THREE ESSAYS IN HEALTH ECONOMICS:

1: AN EQUILIBRIUM MODEL OF WAITING LISTS FOR MEDICAL CARE.

2: AN EVALUATION OF ALTERNATIVE ECONOMETRIC SPECIFICATIONS FOR ESTIMATING A TOBACCO BUDGET SHARE EQUATION.

3: THE DETERMINANTS OF EXPENDITURES ON TOBACCO IN CANADA.

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2: An Evaluation of Alternative Econometric Specifications for Estimating a Tobacco Budget Share Equation

3: The Determinants of Expenditures on Tobacco in Canada

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Abstract

This thesis consists of three essays on health economics. Chapter 1 is an introduction. Chapter 2 studies waiting lists for medical care, and Chapters 3 and 4 study the demand for tobacco products.

The main contribution of Chapter 2 is a game-theoretic model of waiting times for medical care that provides new insights into how health care waiting times and the number of cases treated may be related. The model demonstrates that charging patients for medical care may not result in decreased waiting times. One policy implication of the model is the potential gains from the sharing of information and co-ordination among health-care providers.

Chapters 3 and 4 are on the demand for tobacco products. Estimating the demand for tobacco involves choosing one or more econometric specifications or functional forms. Different econometric specifications can result in conflicting results, raising questions about how to interpret results. A primary objective of Chapter 3 is to identify the similarities and differences between three econometric specifications that have often been applied to tobacco data. A behavioural model is a useful starting point for making these comparisons. In this chapter I compare the results arrived at by applying different specifications to one data set. This data set reports individual's expenditure on tobacco.

Chapter 4 examines a data set that reports household expenditure on tobacco. A number of economics papers examine tobacco data from the United States, the United Kingdom and Spain. Chapter 4 examines tobacco data from Canada. One finding indicates that households that do not own their home and consist of one or more unemployed individuals tend to purchase a relatively high amount of tobacco. This information may be of interest to people involved in tobacco policy.

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Chapter 1

Introduction

This thesis consists of three essays; each is related to health economics. In Chapter 2 I use a game-theoretic model to study waiting lists for medical care. In Chapter 3 I compare three different econometric approaches that have been applied in estimating the demand for tobacco. Chapter 4 identifies who in Canada is likely to purchase tobacco and the factors that affect the amount purchased.

Chapter 2 begins with a review of the health services research literature on waiting lists for medical care. This literature review demonstrates that some institutions have decreased waiting times by increasing the flow of patients being treated. Other institutions have increased the flow of patients being treated and have observed little or no change in waiting times. The Chapter develops a model of waiting times for medical care that provides new insights into how health care waiting times and the number of cases treated may be related.

In the economics literature there are a number of papers on the relationship between time spent standing in a line and the distribution of goods and services. There are also two papers that present models of the relationship between the amount of time patients have been waiting for care with their name on a list and the number of medical care services provided by one institution.

I develop a game-theoretic model in which there are two institutions providing medical care, each with its own waiting list. This model provides insight into why a substantial increase in the number of cases treated at one institution may have little or no effect on waiting times for medical care. For example, one hospital may have its budget increased in order to shorten a waiting list. As the hospital treats more patients the waiting times at this hospital and other hospitals in the region will decrease. As the waiting times fall other hospitals may decrease how many patients they are treating and overall there may be little or no change in waiting times. The model also demonstrates that charging patients for medical care may not result in decreased waiting times. One policy implication of the model is the potential gains from the sharing of information and co-ordination among health-care providers.

Chapters 3 and 4 study the demand for tobacco products. Tobacco consumption offers an important opportunity to investigate the relationships among the biology of addiction, consumer preferences, health and well being. Tobacco is notable because it is one of the few physically addictive goods for which large amounts of purchasing and consumption data are available.

The econometric literature has applied three major specifications to cross sectional and pseudo-panel tobacco data sets. The three specifications are the two-part specification, the sample-selection specification and the double-hurdle specification. A primary objective is to identify the similarities and differences between these three econometric specifications.

The three specifications are compared in five different ways. First, I develop a behavioural model that serves as a reference point for comparing the three specifications. I then survey the literature that compares the two-part specification to the sample-selection specification. I also review the economic literature on tobacco that compares the two-part, sample-selection and double-hurdle specifications. Next I describe a nesting structure that Yen and Jones (1996) have developed for comparing statistically specifications that have been applied to tobacco data. A data set that reports how much individuals spent on tobacco during one year is used to apply the tests that Yen and Jones (1996) had applied and discuss the parameter estimates and policy implications derived from each specification. The final section summarises these five comparisons.

The behavioural model demonstrates how the two-part, sample-selection and double-hurdle specifications can be used to analyse a data set in which the dependent variable is often equal to zero. The two-part specification uses observations that report a strictly positive expenditure on tobacco to estimate the relationship between the strictly positive expenditures on tobacco and the explanatory variables. Both the sample-selection and double-hurdle specifications use all observations (those that report strictly positive expenditure on tobacco and those that report no expenditure on tobacco) to estimate the relationship between strictly positive tobacco budget shares and the explanatory variables. It is challenging to develop an intuitively plausible model that motivates the functional form of the sample-selection or double-hurdle specifications.

The literature review demonstrates that there are strong proponents of each specification. Garcìa and Labeaga 1996 and Yen and Jones 1996 are two recent papers on tobacco that apply a number of statistical tests that support a particular version of the double-hurdle specification. Likelihood ratio tests reported in this paper arrive at similar results. These statistical tests suggest that each specification leads to a different set of results but it is not clear which set of results are the most accurate and plausible. There are some findings that are obtained regardless of the specification applied. Nonetheless, the two-part specification arrives at an intuitively plausible and appealing set of results. Furthermore, the two-part specification is clearly related to a plausible model. For these reasons I have applied the two-part specification in Chapter 4, which studies a data set that reports household expenditure on tobacco in Canada.

The main purpose of Chapter 4 is to identify the factors associated with the probability that a household purchases tobacco and the factors associated with decisions regarding how much tobacco is purchased by households who purchase some.

The probability of purchasing tobacco is relatively high among households who do not own their own home and households that contain one or more people who are unemployed. If such households do purchase some tobacco they are likely to purchase a relatively large amount. These choices may have a strong influence on the health status of the Canadian population. This information might be helpful in formulating tobacco tax policies, tobacco regulation policies and anti-smoking campaigns.

Chapter 2

An Equilibrium Model of Waiting Lists for Medical Care: Introduction

People wait on lists for parking passes, tickets to entertainment events, club memberships, child day care, books in libraries, university courses, housing, child adoption, immigration papers, seniors' homes, and many other goods and services available in the public and private sectors.

Waiting lists are particularly important for understanding health care markets in which consumers often face monetary prices below the market clearing level. In the market for health care services, waiting lists are likely to affect when consumers seek health care, when and where they receive care, what treatment options are selected and how much health care is available and consumed. The goal of this paper is to develop a formal model of how waiting lists operate. New insights into the operation of waiting lists will be useful in predicting how waiting times are likely to change as a health care system evolves. They will also be useful in developing policy directly aimed at changing waiting times.

Waiting lists are distinct from waiting lines, which have been the subject of considerable economic analysis. Order on a waiting list is maintained by a record of names whereas order on a waiting line requires the physical presence of individuals. Many economics papers have been published concerning the mechanics and policy implications of markets that are cleared by waiting lines (Barro and Romer 1987; Barzel 1974; Deacon and Sonstelie 1991; Frech and Lee 1987; Holt and Sherman 1982; Nichols, Smolensky and Tideman 1971; Suen 1989). In these papers order is established according to a 'first come first served' rule and the supply of goods to be distributed is fixed. When an individual reaches the front of a line they receive one unit of the good. In this context waiting discourages demand and the good is allocated, in part, according to each individual's willingness to wait. Money prices may still play a role in such a market, however, if the money price is below the market clearing level waiting time will be positive according to waiting list models.

Waiting in line can discourage demand in two ways. Time spent waiting in line increases the un-discounted costs of obtaining the good in question because individuals give up other activities to hold their position in the ordering. Waiting in line can also discourage demand by altering the timing of the costs and benefits. For example, the present value of a good is decreased when the good is consumed later rather than sooner.

