210 (.07511)
Order: question 3 (*q3*=1)			-.12044 (.07698)
Model fit:			
Observations	1090	1112	1112
Log-likelihood	-711	-645	-639
Information criterion AIC	1433	1301	1296

*, ** and *** indicate statistical significance at the 0.1, 0.05 and 0.01 levels respectively; standard errors are in parentheses.

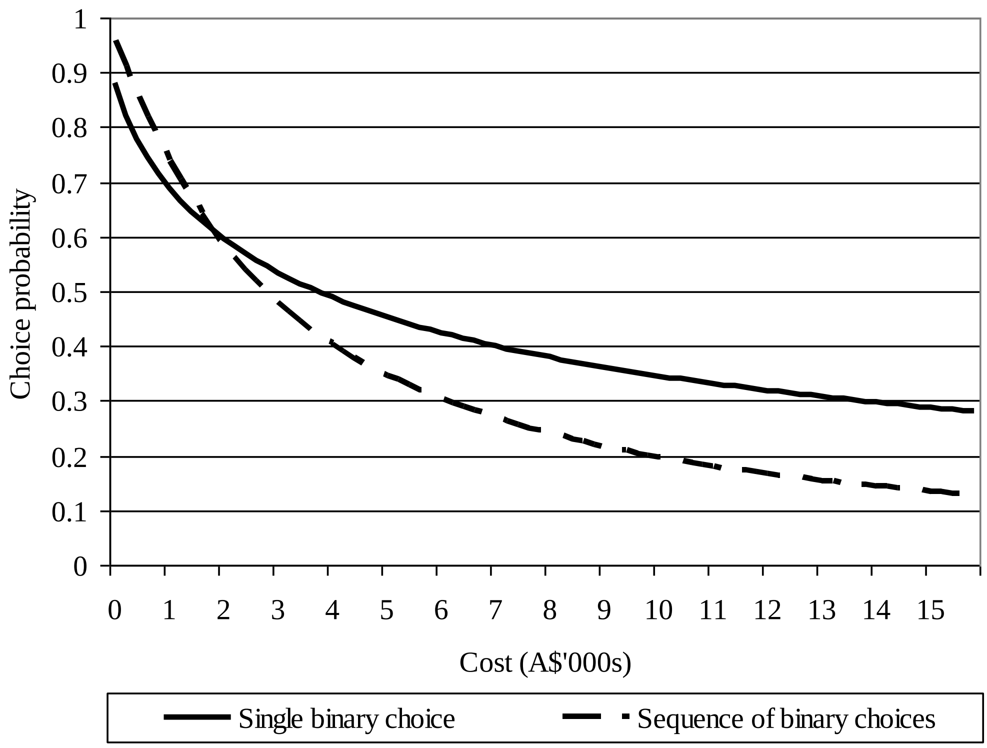


Figure 8.1: Bid acceptance curves derived from Models 1 and 2

Table 8.4: Estimates of willingness to pay for mean undergrounding scenario (2009 $A)

	Mean	95 per cent CI
Model 1 (single binary choice)	6,908	5,212 – 8,595
Model 2 (repeated binary choices)	5,369	4,058 – 6,819
Model 3 evaluated at:		
Question 1	6,586	4,843 – 8,389
Question 2	4,929	3,595 – 6,491
Question 3	4,786	3,483 – 6,257
Question 4	5,236	3,635 – 7,305

8.5 Estimates of willingness to pay from the first question in the repeated choice format

Turning to the second research objective, Model 3 incorporates interactions between cost and effects coded variables for the order in which choice tasks were presented to respondents in the *RB* format (Table 8.3). This model provides separate estimates of cost sensitivity at each of the four order positions in the sequence, where cost sensitivity is defined as:

$$CostSens_t = -\partial U/\partial cost = -(\beta_{cost} + \beta_{q1*cost}\, q1_t + \beta_{q2*cost}\, q2_t + \beta_{q3*cost}\, q3_t)$$

The parameter estimate for the *q1* interaction is positive and significantly higher than the parameter estimates for the other question order interactions. This indicates that cost sensitivity is significantly lower in the first question relative to the later questions in the sequence with all other variables held constant. The modelled relationship between question order and WTP (mean and 95 per cent confidence interval) is presented in Figure 8.2. At A$6,586, the estimate of mean WTP in the first choice task is similar to the point estimate of mean WTP from the incentive compatible *SB* format of A$6,908. The null hypothesis of equivalence cannot be rejected at the 90 per cent confidence level in a one-tailed test based on 1000 randomly drawn paired differences, with a p-value of 0.4078. That is, *there is no evidence to suggest that advance knowledge that multiple choice tasks would be presented has an effect on preferences stated in the first choice task*. Therefore, the difference in WTP estimates from the two response formats is driven by what is happening in the second, third and fourth questions in the sequence. In particular, these results suggest that cost sensitivity increases (and derived WTP decreases) after the first question has been answered. However, this is only proven under preference homogeneity, so, while it may be true on average over the population, it may not describe the behaviour of all respondents.

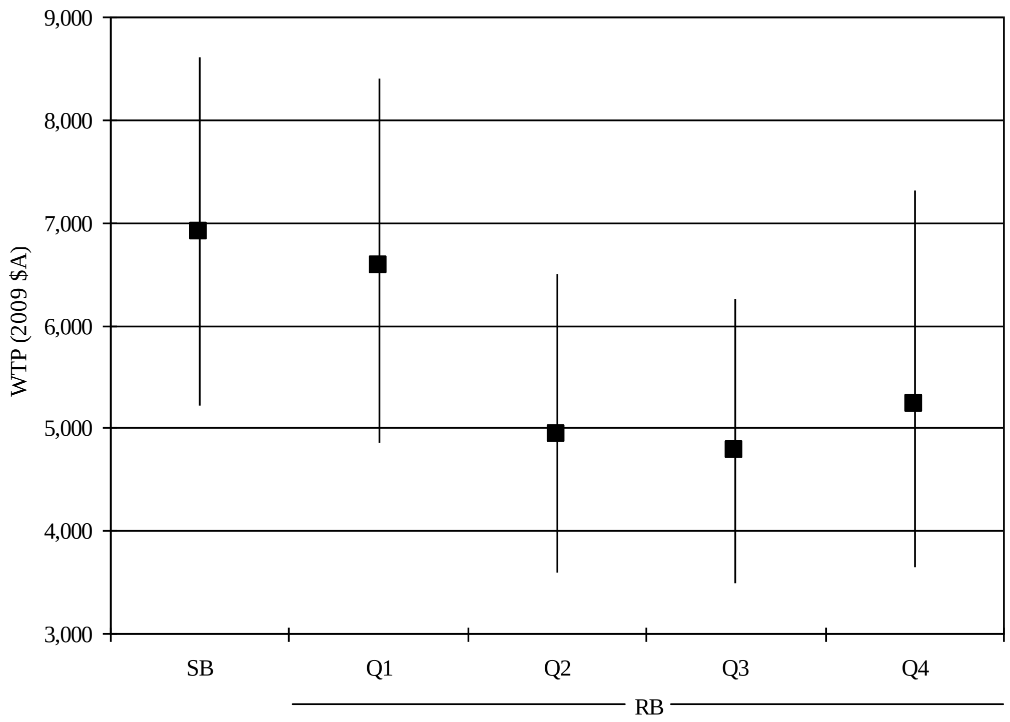


Figure 8.2: Willingness to pay by question order (with 95 per cent confidence intervals)

8.6 Summary and conclusions

In this chapter, spilt-sample comparisons have been made between preferences stated in a sequence of choice tasks and those stated in an incentive compatible attribute-based *SB* choice task. The author is aware of just one existing study (Racevskis and Lupi, 2008) and one concurrent study (Scheufele and Bennett, 2010a) employing a split-sample treatment of these elicitation formats. This chapter also included a comparison of preferences stated in an incentive compatible *SB* choice format and those stated in the first choice task of a sequence.

The evidence presented in this chapter supports (at the 90 per cent confidence level) the finding of Racevskis and Lupi (2008) that estimates of mean WTP from an elicitation format presenting multiple choice tasks to each respondent are lower than those from an incentive compatible single choice task format. The results are also consistent with the finding of Swait and Adamowicz (2001) and Boxall *et al.* (2009) that respondents are more likely to choose the status quo as the number of choice tasks increases. There is no evidence to support the hypothesis that preferences stated in the first choice task presented are affected by advance knowledge that four as opposed to one choice tasks would be presented. In fact, there is equivalence in the evidence on WTP estimates from the first choice task in a sequence and an *SB* choice task. This goes some way to justifying the use of the first choice task in a sequence as an unbiased comparator in studies such as Bateman *et al.* (2008b) and Day and Pinto (2010). It is expected that this equivalence would be at least as strong where respondents are not informed about how many choice tasks will be presented.

Task dependence appears to be present in the data, since respondents rejected some undergrounding options in second, third and fourth questions in the *RB* format that would have been accepted had they been presented in the first question or in the *SB* format.[56] Therefore, this study supports the growing body of literature finding that the standard assumptions of truthful, independent response with stable preferences are violated. The appropriate alternative assumptions depend on the decision processes (or heuristics) underlying the task dependence. The results of this study are consistent with the predictions of the strategic misrepresentation heuristics based on neo-classical economic theory. The explanation provided by

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[56] Rather than decreasing over the full course of the sequence of questions, the point estimate of WTP evaluated at the fourth question is higher than the estimates evaluated at the second and third questions. The difference was not statistically significant in this study. Scheufele and Bennett (2010b) found a similar result in their concurrent study.

these heuristics is that the rejected options mentioned above were rejected because a more preferred option had been accepted earlier in the sequence of questions. However, this is just one possible explanation. The results could also be explained by a form of value learning that is asymmetric in the way in which cost influences preferences. In particular, decreases in stated WTP over the course of the sequence of questions are expected if relatively low costs have a greater effect on preferences than relatively high costs.

As discussed in Chapter 4, the two possible explanations have quite different implications for the way in which the SP models are used to derive a WTP estimate for policy use. It is therefore important to understand the respondent decision processes underlying the results in this chapter. In the following two chapters, two different approaches are taken to developing this understanding. The next chapter focuses on the relationship between cost sensitivity and the positioning of the cost level relative to levels presented in previous choice tasks. Each of the heuristics makes some prediction about this relationship. In the analysis, these predictions are tested against the data. Chapter 10 considers the possibility that each of the heuristics is adopted by a sub-group of the population. The proportion of respondents behaving in accordance with each heuristic is estimated using an equality-constrained latent class model.

9 Modelling response behaviour towards a sequence of choice questions: the effect of relative cost position

The findings of this chapter and Chapter 8 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.

9.1 Introduction

Stated preference (SP) methods are a means of estimating the social value placed on the network quality improvement resulting from undergrounding electricity networks (Chapter 3). A challenge associated with applying these methods when the objective is to estimate values for multiple attributes is that of task dependence, which is a phenomenon that calls for an alternative to the set of assumptions typically made by analysts when estimating values from choice data (Chapter 4). The appropriate alternative set of assumptions depends on the decision processes (or heuristics) used by respondents (which underlie the task dependence). Task dependence can arise from several heuristics. These include strategic misrepresentation heuristics, in which the perceived social choice function leads respondents to answer a different question from that being asked, and, value learning heuristics, in which respondents' underlying preferences are revised, based on information presented in choice tasks. Approaches to investigating these heuristics were presented in Chapter 5. One of those approaches was to use data from a split sample treatment of elicitation format to assess the effect on stated preferences of presenting multiple choice tasks per respondent as opposed to a single incentive compatible choice task.

Using data from a web-based survey in Canberra (Chapter 6), it was shown in Chapter 8 that estimates of willingness to pay (WTP) for undergrounding were significantly lower in the multiple choice task format compared to the single choice task format. It was shown that this difference was due to a lower rate of acceptance of undergrounding options in the second, third and fourth questions in the multiple choice task format (relative to the first question and to the single choice task format). These results suggest that task dependence is present in the data, but the nature of the decision processes underlying the task dependence remains unclear based on the analysis to this point in the thesis (although strategic misrepresentation has been identified as one potential explanation).

This chapter develops an understanding of these decision processes by examining the relationship between cost sensitivity and the positioning of the cost level relative to levels presented in previous choice tasks in the multiple choice task format. A number of authors, including Bateman *et al.* (2008b) and Carson and Groves (2007), have discussed the potential for this relationship, but few studies have modelled it. Holmes and Boyle (2005) model the effects of cost levels in previous and future choice tasks using data from a paper-based survey. Day and Pinto (2010) use non-parametric methods on data from split samples presented with sequences of choice tasks with increasing and decreasing cost levels. A different approach to Day and Pinto (2010) is taken here by using econometric models to control for ordering anomalies. The models differ from Holmes and Boyle (2005) in that they are tailored to data from a survey that prevented backward navigation through the sequence of choice tasks. Rather than specifying cost differences with lead and lag choice tasks as drivers of behaviour, categories are used to represent the positioning of the cost level relative to the full history of cost levels presented to the respondent.

9.2 Summary of the method

As detailed in Chapter 5, the intention is to test for the response patterns predicted by each heuristic in terms of relationships between responses and cost levels observed by respondents in previous choice tasks. The means of achieving this are to incorporate, in mixed logit (ML) and multinomial logit (MNL) models on the repeated binary (*RB*) choice data, variables indicating the four possible "relative positions" for the cost level presented in a choice task. In any given choice task, the cost level presented must be one of the following four relative positions:

1) both the minimum and the maximum level presented in the sequence to that point (*m11*);

2) the minimum, but not the maximum level presented in the sequence to that point (*m10*);

3) the maximum, but not the minimum level presented in the sequence to that point (*m01*); or

4) neither the minimum nor the maximum level presented in the sequence to that point (*m00*).

Indicator variables for the relative cost positions, *m11*, *m10* and *m01*, are interacted with the cost variable to allow estimation of the relationship between cost sensitivity and the positioning of the cost level relative to the levels presented to the respondent in previous choice tasks.

The relationships between the relative cost position interaction coefficients implied by the various heuristics raised in the literature are presented in Table 9.1. *Strong cost minimisation* predicts an increase in cost sensitivity when the cost level is not the minimum presented in the sequence to that point. Alternatives are rejected when cost is the highest level observed by the respondent *or* within the range observed. Under *weak cost minimisation* the relationship between these two relative positions is uncertain since likelihood of acceptance depends on the maximum level of cost *accepted* in the sequence to that point. The parameter relationships implied by *reference point revision* are the same as those implied by *weak cost minimisation*, with likelihood of acceptance decreasing where a lower-cost alternative has been presented in an earlier choice task. *Value learning* implies that cost sensitivity is increased when cost is the highest level observed by the respondent and decreased when cost is the lowest level observed by the respondent, relative to the first question or to questions in which cost lies within the range observed by the respondent. *Cost averaging* implies the opposite set of effects. Finally, the standard assumptions imply that relative cost position has no influence.

The parameter estimates from the models are compared to these implied relationships to determine which heuristics are consistent with, or counter to, the data. Identification of a single over-riding theory may not be possible, but some discrimination will allow a narrowing of the range of potential explanations for the response behaviour witnessed in the *RB* sample.

Table 9.1: Parameter relationships implied by heuristics

Heuristic	Implied parameter relationships
Strong cost minimisation	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}=\beta_{m00*cost}$
Weak cost minimisation	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}$ and
Reference point revision	$\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m00*cost}$
Value learning	$\beta_{m10*cost}>\beta_{m11*cost}>\beta_{m01*cost}$ and $\beta_{m10*cost}>\beta_{m00*cost}>\beta_{m01*cost}$
Cost averaging	$\beta_{m10*cost}<\beta_{m11*cost}<\beta_{m01*cost}$ and $\beta_{m10*cost}<\beta_{m00*cost}<\beta_{m01*cost}$
Standard assumptions	$\beta_{m10*cost}=\beta_{m11*cost}=\beta_{m00*cost}=\beta_{m01*cost}=0$

As foreshadowed in Chapter 5, the null hypothesis of truthful response with stable preferences is to be tested, and, if it is rejected, the parameter relationships are to be compared to those implied by the heuristics.

Hypothesis #4

$$H_0^4: \beta_{m11*cost} = 0 \text{ and } \beta_{m10*cost} = 0 \text{ and } \beta_{m00*cost} = 0 \text{ and } \beta_{m01*cost} = 0$$

$$H_A^4: \beta_{m11*cost} \neq 0 \text{ or } \beta_{m10*cost} \neq 0 \text{ or } \beta_{m00*cost} \neq 0 \text{ or } \beta_{m01*cost} \neq 0$$

The ML model uses the relative cost position indicator variables to explain heterogeneity in the mean and heteroscedasticity of the distribution of cost sensitivity over respondents. The intention is to provide insight into any heterogeneity in the way in which respondents behave in the presence of a particular relative cost position, thereby deepening the understanding of the nature of the heuristic or heuristics being employed by respondents in this survey.

9.3 Summary of the data

The analysis in this chapter uses data from one of the elicitation formats employed in the survey described in Chapter 6 – the *RB* format. A summary of some relevant points is provided here and the reader is referred to Chapter 6 for further detail.

In each binary choice task, respondents were presented with a description of their current (overhead) service and one undergrounding alternative. The attributes used to describe the alternatives and the levels assigned to those attributes are detailed in Chapter 6. The cost levels assigned to undergrounding options ranged from A$1,000 to A$16,000, but the network service scenarios in the undergrounding alternatives were viewed as similar.[57]

Respondents were *not* given information about the range of levels that the attributes could take, and, the survey instrument did not allow respondents to navigate back through the sequence of choice tasks. The survey was programmed to cycle through the various blocks and choice task orderings to ensure approximately equal representation across choice observations. Some 292 respondents completed the questionnaire in the *RB* sample split, but 14 were excluded from the analysis because they completed the survey in less than six minutes. It was judged that these responses were given without consideration

[57] The focus on the cost attribute as a driver of strategic behaviour and value learning was supported by the higher rates of attribute non-attendance for the four supply reliability attributes (as revealed in responses to attribute attendance questions in the questionnaire) relative to the alternative label (type of infrastructure) and the cost attribute.

(possibly randomly) solely as a means of qualifying for the prize draw participation incentive.

Indicator variables for relative cost position were effects-coded as shown in Table 9.2. The full sample of *RB* data contained 289, 299, 297 and 271 choice observations for the *m11*, *m10*, *m01* and *m00* relative cost positions, respectively.