For a given waiting time each individual's cost of waiting is lower when names are recorded on a list rather than requiring individuals to physically wait in line. Consumers on a waiting list are constrained from consuming the good in question but are able to maintain their position on the list in absentia. Although the physical costs of waiting are avoided by means of a list, waiting time on a list can discourage demand by altering the timing of costs and benefits.

Waiting time on a list will not discourage demand if all of the costs and benefits of waiting on a list are incurred once a consumer reaches the top of a list. If, however, some of the costs are incurred when the consumer first joins a list, and those costs can be avoided by not joining the list, then waiting time can discourage consumption. If waiting increases the time between the incurring of costs and the reception of benefits then goods can be allocated according to willingness to wait through the use of a list.

The idea that waiting lists can be used to allocate goods according to willingness to wait was formally developed by Lindsay and Feigenbaum (1984). In the Lindsay and Feigenbaum paper (1984) consumers choose between joining a single waiting list and not joining at all. On the supply side Lindsay and Feigenbaum (1984) assert an ad-hoc relationship between the service rate (i.e. the number of procedures provided during a unit of time) and the waiting time.

The model developed in this paper extends the Lindsay and Feigenbaum (1984) paper in two ways. In this paper consumers choose between two waiting lists, each at a different hospital, and not joining at all. On the supply side each hospital chooses a service rate in order to maximize its utility. These extensions of the Lindsay and Feigenbaum model (1984) allow us to explore the potential importance of the inter-relationships among waiting lists.

The model illustrates why public decision makers may have a difficult time managing waiting lists. If a decision maker would like to achieve a particular waiting time he or she must be able to understand and influence the factors that determine the flow of people onto waiting lists and the flow of people off waiting lists. In this model a policy maker has three policy levers that can be used to influence waiting times. They can apply income and price incentives to hospitals and they can apply price incentives to patients. The model illustrates why it may be difficult to make generalizations about the relationship between income and price incentives and waiting times.

The decision maker's problem arises because of an externality between hospitals. In the model each hospital cares about its service rate, its waiting time and its own provision of other health care services. The externality exists because an increase in the service rate at one hospital, holding the service rate at the other hospital constant, decreases the waiting time at both hospitals. Ceteris paribus an increase in one hospital's service rate decreases that hospital's waiting time because patients leave the list at a faster rate. This in turn attracts patients who would have joined the list at the other hospital. Fewer people joining a list will result in shorter waiting times. There is a positive externality because the actions of one hospital affect the waiting time at the other hospital.

This situation can be modeled as a game between hospitals. In equilibrium each hospital chooses an optimal service rate given the service rate at the other hospital; such an equilibrium is called a Nash equilibrium. Comparative static results demonstrate that income and price incentives may have unexpected effects on waiting times even when the service rate is a normal good for one hospital.

For example, assume there are two hospitals i and k. If k's budget is increased, and the service rate is a normal good, then the service rate at hospital k will increase. This will decrease the waiting time at hospital i, which gives i an incentive to choose a new service rate. Comparative static results demonstrate that i may choose a much lower service rate. In fact at the new equilibrium the total service rate may be lower and waiting times may be longer than they are in the initial equilibrium.

This paper begins by reviewing three bodies of literature. The health services research literature is reviewed in order to identify stylized facts that have been observed in empirical investigations into the operation of waiting lists. Economic models of waiting lines are then reviewed in order to identify models that may be useful for understanding the operation of waiting lists. Finally, two economic models of waiting lists, which are similar to the model developed here, are reviewed in detail.

The game theoretic model of waiting lists is developed in the following stages. First, the constraints and objective functions of patients and hospitals are presented and the equilibrium conditions of the model are characterized. The implications of the model for patient behaviour are then presented in the context of a fixed service rate at each hospital. Next, results concerning the behaviour of a single hospital, taking the service rate at the other hospital as fixed, are presented. These are called partial equilibrium results because only one hospital is choosing its service rate optimally. Finally, Nash equilibrium results are presented. In a Nash equilibrium each hospital chooses its service rate optimally given the behaviour of patients and the service rate provided by the other hospital. Comparative static results of the Nash equilibrium will demonstrate that income and price incentives may have unexpected effects on waiting times.

2.1 Health Services Research

Health services research on waiting lists demonstrates that the relationship between service rates and waiting times is complex and often inconsistent with simple behaviourial models. For example, if behaviour is unaffected by waiting time, and waiting times are not growing, then a temporary increase in throughput will remove a waiting list eventually. This simple model underlies much of the policy debate concerning waiting lists. Empirical analysis in the health services research literature is often inconsistent with this frequently used simple conjecture.

The following is a brief summary of some empirical findings published in the health services research literature. Mackinnon, Smith and Dixon found that a temporary increase in capacity at an orthopaedic surgical unit resulted in an increase in the number of patients waiting while having no effect on waiting times (1992, p.7). Similarly, Parker and Froese found that "the addition of two staff members [to a psychiatric unit] had a substantial impact on the number of open cases but no measurable impact on the length of the waiting list" (1992, p.388). In contrast Mills and Heaton found that a mainly temporary increase in capacity in an ear, nose and throat surgical unit resulted in decreased waiting times (1991, p.406). Harvey, Webb and Dowse (1993) observed the impact of a new surgical unit that was established for the express purpose of decreasing waiting times for the treatment of hernia and varicose veins. In spite of the increased capacity they found that there was no overall increase in the number of hernia repairs performed in the area. For varicose veins, however, there was a net increase in throughput, similar in magnitude to the extra capacity provided by the new surgical centre. Waiting times for both hernia repair and varicose vein treatment decreased in response to the change in capacity (Harvey, Webb and Dowse 1993). Goldacre, Lee and Don analyzed a large data set on hospital waiting lists in Britain. They found a positive correlation between changes in throughput and changes in the number of patients waiting on lists (Goldacre, Lee and Don 1987).

Data on waiting times should be interpreted with caution for at least the following reasons. Ideally data on waiting time will report the difference between the optimal date for receiving the service and the actual date for receiving the service. In practice waiting time data report the time between some event (e.g. contact with a specialist) and the date that the service is received. Also, data on the number of individuals waiting often includes individuals who no longer require the service. Finally, data collected over a relatively short period of time may not reflect long term steady state waiting times.

Despite these problems empirical analysis demonstrates that waiting lists generally do not disappear when service rates are increased. In fact the data show that waiting times may not change at all in response to a change in the service rate at a particular site. In light of these findings it has been suggested that the availability of health-care services affects demand (Mackinnon, Smith and Dixon 1992; Goldacre, Lee and Don 1987). The health service research literature stops short of providing any further insight into how demand and availability may be related.

2.2 Waiting Lines

Waiting lines differ from waiting lists in the way that order is maintained. Waiting lines require the physical presence of an individual for the purpose of securing a position in the ordering while waiting lists require a record of names. Although the costs and benefits associated with waiting lines may be different from waiting lists, some of the modelling approaches or ideas may apply to both forms of rationing.

The following reviews a set of published papers on market clearing models of waiting lines and waiting lists. Two topics are omitted from this review. The review does not address the traditional queuing theory problem[1] and it does not attempt to determine the optimal mechanism for rationing goods. One of the main goals of this paper is to explain why the interaction between health care providing institutions may be important in determining how waiting lists operate. Future research could add stochastic elements to this analysis in order to address queuing theory issues. The analysis could also be extended in order to explore the issue of optimal mechanism design. However, these topics are beyond the scope of the main question addressed in this paper.

Models of waiting lines generally apply to the situation where a fixed number of goods are offered during one time period. There are three general approaches to modelling waiting lines; each of them borrows directly from some other literature. These three approaches are not competing alternatives but rather each emphasizes different aspects of the same phenomenon.

One approach is to assert that time is valuable and can therefore act as a price in a partial equilibrium model of a market (Barzel 1974). A second, and more general approach, draws from the household production theory literature (Nichols, Smolensky and Tideman 1971). In these models households allocate time among market production, household production and leisure time. A third approach borrows

[1]The goal of traditional queuing theory is to determine the optimal service rate given a stochastic arrival rate of consumers wishing to use that service. A high service rate results in a small probability that consumers will have to wait. A low service rate results in a small probability that the service will sit idle. With these two factors in mind there will be some optimal service rate and an associated stochastic waiting time that may be zero in some periods.

from the literature on sealed bid auctions (Holt and Sherman 1982). An arrival time is analogous to a bid for an object because time is valuable to consumers. The bid is sealed in that each consumer is unaware of other consumers' bids until he or she arrives. The idea is that in choosing an arrival time a consumer will consider when other bidders are likely to arrive. For example, if I am going to a movie and I expect a long line, then I might arrive earlier then I would otherwise. In equilibrium each consumer is optimizing given their own valuation and how they expect others to behave.

The central insight of the literature on waiting lines is that consumers receive rent whenever they purchase a good for less than the market clearing price. However, "nonprice methods of allocation will result in the dissipation of rent since (1) goods do not necessarily go to the highest valuing users and (2) competition for the rationed good involves the expenditure of real resources rather than the transfer of wealth" (Suen 1989, p.1385). When a good is rationed by queuing and consumers are identical, rent is fully dissipated. This result continues to hold even when consumers make efforts to capture some rent. For example, two consumers adjacent in line can agree to split the waiting time, or, consumers could decrease the costs of waiting by listening to music. This individually rational action is offset by longer waiting times because all consumers engage in this behaviour. In equilibrium rent is fully dissipated when a fixed number of goods is offered to identical consumers at a price below the market clearing level (Holt and Sherman 1982; Deacon and Sonstelie 1991).

Suen relaxes the assumption that consumers are identical by allowing them to have different valuations of the good and different opportunity costs of time. The length of waiting is determined by the marginal consumers whose rent is fully dissipated. Infra-marginal consumers are able to capture some rent; the amount of rent retained depends on the differences in peoples' time costs and personal valuations, not on their levels (Suen 1989, p.1390). To see this consider the effect of decreasing everyone's time cost of waiting. This will induce people to arrive earlier and further dissipate rents through waiting. If the cost of waiting is decreased for infra-marginal consumers only, then the equilibrium waiting time does not change and infra-marginal consumers capture more rent. In formally deriving this result Suen finds that "a greater degree of consumer heterogeneity will reduce the dissipation of rent if infra-marginal consumers have lower average time costs than marginal consumers" (Suen 1989, p.1393).

Suen applies this idea in analyzing the effects of allowing consumers to sell the good once they have established their property rights through waiting. A secondary market ensures that the highest-valuing users obtain the good and the consumers with the lowest opportunity cost of time will wait in line. For a given waiting time the secondary market increases welfare. However, introducing a secondary market increases the average personal valuation of the good, because the highest valuing consumers obtain the good, and decreases the average time cost, because consumers with the lowest opportunity cost of time will wait in line (Suen 1989, p.1390). As demonstrated earlier this will increase the equilibrium waiting time and hence further dissipate rent. "It is possible (say, because the variance in the wage rates among low wage individuals is sufficiently small compared with the overall variance) that introducing a secondary market will increase the welfare cost of a rationing system"(Suen 1989, p.1390).

A more specific result was derived by Frech and Lee (1987). They showed that when rationing by waiting line is employed in more than one market the implicit time price should be highest in the market with the most elastic demand curve. Frech and Lee demonstrated this result by referring to the textbook model of a price discriminating monopolist. The monopolist will maximize profits by charging a higher price in the less elastic market. If instead we wanted to minimize welfare losses due to waiting, actions opposite of those taken by the monopolist would be required. That is, the longest waiting time should be in the market with the more elastic demand. In some cases the more elastic market should take the full brunt of the non-price rationing.

2.3 Waiting Lists

This section reviews two published papers that are similar to the model developed in this paper. The most recent was written by Iversen (1993). Iversen's paper formally models health care provision in analyzing the operation of a waiting list for medical care. The model I develop is similar to Iversen (1993) because both assume that the hospital is a utility maximizing agent and because both analyse hospital behaviour in a game-theoretic framework. An earlier paper by Lindsay and Feigenbaum (1984) develops a demand side model of a waiting list. The model I developed extends Lindsay and Feigenbaum (1984) by modelling two waiting lists rather than one and by formally modelling health care provision.

Iversen's model describes the behaviour of a utility maximizing hospital and a public funding agency. The hospital derives utility from its expected service rate and derives disutility from expected waiting times at the hospital. Behaviour of a public funding agency is described by the agency's willingness to pay function, defined over expected service rates and expected waiting times.

In Iversen's model a hospital maintains a waiting list in order to reduce the probability of idle capacity in the face of stochastic demand. In Iversen's model a hospital can spend its budget on caring for patients or managing a waiting list. The arrival rate of patients is stochastic and the length of the waiting list is limited by the hospital's budget. If the hospital's budget is exhausted, and the hospital is unwilling to spend less on caring for patients, it will have to turn some patients away.

Iversen argues that for short waiting lists an increase in resources devoted to caring will increase the expected throughput while for long waiting lists the expected throughput decreases because of the relatively large costs associated with maintaining long waiting lists. This implies that there is a unique waiting list length associated with the maximum expected throughput.

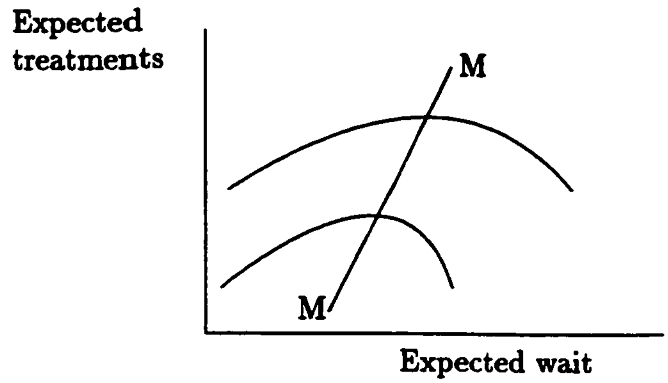

Figure 2.1:

Figure 2.1, taken from Iversen's paper (1993, p.58, fig.1), graphs this production function relationship in the expected waiting and expected treatment space. Each curve represents a different fixed budget; the further the curve from the expected wait axis the higher is the fixed budget. The line $M - M$ represents the maximum number of expected treatments associated with each fixed budget. Any point to the right of $M - M$ represents 'excessive waits' because the same expected throughput could be achieved with a shorter wait (Iversen 1993, p.59).

Iversen assumes that a hospital has a utility function that is upward sloping in the expected treatment and expected wait space. This implies that a utility maximizing hospital facing a fixed production constraint will choose an expected waiting time that is not 'excessive'.

Iversen also models the behaviour of a government funding agency whose willingness to fund depends positively on waiting time. In the first stage of Iversen's model the hospital announces a waiting time. In the second stage the government

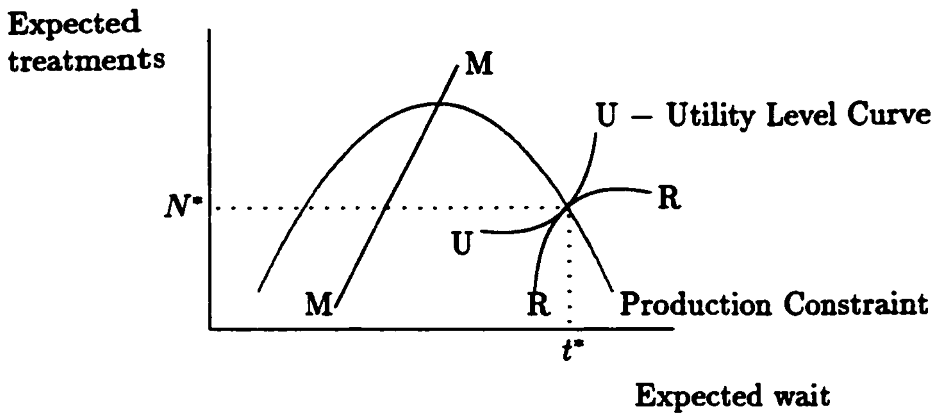

Figure 2.2:

sets the hospital budget taking the waiting time as given.