Table 9.2: Effects-coding of relative cost position variables

Variable	*m11*	*m10*	*m01*
Level when cost is both the minimum and the maximum level presented in the sequence to that point	1	0	0
Level when cost is the minimum, but not the maximum level presented in the sequence to that point	0	1	0
Level when cost is the maximum, but not the minimum level presented in the sequence to that point	0	0	1
Level when cost is neither the minimum nor the maximum level presented in the sequence to that point	-1	-1	-1

9.4 Results

The MNL model, which includes interactions between cost and effects coded variables for relative cost position, is presented in Table 9.3. The model provides separate estimates of cost sensitivity at each of the four relative positions, where cost sensitivity is defined as:

$$CostSens_t = -\partial U/\partial cost = -(\beta_{cost} + \beta_{m11*cost}\ m11_t + \beta_{m10*cost}\ m10_t + \beta_{m01*cost}\ m01_t)$$

Of the coefficient estimates on the interactions, the coefficient on the *m10* interaction is highest, which indicates that cost sensitivity is lowest and WTP is highest when cost is the minimum, but not the maximum level presented in the sequence to that point (holding constant all other variables, including cost). The second highest is the coefficient estimate on the *m11* interaction, followed by the implicit coefficient estimate on the *m00* interaction, which is equal to the negative of the sum of the three estimated coefficients (that is, -0.1038). The coefficient estimate on the *m01* interaction is lowest, indicating that cost sensitivity is highest when cost is the maximum, but not the minimum level presented in the sequence to that point. The null hypothesis of truthful response with stable preferences (H_0^4) is rejected even at the 99 per cent confidence level, indicating that task dependence is present in the data.

Table 9.3: Summary of results from multinomial logit model

	Model 1	
Parameter estimates:		
Undergrounding-specific constant	0.74583***	(0.16589)
Log of household contribution (A$'000s)	-0.92002***	(0.10922)
Change in number of unplanned outages per 5 years	-0.07391*	(0.04433)
Change in unplanned minutes off supply per 5 years	0.00004	(0.00047)
Change in number of planned outages per 5 years	-0.15752*	(0.08932)
Change in planned minutes off supply per 5 years	-0.00023	(0.00025)
Interactions with log of household contribution:		
Relative cost position: m11	0.11544	(0.07307)
Relative cost position: m10	0.35776***	(0.11826)
Relative cost position: m01	-0.36935***	(0.08038)
Model fit:		
Observations	1112	
Log-likelihood	-630	
Correct prediction (y=1 if π_{it}>0.5)	0.613	
Information criterion AIC	1279	

*, ** and *** indicate statistical significance at the 0.1, 0.05 and 0.01 levels respectively; standard errors are in parentheses.

Turning to the decision processes underlying this task dependence, Table 9.4 and Table 9.5 present p-values for one- and two-tailed t-tests of the statistical significance of the differences in the interaction coefficients. The one-tailed null hypotheses are rejected at the 90 per cent confidence level, indicating ordering consistent with the point estimates. At the 95 per cent confidence level, only one of the one-tailed null hypotheses is not rejected – the hypothesis relating to the *m10* and *m11* interactions.

Table 9.4: One-tailed T-tests for differences in coefficients on relative cost position interactions

H_A:	$\beta_{m10*cost} - \beta_{m11*cost} > 0$	$\beta_{m10*cost} - \beta_{m00*cost} > 0$	$\beta_{m10*cost} - \beta_{m01*cost} > 0$	$\beta_{m11*cost} - \beta_{m00*cost} > 0$	$\beta_{m11*cost} - \beta_{m01*cost} > 0$	$\beta_{m00*cost} - \beta_{m01*cost} > 0$
p-value	0.075	0.003	<0.001	0.025	<0.001	0.013

Table 9.5: Two-tailed T-tests for differences in coefficients on relative cost position interactions

H_A:	$\beta_{m10*cost} - \beta_{m11*cost} \neq 0$	$\beta_{m10*cost} - \beta_{m00*cost} \neq 0$	$\beta_{m10*cost} - \beta_{m01*cost} \neq 0$	$\beta_{m11*cost} - \beta_{m00*cost} \neq 0$	$\beta_{m11*cost} - \beta_{m01*cost} \neq 0$	$\beta_{m00*cost} - \beta_{m01*cost} \neq 0$
p-value	0.151	0.006	<0.001	0.050	<0.001	0.026

In Table 9.6 and Table 9.7 (p. 192), the relationships found in the data are compared to those implied by the heuristics raised in the literature. At the 95 per cent confidence level, the relationships between the relative cost position interactions are consistent with the *weak cost minimisation* and *reference point revision* theories, which both imply $\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}$ and $\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m00*cost}$. Both of these theories explain the difference in WTP estimates derived from the *RB* and *SB* formats in Chapter 8. At the 90 per cent confidence level, the parameter relationships are consistent with the *cost-driven value learning* theory ($\beta_{m10*cost}>\beta_{m11*cost}>\beta_{m01*cost}$ and $\beta_{m10*cost}>\beta_{m00*cost}>\beta_{m01*cost}$). However, in order for *cost-driven value learning* to adequately explain the difference in WTP derived from the single and repeated choice task elicitation formats (see Chapter 8), the behaviour would need to be asymmetric, with lower cost levels causing greater preference revisions than higher cost levels. The fact that the coefficient on the *m00* interaction is significantly greater than the coefficient on the *m01* interaction is contrary to the prediction of *strong cost minimisation* ($\beta_{m11*cost}=\beta_{m10*cost}>\beta_{m01*cost}=\beta_{m00*cost}$). The results are clearly contrary to the *cost averaging* theory ($\beta_{m10*cost}<\beta_{m11*cost}<\beta_{m01*cost}$ and $\beta_{m10*cost}<\beta_{m00*cost}<\beta_{m01*cost}$) and, as already identified, to *truthful response with stable preferences* ($\beta_{m10*cost}=\beta_{m11*cost}=\beta_{m00*cost}=\beta_{m01*cost}=0$).

Table 9.6: Comparing results to the predictions of heuristics at 95 per cent confidence level

Relationship implied by data (95 per cent confidence)	$\beta_{m10*cost}=\beta_{m11*cost}$	$\beta_{m10*cost}>\beta_{m00*cost}$	$\beta_{m10*cost}>\beta_{m01*cost}$	$\beta_{m11*cost}>\beta_{m00*cost}$	$\beta_{m11*cost}>\beta_{m01*cost}$	$\beta_{m00*cost}>\beta_{m01*cost}$
Strong cost minimisation	✓	✓	✓	✓	✓	✗
Weak cost minimisation	✓	✓	✓	✓	✓	✓
Reference point revision	✓	✓	✓	✓	✓	✓
Value learning	✗	✓	✓	✓	✓	✓
Cost averaging	✗	✗	✗	✗	✗	✗
Standard assumptions	✓	✗	✗	✗	✗	✗

The modelled relationship between relative cost position and WTP is presented in Figure 9.1 (p. 193). The non-zero estimates of WTP when evaluated at the *m01* and *m00* relative positions provide further evidence to suggest that *strong cost minimisation* was not widely employed. The figure also shows that the WTP estimate evaluated at the *m11* relative cost position of A$6,543 is similar to the estimate from the incentive compatible *SB* choice data of A$6,908 (see Chapter 8). This is consistent with the fact that a necessary and sufficient condition for the *m11* relative cost position is that the question is the first in the sequence. The null hypothesis of equivalence cannot be rejected based on a two-tailed test using 1000 randomly drawn paired differences with a p-value of 0.8024. Estimates of WTP derived from responses to questions beyond the first vary significantly depending on the positioning of cost relative to levels observed in previous choice tasks. The point estimate of WTP when the cost level is the minimum observed is approximately double the point estimate when cost is the maximum level observed.

Table 9.7: Comparing results to the predictions of heuristics at 90 per cent confidence level

Relationship implied by data (90 per cent confidence)	$\beta_{m10*cost} > \beta_{m11*cost}$	$\beta_{m10*cost} > \beta_{m00*cost}$	$\beta_{m10*cost} > \beta_{m01*cost}$	$\beta_{m11*cost} > \beta_{m00*cost}$	$\beta_{m11*cost} > \beta_{m01*cost}$	$\beta_{m00*cost} > \beta_{m01*cost}$
Strong cost minimisation	✗	✓	✓	✓	✓	✗
Weak cost minimisation	✗	✓	✓	✓	✓	✓
Reference point revision	✗	✓	✓	✓	✓	✓
Value learning	✓	✓	✓	✓	✓	✓
Cost averaging	✗	✗	✗	✗	✗	✗
Standard assumptions	✗	✗	✗	✗	✗	✗

In the ML model presented in Table 9.8, the relative cost position variables are used to describe heterogeneity in the mean and heteroscedasticity of a random cost parameter. The outcomes are estimated distributions of cost sensitivity across the population evaluated at each of the relative cost positions (see Figure 9.2),[58] where cost sensitivity is defined as:

[58] The distributions imply that some respondents exhibit a behaviourally implausible positive cost coefficient, which is not uncommon when using unconstrained random parameters, particularly

$$CostSens_{it} = -\partial U/\partial cost$$

$$= -\beta_{it}^{cost}$$

$$= -[\beta^{cost} + \beta^{m11*cost}m11_t + \beta^{m10*cost}m10_t + \beta^{m01*cost}m01_t + (\sigma^{cost} + \sigma^{m11*cost}m11_t + \sigma^{m10*cost}m10_t + \sigma^{m01*cost}m01_t)\, v_i],\ v_i \sim \mathrm{N}[0,1]$$

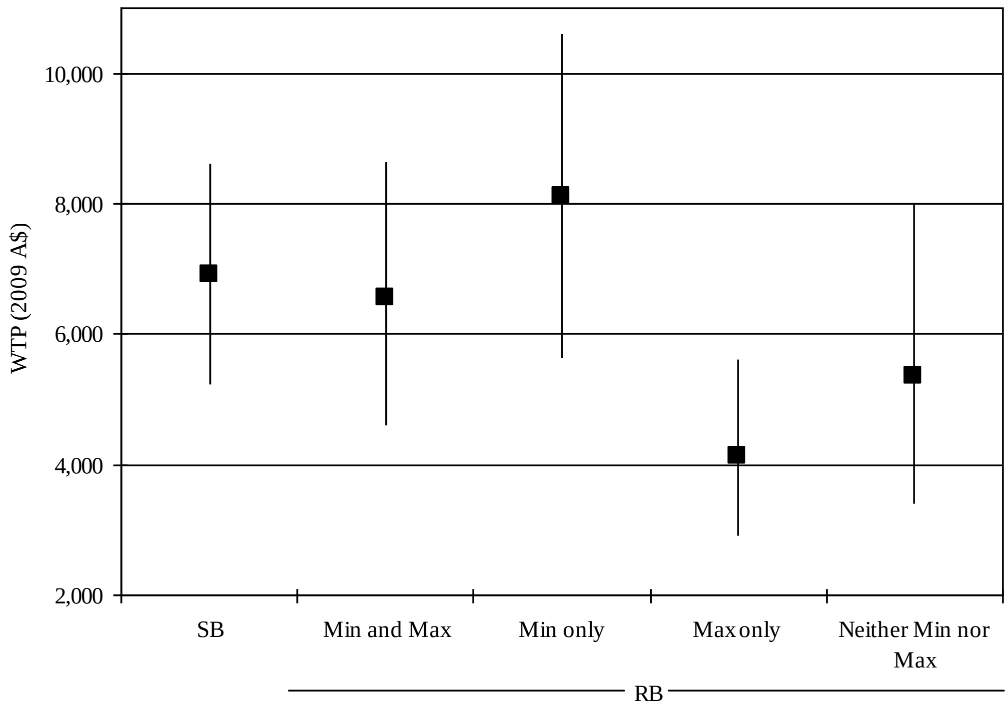

Figure 9.1: Willingness to pay by relative cost position (with 95 per cent confidence intervals)

The result of interest is the distribution of cost sensitivity when cost is the minimum and not the maximum presented in the sequence to that point (*m10*). Mean cost sensitivity is reduced relative to the first question (*m11*) and the variance in cost sensitivity is significantly increased (one-tailed t-tests have p-values 0.0355 and 0.0001, respectively). This indicates there is significant

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when adding variables to describe heterogeneity around the mean (Hensher and Greene, 2009; Hensher *et al.*, 2005).

heterogeneity in response behaviour when cost is lower than the levels previously observed. The combination of the shift and the change in shape of the distribution indicates that most respondents answered *m10* questions differently than if the question had been presented as the first in the sequence, but to differing degrees. This evidence supports a *cost-driven value learning* theory in which the magnitude of upward preference revision varies across respondents. Alternatively, it supports a mixture of behaviours across respondents, dominated by *cost-driven value learning* and one or both of *weak cost minimisation* and *reference point revision*.

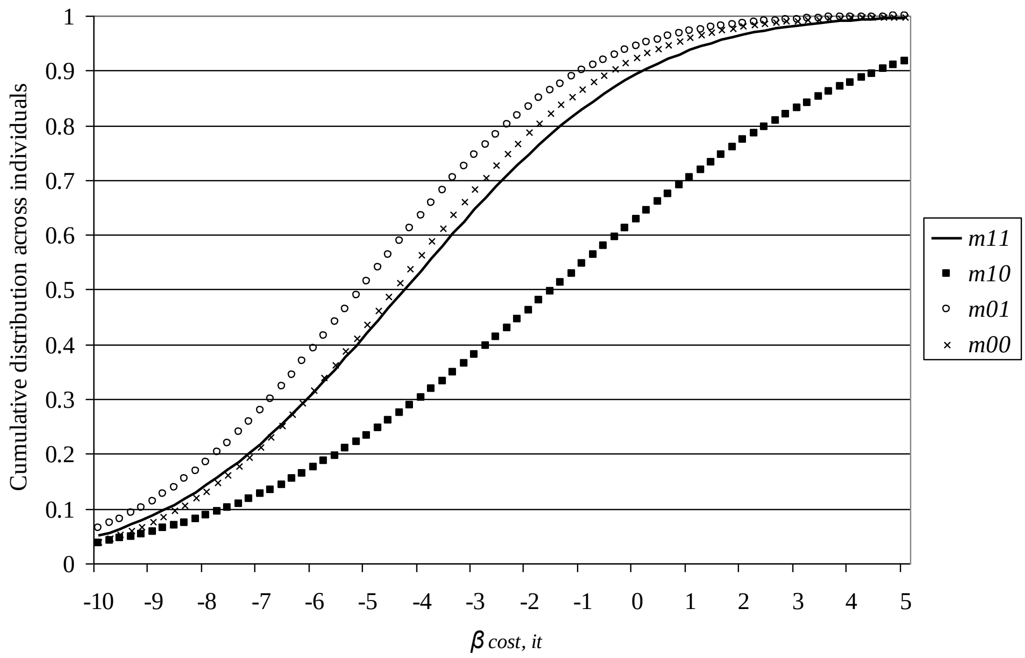

Figure 9.2: Cumulative distributions of cost sensitivity across individuals by relative cost position

Table 9.8: Summary of results from mixed logit model

	Model 2	
Random parameter: mean		
Log of [1 + household contribution (A$'000s)] [a]	-3.86793***	(0.84452)
Non-random parameters:		
Change in number of unplanned outages per 5 years	0.10437	(0.10608)
Change in unplanned minutes off supply per 5 years	-0.00122	(0.00132)
Change in number of planned outages per 5 years	-0.62662**	(0.26552)
Change in planned minutes off supply per 5 years	-0.00057	(0.00073)
Alternative specific constant (undergrounding = 1)	5.36297***	(0.97546)
Random parameter: heterogeneity in mean		
Relative cost position: m11	-0.43187	(0.44391)
Relative cost position: m10	2.31286**	(1.13387)
Relative cost position: m01	-1.25095**	(0.59936)
Random parameter: standard deviation		
Log of household contribution (A$'000s)	3.64465***	(0.53801)
Random parameter: heteroscedasticity		
Relative cost position: m11	-0.18012	(0.15211)
Relative cost position: m10	1.10898***	(0.26896)
Relative cost position: m01	-0.42847**	(0.20356)
Model fit:		
Observations	1112	
Log-likelihood	-461	
Information criterion AIC	947	

*, ** and *** indicate statistical significance at the 0.1, 0.05 and 0.01 levels respectively; standard errors are in parentheses; random parameter estimation is based on 200 Halton draws.

[a] In this model, ln(1+cost) is used rather than ln(cost), to allow for the status quo alternative (with cost=0) to be included in the mixed logit model using two spreadsheet rows per choice observation (as opposed to the binary logit model using one spreadsheet row per choice observation used elsewhere in this research).

9.5 Summary and conclusions

This chapter has developed an understanding of the decision processes that lead to task dependence by examining the relationship between cost sensitivity and the positioning of the cost level relative to levels presented in previous choice tasks in the multiple choice task format. While there are several possible interpretations for the decrease in WTP after the first question in the *RB* format (identified in Chapter 8), the results discussed in this chapter show that the cost levels presented in previous choice tasks play a role. Three of the decision processes (or heuristics) raised in the literature are supported by the evidence. The first of these is the *weak cost minimisation* heuristic in which respondents might reject an alternative that is preferred to the status quo if a similar good was offered at a lower cost in a previous choice task. The second is the *reference point revision* heuristic in which value functions shift when a non-status-quo option is chosen and the third is a *cost-driven value learning* heuristic in which respondents revise the value they place on the good towards a weighted average of the cost levels presented in the sequence to that point (with a higher weight placed on lower cost levels than higher cost levels). As discussed in Chapter 4, these behavioural explanations have quite different implications for the way in which WTP estimates should be derived from stated choice data. These implications are discussed further in the concluding chapter of this thesis.

The design used in this study does not allow further discrimination between the heuristics (for example, using the scope test applied by Bateman *et al.*, 2008b). Regardless, this study adds further support to the growing body of literature casting serious doubt on the standard assumptions of truthful, independent response with stable preferences (Bateman *et al.*, 2008b; Day *et al.*, 2009). It confirms the finding of Day and Pinto (2010) that the order in which choice tasks are presented may have a significant effect on WTP estimates. An order with increasing cost levels will underestimate WTP relative to an incentive compatible *SB* choice format, while an order with declining cost levels might overestimate WTP (depending on whether a 90 or 95 per cent confidence level is applied).

This study focuses only on a case where similar goods were offered at quite different cost levels over the course of a sequence of choice tasks, making opportunities for strategic response relatively obvious and, potentially, exacerbating *cost-driven value learning* behaviour. However, Scheufele and Bennett (2010b), in their concurrent and similar study focusing on the case of a pure public environmental good, and Day and Pinto (2010) arrived at similar findings using surveys in which the cost attribute was less dominant.

The primary analysis in this chapter sought to identify which heuristic best describes the response patterns in the data on average across individuals. Although the ML model in this chapter has identified some heterogeneity in the way in which respondents behave beyond the first question when cost is the minimum level presented to that point, it is difficult to interpret this result in behavioural terms. It is concluded that it may be caused by differences in the way in which preference revisions occur under value learning, or, that it may arise because sub-groups of respondents are employing different heuristics. This latter possibility is investigated in detail in the next chapter.

10 Modelling response behaviour towards a sequence of choice questions: a latent class approach

The findings of this chapter 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.