Under certain assumptions the government's reaction to an announced waiting time can be represented by the curve $R - R$ in Figure 2.2 (Iversen 1993, p.65, fig.2). Iversen assumes that the hospital has full knowledge of the government's reaction function. Therefore, when the hospital announces an expected waiting time they know how much funding they will receive and the corresponding number of expected treatments. In other words the hospital can choose any point along $R - R$ by announcing the appropriate expected wait in the first stage of the game.

Given the reaction function $R - R$ the hospital's maximum utility level is $U - U$ in figure 2.2. In the first stage of the game the hospital announces the waiting time t^*. The government will then agree to funding that will be used to pay for N^* expected treatments and to maintain the waiting list at t^*. Iversen concludes that, "if patients' waiting time increases the government's willingness to pay, the result may be excessive waits [for medical care]" (1993, p.69).

An earlier paper, by Lindsay and Feignbaum (1984) models consumer behavior in response to a single waiting list where there are no substitutes for the good in question. They also test whether the predictions of the model are consistent with British health care experience. In the Lindsay and Feignbaum model consumers have a very simple choice: they can join a single waiting list or not. On the supply side the authors assert that the health-care service rate is an upward sloping function of waiting time. In this model waiting time encourages a higher throughput as well as discouraging demand for the good.

The central assumption in the Lindsay and Feignbaum paper is that an individual's present value of a good is negatively related to waiting time. When an individual's instantaneous value of a service is v, and this value decays continuously at a rate g over the waiting time T, then the present value (PV) of the service is

$$PV = v \cdot e^{-gT} \tag{2.1}$$

(Lindsay and Feigenbaum 1984, p.407)

Lindsay and Feignbaum argue that "unpredictability in individual demand is a necessary condition for equilibrium in a market cleared by waiting lists" (Lindsay and Feigenbaum 1984, p.405, footnote 1). The argument is put forth as follows:

> For demands which are readily predictable (like newspapers, but unlike high fashion clothing), delay from the date of order to date of receipt need not reduce the number of demanders. As each demander of this type of good may forecast his desired quantity in each future period, he may simply "order in advance" to obtain it. Lists will grow indefinitely is such cases and fail to perform a rationing function. (Lindsay and Feigenbaum 1984, p.405)

The central assumption, that the present value of a good is negatively related to waiting time, does not hold when demand is predictable and the present value function is represented by equation 2.1 because individuals can offset waiting time by selecting the appropriate joining time. I suspect that if the present value function takes a more general form, then Lindsay and Feignbaum's central assumption can hold even when demand is entirely predictable. This implies that waiting times can be used to distribute many goods and services whose demand is predictable. This issue is not explored here but could be further investigated in the future.

Consumers in the Lindsay and Feignbaum model first decide whether they would like to consume the service in the current period. If the answer is yes then they are potential waiting list joiners.

If the supply rate is not enough to satisfy all the potential joiners the waiting list will grow without bound. However, if individuals face a cost to joining the list the model predicts a finite steady state waiting time. These joining costs include the "costs of taking examinations, obtaining approvals and referrals, and such transaction costs as expenditures for transportation, legal advice, and market information" (Lindsay and Feigenbaum 1984, p.407). Given equation 2.1, and a fixed joining cost, we can solve for the critical waiting time beyond which the individual will not join the list.

Lindsay and Feignbaum assume that the instantaneous value of the good varies among individuals and that the valuations are distributed according to the function

F, where $F(v)$ equals the proportion of potential waiting list joiners with a valuation of v or less. In deriving some of their theoretical results Lindsay and Feignbaum also assume that individuals have the same discount rate.

Given a particular waiting time we can identify the individual who is on the margin between joining or not by setting equation 2.1 equal to the joining costs (c) and solving for v. This valuation is

$$v^m(T) = c \cdot e^{gT} \tag{2.2}$$

The superscript m identifies the valuation held by the individual who is on the margin between joining or not.

Under the assumptions given above Lindsay and Feigenbaum are able to specify the market joining function

$$J(T) = N[1 - F(v^m(T))] \tag{2.3}$$

(Lindsay and Feignbaum 1984, p.408) The variable N represents the arrival rate of potential joiners. The term in square brackets represents the proportion of potential joiners with $v > v^m(T)$. The function $J(T)$ represents the joining rate for any given waiting time.

To complete the model Lindsay and Feignbaum assert that the supply rate, S, will be positively related to waiting time. The steady state is attained when

$$S(T) = J(T) \tag{2.4}$$

Given equations 2.3 and 2.4 we can now solve for the equilibrium waiting time, joining rate, and service rate. The equilibrium waiting time also equals the number of people waiting divided by the service rate. For example, if 10 people are served during each unit of time and there are 90 people currently waiting then the last person joining must wait 9 periods to reach the top of the list. Rearranging this relationship shows that the equilibrium number of patients waiting can be found by multiplying T by $S(T)$:

$$Q(T) = T \cdot S(T) \tag{2.5}$$

It has been observed that an increase in the service rate can result in a higher number of people on the waiting list. In the Lindsay and Feigenbaum model the effect of an increase in the service rate depends on two opposing factors. Ceteris paribus an increase in the service rate decreases the number of people waiting and their waiting time. However, the decreased waiting time will induce more people to join the waiting list thereby increasing the number of people waiting.

These two effects can be illustrated more precisely by substituting equation 2.4 into equation 2.5 and differentiating with respect to T which gives

$$Q'(T) = \left[\frac{T}{J(T)} J'(T) + 1\right] J(T) \tag{2.6}$$

(Lindsay and Feigenbaum 1984, p.411)

Equation 2.6 shows that a decrease in the equilibrium waiting time will increase the number of people on the list if the elasticity of the joining rate with respect to the waiting time is less than minus one (Lindsay and Feigenbaum 1984, p.411).

The testable implications of the Lindsay and Feignbaum model are that the joining rate will be inversely related to the expected delay, the decay rate and the cost of joining while being positively related to the value of the service provided (1984, p.412).

Lindsay and Feignbaum use data from the British National Health Service to test these implications. Unfortunately they have no data on the cost of joining and are unable to test that particular implication. The other three implications are supported by their data according to Lindsay and Feignbaum (1984, p.417).

Katz and Owen (1986) extend the Lindsay and Feignbaum model by introducing exogenous stochastic service times and arrival rates for potential waiting list joiners. Once potential consumers 'arrive' they maximize expected utility in deciding whether or not to incur the costs of joining a waiting list. Katz and Owen's goal is to predict the effect of a decrease in the mean service time, or equivalently an increase in the service rate.

Katz and Owen derive the result that when "the arrival rate and the expected service time are assumed independent, a decrease in the mean service time cannot lead to a decrease, and may lead to an increase, in the waiting list size" (1986, p.314). When the arrival rate is functionally dependent on the mean service time this conclusion holds under a set of assumptions on the parameters of the exogenous stochastic functions (Katz and Owen 1986, p.314). As in the Lindsay and Feigenbaum model (1984) the effect of a change in the service rate on the number of people waiting is ambiguous. However, when the stochastic arrival rate and the service time are independent this result no longer holds.

2.4 The Model

The model I develop rests on three basic assumptions. I assume that the behaviour of an individual who can benefit from the service in question is described by a function relating waiting times to the value of the service to the individual. This assumption does not ignore the fact that patients often rely on physicians to assist in making health care decisions. The source of each patient's value function is left unspecified and could be determined by patient and physician expectations and preferences. Although the rest of the paper refers to potential joiners and their behaviour, a physician-patient relationship could underly patient decision making. In other words I am assuming perfect agency.

A utility function is assumed to describe a hospital's objectives, which are constrained by a budget and the behaviour of patients. Internal hospital resource allocation decisions are the result of a complex decision making process that involves many different individuals, groups of individuals and institutions within the hospital. Given this complexity it is difficult to imagine that one function can capture the objectives of an organization as large as a hospital. It is possible, perhaps even likely, that a well behaved hospital utility function does not exist.

It is also assumed that the behaviour of hospitals and the behaviour of individuals who can benefit from the service in question are linked only through waiting times and a money price charged to patients. This assumption rules out more complex relationships between referring physicians and hospitals. For example, referring physicians may have some influence over how a hospital's budget is spent as well as having influence over patient decision making.

Despite these simplifications the model remains relatively complex and displays a wide range of comparative static results that challenge simple conjectures concerning service rates, financial incentives and waiting times.

Individuals who can benefit from medical care must often choose where they will receive care. In the model I develop, potential waiting list joiners, in conjunction with their family physicians, have a relatively small number of options. They can join one of two waiting lists or they can decide not to join at all. One list is for services at hospital i and the other is for services at hospital k. Hospital k charges a price to patients when they receive the service while hospital i does not. From the patient's point of view the hospitals are identical except for the price (possibly zero) charged to patients and the waiting time associated with each hospital.

Equation 2.7 represents an individual's present value of joining the list at hospital k when hospital k charges patients a money price of p, the cost of joining the list is c_j, the costs incurred by patients when the service is received are c_r and the waiting time at hospital k is T_k. The cost of joining a list could include travel costs, time away from other activities, and the costs of gathering information. Costs incurred when the service is received could include, time away from other activities and any physical restrictions associated with recovery from the service. The variable V represents the individual's instantaneous value of receiving the service and g represents the rate at which the value of the service decays over time.

$$PV_k = (V - c_r - p)e^{-gT_k} - c_j \tag{2.7}$$

Equation 2.8 represents the same individual's present value of joining the list at hospital i when hospital i does not charge patients a price for the service and the waiting time at hospital i is T_i.

$$PV_i = (V - c_r)e^{-gT_i} - c_j \tag{2.8}$$

The present value of not joining a list is normalized to zero. Patients are therefore guaranteed at least a present value of zero because they can always decide not to join either list. Each individual maximizes their present value by joining at k, joining at i, or not joining at all. For example, if both waiting times were zero a potential waiting list joiner would join at hospital i and would receive a present value equal to their value of the service (V) minus the costs incurred in joining the list (c_j) and the costs incurred in receiving (c_r) the service. If this individual had to wait for the service her present value of receiving it would be lower. The lower present value could be caused by a number of different factors such as time preference, deteriorating health, a decrease in the effectiveness of the intervention when it is applied in a later stage in the development of a health problem, and the anxiety and uncertainty associated with waiting. All of these factors decrease the present value of the service through the decay rate g. If the decay rate g were equal to zero the individual would not care when they received the service; tomorrow would be as good as next year. When the decay rate is positive, and both waiting times are very long, each present value will be negative and the individual will not join at all.

Each potential joiner in this model has a positive instantaneous valuation, V, that is between 0 and $\bar{V}$. The minimum valuation is zero because if an individual had a valuation less than zero they would never join either list. I put an upper bound on the range of valuations for analytical convenience. The arrival rate of individuals with a valuation of V or less is represented by a continuous function $G(V)$. The function $G(V)$ is non-decreasing in V. This says, for example, that the arrival rate of individuals with $V \leq 5$ must be less than or equal to the arrival rate of individuals with $V \leq 10$. By definition $G(\bar{V}) = N$, where N is the arrival rate of all potential joiners and $\bar{V}$ is the highest valuation a potential joiner can have.

On the supply side hospitals face choices concerning which type of care to provide. These choices have implications concerning waiting times and expenditures. Each hospital in this model has a utility function defined over its service rate for the particular service we are examining, the waiting time for that service, and a composite good representing the other services offered by the hospital. The composite good could represent services such as public health promotion or other services for which there is no waiting list. Each hospital maximizes utility given a budget constraint and a constraint that relates service rates to waiting times. Hospital k's maximization problem is represented by equations 2.9 to 2.11 where equation 2.9 is a utility function, equation 2.10 is budget constraint and equation 2.11 is a constraint that relates waiting times to service rates. The variable S_k represents hospital k's service rate, Γ_k is a parameter in the utility function and X_k is the quantity of the composite good provided by hospital k. The variable M_k represents hospital k's flow of money that they can spend. The parameters P_x and P_s represent the cost, incurred by a hospital, in providing a unit of the composite good and one unit of the service rate respectively. Hospital k's net cost of providing S_k is $P_s - p$. So for example, if the composite good were health promotion then the hospital would be providing a constant flow of health promotion equal to X_k and would be spending a constant flow of dollars on health promotion equal to $P_x X_k$. Similarly, if the service in question were cataract repairs and the hospital was providing a constant flow of 10 repairs then the flow of expenditure on cataract repairs would be $(P_s - p)10$. These two expenditure flows must equal the flow of money to which the hospital has access. The joining constraint is imposed by the joining behaviour of patients. In other words if a hospital chooses a particular service rate then potential joiners will make joining decisions and in doing so they will determine the waiting time that the hospital must accept. The functional form of the joining constraints will be formally derived later in the paper.

$$\max_{S_k, T_k, X_k} U_k(S_k, \Gamma_k - T_k, X_k) \tag{2.9}$$

subject to

$$P_x X_k + (P_s - p) S_k = M_k \tag{2.10}$$

and

$$T_k = F_k(S_i, S_k, p) \tag{2.11}$$

Similarly, hospital i's maximization problem is

$$\max_{S_i, T_i, X_i} U_i(S_i, \Gamma_i - T_i, X_i) \tag{2.12}$$

subject to

$$P_x X_i + P_s S_i = M_i \tag{2.13}$$

and

$$T_i = F_i(S_i, S_k) \tag{2.14}$$

Substituting the constraints into the utility functions reduces the maximization problem to the choice of a service rate. Once the service rate is chosen the other two choice variables are determined by the constraints. Hospital k's decision problem, taking hospital i's decision as fixed, is illustrated in figure 2.3. When a hospital chooses a service rate the waiting time will be determined by the joining constraint and the composite good provision will be determined by the budget constraint. The superscript $*$ in figure 2.3 indicates the optimal choice given the service rate provided by hospital i.

Appendix 2.11 reports the first and second order conditions for a local maximum. A number of different sets of assumptions are consistent with the second order