10.1 Introduction

One of the challenges associated with using stated choice methods to estimate the benefits to households from undergrounding is that of task dependence (Chapter 4). Task dependence refers to the situation in which stated choices are influenced by the information observed in the course of completed choice tasks. It represents a violation of the assumptions that are typically made when modelling responses to a sequence of choice tasks – that each question is answered truthfully and independently of the other questions, and that underlying preferences are not influenced by the choice tasks. When these assumptions are violated, and a growing body of evidence suggests that they typically are violated (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; Herriges and Shogren, 1996; Holmes and Boyle, 2005; Ladenburg and Olsen, 2008; McFadden and Leonard, 1995), the analyst needs to make alternative assumptions in order to use the stated choice data to estimate values. The appropriate set of alternative assumptions depends on the nature of the respondent decision processes (or heuristics) that lead to task dependence (and the violation of the standard assumptions). Several candidate heuristics have been raised in the literature. In Chapter 4, these heuristics were grouped into two broad categories – strategic misrepresentation, in which the perceived social choice function leads respondents to answer a different question from that being asked, and, value learning, in which respondents' underlying preferences are revised, based on information presented in choice tasks.

Analysis of the stated choice data collected for the present research using a web-based survey in Canberra (Chapter 6) commenced in Chapter 8. It became clear that task dependence was present in the data from the repeated binary choice format, with a lower rate of acceptance of undergrounding options in questions presented second, third and fourth, relative to the question presented first. The nature of the decision processes underlying the task dependence was investigated in Chapter 9 by examining the relationship between cost sensitivity and the positioning of the cost level relative to levels presented in previous choice tasks in the multiple choice task format. It was shown that the relationship was clearly inconsistent with the standard assumptions of truthful response with stable preferences. Of the specific heuristics raised in the literature, only three could not be ruled out based on the relationship – weak cost minimisation, reference point revision, and (an asymmetric form of) value learning. A mixed logit model showed that there was some heterogeneity in response behaviour towards the sequence of choice tasks. However, it is not clear, based on the analysis to this point, whether the heterogeneity arose because sub-groups of the population were employing different heuristics.

In Chapter 9, the focus was on identifying the heuristic that best explains the responses in the entire data set. This is the approach that is typically taken when investigating behavioural explanations for task dependence (Day *et al.*, 2009; Day and Pinto, 2010; DeShazo, 2002). However, it appears that no studies have investigated the possibility that each of the proposed heuristics explains the response behaviour of a sub-group of respondents in the survey (up to a probability). This chapter offers a contribution towards addressing this research gap. The objective is to demonstrate, using both binary and multinomial choice data, how an equality-constrained latent class (ECLC) model can be used to account for discrete levels of heterogeneity in response behaviour towards a sequence of choice questions. The chosen framework is similar to that previously used to account for attribute non-attendance (Scarpa *et al.*, 2009) and dual processing of common-metric attributes (Hensher and Greene, 2010). Classes of respondents are defined by separate utility functions specified by restricting certain parameters to be zero in each class. Estimated parameters are restricted to be equal across classes to ensure that class membership is determined by response behaviour towards a sequence rather than by taste heterogeneity.

In the following section, the ECLC model is summarised. The data to which it is applied are summarised in Section 10.3. Section 10.4 details the results from the analysis. Section 10.5 concludes.

10.2 Summary of the method

As in Chapter 9, the intention when analysing the stated choice data is to identify the response patterns predicted by a given heuristic in terms of relationships between responses and attribute levels observed by respondents in previous choice tasks. In this study, an ECLC model is used to estimate the latent (or unknown) proportions of respondents behaving in accordance with the three broad types of decision process (or heuristic) outlined in Chapter 4:

1) the standard assumptions (truthful, independent response with stable preferences);
2) value learning; and
3) strategic misrepresentation.

A summary of the method is provided here, and the reader is referred to Chapter 5 for more detail.

Three sets of utility functions are specified to capture the response patterns associated with each of the classes of response behaviour. Consistent with the approach taken throughout this research, they are tailored to analyse responses to stated choice surveys in which similar goods are offered at different prices over the course of a sequence. The consequence is that value learning and strategic behaviour tend to be driven mainly by the cost attribute. The utility functions in this study are specified accordingly. The standard attributes, $\mathbf{x}$, which enter the utility functions, are defined so that they take the value zero in the status quo option. This is achieved by defining the attributes in terms of changes relative to the status quo. The reason for this redefinition becomes clearer as the description of the utility functions proceeds. The ECLC model assigns respondents to these utility functions up to a probability to maximise the log-likelihood function (as described in Chapter 5).

10.2.1 Class 1 (standard assumptions)

The utility functions specified for the latent class of respondents behaving in accordance with the standard assumptions are the conventional sum-product of the *k* attributes as they appear in the choice task being answered and their associated taste intensities.

$$U_{it,\mathrm{SQ,class1}} = \beta_1 x_{1,it,\mathrm{SQ}} + \ldots + \beta_k x_{k,it,\mathrm{SQ}}$$

$$U_{it,\mathrm{ALT,class1}} = \beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}}$$

10.2.2 Class 2 (value learning)

The second latent class represents those responding in accordance with a value learning heuristic. The utility functions are specified to capture the response patterns of this group by allowing the alternative-specific preference to vary with the average of cost levels observed in the sequence up to and including the current choice task. The utility functions are as follows:

$$U_{it,\mathrm{SQ,class2}} = \beta_1 x_{1,it,\mathrm{SQ}} + \ldots + \beta_k x_{k,it,\mathrm{SQ}}$$

$$U_{it,\mathrm{ALT,class2}} = \beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}} + \beta_{k+1} z_{it,\mathrm{ALT}}$$

where

z_{itj} $= z^o_{itj} - \check{z}_j$

z^o_{itj} = the average of cost levels observed up to and including the current choice task

$\check{z}_j$ = the average of cost levels in the sample (across all respondents and all choice tasks)

As discussed in Chapter 5, the average observed cost variable, $z_{it,\mathrm{ALT}}$, is based on cost levels only in undergrounding alternatives, since the cost level was zero in the status quo (overhead) alternative presented in each choice task. The average of undergrounding cost levels observed, $\check{z}_{\mathrm{ALT}}$, was A$6,503 in the *RB* sample and A$6,508 in the *MN* sample.

10.2.3 Class 3 (strategic misrepresentation)

In a third class of response behaviour, utility functions are specified to capture the response patterns predicted by a strategic misrepresentation heuristic. Consistent with the *weak cost minimisation* and *reference point revision* heuristics that were found in Chapter 9 to be consistent with the response patterns in the data on average, the strategic misrepresentation heuristic specified here has two features. The first is that respondents compare alternatives to those accepted in previous choice tasks. It is assumed that respondents effectively replace the status quo with a reference alternative once they have expressed a preference for an alternative over the status quo. The reference alternative is defined as the highest-cost alternative previously accepted in the sequence. Over the range of cost and willingness to pay (WTP) levels that matter, this reference alternative yields the highest *expected* utility (based on the provision probabilities discussed below) of all previously accepted alternatives.

The second feature of this heuristic is that respondents consider the probability of provision. When a similar good is offered at very different cost levels over the course of a sequence of choice tasks, respondents may assume that higher-cost goods are more likely to be provided because the agency is more likely to proceed with the project the higher respondents' stated WTP. It is assumed that the perceived probability of project provision is equal to the ratio of the maximum cost level *accepted* and the maximum cost level *observed*.

The utility equations represent the expected utilities from the reference and current alternatives:[59]

$$U_{it,\mathrm{SQ,class3}} = p_{it,\mathrm{SQ}}(\beta_0 + \beta_1 x^{a}_{1,it} + \ldots + \beta_k x^{a}_{k,it})$$

$$U_{it,\mathrm{ALT,class3}} = p_{it,\mathrm{ALT}}(\beta_0 + \beta_1 x_{1,it,\mathrm{ALT}} + \ldots + \beta_k x_{k,it,\mathrm{ALT}})$$

where

$\mathbf{x}^{a}_{it}$ = the levels of attributes in the highest-cost alternative accepted in previous choice tasks ($x^{a}_{1,it}$ is the maximum cost level accepted in previous choice tasks)

$p_{it,\mathrm{SQ}} = x^{a}_{1,it}/x^{o}_{1,it}$

$x^{o}_{1,it}$ = the maximum cost level observed up to and including the current choice task

$p_{it,\mathrm{ALT}} = max[p_{it,\mathrm{SQ}}, x_{1,it,\mathrm{ALT}}/x^{o}_{1,it}]$

10.2.4 Class structure in the equality-constrained latent class model

The three sets of utility functions are operationalised in the latent class model by three separate sets of restrictions on a “master” utility function. Certain parameters are restricted to zero and certain parameters are restricted to equality both within and across classes as shown in Table 10.1. The alternative-specific constants and the standard attributes, **x,** are divided into two parts – one multiplied by $p_{it,\mathrm{ALT}}$ and another by 1- $p_{it,\mathrm{ALT}}$. In Classes 1 and 2, coefficients on attributes

[59] The (1-p) terms are not required since utility from the status quo is zero.

multiplied by $p_{it,\mathrm{ALT}}$ and 1- $p_{it,\mathrm{ALT}}$ are assumed to be equal so that they represent the marginal utility of the standard attribute without consideration of the probability of provision. In Class 3, the coefficients on attributes multiplied by 1- $p_{it,\mathrm{ALT}}$ are set to zero so that utility does depend on the probability of provision. A set of reference alternative variables are restricted to hold zero value in Classes 1 and 2 (in which previously accepted alternatives are ignored), but in Class 3, they are assumed to have the same taste intensities as the equivalent variables in the "non status quo" alternatives in the current choice task. All non-zero attributes are assumed to take the same value across classes.

Table 10.1: Class structure

Variable	Alternative	Parameters$_a$		
		Class 1 (Standard)	Class 2 (Learning)	Class 3 (Strategic)
$p_{it,\mathrm{SQ}}$	Status quo	0	0	β_0
$\mathbf{x}^a_{it} p_{it,\mathrm{SQ}}$	Status quo	0	0	$\boldsymbol{\beta}$
$p_{it,\mathrm{ALT}}$	Underground alternative	β_0	β_0	β_0
$\mathbf{x}_{it} p_{it,\mathrm{ALT}}$	Underground alternative	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$
$1\text{-}p_{it,\mathrm{ALT}}$	Underground alternative	β_0	β_0	0
$\mathbf{x}_{it}(1\text{-}p_{it,\mathrm{ALT}})$	Underground alternative	$\boldsymbol{\beta}$	$\boldsymbol{\beta}$	0
$z_{it,\mathrm{ALT}}$	Underground alternative	0	β_{k+1}	0

$_a$ $\boldsymbol{\beta}$ refers to a coefficient vector, $\beta_1, \beta_2, \ldots, \beta_k$, associated with $x_1, \ldots, x_k$.

Two sets of hypothesis tests were set out in Chapter 5. The first set tests whether each heuristic explains the behaviour of a significant proportion of respondents, where G_q is the estimated proportion of respondents behaving in accordance with heuristic q of Q.

Hypothesis #5 $\quad H_0^5 : G_1^{RB} = 0$

$$H_A^5 : G_1^{RB} \neq 0$$

Hypothesis #6 $H_0^6: G_2^{RB} = 0$

$H_A^6: G_2^{RB} \neq 0$

Hypothesis #7 $H_0^7: G_3^{RB} = 0$

$H_A^7: G_3^{RB} \neq 0$

Hypothesis #8 $H_0^8: G_1^{MN} = 0$

$H_A^8: G_1^{MN} \neq 0$

Hypothesis #9 $H_0^9: G_2^{MN} = 0$

$H_A^9: G_2^{MN} \neq 0$

Hypothesis #10 $H_0^{10}: G_3^{MN} = 0$

$H_A^{10}: G_3^{MN} \neq 0$

The second set of hypotheses test whether the proportions differ between data from the *RB* and *MN* formats.

Hypothesis #11 $H_0^{11}: G_1^{RB} - G_1^{MN} = 0$

$H_A^{11}: G_1^{RB} - G_1^{MN} \neq 0$

Hypothesis #12 $H_0^{12}: G_2^{RB} - G_2^{MN} = 0$

$H_A^{12}: G_2^{RB} - G_2^{MN} \neq 0$

Hypothesis #13 $H_0^{13}: G_3^{RB} - G_3^{MN} = 0$

$H_A^{13}: G_3^{RB} - G_3^{MN} \neq 0$

10.3 Summary of the data

The model is implemented on data from two elicitation formats used in the stated choice survey detailed in Chapter 6. The first is the format comprising a sequence of four binary choice tasks in which respondents were presented with a description of their current (overhead) service and one undergrounding alternative (the repeated binary, *RB*, choice format). The second format is that comprising a sequence of four choice tasks, where each task contained the current service and *two* undergrounding alternatives (the multinomial, *MN*, choice format). A few relevant points are summarised here and the reader is referred to Chapter 6 for further detail.

The network service was viewed by respondents as similar across the undergrounding options, but the cost of the options varied considerably from A$1,000 to A$16,000. Two blocks of four choice tasks were constructed in the *MN* choice format. The *RB* design was created by splitting these two blocks into four blocks of four binary choice tasks as detailed in Chapter 6. Some 292 respondents completed the web-based questionnaire in the *RB* choice format and 290 in the *MN* choice format. The questionnaire advised respondents of the number of choice tasks that would be presented, the number of alternatives that would be presented in each task and the attributes that would be used to describe each alternative. However, respondents were *not* given information about the range of levels that the attributes could take, and, the questionnaire did not allow respondents to navigate back through the sequence of choice tasks.

As many as 30 per cent of respondents completing the *RB* format and 24 per cent of respondents completing the *MN* format chose the status quo scenario in all four choice tasks. The response behaviour of this group is difficult to determine because, if the value placed on undergrounding by a respondent is sufficiently low, then all three heuristics result in the same pattern of responses – selection of the status quo in every task. These respondents are omitted from the latent class model to ensure that the method can be demonstrated effectively.

An important part of the modelling approach is the manipulation of variables prior to estimation. A spreadsheet was used to create the normalised average observed cost variable, $z_{it,\mathrm{ALT}}$, the provision probability proxies for the reference and current alternatives, $\mathrm{p}_{it,\mathrm{SQ}}$ and $\mathrm{p}_{it,\mathrm{ALT}}$, the attribute levels associated with the highest-cost alternative previously accepted, $\mathbf{x}^{\mathbf{a}}_{\boldsymbol{it}}$, and the maximum cost level observed up to and including the current choice task, $x^{\mathrm{o}}_{1,it}$.

10.4 Results

A summary of the ECLC model results for the *RB* (Model 1) and *MN* (Model 2) formats is presented in Table 10.2 with full estimation results detailed in Table 10.3 and Table 10.4 (pp. 215-216). The seven parameter estimates in each model have the expected sign where they are significant at the 95 per cent confidence level.[60] The positive coefficient on the normalised average observed cost variable indicates that, within Class 2, the value placed on undergrounding is influenced by the cost levels observed in previous choice tasks and the current choice task. A respondent in this class is more likely to accept an undergrounding alternative priced at $4,000 in the second choice task if the alternative offered in the first

[60] As expected when designing the survey, coefficients on the supply reliability attributes are more statistically significant in the multinomial choice data where respondents were asked to discriminate between two undergrounding options on the basis of these attributes (and A$100 or A$200 cost differences).

choice task was priced at $6,000 than if it was priced at $2,000 (all else held constant).

Table 10.2: Summary of estimation results

Model type	Equality-constrained latent class				Standard multinomial logit			
Choice format	Binary choice		Multinomial choice		Binary choice		Multinomial choice	
	(Model 1)		(Model 2)		(Model 3)		(Model 4)	
Variable	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Undergrounding-specific constant	8.271	8.42	5.592	7.98	4.634	13.37	3.564	10.54
Log of household contribution	-4.139	-9.28	-2.852	-9.31	-2.409	-13.91	-1.963	-12.57
Change in frequency of unplanned power cuts	-0.067	-1.07	-0.153	-2.76	-0.051	-1.07	-0.173	-3.52
Change in frequency of planned power cuts	-0.169	-1.62	0.062	0.94	-0.155	-1.93	0.046	0.82
Change in average duration of unplanned power cuts	0.000	-0.02	-0.006	-3.57	-0.002	-0.49	-0.005	-3.72
Change in average duration of planned power cuts	-0.001	-0.80	-0.004	-7.24	-0.002	-1.49	-0.004	-7.55
Normalised average observed cost (Class 2 only)	0.611	3.42	0.389	2.40				
Estimated class probabilities								
Class 1 (standard assumptions)	0.229	2.23	0.114	0.36				
Class 2 (value learning)	0.383	5.08	0.386	2.15				
Class 3 (strategic misrepresentation)	0.388	5.25	0.500	3.13				
Model fit:								
N	800		872		800		872	
Log-likelihood	-348		-762		-373		-778	
AIC	714		1543		759		1568	

Turning to the estimated class probabilities, all except one are significant at the 95 per cent confidence level across the two models. The one insignificant class probability refers to the class responding according to the standard assumptions in the *MN* choice format. In terms of the hypotheses set out in Chapter 5 and Section 10.2, the null hypotheses, H_0^5, H_0^6, H_0^7, H_0^9, and H_0^{10} are rejected at the 95 per cent confidence level, but H_0^8 cannot be rejected. Both models estimate that 39 per cent of respondents behaved according to the value learning utility specification. The proportion behaving in line with the strategic misrepresentation specification is estimated at 38 per cent in the binary format and 50 per cent in the *MN* format. The class with the lowest membership probability in both models was that based on the standard assumptions of truthful response and stable preferences, with 23 and 11 per cent predicted by Model 1 and Model 2, respectively. No single class dominates either model, indicating significant heterogeneity in the response behaviour towards both the *RB* and *MN* choice formats. There is no evidence of a relationship between choice format and response behaviour, with the class probabilities statistically indistinguishable at the 95 per cent confidence level across the two models. In terms of the hypotheses set out in Chapter 5, none of the null hypotheses, H_0^{11}, H_0^{12}, and H_0^{13}, are rejected, with p-values of 0.74, 0.99, and 0.55 based on 1000 paired differences.

The log-likelihood values associated with the ECLC models indicate an improvement in model fit over the standard multinomial logit (MNL) models (also presented in Table 10.2). This improvement is expected given the additional parameters accommodating heterogeneity in the ECLC models. Of greater interest is the improvement in the Akaike information criterion (AIC) value, which accounts for parameter proliferation. The improvement in this criterion suggests that accounting for heterogeneity in response behaviour using the ECLC model is important even when model parsimony is considered desirable.

Turning to implications for welfare estimates, the undergrounding choice probability (or bid acceptance) functions for the *RB* and *MN* choice format models are shown in Figure 10.1 and Figure 10.2 (p. 212) with all non-cost attributes set at their sample means. Estimates of the (improper) expectation of total WTP, calculated as the truncated areas under the undergrounding choice probability curves, are not significantly different at the 95 per cent confidence level across the ECLC and MNL models. However, this may not be the case in other data sources. The changes in the curves when moving from the MNL to the latent class model are the net effect of two separate influences – the effect of accounting for value learning (Class 2); and the effect of accounting for strategic misrepresentation (Class 3). The overall effect on WTP depends on the magnitude of each of these effects, which are determined, in part, by the associated class probabilities.