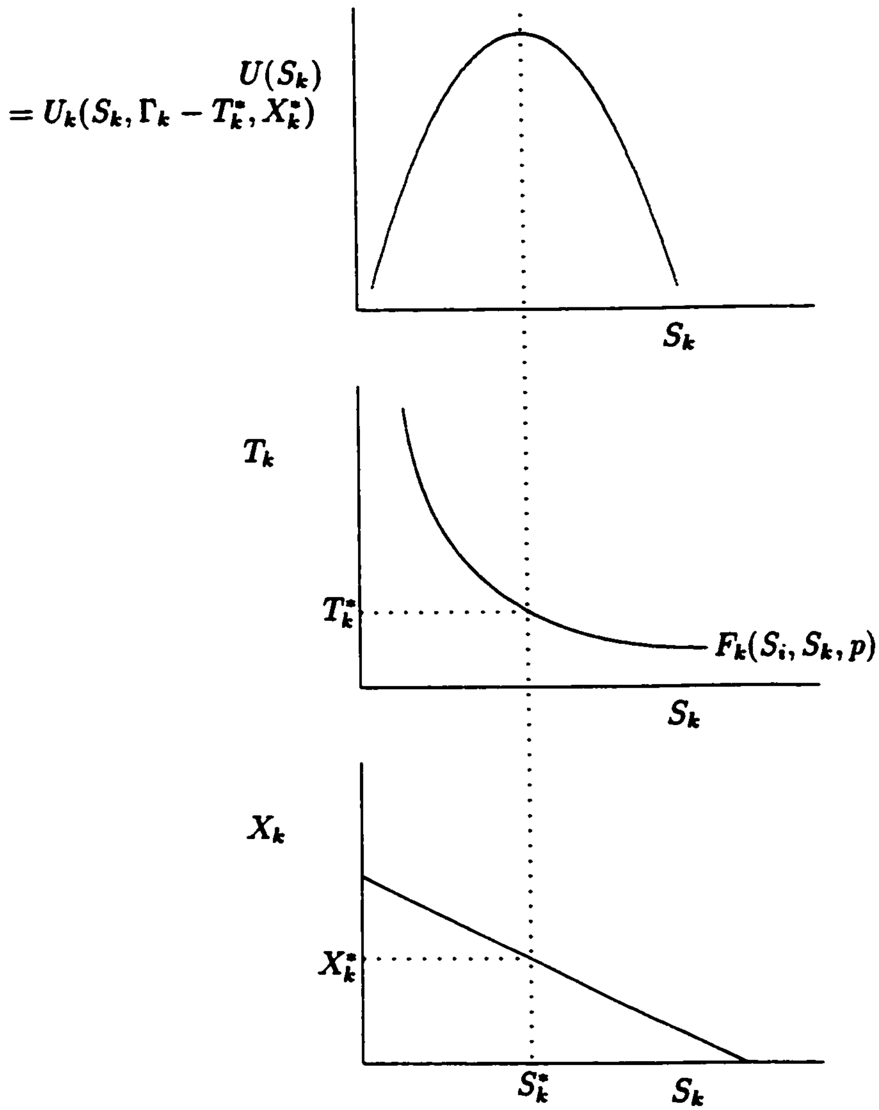

Figure 2.3: Hospital k's Decision Problem

condition. The following set of assumptions will be used in determining the sign of the comparative static results. All marginal utility functions are assumed to be positive and downward sloping in their own arguments. This is a standard assumption in almost any economic optimization problem. The joining constraints are assumed to have an increasing slope. Later in the paper I will show the conditions that must hold in order for this assumption to be true. I also assume that the marginal utility of the service rate falls when the waiting time falls, the marginal utility of the service rate increases when provision of the composite good increases and the marginal utility of the composite good increases when the waiting time falls. These last three assumptions all depend on the hospital's preferences and there is nothing implausible about them but it is possible that they do not hold. The assumed sign of each second derivative of the hospital's utility function, and the joining constraints, ensure that the second order condition holds. In other words these assumptions are sufficient to ensure that the second order condition holds. These sufficient conditions will be useful for determining the sign of the comparative static results. The sufficient assumptions are formally stated in appendix 2.11.

In order to maintain as much generality as possible I also make a set of assumptions that are consistent with the second order condition for a local maximum. In order to sign the comparative static results under these assumptions I assume that the second order condition holds and that the following assumptions are true. As in the sufficient conditions, all marginal utilities are assumed to be positive and downward sloping and the joining functions are assumed to have an increasing slope. However, under these alternative assumptions the marginal utility of the service rate increases when the waiting time falls, the marginal utility of the service rate decreases when the provision of the composite good increases and the marginal utility of the composite good decreases when the waiting time falls. These last three assumptions are exactly the opposite of the sufficient condition assumptions. Under the consistent assumptions the sign of each second derivative of the hospital's utility function and the joining constraints do not ensure that the second order condition holds.

Neither set of assumptions have a more plausible interpretation than the other. In fact there may be other sets of assumptions that one could reasonably make and which are consistent with the second order condition. Both the sufficient assumptions and the consistent assumptions are plausible and often these two sets of assumptions result in different comparative static results. Later in the paper it will become clear that there are a very wide range of results that come from the consistent assumptions and that there would be little value in examining a third set of assumptions. The consistent assumptions are formally stated in appendix 2.11.

A Nash equilibrium of the model is achieved when the waiting times are not changing over time, each individual is behaving optimally given the waiting times that they face, and each hospital is providing its optimal service rate given the service rate provided by the other hospital. The comparative static results compare different equilibria where both hospitals have strictly positive waiting times and each provides a strictly positive service rate.

The results of the model are derived in the following stages. In section 2.5 both hospital service rates are exogenous. This allows us to focus on the behaviour of potential joiners and to derive each hospital's joining constraint. In section 2.6 hospital i's service rate is exogenous and hospital k chooses its optimal service rate. One goal of section 2.6 is to derive how a hospital reacts to an exogenous change in the other hospital's service rate. A function relating one hospital's optimal service rate to the other hospital's service rate is called a reaction function. The two reaction functions, one for each hospital, will determine the two optimally chosen service rates. In section 2.7 both hospitals choose their service rates optimally.

2.5 Potential Joiners

In this section the service rate at each hospital is fixed exogenously. The goal is to derive the joining constraint for each hospital.

Result 2.5.1 *The individual on waiting list k who is on the margin between joining or not must have the same valuation as the individual on waiting list i who is on the margin between joining or not.*

This result is useful in deriving many other results of the model. Result 2.5.1 holds because individuals maximize their present value and there is a continuous distribution of valuations.

More precisely, the argument for result 2.5.1 is as follows. Individuals in this model are always optimizing given the current waiting times. For convenience I assume that waiting times are always strictly positive. This means that the present value of joining a list must be zero for the lowest valuing, or marginal, individual. If a marginal individual's present value were negative they would be better off not joining that list. If the marginal individual had a positive present value then an individual who is not joining could do better by joining. Let the marginal valuation on list k be represented by V_k^m and the marginal valuation on list i be V_i^m. Equations 2.15 and 2.16 represent these conditions.

$$V_k^m e^{-gT_k} - c_j - (c_r + p)e^{-gT_k} = 0 \tag{2.15}$$

$$V_i^m e^{-gT_i} - c_j - c_r e^{-gT_i} = 0 \tag{2.16}$$

If the individual with valuation V_k^m were to join waiting list i their resulting present value would be non-positive. If it were not, then the individual with valuation V_k^m would not be optimizing by joining list k. This condition is represented by equation 2.17.

$$V_k^m e^{-gT_i} - c_j - c_r e^{-gT_i} \leq 0 \tag{2.17}$$

Analogous arguments can be applied to list i so that equation 2.18 must also hold.

$$V_i^m e^{-gT_k} - c_j - (c_r + p)e^{-gT_k} \leq 0 \tag{2.18}$$

From equations 2.15 and 2.18 we can derive the condition that $V_k^m \leq V_i^m$ and from equations 2.16 and 2.17 we can derive the condition that $V_i^m \leq V_k^m$. Both of these conditions must hold, therefore V_k^m must equal V_i^m. With this in mind the marginal valuation will be represented by V^m from now on.

Result 2.5.2 *Waiting times depend on the total service rate; the way in which this total is divided between the hospitals has no effect on waiting times.*

The proof of this result is in appendix 2.11 and it depends on the assumption that waiting times are always strictly positive in each hospital. This assumption implies that each hospital's service rate is strictly positive. Result 2.5.2 holds because waiting times must adjust such that the total joining rate equals the total service rate, the lowest valuing individual on a list receives a present value of zero, and marginal individuals have no incentive to join another list. These conditions, which are represented by equations 2.15 to 2.18, pin down a unique pair of waiting times that do not depend on the proportion of the total service rate provided be each hospital.

The total joining rate (J) is equal to the arrival rate of potential joiners minus the arrival rate of potential joiners with a valuation less than the marginal valuation (i.e. those whose do not join):

$$J = N - G(V^m) \tag{2.19}$$

From equations 2.15, 2.16, and 2.19 we can derive the unique pair of waiting times ($\Omega(J)$) associated with a particular joining rate.

$$\Omega(J) = \left\{ (T_k, T_i) : \begin{array}{c} T_k = \frac{1}{g} \ln\left(\frac{G^{-1}(N-J)-c_r-p}{c_j}\right) \\ T_i = \frac{1}{g} \ln\left(\frac{G^{-1}(N-J)-c_r}{c_j}\right) \end{array} \right\} \tag{2.20}$$

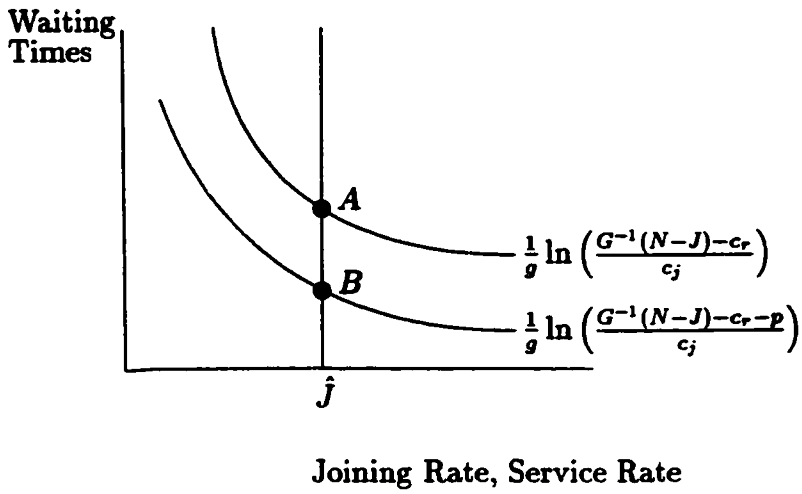

Figure 2.4: Joining Rate and Waiting Times

Figure 2.4 illustrates equation 2.20. The points A and B show the unique pair of equilibrium waiting times associated with the total joining rate $\hat{J}$. The waiting time at k is less than the waiting time at i because individuals on the list at k face a money price in addition to their wait. The fact that the points A and B are on the two curves ensures that the lowest valuing individual on each list has a present value of zero. When the total service rate is $\hat{J}$ any pair of waiting times whose difference is equal to $\hat{T}_i - \hat{T}_k$ will ensure that the marginal individuals on each list have no incentive to join the other list. For example, if both waiting times were lower but the difference between them was the same, the marginal individual on list k would have no incentive to join list i. The condition that the marginal individuals must have a present value of zero and the condition that marginal individuals must have no incentive to join the other list together ensure that the total joining rate $\hat{J}$ can only be supported by the waiting times $\hat{T}_k$ and $\hat{T}_i$.

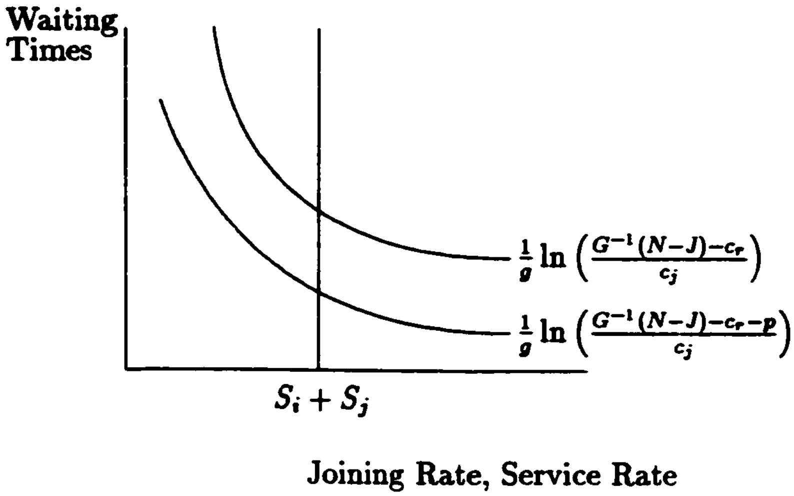

Figure 2.5: Joining Rate, Service Rate and Waiting Times

A steady state is achieved when the total service rate equals the total joining rate. Figure 2.5 illustrates the fact that the total service rate determines the individual waiting times. The proportion of the total service rate provided by each hospital is unimportant with regards to waiting times.

This result could be tested against an appropriate data set. The result implies that moving health care services from a hospital with short waiting times to a hospital with long waiting times will have no effect on either waiting time provided that the total service rate is held constant.

Setting the total service rate equal to the total joining rate and solving for each waiting time gives the joining constraints. The functional form of the joining constraints is reported in appendix 2.11.

Result 2.5.3 *Each hospital's waiting time is negatively related to the total service rate.*

If the total service rate is increased then, all else equal, the flow off the lists will be greater than the flow onto the lists. Over time there will be fewer people waiting and the waiting times will be lower. Lower waiting times will attract more people to the waiting lists until the flow onto the waiting lists is once again equal to the flow off of the waiting lists. This relationship can be illustrated by moving the total service rate in figure 2.5 to the right and shifting both joining curves down.

Result 2.5.4 *The previous result showed that waiting times fall when the total service rate increases. The change in the waiting times may grow or shrink as the total service rate increases.*

This model predicts that a decrease in waiting times will encourage people to join a waiting list. Result 2.5.4 implies that it is difficult to make further generalizations about the functional form of this relationship. The second derivatives of the waiting times with respect to the joining rate are ambiguous because the second derivative of the distribution of valuations ($G''(V)$) has not been specified. It was not specified because there is no reason to believe that the distribution of valuations has a positive or negative second derivative.

In both the sufficient conditions and the consistent conditions I assume that the second derivative of each waiting time with respect to the total service rate is positive. Appendix 2.11 formally demonstrates that this assumption will hold if the second derivative of the distribution of valuations ($G''(V)$) is sufficiently negative. Despite this possibly restrictive assumption the implications of this model are very

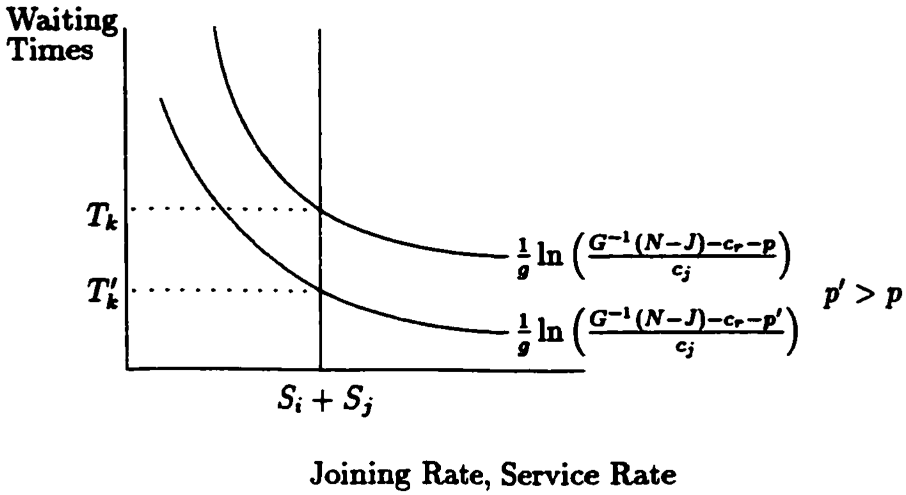

Figure 2.6: Waiting Times at k given a Total Service Rate

general.

Result 2.5.5 *An increase in the price charged to patients at hospital k will decrease the waiting time at hospital k and T_k will become more sensitive to changes in the total service rate.*

An increase in the price charged to patients at hospital k will decrease the flow of people onto list k because more people will decide not to join at either hospital. As time passes fewer people will be waiting and T_k will fall. The waiting time at k will not fall indefinitely because a lower waiting time will counteract the price effect such that an equality between the joining rate and the service rate is re-established at a lower waiting time. Figure 2.6 illustrates the relationship between the waiting time at hospital k and the total joining rate at two different prices. The waiting time at hospital i will remain constant in the face of this price change.

A higher price charged to patients means that T_k is more sensitive to changes in the total service rate because the higher price will make individuals more reluctant

Table 2.1: Comparative Statics (Total Service Rate is Exogenous)

Hospital k	Hospital i
$D_1F_k(\bar{S}_i + \bar{S}_k, p) < 0$	$D_1F_i(\bar{S}_i + \bar{S}_k) < 0$
$D_2F_k(\bar{S}_i + \bar{S}_k, p) < 0$	—
$D_{2,2}F_k(\bar{S}_i + \bar{S}_k, p) < 0$	—
$D_{1,1}F_k(\bar{S}_i + \bar{S}_k, p) \gtrless 0$	$D_{1,1}F_i(\bar{S}_i + \bar{S}_k) \gtrless 0$

to join list k. For example, if the service rate at k is exogenously increased from 10 to 15 then the joining rate at k must also increase from 10 to 15 in order to achieve a new steady state. When individuals face a high price the waiting time must fall more in order to attract 5 more people to list k.

To summarize, the joining constraint described in this section depends on the behaviour of patients. The results of this section were derived on the assumption that the service rates are exogenous. In the next section hospital k's service rate will be determined endogenously. The joining constraint limits each hospital's choice set and provides incentive for the hospital to provide a certain mix of health care services.

Table 2.1 reports the results of this section that will be useful in the next section. The bars over the service rates indicate that the total service rate is exogenous.[2]

[2]The notation $D_iF(x, y)$ represents the derivative of the function F with respect to its ith argument.