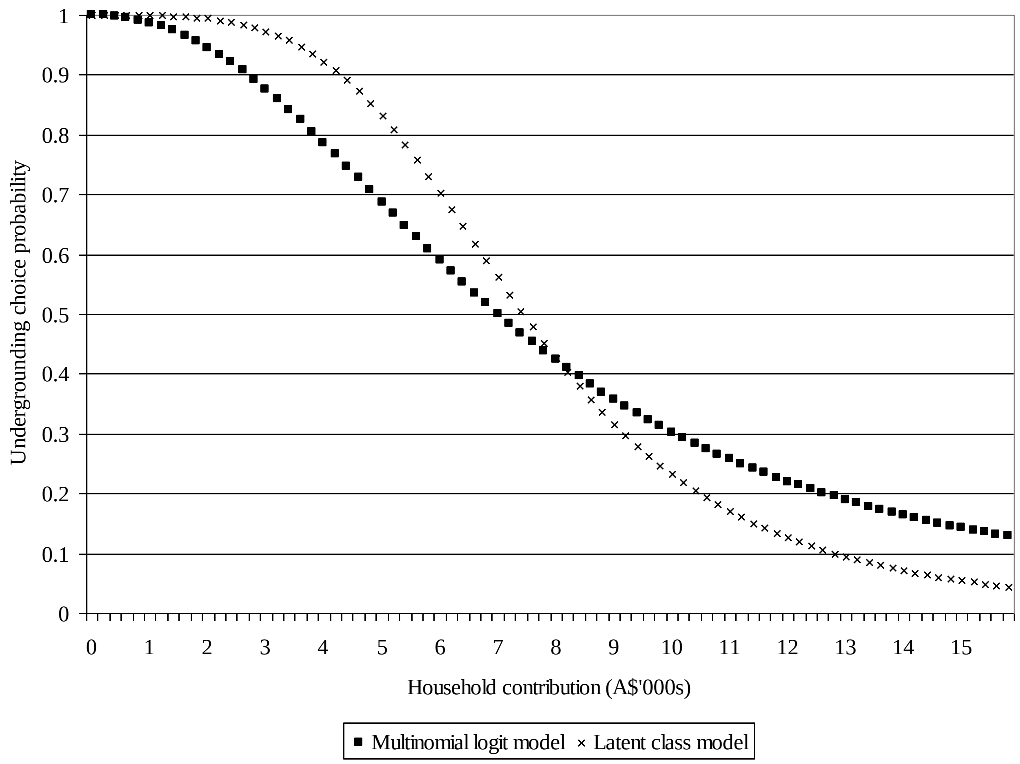

Figure 10.1: Undergrounding choice probability implied by models on binary choice format

The expected effect of accounting for value learning behaviour is an increase in probabilities at lower costs and a decrease in probabilities at higher costs. The reason is as follows. Average observed cost, z, is positively related to cost, x_1, for a given set of cost levels in previous choice tasks. Utility from undergrounding alternatives net of the effect of average observed cost therefore needs to be higher at lower cost levels and vice versa in order to adequately explain respondents' choices. The latent class model achieves this by altering the remaining parameters, $\boldsymbol{\beta}$. The effect is a narrowing of the distribution of total WTP (with average observed cost held constant) around the mean cost level presented across all choice observations. Accounting for value learning has a relatively small effect on estimates of mean WTP in this case, because the mean cost level presented in the survey (approximately A$6,300) is similar to mean WTP.

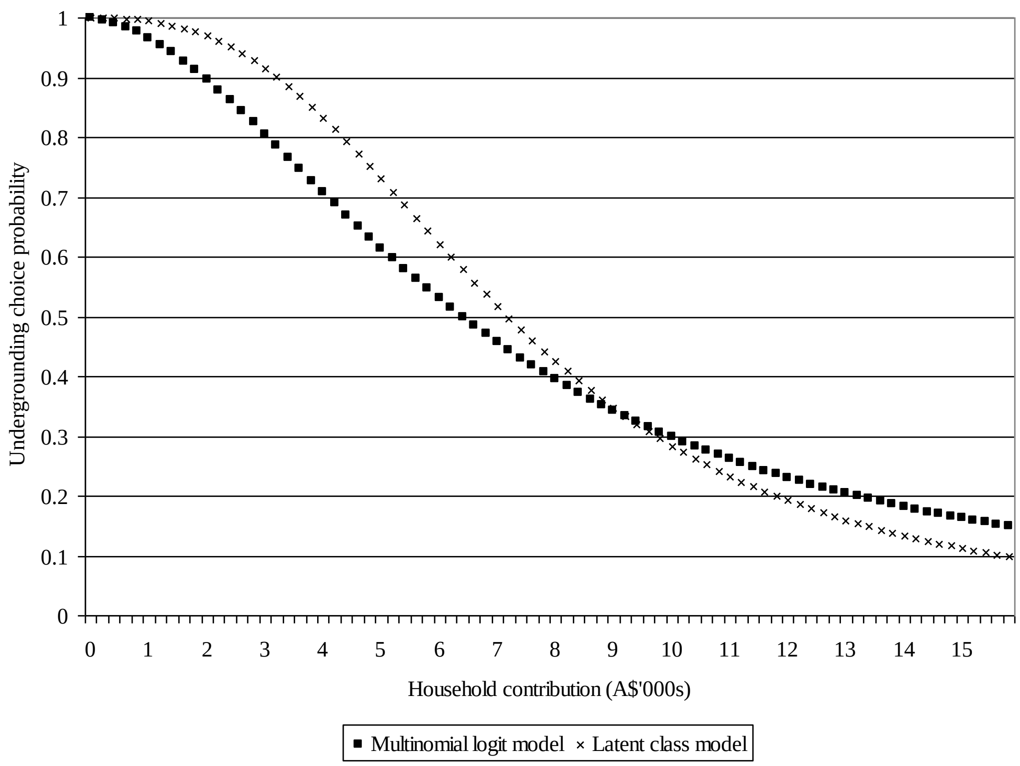

Figure 10.2: Undergrounding choice probability implied by models on multinomial choice format

The expected effect of accounting for strategic misrepresentation is an increase in undergrounding choice probability at all cost levels (albeit not in a linear fashion). For a given set of parameters, $\boldsymbol{\beta}$, the undergrounding choice probability for Class 3 is always less than or equal to that for Class 1 since $U_{it,\mathrm{SQ,class3}} \geq U_{it,\mathrm{SQ,class1}}$ and

$U_{it,\mathrm{ALT,class3}} \leq U_{it,\mathrm{ALT,class1}}$.[61] Therefore, when switching from a Class 1 to a Class 3 utility specification, the parameters must be altered in such a way that increases the undergrounding choice probability. Accounting for strategic misrepresentation therefore leads to increased estimates of mean WTP, which is expected since strategic misrepresentation effectively involves an under-stating of true WTP.

10.5 Summary and conclusions

This chapter has presented an ECLC model that can be used to identify heterogeneity in response behaviour towards a sequence of choice tasks, and, potentially, account for heuristics that cause task dependence when estimating WTP for policy purposes. The utility functions specified to capture strategic misrepresentation and value learning represent alternatives to the standard assumptions of truthful, independent response with stable preferences. The illustrative evidence herein shows the model can be applied to choice data from both binary and multinomial choice formats where a status quo alternative is present and similar goods are offered at very different prices over the course of a sequence of questions.

The ECLC models achieved an improvement in fit over standard MNL models, even based on information criteria that account for model parsimony. Estimates of total WTP were statistically indistinguishable between the two types of model.

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[61] Note that in the first question in a sequence, the utility functions in Classes 1 and 3 are identical. An assumption has been made in the analysis in this chapter that there are no scale effects across classes. If different classes do in fact have different scales, then ratios of coefficients are comparable across classes, but the coefficients themselves are not.

However, this may not be the case for other data sources as it depends on several factors including the relative mix of class probabilities.

Three distinct groups were identified in both the binary and multinomial choice data. The group behaving in accordance with the standard assumptions was the smallest of the three in both models, providing further evidence that the standard assumptions do not adequately reflect the response behaviour of the majority of respondents in a survey of this type. The heterogeneity in response behaviour identified herein may explain the variation in findings across studies and the ambiguity of evidence within studies (Day and Pinto, 2010) that have attempted to identify a single heuristic that best describes respondent behaviour towards a sequence of choice questions. It suggests that the literature may never converge to agreement on a single heuristic. The best way forward would appear to be to consider the possibility of heterogeneity in response behaviour. The method presented in this paper is one approach that could be used in future studies. Clearly, other approaches are possible and this is likely to be a fertile area for future research.

In the next chapter, the findings of the studies presented to this point in the thesis are used to inform the estimation of the household benefits that would result from undergrounding in the case study area.

Table 10.3: Equality-constrained latent class model on binary choice data (Model 1)

		Class 1		Class 2		Class 3	
Variable	Alternative	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
p_{SQ} [a]	Status quo					8.271	8.42
p_{SQ} * Log of household contribution in highest-cost alternative accepted previously	Status quo					-4.139	-9.28
p_{SQ} * Change in frequency of unplanned power cuts in highest-cost alternative previously accepted	Status quo					-0.067	-1.07
p_{SQ} * Change in frequency of planned power cuts in highest-cost alternative previously accepted	Status quo					-0.169	-1.62
p_{SQ} * Change in average duration of unplanned power cuts in highest-cost alternative previously accepted	Status quo					0.000	-0.02
p_{SQ} * Change in average duration of planned power cuts in highest-cost alternative previously accepted	Status quo					-0.001	-0.80
p_{ALT} [a]	Underground	8.271	8.42	8.271	8.42	8.271	8.42
p_{ALT} * Log of household contribution	Underground	-4.139	-9.28	-4.139	-9.28	-4.139	-9.28
p_{ALT} * Change in frequency of unplanned power cuts	Underground	-0.067	-1.07	-0.067	-1.07	-0.067	-1.07
p_{ALT} * Change in frequency of planned power cuts	Underground	-0.169	-1.62	-0.169	-1.62	-0.169	-1.62
p_{ALT} * Change in average duration of unplanned power cuts	Underground	0.000	-0.02	0.000	-0.02	0.000	-0.02
p_{ALT} * Change in average duration of planned power cuts	Underground	-0.001	-0.80	-0.001	-0.80	-0.001	-0.80
$(1-p_{ALT})$	Underground	8.271	8.42	8.271	8.42		
$(1-p_{ALT})$ * Log of household contribution	Underground	-4.139	-9.28	-4.139	-9.28		
$(1-p_{ALT})$ * Change in frequency of unplanned power cuts	Underground	-0.067	-1.07	-0.067	-1.07		
$(1-p_{ALT})$ * Change in frequency of planned power cuts	Underground	-0.169	-1.62	-0.169	-1.62		
$(1-p_{ALT})$ * Change in average duration of unplanned power cuts	Underground	0.000	-0.02	0.000	-0.02		
$(1-p_{ALT})$ * Change in average duration of planned power cuts	Underground	-0.001	-0.80	-0.001	-0.80		
Normalised average observed cost	All			0.611	3.42		
Class probabilities:							
Estimated latent class probabilities		0.229	2.23	0.383	5.08	0.388	5.25
Model fit:							
N		800					
Log-likelihood		-348					
AIC		714					

[a] Probabilities are variables, not coefficients. The coefficient on the probability variables, β_0, can therefore take values outside the 0-1 range.

Table 10.4: Equality-constrained latent class model on multinomial choice data (Model 2)

		Class 1		Class 2		Class 3	
Variable	Alternative	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
p_{SQ}	Status quo					5.592	7.98
p_{SQ} * Log of household contribution in highest-cost alternative accepted previously	Status quo					-2.852	-9.31
p_{SQ} * Change in frequency of unplanned power cuts in highest-cost alternative previously accepted	Status quo					-0.153	-2.76
p_{SQ} * Change in frequency of planned power cuts in highest-cost alternative previously accepted	Status quo					0.062	0.94
p_{SQ} * Change in average duration of unplanned power cuts in highest-cost alternative previously accepted	Status quo					-0.006	-3.57
p_{SQ} * Change in average duration of planned power cuts in highest-cost alternative previously accepted	Status quo					-0.004	-7.24
p_{ALT}	Underground	5.592	7.98	5.592	7.98	5.592	7.98
p_{ALT} * Log of household contribution	Underground	-2.852	-9.31	-2.852	-9.31	-2.852	-9.31
p_{ALT} * Change in frequency of unplanned power cuts	Underground	-0.153	-2.76	-0.153	-2.76	-0.153	-2.76
p_{ALT} * Change in frequency of planned power cuts	Underground	0.062	0.94	0.062	0.94	0.062	0.94
p_{ALT} * Change in average duration of unplanned power cuts	Underground	-0.006	-3.57	-0.006	-3.57	-0.006	-3.57
p_{ALT} * Change in average duration of planned power cuts	Underground	-0.004	-7.24	-0.004	-7.24	-0.004	-7.24
$(1-p_{ALT})$	Underground	5.592	7.98	5.592	7.98		
$(1-p_{ALT})$ * Log of household contribution	Underground	-2.852	-9.31	-2.852	-9.31		
$(1-p_{ALT})$ * Change in frequency of unplanned power cuts	Underground	-0.153	-2.76	-0.153	-2.76		
$(1-p_{ALT})$ * Change in frequency of planned power cuts	Underground	0.062	0.94	0.062	0.94		
$(1-p_{ALT})$ * Change in average duration of unplanned power cuts	Underground	-0.006	-3.57	-0.006	-3.57		
$(1-p_{ALT})$ * Change in average duration of planned power cuts	Underground	-0.004	-7.24	-0.004	-7.24		
Normalised average observed cost	All			0.389	2.40		
Class probabilities:							
Estimated latent class probabilities		0.114	0.36	0.386	2.15	0.500	3.13
Model fit:							
N		872					
Log-likelihood		-762					
AIC		1543					

11 Estimates of household benefits for the case study area

The findings of this chapter 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.

11.1 Introduction

In the introductory chapter, a broad research question was established in relation to the evaluation of net economic benefits from undergrounding electricity networks in residential areas. The social value placed on the broadly-defined network service quality improvement that would result from undergrounding is a crucial element in this evaluation, irrespective of governance structure in the industry (Chapter 2). Inaccurate estimation of the values could lead to investments with a net economic cost being undertaken and, conversely, investments with a net benefit *not* being undertaken. Considerable reliance is therefore placed on two methods for gathering information about preferences for the network quality improvement resulting from undergrounding – the hedonic price method and stated preference methods. In Chapter 4, the focus of this thesis was narrowed to two specific challenges associated with applying the methods – *multicollinearity* in the hedonic price method and *task dependence* in stated preference methods. Four of the five research questions set out in Chapter 5 focused on these challenges and how the methods could be adapted to understand and overcome them. The focus of the studies conducted in the four chapters preceding this chapter was on addressing these four questions. A fifth research question related to estimating the household benefits of undergrounding in the case study area. This question was addressed, in part, by the hedonic price study conducted in Chapter 7, but, to this point in the thesis, no analysis has been conducted on the stated choice survey data with a focus on estimating values for policy use. The objective of this chapter is to use the results of the studies conducted in the thesis to this point to inform the estimation of the benefits of undergrounding in the case study area. The intention is for this estimate to be used in economic cost-benefit analyses by the local electricity network service provider, ActewAGL.

The hedonic price study conducted in Chapter 7 provided an estimate of the implicit price of underground wires in the market for real estate in three selected suburbs in the case study area. This implicit price represents the value placed on underground wires by the *marginal* purchaser in the market. The value of interest when estimating economic benefits is the total (or the mean) value placed on underground wires across all households. The implicit price provides very little information about this value. The analysis in this chapter therefore focuses on the stated choice survey data since they can be used to estimate the value of interest. However, the evidence from the hedonic price study is compared to the demand curve estimated using the stated choice data as a check on the robustness of the results.

Chapters 8 to 10 show the importance of accounting for the decision processes that lead to task dependence when analysing the stated choice data. In Chapter 8, it was shown that estimates of willingness to pay (WTP) from an incentive compatible single binary choice format were higher than those from a choice format comprising multiple choice tasks per respondent. Preferences stated in the first of a sequence of choice tasks were not significantly different from those stated in the single binary choice task, but, in subsequent choice tasks, the rate of acceptance of undergrounding options was lower. In Chapter 9, it was shown that responses in these choice tasks are influenced by cost levels observed in past questions. Three of the heuristics raised in the literature can be used to explain the relationship – weak cost minimisation, reference point revision, and cost-driven value learning. The latter heuristic can only explain the decrease in WTP in questions subsequent to the first if it is asymmetric in the sense that lower cost levels cause greater preference revision than higher cost levels. The evidence from Chapter 10 suggests that these heuristics may explain the response behaviour of significant sub-groups of the population.

The weight of evidence suggests that strategic misrepresentation was one of the primary types, if not the primary type, of decision process employed by respondents in the survey. One approach to estimating the household benefits of undergrounding where this heuristic is present is a simple sample selection approach focusing on data from the incentive compatible single binary choice format and the first question in the repeated binary choice format (which was shown in Chapter 8 to elicit statistically equivalent responses). There is evidence that some respondents may have employed a value learning heuristic; possibly one that is asymmetric in the way in which lower and higher cost levels influence preferences. The implications of this evidence for estimating the household benefits of undergrounding are not clear. One of the arguments put forward in the literature is that the analyst should be interested in the prior distribution of WTP, rather than the posterior distribution influenced by the experimental design (Herriges and Shogren, 1996). Like the strategic misrepresentation heuristic, this interpretation calls for a focus on the single binary choice and the first question from the multiple choice formats, since these questions provide the best information on the prior distribution of WTP. Although other interpretations have been raised in the literature (Bateman *et al.*, 2008a), this "prior distribution" approach is adopted in this chapter. Under this assumption, an impasse is avoided since the simple sample selection approach to accounting for both of the candidate decision processes is the use of single binary choice data and the first question from the repeated binary choice data. This chapter proceeds on that basis and alternative approaches are discussed in the concluding chapter.

To provide information about how household benefits may vary from one area to another, this study investigates sources of observed heterogeneity in WTP for undergrounding. In particular, WTP is related to the socio-economic characteristics of respondents, including age and household income. WTP is also related to the specific benefits of undergrounding viewed as most important by each respondent. This analysis develops the understanding of the relative importance of the components of the mixed bundle of benefits associated with undergrounding.

11.2 Summary of the data

The household benefits of undergrounding in Canberra are estimated using data from the stated choice survey detailed in Chapter 6. A few relevant comments are provided here, with readers referred to Chapter 6 for more detail. Three parts of the survey questionnaire are of particular interest in this chapter. The first is a question about the specific benefits from undergrounding. Respondents were asked to select two of the following specific benefits in response to the question:

“What would be the two most significant benefits to your household from undergrounding?

1) improved appearance and unobstructed views;

2) fewer power cuts;

3) better safety, particularly during storms and bushfires;

4) reduced tree trimming requirements and associated costs;

5) fewer restrictions on use of yard space (eg for construction of a garage or swimming pool);

6) less need for ActewAGL to access your backyard; or

7) other (please specify below).”

In the analysis in this chapter, responses to this question are related to stated choices, providing an indication of the relative value of the specific benefits. Indicator variables were created for the selection of each pair of specific benefits to facilitate this analysis.

The key part of the questionnaire in terms of valuation of overall household benefits is the stated choice component. Some 1,163 households responded to a single choice task and 292 households responded to a sequence of four choice tasks (the repeated binary, *RB*, format). Data from questions subsequent to the first in the *RB* format are excluded from the analysis to account for respondents’ decision processes, as discussed in the introductory section of this chapter. Some 82 choice observations where respondents took less than five minutes to complete the survey are excluded from the analysis in this chapter.[62] The final data set comprises 1,373 binary choice observations.

Sixteen choice tasks were designed. The survey instrument was programmed to cycle through these choice tasks, ensuring approximately equal representation across choice observations. The scenarios in the tasks were described in terms of the number and duration of planned and unplanned power cuts. Undergrounding scenarios included a one-off household contribution. Respondents were instructed that their contribution would be payable either up-front with a three per cent discount or in instalments for up to five years at an interest rate of 6.5 per cent. The level of this contribution ranged from A$1,000 to A$16,000. The levels assigned to other attributes are detailed in Chapter 6. Of the specific benefits of undergrounding, only supply reliability could be included as a variable in the choice tasks. The other benefits of undergrounding are effectively embodied in the alternative label. To ensure the prominence of supply reliability benefits in choice tasks did not cause a disproportionate focus on this benefit, each choice task page included a reminder of the two most important benefits and the most important disadvantage of undergrounding selected by the respondent in earlier questions.[63]

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[62] As discussed earlier, it was judged that these responses were given without consideration solely as a means of qualifying for the prize draw participation incentive.

[63] In the question about disadvantages of undergrounding, respondents were asked “Other than cost, what would be the most significant disadvantage to your household?” The options provided were: “power cuts may be longer”, “inconvenience during undergrounding works”, “service pillar in front of property”, and “other (please specify below)”.

The final part of the questionnaire comprised questions about the socio-economic characteristics of the respondent and their household. In particular, questions related to the age, gender and education of the respondent, the number of persons in the household, the suburb location of the household and annual household income. These characteristics are related to stated choices in the analysis in this chapter. The age and household income characteristics are effects-coded to form the variables described in Table 11.1 and Table 11.2.

Table 11.1: Effects-coding of age variables

Variable	*Age: 18-29*	*Age: 30-39*	*Age: 50-64*	*Age: 65 and over*
Level when age is 18-29	1	0	0	0
Level when age is 30-39	0	1	0	0
Level when age is 40-49 [a]	-1	-1	-1	-1
Level when age is 50-64	0	0	1	0
Level when age is 65 or over	0	0	0	1

[a] 23 per cent of the sample.

Table 11.2: Effects-coding of household income variables

Variable[a]	*$18,199 or less*	*$18,200 - $51,999*	*$52,000 - $88,399*	*$88,400 - $129,999*	*$130,000 - $181,999*	*$182,000 or more*
Level when income is $18,199 or less	1	0	0	0	0	0
Level when income is $18,200 - $51,999	0	1	0	0	0	0
Level when income is $52,000 - $88,399	0	0	1	0	0	0
Level when income is $88,400 - $129,999	0	0	0	1	0	0
Level when income is $130,000 - $181,999	0	0	0	0	1	0
Level when income is $182,000 or more	0	0	0	0	0	1
Level when income is not provided [b]	-1	-1	-1	-1	-1	-1

[a] All dollars are 2009 A$.

[b] 19 per cent of the sample.

11.3 Method

Respondents' choices were modelled with a standard binary logit model (equivalent to the multinomial logit (MNL) model described in Chapter 3, but where status quo utility is zero) based on random utility theory (McFadden, 1974). The utility that respondent i derives from alternative j in choice task t is $U_{ijt} = \alpha_{ij} + \delta'\mathbf{z}_{ij} + \beta'\mathbf{x}_{itj} + \varepsilon_{itj}$ where α_{ij} is the coefficient on a constant specific to undergrounding options, $\mathbf{z}_{ij}$ is a vector of respondent characteristics (also specific to undergrounding options), $\mathbf{x}_{itj}$ is a vector of observed variables, and $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ are vectors of coefficients to be estimated. The assumption that the random element, ε, is independently and identically distributed according to the extreme value type I function gives the logit model form. In the models in this chapter, all choice tasks comprise two alternatives and all observed variables are defined in such a way that $\mathbf{x}_{it} = 0$ in the current service alternative (j=1). This allows estimation of a binary logit model on data with a single spreadsheet row per choice observation (as opposed to the MNL model which is estimated on data with two or more spreadsheet rows per choice observation). The choice probability function for respondent i in choice task t is:

$$\pi_{\mathrm{it}} = \Pr\left(y_{it} = 1 \mid x_{it}, z_i\right) = \frac{\exp(\alpha_i + \delta' z_i + \beta' x_{it})}{1 + \exp(\alpha_i + \delta' z_i + \beta' x_{it})}$$

Consistent with the approach developed in Chapter 5, household benefits are measured as the truncated (improper) expectation of WTP for the representative household – a Hicksian compensating measure of welfare change. It is calculated as the area under the choice probability function truncated at the maximum cost level used in the survey (A$16,000) with supply reliability variables set at their population means:

$$E*(WTP) = \int_0^{\max x_1} \overline{\pi}_{it} dx_1 = \int_0^{\max x_1} \frac{\exp(\overline{W}_{it})}{1+\exp(\overline{W}_{it})} dx_1$$

where

x_1 = the cost attribute (*max* x_1 is the maximum cost level in the survey)

$\overline{W}_{it} = \alpha_i + \beta' \overline{x} + \beta_1 x_{1,it}$

$\overline{x}$ = a vector of the means of supply reliability variables

Truncation at the maximum cost level used in the survey is common in analysis of dichotomous choice contingent valuation data. However, it is important to note the implications of the approach. By effectively assuming the cumulative density function jumps to the value one at the WTP value A$16,000, the effect in this case is to assume a WTP estimate of A$16,000 for all respondents whose WTP is A$16,000 *or more*. This results in an underestimate of the true mean WTP, but to an unknown extent. To estimate true WTP, the analyst requires information about the shape of the estimated density function for WTP values exceeding A$16,000. However, estimating this shape invariably relies on the interpolation within the A$0-A$16,000 range, resulting in significant positive density at implausibly large WTP values – the so-called “fat tail” problem. It is possible to rescale a density function by the missing density to force the integral of the modified density to equal one over the range supported by the data, but this is theoretically undesirable as it is inconsistent with random utility maximisation. In this research, a simple truncation has been applied, resulting in an improper expectation, with implications discussed where appropriate.

11.4 Results

The estimation results for three choice models are presented in Table 11.3 (p. 230). Model 1 includes the undergrounding-specific constant, the natural logarithm of the household contribution and the change in the various power supply reliability attributes between the current service and undergrounding alternatives. The log transformation of the cost variable is utilised because it results in a better model fit. The choice probability curve, derived from Model 1, for an undergrounding option with supply reliability variables set at their population means is presented in Figure 11.1. The figure shows that there is significant heterogeneity in WTP for undergrounding across the population. Approximately one-quarter of households are not willing to pay A$1,000 towards undergrounding in their suburb, while another quarter are willing to pay A$16,000 or more. As a result of the log transformation on the cost variable, the estimated choice probability approaches one as cost approaches zero. The model therefore rules out the possibility of negative WTP for undergrounding. This restriction was judged to be reasonable since 97 per cent of respondents agreed that undergrounding is a good idea in principle putting cost aside.

The truncated mean WTP is A$6,838 with a 95 per cent confidence interval of A$5,444 to A$8,253.[64] This is a conservative estimate of mean WTP since approximately one-quarter of households have been assigned a WTP of A$16,000

[64] Confidence intervals are generated using a bootstrapping procedure with 1,000 random draws from normal distributions for relevant parameters, with moments set at their coefficient point estimates and standard errors (Krinsky and Robb, 1986). This procedure did not use the full covariance matrix through the Cholesky decomposition.

in the calculation when in fact their value may be higher. The true mean WTP is higher than A$6,838, but to an unknown extent.[65] The median WTP, which may be important from a political perspective, is approximately A$4,000.

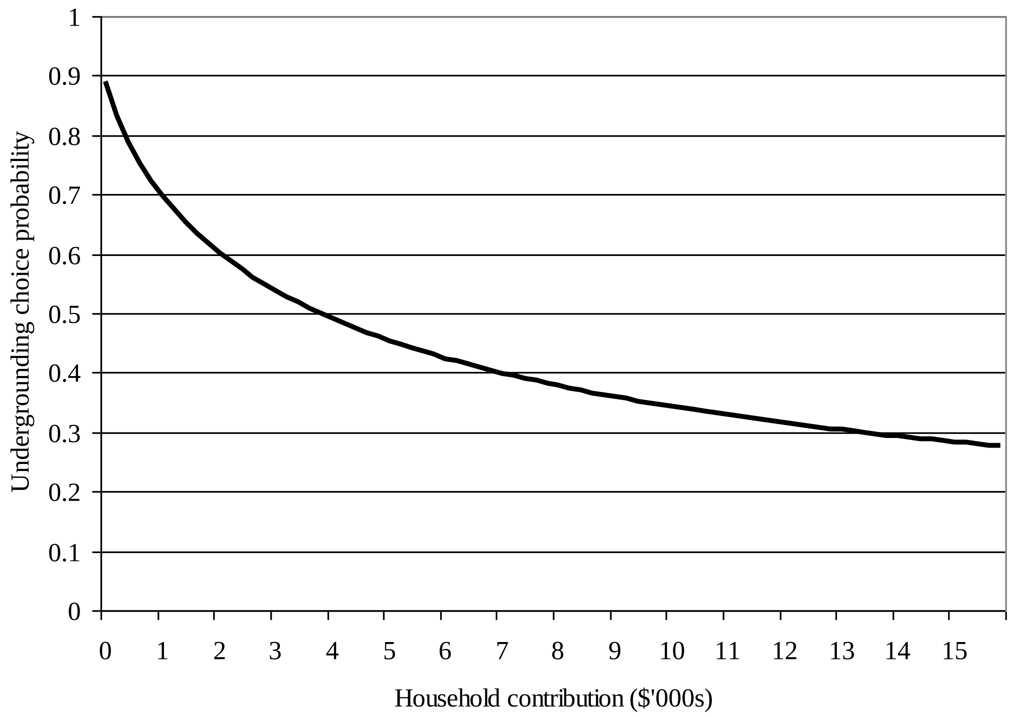

Figure 11.1: Estimated undergrounding choice probability curve

Model 2 incorporates effects-coded variables for household income and the age of the respondent. Other socio-demographic characteristics, namely gender, education and household size were found to be statistically insignificant and

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[65] A higher maximum cost level (or “choke price”) in the choice tasks would be required to resolve this uncertainty. The maximum level used in this survey, $16,000, was determined based on evidence of household WTP from pre-testing interviews. The proportion of respondents stating a WTP this amount in the main survey was higher than anticipated. There is some debate as to how best to select this “choke price” level given evidence suggesting that it affects stated preferences (Cooper and Loomis, 1992; Mørkbak *et al.*, 2010).

omitted from the final model. Of the coefficient estimates on the age variables, the estimate for respondents over 65 years old is highest, indicating a stronger preference for undergrounding among that group (holding constant other variables, including income). Figure 11.2 confirms the point estimate of mean WTP is highest when evaluated for this age group.

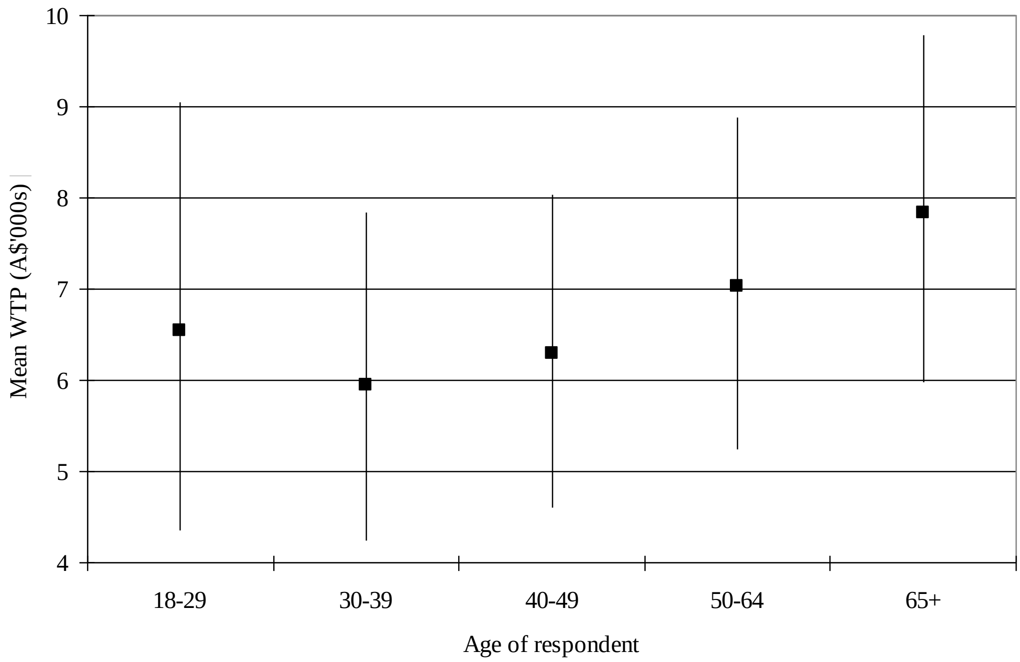

Figure 11.2: Willingness to pay by age (with 95 per cent confidence intervals)

Turning to the household income variables, the coefficient estimates are negative for lower income levels and positive for higher income levels, suggesting a positive relationship between income and WTP for undergrounding. Figure 11.3 confirms there is a strong relationship. The point estimate of mean WTP is less than A$3,000 for the lowest income bracket. It rises with each successive income bracket to more than A$9,000 for the highest bracket.[66]

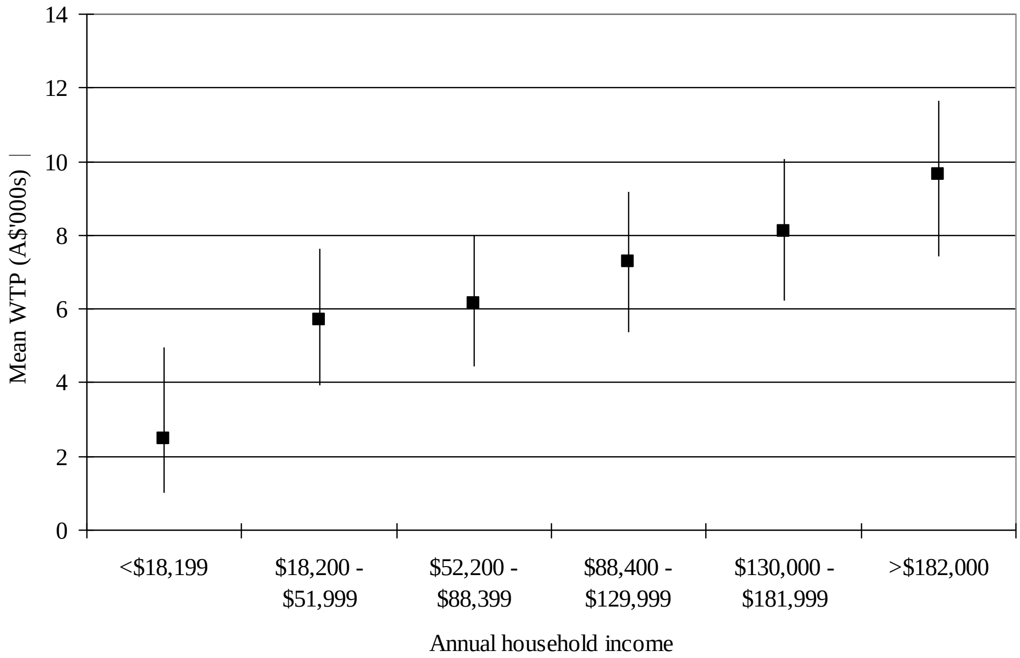

Figure 11.3: Willingness to pay by household income (with 95 per cent confidence intervals)

Response shares for the qualitative question about specific benefits are presented in Figure 11.4 (p. 231). Consistent with prior expectations, more than half of respondents indicated that improved appearance would be one of the two most significant benefits of undergrounding for their household. A similar proportion of respondents indicated that improved safety was a significant benefit, while just 12 per cent of respondents viewed a reduction in the frequency of power cuts as one of the most significant benefits to their household.

[66] At approximately A$5,000, the mean WTP for respondents that chose not to report their income was lower than that for all income brackets except the lowest income bracket (<A$18,199).

Table 11.3: Models of household choice between network scenarios

Variable	Model 1		Model 2		Model 3	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Undergrounding-specific constant	0.7476 ***	0.1335	0.6333***	0.1650	0.3212*	0.1831
Log of household contribution (A$'000s)	-0.6944 ***	0.0706	-0.7407***	0.0728	-0.7363***	0.0740
Change in number of power cuts without warning each 5 years	-0.0691 *	0.0383	-0.0652*	0.0390	-0.0525	0.0397
Change in average duration of power cuts without warning each 5 years	-0.0016	0.0017	-0.0021	0.0017	-0.0017	0.0018
Change in number of power cuts with notice each 5 years	-0.1050 *	0.0538	-0.0921*	0.0542	-0.0973*	0.0520
Change in average duration of power cuts with notice each 5 years	-0.0004	0.0006	-0.0003	0.0006	-0.0005	0.0006
Interactions with undergrounding-specific constant:						
Age: 18-29			-0.0513	0.2648		
Age: 30-39			-0.2302	0.1456		
Age: 50-64			0.0905	0.1072		
Age: 65 and over			0.3145**	0.1452		
Household income: A$18,199 or less			-1.4401***	0.5076		
Household income: A$18,200 - A$51,999			-0.1429	0.1864		
Household income: A$52,000 - A$88,399			0.0036	0.1480		
Household income: A$88,400 - A$129,999			0.3162**	0.1422		
Household income: A$130,000 - A$181,999			0.5444***	0.1564		
Household income: A$182,000 or more			0.9787***	0.1970		
Benefits: Appearance and power cuts					1.0026***	0.3644
Benefits: Appearance and safety					0.9145***	0.1874
Benefits: Appearance and tree trimming					0.8710***	0.1928
Benefits: Appearance and yard space					0.9053***	0.2536
Benefits: Appearance and DNSP access					0.1898	0.3285
Benefits: Appearance and other					-0.0408	0.5292
Benefits: Power cuts and safety					-0.3641	0.2749
Benefits: Power cuts and tree trimming					-0.0938	0.4558
Benefits: Power cuts and yard space					-0.4181	1.2326
Benefits: Power cuts and DNSP access					-1.1155	1.0959
Benefits: Power cuts and other					-0.4081	1.1816
Benefits: Safety and tree trimming					0.7558***	0.2029
Benefits: Safety and yard space					0.8063***	0.2963
Benefits: Safety and other					-0.8147	0.5604
Benefits: Tree trimming and yard pace					0.8859***	0.2886
Benefits: Tree trimming and DNSP access					-0.4708	0.3084
Benefits: Tree trimming and other					-0.3658	0.6606
Benefits: Yard space and DNSP access					0.1058	0.4361
Benefits: Yard space and other					-0.5495	1.2186
Benefits: DNSP access and other					-1.5290**	0.7446
Model fit:						
Observations	1373		1373		1373	
Log-likelihood	-891		-867		-844	
Information criterion AIC	1795		1765		1741	

*, ** and *** indicate statistical significance at the 0.1, 0.05 and 0.01 levels, respectively.

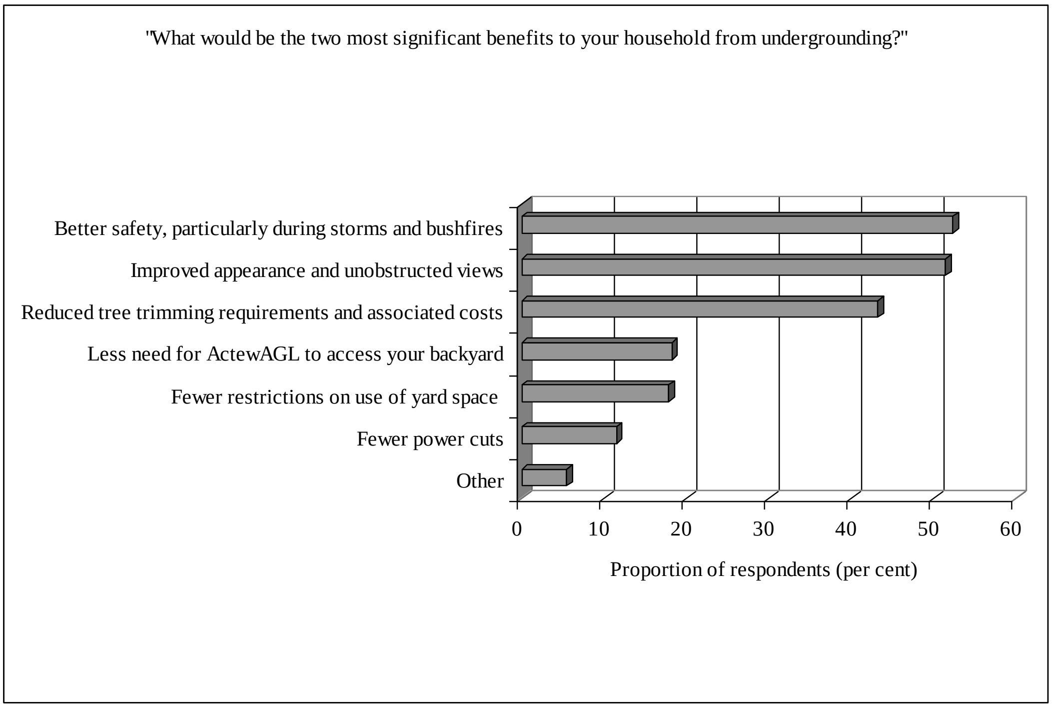

Figure 11.4: Specific benefits of undergrounding

Model 3 includes effects-coded variables for the pairs of specific benefits chosen by the respondent in the qualitative question. The purpose of the model is to reveal whether there is a relationship between WTP and the specific benefits viewed as most significant by the respondent. While the simple response shares discussed above are useful information, they can be misleading. A specific benefit may be viewed as one of the most significant by a large number of respondents that place a low value on undergrounding. Conversely, a specific benefit may be significant to a small group of respondents that place a high value on undergrounding.

Despite the large number of additional variables, the Akaike information criterion (AIC) is improved relative to Model 1, indicating a significant relationship between WTP for undergrounding and responses to the qualitative question about specific benefits. Estimates of mean WTP evaluated at each pairing of specific benefits are presented in Table 11.4. Although only 18 per cent of respondents indicated that fewer restrictions on use of yard space would be one of the most significant benefits, these respondents tended to place a higher-than-average value on undergrounding. Respondents indicating reduced need for network operator access to their yard, or some other (respondent-specified) benefit as one of the most significant benefits, tended to place a lower-than-average value on undergrounding.[67] All pairings of specific benefits from improved appearance, safety, tree trimming or use of yard space were associated with higher levels of WTP for undergrounding.

Table 11.4: Willingness to pay by pairings of specific benefits

	Appearance	Power cuts	Safety	Tree trimming	Yard space	DNSP access
Power cuts	8,469 [38] (5,350 - 11,529)					
Safety	8,172 [274] (5,995 - 10,378)	4,024 [86] (2,322 - 6,248)				
Tree trimming	8,016 [237] (5,818 - 10,243)	4,839 [22] (2,285 - 8,289)	7,602 [190] (5,388 - 9,906)			
Yard space	8,134 [92] (5,598 - 10,737)	4,473 [3] (502 - 12,224)	7,779 [59] (5,132 - 10,565)	8,062 [63] (5,398 - 10,826)		
DNSP access	5,674 [47] (3,293 - 8,547)	2,862 [6] (333 - 9,105)	4,289 [87] (2,506 - 6,570)	3,755 [68] (2,062 - 6,030)	5,435 [25] (2,730 - 8,895)	
Other	5,024 [17] (2,142 - 9,022)	4,456 [3] (555 - 11,979)	3,060 [22] (1,072 - 6,424)	4,187 [13] (1,344 - 8,806)	4,154 [3] (457 - 11,771)	1,897 [17] (418 - 5,253)

Note: 95 per cent confidence intervals in parentheses; number of choice observations in square brackets; all figures are 2009 A$.

The few respondents who viewed a reduction in the frequency of power cuts as one of the most significant benefits from undergrounding exhibited below-average

[67] Some of the respondents selecting "other" used the text field to indicate that they did not see any benefit in undergrounding or that only one specific benefit was important to them. Others used the field to express the view that the benefits are insufficient to justify the cost of undergrounding.

WTP for undergrounding. This result is consistent with the lack of statistical significance for coefficient estimates on the supply reliability attributes included in the choice tasks. Evidence from pre-testing interviews suggests this lack of WTP is due to the relatively high level of reliability of electricity supply from the current overhead service in Canberra.

11.5 Comparison with the hedonic price estimate

The key finding from the hedonic price study in Chapter 7 was that 31 per cent of households in the sample paid an estimated property price premium of 2.9 per cent for houses serviced by underground wires. This premium equates to approximately A$12,350 at the mean property sale price in the sample. The chosen functional form for the hedonic price function implies that the premium paid was lower for less expensive properties and higher for more expensive properties. However, assuming a relatively symmetric distribution of house prices around the mean, a broad conclusion can be drawn that approximately one-third of households in the sample area revealed they were willing to pay A$12,350 for underground networks.

In the stated choice study, the estimated choice probability function implies that 31 per cent of households across all suburbs with overhead wires would be willing to pay that amount or more for undergrounding in their suburb. Given that the proportion of houses serviced by underground wires in Canberra as a whole is similar to the proportion in the hedonic price study suburbs, the point on the demand curve implied by the hedonic price study lies on or very near to the demand curve estimated using the stated choice survey as shown in Figure 11.5.

This consistency across two distinct data sources instils confidence in the estimate of household benefits calculated in this chapter.

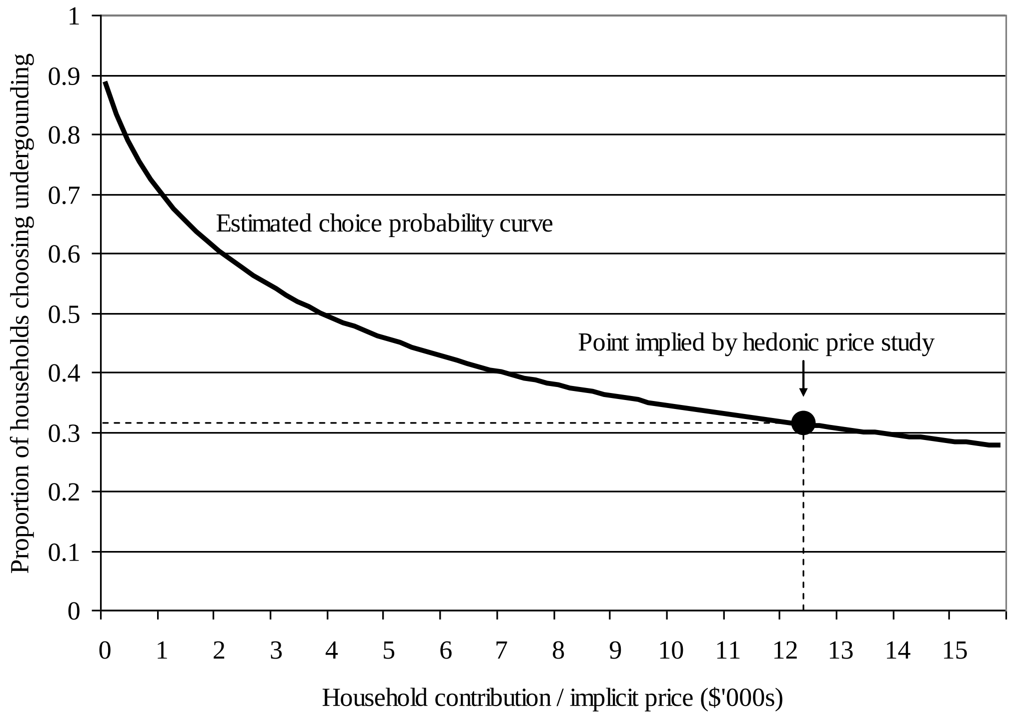

Figure 11.5: Comparing evidence from the hedonic price and stated choice studies

11.6 Summary and conclusions

In this chapter, data from the stated choice survey described in Chapter 6 has been used to estimate the benefits to households from replacing existing overhead electricity and telecommunications networks in Canberra with new underground infrastructure. The evidence from the analysis suggests the value of these benefits would be at least A$6,838 per household on average. This is a conservative estimate of average WTP calculated by effectively assuming a WTP level of A$16,000 for households indicating that they would be willing to pay A$16,000 *or more* for undergrounding in their suburb. There is significant heterogeneity in benefits across households with approximately one-quarter of households falling into this category and another quarter of households not willing to pay A$1,000 for undergrounding in their suburb. An undergrounding program would receive majority support across all areas currently serviced by overhead wires if the household contribution were A$4,000 or less. These findings are consistent with evidence from the hedonic price study in Chapter 7, with the demand point derived from that study lying on the demand curve for undergrounding estimated in this chapter.

The implications of this estimate, in terms of whether *net* economic benefits from undergrounding would be positive are discussed in the concluding chapter. Comments are also made with respect to matters that should be taken into consideration when transferring this estimate to cost-benefit analyses of potential undergrounding projects in other cities.

12 Conclusion

12.1 Introduction

A number of cities around the world have implemented, or are considering, programs to replace overhead low-voltage electricity and telecommunications networks with new underground infrastructure in residential areas. This process of *undergrounding* is an expensive exercise, with major civil works required to install new wires and remove existing infrastructure. In order for undergrounding to be economically viable, this expense must be justified by the mixed bundle of benefits conferred by undergrounding, which includes benefits to network businesses, such as reduced ongoing network maintenance costs, and benefits to households, such as improved aesthetics, better safety during storms and fires, and improved supply reliability. The ongoing cost savings to network businesses are typically small relative to the cost of undergrounding. The estimated value of the benefits to households is therefore a crucial component in the economic evaluation of undergrounding programs. This presents a major problem, since there appears to be no complete estimate of the benefits to households available in the literature. This thesis represents a contribution towards addressing that research gap. Two non-market valuation methods have been used in this research to inform an estimate of the benefits that households would derive from undergrounding in Canberra, Australia – the hedonic property price method and the stated choice method.

In addition to providing a benefit estimate where little or no information was previously available, this thesis has focused on one of the many challenges associated with applying each of these methods. It has improved the understanding of those challenges and developed techniques for overcoming them. The challenge examined with respect to the hedonic price method was the difficulty posed by highly-correlated explanatory variables in the estimated price function. This *multicollinearity* problem is common when applying the method 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. This thesis has shown how a selective sampling approach, similar to the boundary discontinuity approach used to value school quality (Black, 1999; Davidoff and Leigh, 2008; Gibbons and Machin, 2003), can be used to overcome this challenge in certain circumstances.

The challenge examined with respect to the stated choice method is that of understanding the implications of *task dependence* in choice data, where task dependence refers to a 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 the standard assumptions of truthful response with 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; Herriges and Shogren, 1996; Holmes and Boyle, 2005; Ladenburg and Olsen, 2008; McFadden and Leonard, 1995; Swait and Adamowicz, 2001). The appropriate set of alternative assumptions depends on the decision processes (or heuristics) underlying the stated choices. Some of the authors cited above have speculated as to which heuristics may have led to task dependence in their studies. These heuristics include 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.

This thesis makes a contribution to this line of investigation by developing an understanding of the decision processes employed by respondents in a specific study and by developing novel techniques that could be used in other studies to analyse and account for those decision processes. One of those techniques explains within-subject variation in cost sensitivity over a sequence of discrete choice questions by incorporating, in parametric choice models, indicator variables for the positioning of cost relative to the levels observed in previous choice tasks. Another uses an equality-constrained latent class (ECLC) model to estimate the proportion of respondents behaving in accordance with each of the broad types of task-dependence-inducing heuristics raised in the literature.

The following section outlines the research findings of this thesis in relation to the objectives set out in the introductory chapter. In the remainder of this chapter, the implications of those findings for policy and the application of methods are discussed, and recommendations for further research are provided.

12.2 Research findings

The objective of this thesis has been to make a contribution towards addressing the research gaps identified in the discussion above. In particular, the specific objectives outlined in the introductory chapter were 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.

This section demonstrates that these objectives have been achieved and provides a brief summary of findings in relation to each objective.

12.2.1 Household benefits in the case study area

The benefits to households from replacing existing overhead electricity and telecommunications networks in Canberra with new underground infrastructure were estimated in Chapter 11 using data from the stated choice survey described in Chapter 6. The evidence from the analysis suggests the value of these benefits would be at least A$6,838 per household on average. This is a conservative estimate of average willingness to pay (WTP) calculated by assigning a WTP level of A$16,000 to households indicating that they would be willing to pay A$16,000 *or more* for undergrounding in their suburb. There is significant heterogeneity in benefits across households, with approximately one-quarter of households falling into this category, and another quarter of households not willing to pay A$1,000 for undergrounding in their suburb. An undergrounding program would receive majority support across all areas currently serviced by overhead wires if the household contribution were A$4,000 or less.

These results were found to be consistent with evidence from the hedonic price study in Chapter 7. Undergrounding was found to increase house price by 2.9 per cent with other property characteristics held constant. This equates to approximately A$12,350 based on the mean sale price in the data. Approximately 31 per cent of households in the study areas chose to pay the price premium for a property serviced by underground wires (and the proportion of households serviced by underground wires in Canberra as a whole is also around 30 per cent). The choice probability function estimated using the stated choice data implied that 31 per cent of respondents would be willing to pay A$12,350 or more for undergrounding in their suburb. This consistency of evidence instils additional confidence in the accuracy of the benefit estimate derived from the stated choice study.

12.2.2 Multicollinearity and the hedonic price method

A sample selection approach was developed in Chapters 5 and 6 as a potential means of overcoming the problems caused by multicollinearity that tend to arise in a city-wide sample where retro-fit undergrounding has yet to take place. The approach utilises real estate sales data from areas with a mix of overhead and underground infrastructure where neighbourhoods and housing stock are relatively homogeneous. In Chapter 7, the data were analysed to assess whether the approach was successful in a specific study. The two main problems caused by multicollinearity are large standard errors on the coefficient estimates for the affected variables, and a lack of robustness in those estimates to changes in model specification. The results in Chapter 7 confirm that these problems were successfully overcome by the sample selection approach in the case study. The coefficient on the indicator variable for underground wires was significantly different from zero at the 95 per cent confidence level in the estimated price function. The value and significance of this estimate were both robust against four alternative model specifications.

12.2.3 Task dependence and the stated choice method

An understanding of the respondent decision processes that lead to task dependence in stated choice data was developed using three studies. In the first (Chapter 8), split-sample comparisons were made between preferences stated in a sequence of choice tasks and those stated in an incentive compatible attribute-based single binary (*SB*) choice task. It was concluded, at the 90 per cent confidence level, that estimates of mean WTP from an elicitation format presenting multiple choice tasks to each respondent were lower than those from an incentive compatible single choice task format.[68] That study also made a comparison between preferences stated in an incentive compatible *SB* choice format and those stated in the first choice task of a sequence. No evidence was found to support the hypothesis that stated preferences in the first choice task presented were affected by advance knowledge that four as opposed to one choice task would be presented. In fact, there was equivalence in the evidence on WTP estimates from the first choice task in a sequence and an *SB* choice task. The evidence suggests that task dependence is present in the data, with cost sensitivity clearly increasing (and implied WTP decreasing) in questions subsequent to the first in the sequence.[69]

In a second study (Chapter 9), the understanding of the decision processes underlying this task dependence was developed by examining the relationship between cost sensitivity and the positioning of the cost level relative to levels presented in previous choice tasks in the multiple choice task format. A significant

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[68] The question as to which estimate is closer to true WTP depends on the respondent decision process (or processes) underlying the result. These decision processes were investigated by the second and third studies of the stated choice data as discussed below.

[69] There may have been another (separate) relationship – one between scale and choice task ordering. It is possible that WTP could decrease over the course of a sequence (due to strategic misrepresentation or some other heuristic), with scale increasing over the course of the sequence as choices become more deterministic (as respondents become more familiar with the choice task format) as per the findings of other studies (Caussade *et al.*, 2005). This was not investigated in this study, but could be examined in future research by making scale a function of a choice task's position in the sequence.

relationship was found, with cost sensitivity tending to be higher when cost levels observed in previous questions were relatively low. The result confirms the finding of Day and Pinto (2010) that the order in which choice tasks are presented can have a significant effect on WTP estimates. An order with increasing cost levels will underestimate WTP relative to an incentive compatible *SB* choice format, while an order with declining cost levels might overestimate WTP.

Three of the decision processes (or heuristics) raised in the literature are supported by this evidence. The first is the *weak cost minimisation* heuristic in which respondents might reject an alternative that is preferred to the status quo if a similar good was offered at a lower cost in a previous choice task. The second is the *reference point revision* heuristic in which value functions shift when a non-status-quo option is chosen. The third is a *cost-driven value learning* heuristic in which respondents revise their valuation of the good towards a weighted average of the cost levels presented in the sequence to that point, albeit the latter heuristic can only explain the decrease in WTP beyond the first question in a sequence if lower costs levels have greater influence on the value revision process than higher cost levels.[70]

A third study (Chapter 10) showed how an ECLC model can be used to identify discrete heterogeneity in response behaviour towards a sequence of choice tasks

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[70] Further research could investigate the nature of the preference revision process in more detail. For example, it may be that information observed in more recent questions has a greater influence on preferences than that observed in questions earlier in the sequence, particularly in longer sequences (Day *et al.*, 2009). Alternatively, information observed in the first choice task may continue to play an important role throughout a sequence of questions (Ariely *et al.*, 2003).

by estimating the proportion of respondents behaving in accordance with each of the broad types of heuristic. The results showed the model can be applied to choice data from both binary and multinomial choice formats where a status quo alternative is present and similar goods are offered at very different prices over the course of a sequence of questions. The ECLC models achieved an improvement in fit over standard multinomial logit models, even based on information criteria that account for model parsimony. Estimates of WTP were statistically indistinguishable between the two types of model. However, this may not be the case in other data sources as the effect on WTP of accounting for heterogeneity in decision process depends on several factors including the difference between mean WTP and the mean cost level used in the survey, and the relative mix of class probabilities.

Three distinct groups were identified in both the binary and multinomial choice data, corresponding to the broad types of heuristic – strategic misrepresentation, value learning, and truthful response with stable preferences (the *standard assumptions*). The relative sizes of these classes were not significantly different across the binary and multinomial choice formats. The group behaving in accordance with the standard assumptions was the smallest of the three groups in both models, providing further evidence that the standard assumptions do not adequately reflect the response behaviour of the majority of respondents in a survey of this type.

12.3 Implications for policy and application of methods

12.3.1 The economic viability of undergrounding

The key question from an economic evaluation perspective is whether the (conservative) benefit estimate of A$6,838 per household exceeds the difference between the capital cost of undergrounding and the present value of ongoing cost savings to network businesses. This seems most likely where capital costs are similar to those experienced in Perth of approximately A$10,000 per property (Office of Energy, 2008). If capital costs exceed A$20,000 per property as they have in South Australia (ETSA Utilities, 2009), then the economic viability of widespread undergrounding would depend on the avoided costs of complementary projects (such as the National Broadband Network in Australia) and wider community benefits.[71] Where widespread undergrounding is not justified, there may be merit in programs targeting particular areas where the costs and benefits are favourable. Evidence from this research suggests benefits would be highest in areas with higher household income and older residents where improved appearance, safety, tree trimming or restrictions on the use of yard space are of concern.

Care should be taken when transferring this benefit estimate to other cities. In Canberra, most overhead electricity and telecommunications networks are reticulated along the rear boundary of properties rather than the much more

[71] This research estimates the benefit to households from undergrounding in their own suburb. There may be further benefits to households from undergrounding in neighbouring suburbs and other parts of the city.

common street verge reticulation. Electricity supply is relatively reliable and households are responsible for keeping trees clear of power lines. The value of amenity and supply reliability benefits may be higher in other cities, while the value of relaxing tree trimming requirements and restrictions on the use of yard space may be lower. Despite these limitations, the estimate derived here provides valuable information to policy makers considering the economic merits of undergrounding programs where little or no information was previously available.

12.3.2 Application of the hedonic property price method

Turning to implications for the application of methods, the first stage of the hedonic price method is of some use to policy makers since it indicates a point on the demand curve for underground networks (corresponding to the value placed on underground networks by the *marginal* purchaser in the market). However, the value of interest – the *average* value placed on underground networks – is equal to the area under this demand curve. In cases where the second stage of hedonic analysis (discussed in Chapter 3) is not possible, the stated choice method should be preferred by policy makers when assessing the benefits of a potential undergrounding program since it allows direct estimation of this value. However, the indication of demand provided by the first stage of the hedonic price method would be valuable to policy makers where no other information is available and where practical constraints necessitate a study that can be conducted quickly and inexpensively. The sample selection approach developed in this thesis provides a means by which such a study can take place in cities where retro-fit undergrounding has yet to take place. In other cities, a difference-in-difference approach, comparing price increases in undergrounding project areas to price increases elsewhere, may be preferred.

12.3.3 Application of stated choice methods

Evidence from the split-sample comparison of stated choice elicitation formats (Chapter 8) suggests that responses to the first question in a sequence of binary choice tasks can be considered equivalent to those from an incentive compatible *SB* choice. This is an important result because it suggests that the potentially considerable expense associated with collecting single choice observations from each respondent can be avoided (by collecting multiple observations from a smaller sample of respondents). It goes some way to justifying the use of the first choice task in a sequence as an unbiased comparator in studies such as Bateman *et al.* (2008b) and Day and Pinto (2010).

However, the finding of a decrease in implied WTP in questions subsequent to the first in a sequence suggests that care should be taken when analysing data from choice formats with multiple questions per respondent. Indeed, the finding of a relationship between WTP and the cost levels observed in previous choice tasks (in Chapter 9) adds to a growing body of evidence that casts serious doubt on the standard assumption that all responses are truthful and preferences are stable over the course of a sequence of questions. The appropriate approach to deriving a WTP estimate for policy use from repeated choice data depends on the decision processes (or heuristics) underlying this relationship. Unfortunately, the two types of heuristic consistent with the response patterns identified in this thesis may have quite different implications.

Strategic misrepresentation heuristics, such as weak cost minimisation and reference point revision, imply that more reliance should be placed on responses to an incentive compatible *SB* choice format or to the first question presented to each respondent in repeated question formats. A simple sample selection technique to account for this behaviour would be to limit analysis to choice data generated by these questions.

The presence of value learning presents a more fundamental problem since a decision process in which values are influenced by prices is incompatible with standard microeconomic theory.[72] Some authors have argued that the analyst should be interested in the prior distribution of WTP, uncertain as it may be, rather than the posterior distribution influenced by the experimental design (Herriges and Shogren, 1996). Others have suggested that greater weight be placed on responses towards the end of a sequence of questions, after respondents have experienced the (typically unfamiliar) good in the simulated market setting (Bateman *et al.*, 2008a). The latter approach may be more appropriate when cost levels in the experimental design are roughly equal to the actual production cost of the associated scenario (since the choice tasks are then roughly reflective of a real competitive market), while the former approach may be preferred when cost levels are set well above or below the production cost as a means of capturing the anticipated distribution of preferences across the population (since this may constitute an influence on values that would not occur in a real market). This debate highlights the fact that the implications of the cost-driven value learning heuristic extend beyond the *analysis* of choice data to the *design* of the choice

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[72] Ariely *et al.* (2003) point out that this problem is not confined to the stated preference context, but extends to real markets.

experiments themselves, and, in particular, to the selection of cost levels in the design.[73]

The approach to accounting for the heuristics that lead to task dependence is further complicated by the finding of heterogeneity in response behaviour described in Chapter 10. The presence of multiple heuristics within a choice data source renders simple sample selection techniques ineffective. According to the interpretation of at least some authors, omitting data from the first question presented to each respondent may be appropriate for a sub-group of the population exhibiting a value learning heuristic. However, it is entirely inappropriate to apply this approach to those behaving in accordance with a strategic misrepresentation heuristic. The presence of heterogeneity in response behaviour calls for the application of an econometric approach to accounting for the heuristics in the full set of choice data. The method presented in Chapter 10 is one approach that could be used to do so in future studies. As well as estimating the proportion of respondents behaving in accordance with different heuristics, it takes that behaviour into account when estimating the underlying taste intensities that are used to derive benefit estimates.[74]

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[73] Future research could investigate the role of experience in value learning; in particular, whether preferences for unfamiliar goods are more heavily influenced by the experimental design than preferences for familiar goods.

[74] Application of these econometric approaches is not restricted to the case of heterogeneity. Any utility function specified to capture an heuristic in these models can also be used in place of the standard utility function typically used in models assuming homogeneity. This type of model represents an alternative to simple sample selection approaches.

Turning to experimental design, the typical approach of designing a mixture of cost level profiles over the sequences of choice tasks presented to respondents seems appropriate given uncertainty over whether strategic misrepresentation or value learning is the more dominant heuristic. If strategic misrepresentation were expected to dominate, then an order with declining cost levels may be preferred.

12.4 Limitations and areas for further research

This thesis provides an estimate of the benefits to households from undergrounding in a specific case study area. While this information is likely to be valuable to policy makers considering the merits of undergrounding in other cities, there would be significant value in conducting further case studies to develop an understanding of any differences in preferences between cities and of the conditions that may drive those differences.

Turning to research on methods, this thesis has focused on the heuristics that can lead to task dependence in a maintained full compensatory framework. Many other aspects of respondents' decision processes have been studied in the literature, including changes in the extent to which responses are deterministic in terms of institutional learning (Braga and Starmer, 2005) and fatigue (Caussade *et al.*, 2005), and the use of simplifying heuristics (Hensher and Greene, 2010; Hensher and Layton, 2010; Hensher and Rose, 2010; Layton and Hensher, 2010; Swait and Adamowicz, 2001). Incorporating these aspects of respondents' decision processes with the aspects studied in this thesis in a single model would provide a rich understanding of the preferences underlying stated choices. This remains a challenge for future research.

One of the key findings in Chapter 8 was that respondents' sensitivity to cost increased after the first question in a sequence of binary choice tasks. However, cost sensitivity did not increase monotonically over the course of the sequence. The point estimate of WTP evaluated at the fourth question is higher (and cost sensitivity is lower) than the estimates evaluated at the second and third questions, giving a skewed "u-shape" to the diagram plotting estimated WTP against question position order. The difference was not statistically significant in this case. However, Scheufele and Bennett (2010b) found an identical situation in their concurrent study. Future research could investigate whether these findings are a coincidence. That is, it could investigate whether a significant difference can be found using a larger number of choice observations and whether such a result could be linked to the fact that the final question in a sequence holds a "take it or leave it" property.

Although the good valued in this thesis is familiar to respondents in the sense that they see and use the overhead network almost daily (and have probably visited residential areas serviced by underground networks), the situation in which a choice of network services is offered is unfamiliar. This lack of real, and possibly stated, choice experience is typical in the context of non-market valuation surveys. It seems possible that accumulated choice experience may play a role in any value learning that takes place when a respondent is presented with a sequence of choice tasks. In particular, future research could investigate whether preferences for unfamiliar goods are more heavily influenced by an experimental design than are preferences for familiar goods.

In the stated choice survey analysed in this thesis, similar goods were offered at quite different cost levels over the course of a sequence of choice tasks, making opportunities for strategic response relatively obvious and, potentially, exacerbating cost-driven value learning behaviour. Scheufele and Bennett (2010b), in their concurrent and similar study focusing on the case of a pure public environmental good, and Day and Pinto (2010) found similar evidence with respect to task dependence using surveys in which the cost attribute was less dominant. However, in all of these studies, the cognitive burden of choice tasks was low, particularly relative to many studies undertaken in the transportation and marketing disciplines. Day and Pinto (2010) and Scheufele and Bennett (2010b) employ binary choices between alternatives described by one cost and either one or two non-cost attributes. An important objective for future research will be to establish whether the decision processes identified in these studies become less prevalent as the cognitive burden of the trade-offs in the choice task (potentially measured by the number of attributes attended to and the number of alternatives per choice task) is increased.

The economic benefits of undergrounding distribution networks is a topic that is likely to remain of interest to policy makers around the world as households serviced by ageing overhead networks contrast their service with that in the growing suburban areas in which networks were installed underground. This thesis provides an estimate of the value of the benefits to households in a specific case study area and makes a contribution towards understanding and overcoming certain challenges associated with estimating those benefits. The agenda for future research discussed above would further increase confidence in the cost-benefit analyses used by policy makers when considering the merits of undergrounding programs.

Appendix A: Derivation of general equilibrium welfare effects

Using a general equilibrium framework to identify conditions for optimal provision gives a rich understanding of the full social impact of provision including related market and distributional effects. The limitations of the general equilibrium framework in the natural monopoly setting are the assumptions of exogenous productivity and a benevolent social planner with full information. However, the framework is discussed here to show how the welfare effects of network service provision are derived from consumers' constrained utility maximisation problem.

Consider an economy comprising *I* consumers who derive utility, *U*, from electricity, *X*, network quality, *Q*, and a composite of all other goods, *Y* (which is numeraire).[75] Network quality is assumed to be a public good that cannot be differentiated between consumers. Each consumer is endowed with an equal share of a composite resource, which is allocated as an input, N_j, in production of good *j* (where *j = X, Q or Y*).[76] The price of this composite resource is *c*. Each consumer receives an equal share of profits from private production. These simplifying assumptions of equal endowment and shareholding across consumers allow the model to focus on the efficiency of provision rather than on distributional effects, which can be isolated through pricing/taxation decisions. Consumers choose the allocation of their resources except with regard to production of network service

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[75] $U'>0$, $U''<0$ and there is heterogeneity in preferences across consumers.

[76] $dj/dN_j>0$, $d^2j/dN_j^2<0$ and productivity is held constant.

quality, which is an exogenous policy variable.[77] Production of network quality is funded via a fixed charge (A) and/or a consumption charge (a specific tax, t, on electricity). All markets other than that for Q are competitive, including the market for electricity.[78] The consumption charge, t, is representative of the distribution-use-of-system (DUoS) component of the final retail electricity consumption price, $q = p + t$, where p is the producer price of electricity.

Each consumer, i, faces an identical resource constraint (where total resources in the economy is equal to 1) and a budget constraint:[79]

$$1/\mathrm{I} = N^i_X + N^i_Q + N^i_Y.$$

$$Y^i + A + qX^i = c\,(N^i_X + N^i_Q + N^i_Y) + 1/\mathrm{I}\ [\pi_Q + Y - cN_Y + pX - cN_X]$$

Profit from production of network service quality is defined as:[80]

$$\pi_Q = AI + tX - cN_Q$$

Consumers maximise their utility subject to these two constraints. This maximisation problem is represented by the following Lagrange function:

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[77] Q is non-rivalrous, so $\mathrm{d}Q_i/\mathrm{d}X = 0$, and the level of X has no bearing on the cost of providing Q (Q has zero marginal cost in X).

[78] This is consistent with the institutional arrangements for electricity markets in the US, the UK and Australia, where generation and retail markets are privatised and competitive, but the networks used to distribute the electricity are regulated natural monopolies.

[79] Consumers may have non-identical preferences.

[80] Importantly, it is assumed that π_Q does not enter into the first-order condition (FOC) for consumers' choice of X. That is, consumers select their consumption of X based on the final retail price, without regard to the fact that as a shareholder in the firm, they would receive a share of any profit.

$W^i = U^i(X^i, Q^i, Y^i) + \lambda^i[c/I + 1/I \{\pi_Q + Y - cN_Y + pX - cN_X] - Y^i - A - qX^i\}$

where λ^i is the marginal utility of income for consumer *i*.

Total differentiation and substitution of the FOCs for consumer choice variables, N_X and N_Y, the FOCs for private production of *X* and *Y*, and the definition of π_Q, leads to the following expression for the welfare of consumer *i* in units of the numeraire, *Y*:

$$\frac{dW^i}{\lambda^i} = \frac{U_Q^i}{\lambda^i} dQ + \left(\frac{1}{I} X - X^i\right) dq + \frac{1}{I}\left(tdX - cdN_Q\right)$$

This expression for the individual consumer describes the various welfare effects of investment in network quality. The major benefit of improved network service quality is the increase in consumer utility. The major cost of improved network service quality is the required increase in expenditure of resources. Additional welfare effects arise due to related market effects (changes in activity in other, distorted markets) and the distributional effects of changes in market prices.

To a large extent, related market and distributional effects can be isolated from analysis of provision decisions because they can be influenced by pricing policy decisions. Recovery of network costs via a consumption charge will increase the price of electricity above marginal cost and impose a social cost due to the consequent reduction in electricity use. However, recovering some costs via a consumption charge may result in a preferable distributional outcome if lower-income consumers tend to use less electricity and are given greater weight in the social welfare function than their higher-income counterparts. In order to focus on provision rather than pricing decisions, simplifying assumptions can be made so as to ignore these related market and distributional effects. First, the social welfare function can be assumed to be an *unweighted* sum of individual welfare. This ignores the welfare effects of changes in market prices by assuming that they simply transfer welfare from one consumer to another (sometimes referred to as the “dollar is a dollar” assumption). Second, *all* network service provision costs can be assumed to be recovered via fixed charges (lump-sum transfers).[81] This ignores effects in the related electricity market by assuming that it is a non-distorted market. Under these simplifying assumptions, changes in social welfare are represented by the following expression:

$$\sum_i \frac{dW^i}{\lambda^i} = \sum_i \frac{U_Q^i}{\lambda^i} dQ - cdN_Q$$

The condition for welfare maximising provision of network services is:[82]

$$\frac{dW}{dN_Q}\frac{1}{\lambda} = \frac{U_Q}{\lambda}\frac{dQ}{dN_Q} - c = 0$$

[81] It is assumed that these fixed charges would not exclude any consumers from the market.

[82] It is assumed that a benevolent social planner chooses N_Q and that Q is a known function of N_Q. The Hatta (1982) Decomposition implies that the actual welfare change can be used to evaluate the social optimum, without the need to calculate compensated welfare changes. It is used to show how, for individual consumers, dollars are a reliable proxy for utility, whenever policy changes are incrementally small. This decomposition finds that income effects are a scaling coefficient on the efficiency effects from marginal policy changes that play no role in single consumer economies.

Appendix B: Correlation matrix for property sales data

	TIME	*SIZE*	*BED3*	*BED4*	*BED5UP*	*GARAGE*	*ENSUITE*	*UG*	*TRAFFIC*	*DIST_LN*	*VIEW2*	*VIEW3*	*COND2*	*COND3*	*CALWELL*	*MACARTH*	*TIMESQ*	*SIZESQ*
TIME	1.00																	
SIZE	0.02	1.00																
BED3	-0.02	-0.29	1.00															
BED4	-0.04	0.33	-0.82	1.00														
BED5UP	0.09	0.18	-0.25	-0.23	1.00													
GARAGE	0.02	0.35	-0.30	0.32	0.11	1.00												
ENSUITE	-0.05	0.39	-0.55	0.57	0.16	0.48	1.00											
UG	0.04	-0.25	0.09	-0.14	0.01	-0.14	-0.11	1.00										
TRAFFIC	-0.03	0.10	0.03	0.02	-0.06	0.03	0.04	-0.19	1.00									
DIST_LN	0.05	0.16	0.01	0.02	0.10	0.03	0.02	-0.12	0.15	1.00								
VIEW2	0.02	0.17	-0.17	0.16	0.10	0.19	0.20	-0.27	0.17	0.42	1.00							
VIEW3	-0.04	0.23	-0.16	0.09	0.17	0.10	0.17	-0.06	0.03	0.16	-0.20	1.00						
COND2	-0.06	0.23	-0.10	0.16	-0.03	0.21	0.21	-0.19	0.00	-0.06	0.15	-0.05	1.00					
COND3	0.04	0.13	-0.23	0.15	0.22	0.14	0.18	-0.13	-0.01	0.15	0.14	0.26	-0.45	1.00				
CALWELL	0.08	-0.01	0.06	-0.06	0.10	-0.03	-0.06	-0.06	0.04	0.88	0.34	0.10	-0.08	0.09	1.00			
MACARTH	-0.08	0.29	-0.12	0.16	-0.01	0.13	0.17	-0.18	0.22	0.01	0.08	0.08	0.10	0.08	-0.47	1.00		
TIMESQ	0.97	0.02	-0.02	-0.06	0.12	0.03	-0.04	0.03	-0.05	0.06	0.01	-0.03	-0.07	0.05	0.09	-0.08	1.00	
SIZESQ	0.03	0.98	-0.29	0.29	0.19	0.31	0.35	-0.19	0.08	0.14	0.12	0.27	0.19	0.11	-0.02	0.27	0.04	1.00

Appendix C: Example of questionnaire contents

Dear respondent,

Thank you for participating in this survey. As a home owner in an area with overhead wires, you could be affected by decisions about placing electricity and telecommunications wires underground.

This survey is being conducted by ActewAGL and the Australian National University (ANU) in partnership with the Institute of Transport and Logistics Studies (ITLS) at the University of Sydney.

Please answer these questions on behalf of your household. Please do not use your internet browser's 'back' or 'forward' buttons, as your responses may not be saved correctly. It should take about 15 minutes to complete this survey.

ORIMA Research will not reveal your identity to ActewAGL, the ANU or ITLS. The information you provide will only be used in a grouped format.

The survey results will be used to assess options for undergrounding of existing overhead wires in your suburb and other suburbs in Canberra.

If you have any technical problems accessing the questionnaire, please contact Kim Sullivan or Daniel Prior at ORIMA Research on (02) 6175 1000 or by email at kim.sullivan@orima.com or daniel.prior@orima.com.

If you have any enquiries about the content of the questionnaire, please contact me by email at ben.mcnair@anu.edu.au.

If you have any concerns regarding the way in which this survey was conducted, please contact the ANU Human Research Ethics Committee on (02) 6125 7945 or by e-mail at Human.Ethics.Officer@anu.edu.au.

Yours sincerely,

Ben McNair
Crawford School of Economics and Government
The Australian National University
Canberra ACT 0200

Login code:

The reason for this survey

ActewAGL Distribution owns and manages the poles, wires and other network infrastructure used to transport electricity to your home.

Canberra suburbs developed after 1990 have underground wires.

Many residential areas in Canberra still have overhead wires on poles.

ActewAGL Distribution is considering the merits of replacing these overhead wires with new underground wires in the street verge.

This survey forms part of an initial feasibility study. Depending on survey responses from your suburb, ActewAGL may proceed to a full investigation of undergrounding in your suburb including consultation with the community, stakeholders, Government and independent regulators.

Why underground wires?

Placing wires underground is a means of avoiding the ongoing costs of maintaining and replacing poles in backyards, which would otherwise need to be recovered through electricity bills.

Underground wires have several advantages over overhead wires, including:

- Improved neighbourhood appearance and unobstructed views
- Fewer power cuts
- Better community safety, particularly in storms and bushfires
- Reduced tree trimming requirements and associated costs
- Fewer restrictions on use of yard space (eg for construction of a garage or swimming pool)
- Less need for ActewAGL to access your backyard

A disadvantage of underground wires is that when unplanned power cuts occur it can take longer to restore power than with overhead wires as it may be harder for ActewAGL to find and repair the fault.

Example of improved neighbourhood appearance

Overhead

Underground (simulation)

Example of unobstructed views

Overhead

Underground (simulation)

Undergrounding in other cities

Perth, Darwin and several other cities around the world are 'undergrounding'. The photos below are from East Victoria Park in Perth before and after undergrounding.

How is it done?

Undergrounding would include both electricity and telecommunications wires. It would involve:

- Underground horizontal drilling to install new wires under the verge in each street.
- Underground horizontal drilling to install new wires from connection pillars (usually a green minipillar (pictured) near the front corner of every second property) to the meter box at each house.
- Connection of the new underground wires to the existing meter box and telecommunications connection box within each residence.
- Re-instatement and repair of all disturbed work areas.
- Changeover of supply from the overhead to the underground network.
- Removal of existing poles and overhead wires.

The use of underground drilling instead of open trenching will limit the areas disturbed and reduce the impact on local residents during the underground installation works.

Who would pay for undergrounding?

Funding arrangements for any undergrounding program in the ACT would be developed in consultation with the community, stakeholders, Government and independent regulators.

One of the options that would be considered as part of this process is the following approach, which has been used as part of the Underground Power Program in Perth.

All property owners in an area to be 'undergrounded' are required to make a specific contribution towards the cost of undergrounding in their suburb. Two payment methods are offered:

1. Upfront (within 35 days) with a 3% discount; or
2. Instalments (for up to 5 years) at a 6.5% p.a. interest rate (to cover financing and administration costs). If a house is sold, the balance would be paid at the time of sale.

For the purpose of this survey, you should assume that this approach would be used in the ACT.

Your views on undergrounding

We want to know your views on some undergrounding options for the ACT.

First, we would like to know:

- how you think undergrounding would benefit or disadvantage you; and
- some details about your current electricity service.

Benefits of undergrounding

Do you incur costs trimming trees near overhead power lines?
☐ Yes
☐ No

Do you have views from your property that are affected by power lines?
☐ Yes
☐ No

Is the service line (from the pole to your house) obstructing potential development on your property (eg construction of a garage or swimming pool)?
☐ Yes
☐ No

What would be the two most significant benefits to your household from undergrounding? (please tick <u>two</u> boxes)

☐ Improved <u>appearance</u> and unobstructed <u>views</u>
☐ Fewer <u>power cuts</u>
☐ Better <u>safety</u>, particularly during storms and bushfires
☐ Reduced <u>tree trimming</u> requirements and associated costs
☐ Fewer restrictions on use of <u>yard space</u> (eg for construction of a garage or swimming pool)
☐ Less need for ActewAGL to <u>access</u> your backyard
☐ Other (please specify below)

Disadvantages of undergrounding

Other than cost, what would be the most significant disadvantage to your household? (please tick <u>one</u> box)

☐ <u>Power cuts</u> may be longer
☐ <u>Inconvenience</u> during undergrounding works
☐ <u>Service pillar</u> in front of property
☐ Other (please specify below)

Overall view on undergrounding

Putting cost aside, do you think undergrounding is a good idea in principle?
☐ Yes
☐ No

Your current electricity service

In the next part of this questionnaire, the power cuts you would experience with your current overhead service will be compared to the power cuts that could occur with an underground service.

Typical power cuts to be expected over a 5-year period with an overhead service are:

a) 4 power cuts without warning, with an average duration of 1 hour; and
b) 3 power cuts with written notice, with an average duration of 3 hours.

Please choose how you would like your current service to be presented:

☐ I would like my current service to be presented as the typical power cuts described above.
☐ I would like to specify the number and duration of power cuts to be presented as my current service.

[ONLY SHOW THIS PAGE IF TICKED 'I WOULD LIKE TO SPECIFY…' IN PREVIOUS QUESTION]

Your current electricity service

Please describe the power cuts you believe you would experience over a five-year period with your current overhead service. In doing so, think about instances where you are not at home, but you notice that digital clocks are reset. These details will be used for comparison with undergrounding in the next part of this questionnaire.

How many power cuts <u>without warning</u> would there be over a 5 year period?
[4]

How many power cuts <u>with written notice</u> would there be over a 5 year period?
[3]

How long would the power cuts <u>without warning</u> be on average?
[60] minutes

How long would the power cuts <u>with written notice</u> be on average?
[180] minutes

Your input

There are a number of different options for undergrounding wires. Different types of wires, different service connections and different maintenance programs will affect both cost and supply reliability outcomes.

This survey is seeking your input on which option, if any, should be considered for your suburb.

In the following questions you will be presented with 4 sets of options. Each set contains 3 options – your current service and two undergrounding options. Each option is described by the number and duration of power cuts and the cost to your household.

In each set you will be asked to choose your preferred option.

Please answer each question as though the options presented are the only ones available.

The number and duration of power cuts vary from one option to the next. Your input will help ActewAGL develop a maintenance program to suit community preferences.

How your input will be used

Decisions whether to underground would generally be made at the suburb level.

ActewAGL will proceed with further investigation of an undergrounding option in your suburb if it is preferred to the current service by more than 50% of survey respondents in your suburb.

Option set 1 of 4

> *Reminder*
>
> Your two most important benefits of underground wires are:
> <insert chosen benefit 1>
> <insert chosen benefit 2>
>
> Your most important disadvantage of underground wires is:
> <insert chosen disadvantage 1>

Please choose your preferred option using the checkboxes below.

<choice set>

If one of these undergrounding options were to take place in your suburb, which payment method would you choose?

☐ Upfront (within 35 days) with 3% discount
☐ Instalments (for up to 5 years) at 6.5% p.a. interest rate (with balance paid if house is sold)

Please use the checkboxes in the table below to indicate the extent to which you considered each of the service attributes when choosing between the options in the 'option set' above (please tick one box in each row).

	I did not consider this at all	I considered this, but it did not influence my choice	This did influence my choice
Type of infrastructure (underground or overhead)	☐	☐	☐
Power cuts without warning:			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Power cuts with written notice (occurring in normal business hours):			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Your one-off undergrounding contribution	☐	☐	☐

Option set 2 of 4

> *Reminder*
>
> Your two most important benefits of underground wires are:
> <insert chosen benefit 1>
> <insert chosen benefit 2>
>
> Your most important disadvantage of underground wires is:
> <insert chosen disadvantage 1>

Please choose your preferred option using the checkboxes below.

<choice set>

If one of these undergrounding options were to take place in your suburb, which payment method would you choose?

☐ Upfront (within 35 days) with 3% discount

☐ Instalments (for up to 5 years) at 6.5% p.a. interest rate (with balance paid if house is sold)

Please use the checkboxes in the table below to indicate the extent to which you considered each of the service attributes when choosing between the options in the 'option set' above (please tick one box in each row).

	I did not consider this at all	I considered this, but it did not influence my choice	This did influence my choice
Type of infrastructure (underground or overhead)	☐	☐	☐
Power cuts without warning:			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Power cuts with written notice (occurring in normal business hours):			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Your one-off undergrounding contribution	☐	☐	☐

Option set 3 of 4

> *Reminder*
>
> Your two most important benefits of underground wires are:
> <insert chosen benefit 1>
> <insert chosen benefit 2>
>
> Your most important disadvantage of underground wires is:
> <insert chosen disadvantage 1>

Please choose your preferred option using the checkboxes below.

<choice set>

If one of these undergrounding options were to take place in your suburb, which payment method would you choose?

☐ Upfront (within 35 days) with 3% discount
☐ Instalments (for up to 5 years) at 6.5% p.a. interest rate (with balance paid if house is sold)

Please use the checkboxes in the table below to indicate the extent to which you considered each of the service attributes when choosing between the options in the 'option set' above (please tick one box in each row).

	I did not consider this at all	I considered this, but it did not influence my choice	This did influence my choice
Type of infrastructure (underground or overhead)	☐	☐	☐
Power cuts without warning:			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Power cuts with written notice (occurring in normal business hours):			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Your one-off undergrounding contribution	☐	☐	☐

Option set 4 of 4

Reminder

Your two most important benefits of underground wires are:
<insert chosen benefit 1>
<insert chosen benefit 2>

Your most important disadvantage of underground wires is:
<insert chosen disadvantage 1>

Please choose your preferred option using the checkboxes below.

<choice set>

If one of these undergrounding options were to take place in your suburb, which payment method would you choose?

☐ Upfront (within 35 days) with 3% discount
☐ Instalments (for up to 5 years) at 6.5% p.a. interest rate (with balance paid if house is sold)

Please use the checkboxes in the table below to indicate the extent to which you considered each of the service attributes when choosing between the options in the 'option set' above (please tick one box in each row).

	I did not consider this at all	I considered this, but it did not influence my choice	This did influence my choice
Type of infrastructure (underground or overhead)	☐	☐	☐
Power cuts without warning:			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Power cuts with written notice (occurring in normal business hours):			
Number of power cuts each 5 years	☐	☐	☐
Average duration of power cuts	☐	☐	☐
Your one-off undergrounding contribution	☐	☐	☐

Thankyou for making your choices

Before finishing this survey please answer the following questions about the survey and about yourself.

Questions about how you made your choices

In order to compare the options, did you add together the number of power cuts without warning and the number of power cuts with written notice for each option?
☐ Yes
☐ No

In order to compare the options, did you calculate the total number of hours of power cuts for each option?
☐ Yes
☐ No

Were any of your later choices influenced by options you remembered from earlier 'option sets' in the survey?
☐ Yes
☐ No

Were any of your choices influenced by what you think other respondents would choose?
☐ Yes
☐ No

Do you feel you had enough time to make the decisions asked of you?
☐ Yes
☐ No

Do you feel you had enough information to make the decisions asked of you?
☐ Yes
☐ No

Have you seen or heard any media stories on undergrounding in Canberra?
☐ Yes
☐ No

Demographic questions

In which suburb do you live?

[ ]

What is your age?

☐ 18-29
☐ 30-39
☐ 40-49
☐ 50-64
☐ 65 or over

What is your gender?

☐ Male
☐ Female

How many persons live in your household?

☐

What is the highest level of education you have obtained (so far)?

☐ Less than year 10
☐ Year 10
☐ Year 12
☐ Diploma or certificate
☐ Undergraduate degree
☐ Postgraduate degree

Please approximate your annual household income (before tax) in 2007-08. All answers in this survey are strictly confidential.

☐ Under $7,800
☐ $7,800 - $18,199
☐ $18,200 - $33,799
☐ $33,800 - $51,999
☐ $52,000 - $72,799
☐ $72,800 - $88,399
☐ $88,400 - $103,999
☐ $104,000 - $129,999
☐ $130,000 - $155,999
☐ $156,000 - $181,999
☐ $182,000 - $207,999
☐ $208,000 or more
☐ I don't know
☐ I don't want to provide this information

Thank you

Thank you for participating in this survey. Your opinions are very important.

If you would like to make any other comments, please use the space below.

<submit button>

<Thank you for your cooperation and comments>

You have been automatically entered into the prize draw (ACT TP 09/01953).

The prizes are:

1st prize: $1500
2nd prize: $1000
3rd prize: $500

Prize winners will be notified by email on 5 August 2009 and published in the public notice section of the Canberra Times on Saturday 8 August 2009. The email and notice will include ORIMA Research's contact details for winners to claim their prize. Each prize will be in the form of a cheque made out to the named prize winner. The cheque will be posted to the named prize winner via registered post within two days of the prize being claimed.

Full terms and conditions are attached to the email from ORIMA Research inviting you to participate in this survey.

Appendix D: Email invitation to stated choice survey

EMAIL SUBJECT: ActewAGL Undergrounding Survey

Dear <First Name>,

Re: Undergrounding overhead wires in residential areas in the ACT – a survey of community preferences

Recently you were telephoned and invited to participate in an online survey about undergrounding overhead wires in the ACT. Thank you for agreeing to participate in this research process. As a home owner in an area with overhead wires, you could be affected by decisions about undergrounding.

What is this project about?

We are assessing community support for replacing existing overhead wires with new underground wires in residential areas in the ACT.

This research is part of a joint project between ActewAGL, the Australian National University (ANU) and the University of Sydney, supported by funding from ActewAGL and a grant from the Australian Research Council. ORIMA Research is assisting with the survey process.

Why were you invited to participate in the research?

You have been invited because you are a home owner in a residential area with overhead wires. Participation in this survey is purely voluntary and you are free to withdraw at any stage.

How will the research results by used?

The results of this study will be reported to ActewAGL and used to assess options for undergrounding existing overhead wires in your suburb and other suburbs in Canberra. Results may be published in academic journals. However, published results will only report on survey responses in a grouped format. Individuals' responses will be de-identified in any publication. ORIMA Research will not reveal your identity to the ANU, University of Sydney or ActewAGL.

How to complete the questionnaire?

We invite you to click on the link below to access the web-based questionnaire.

<insert URL here>

On the first page of the questionnaire you will need to enter the login code provided below.

<insert password here>

The survey should take about 15 minutes to complete.

Once you have completed and submitted the questionnaire, you will be entered into a prize draw. First prize is $1500, second prize is $1000 and third prize is $500. A maximum of 2500 respondents will be entered into the draw. Full terms and conditions for this draw are included below.

Who to contact for information or clarification?

If you have any technical problems accessing the questionnaire, please contact Kim Sullivan or Daniel Prior at ORIMA Research on (02) 6175 1000 or by email at kim.sullivan@orima.com or daniel.prior@orima.com.

If you have any enquiries about the content of the questionnaire, please contact Ben McNair at the ANU by email at ben.mcnair@anu.edu.au.

If you have any concerns regarding the way in which this survey was conducted, please contact the ANU Human Research Ethics Committee on (02) 6125 7945 or by email at Human.Ethics.Officer@anu.edu.au.

Yours sincerely,

Kim Sullivan

Kim Sullivan
Senior Research Consultant
ORIMA Research Pty Ltd
CANBERRA |MELBOURNE
Ground Floor, 2 Brindabella Circuit
Brindabella Business Park
CANBERRA AIRPORT ACT 2609

T: 02 6175 1000
www.orima.com

Competition terms and conditions TP 09/01953: Win up to $1500 by completing an online questionnaire

1. To be eligible to enter and win up to $1500 participants must complete and submit an online questionnaire, comprising up to 40 questions. A link to the questionnaire will be sent by email by ORIMA Research Pty Ltd to persons who have agreed to participate in a research survey conducted on behalf of the promoter.

2. Participants will be automatically entered into the prize draw once they have completed and submitted the online questionnaire. The online questionnaire must be fully completed and submitted between 9:00am 15 June 2009 and 5:00pm 10 July 2009. Incomplete questionnaires cannot be submitted and will not be entered into the draw.

3. The prizes are
    - 1st prize: $1500
    - 2nd prize: $1000

- 3rd prize: $500
- Total prizes: $3,000 including GST.

4. Each prize will be in the form of a cheque made out to the named prize winner. The cheque will be posted to the named prize winner via registered post within two days of the prize being claimed.
5. The prize draw will involve the generation of a random number by computer for each entry received. 1st prize will be awarded to the entry with the lowest number, 2nd prize will be awarded to the entry with the second lowest number and the 3rd prize will be awarded to the third lowest number.
6. The winners will be drawn on 3 August 2009 at 10am at the ORIMA Research offices, Ground Floor, 2 Brindabella Cct, Canberra Airport ACT 2609.
7. Prize winners will be notified by email two days after the draw and published in the public notice section of the Canberra Times on Saturday 8 August 2009. The email and notice will include ORIMA Research's contact details for winners to claim their prize.
8. In the case of an ineligible participant being drawn as the winner, a re-draw will take place immediately.
9. Except as expressly provided by these terms and conditions, the prize is not transferable, not exchangeable and cannot be redeemed as cash.
10. In the event that a prize is unclaimed, a redraw will take place at 10am on 9 November at ORIMA Research offices, Ground Floor, 2 Brindabella Cct, Canberra Airport ACT 2609
11. The promoter is ActewAGL Distribution ABN 76 670 568 688, a partnership of ACTEW Distribution ABN 83 073 025 224 and Jemena Networks (ACT) Pty Ltd ABN 24 008 552 663 and is being administered by ORIMA Research Pty Ltd ABN 77 076 347 914.

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