2.6 Partial Equilibrium

In the previous section I assumed that the service rate at each hospital was fixed. In this section I explore how hospital k chooses its service rate when the service rate at hospital i is fixed. Investigators who observe waiting times at a single hospital before and after a change in the service rate may be tempted to assume that the service rates at other hospitals are fixed, thereby ignoring the fact that other hospitals may modify their behaviour. The difference between the results of this section and those of section 2.7 illustrates the implications of assuming that one hospital has a fixed service rate when in fact it does not. The comparative static results in this section address the following questions. What happens to hospital k's service rate when its budget is increased? What happens to hospital k's service rate when the unit cost of the service rate is decreased? What happens to hospital k's service rate when the price charged to patients is increased? What happens to hospital k's service rate when hospital i's service rate is exogenously increased? Each of these results applies to hospital i as well as hospital k except the one concerning the price charged to patients because p does not enter hospital i's budget constraint. All of the results are derived under the sufficient assumptions. A proof of each comparative static result is in appendix 2.11. The results under the consistent assumptions are simply mentioned and are not stated precisely but are proved in the appendix.

Result 2.6.1 *When hospital k's budget is increased it will choose to increase its service rate.*

The proof of this result is in appendix 2.11. It seems intuitively plausible that a larger budget will not result in a lower service rate and this is what the sufficient assumptions imply. However, under the consistent assumptions it is possible that a larger budget will result in a lower service rate.

Result 2.6.2 *When the service rate becomes less costly to provide (P_s decreases) the hospital will provide a higher service rate.*

The proof of this result is in appendix 2.11. This result is analogous to the standard consumer theory result that demand curves are downward sloping when income effects are positive. A decrease in P_s decreases the hospital's minimum cost of achieving a given level of utility (this is analogous to an income effect in consumer theory). The lower cost will also induce the hospital to substitute a higher service rate for the composite good. Both the substitution effect and the income effect give the hospital incentive to provide a higher service rate when P_s falls. Again this result seems plausible but under the consistent assumptions it is possible that a decrease in P_s will result in a lower service rate. If this were the case the service rate would be analogous to the Giffen good from consumer theory. A Giffen good can only exist if an income effect outweighs a substitution effect. Evidence suggests that this situation is highly improbable for the overwhelming majority of goods and services available to consumers.

Result 2.6.3 *The effect of a change in the price charged to patients on the service rate is ambiguous.*

The proof of this result is in appendix 2.11. The effect of an increase in the price charged to patients operates through three channels. It relaxes the hospital's budget constraint by decreasing the hospital's net cost of providing the service, it alters the joining constraint by increasing the price that potential joiners face and it decreases the hospital's cost of achieving a given level of utility because for a given level of $P_s - p$, S_k and X_k the hospital achieves a lower waiting time and hence a higher level of utility.

An increase in the price charged to patients means hospital k's net cost of providing a given service rate falls. This implies that there are income and substitution effects operating through the budget constraint which will encourage the hospital to provide a higher service rate.

Result 2.5.5 demonstrates that an increase in the price charged to patients will make the waiting time at hospital k more sensitive to changes in the total service rate because potential joiners become more reluctant to join at k. In an extreme case T_k goes from remaining constant in the face of changes in the total service rate to being very responsive to changes in the total service rate. When T_k is unaffected by changes in the total service rate the hospital balances the utility of the service rate against the utility of providing the composite good and takes the waiting time as given. When T_k is very sensitive to changes in the total service rate the hospital has an added incentive to choose a high service rate. In other words when the price charged to patients increases T_k becomes more responsive to changes in the service rate which gives the hospital incentive to substitute away from the composite good and towards the service rate.

To summarize, there is a price effect operating through the budget constraint, which can be separated into a substitution and income effect, and a substitution effect operating through the joining constraint. All of these effects encourage a higher service rate when the price charged to patients is increased.

There is also a third effect that opposes the other two. To isolate this effect consider what would happen if $P_s - p$, S_k and X_k were held constant when p is increased. The price increase discourages some people from joining, which results in a shorter waiting time at k. Marginal utility functions are assumed to be downward sloping which means that the hospital is less inclined to devote scarce resource towards achieving a short waiting time.

This third effect is unusual because it operates directly though the utility function. Holding the hospital's behaviour constant, one of its choice variables, its waiting time, is exogenously decreased. An analogy will further clarify this idea. Consider an individual who consumes apples because he likes the taste and he appreciates the health effects of the vitamin C in apples. If he were given free vitamin C supplements he might choose to decrease his apple consumption. By analogy, an increase in the price charged to patients gives the hospital a 'free' decrease in the waiting time. In response the hospital may choose to provide a lower service rate. The total effect depends on the relative strength of the income and substitution effects operating through the two constraints and the effect operating directly on the hospital's utility function. This argument assumes that the sufficient assumptions hold. The result is ambiguous under the consistent assumptions as well.

Result 2.6.4 *When hospital i increases its service rate hospital k will react by decreasing its service rate. This reaction will at most be exactly offsetting.*

A proof of this result is in appendix 2.11. Equation 2.21 restates result 2.6.4 using mathematical symbols.

$$-1 \leq D_{S_i} S_k \leq 0 \tag{2.21}$$

If S_k and X_k are held constant when the service rate at hospital i is increased then the waiting time at hospital k will fall because the total service rate is higher. Hospital k could therefore enjoy the benefits of a lower waiting time and not alter its service rate or composite good provision. In this extreme case the effect of a change in the service rate at hospital i on S_k is zero.

On the other hand, the hospital could enjoy the benefits of this change by decreasing S_k and spending more of its budget on the composite good. Loosely speaking, the hospital may observe a decrease in its waiting time and interpret this as a decrease in demand for this service and therefore, direct more of its budget towards the composite good. In an extreme case hospital k will completely offset the change in S_i.

This comparative static result is consistent with evidence presented by Harvey, Webb and Dowse (1993). They find that a new surgical unit for the treatment of

Table 2.2: Partial Equilibrium Results Under the Sufficient Conditions

Hospital k	Hospital i
$D_{M_k}S_k \mid_{\bar{S}_i} \equiv \theta_1 \geq 0$	$D_{M_i}S_i \mid_{\bar{S}_k} \equiv \beta_1 \geq 0$
$D_{P_s}S_k \mid_{\bar{S}_i} \equiv \theta_2 \leq 0$	$D_{P_s}S_i \mid_{\bar{S}_k} \equiv \beta_2 \leq 0$
$D_pS_k \mid_{\bar{S}_i} \equiv \theta_3 \gtreqless 0$	—
$D_{\bar{S}_i}S_k \equiv \theta_4 \leq 0$ and ≥ -1	$D_{\bar{S}_k}S_i \equiv \beta_4 \leq 0$ and ≥ -1

hernia and varicose veins had no impact on the number of hernia repairs done in the area while there was a net increase in the total service rate for varicose veins. The increase in the varicose vein service rate was similar in magnitude to the varicose vein service rate provided by the new surgical unit.

The sufficient assumptions imply that this comparative static result is bounded between zero and minus one. Under the consistent assumptions this result could be greater than zero, or, less than minus one. This means that k's reaction could amplify, or more than offset, the effect of an exogenous increase in S_i on the total service rate.

Results 2.6.1, 2.6.2, and 2.6.4 apply to hospital i as well as k. Table 2.2 reports the findings from this section under the sufficient assumptions. The θ's and β's introduced in Table 2.2 will be useful notation in the next section.

2.7 Nash Equilibrium

In a Nash equilibrium each hospital chooses an optimal service rate given the other hospital's service rate. To illustrate one possible adjustment process that describes the movement from one Nash equilibrium to another imagine an increase in hospital k's budget. Hospital k's partial equilibrium response is to increase its service rate. According to result 2.6.4 hospital i will react by decreasing its service rate and hospital k will react to the change in S_i by increasing its service rate. Each hospital will continuously react to the other and the market will approach a new Nash equilibrium. Each of the comparative static results of this section depends on hospital k's partial equilibrium response, hospital i's reaction, and hospital k's reaction.

A Nash equilibrium of this model can be derived by solving each hospital's first-order condition for an optimal service rate. The first-order conditions are called reaction functions because they show how the optimally chosen service rate at one hospital is related to the service rate at the other hospital. The two reaction functions can then be solved for the two optimally chosen service rates which by definition is a Nash equilibrium. Figure 2.7 illustrates two reaction functions and an associated Nash equilibrium. It is often difficult or impossible to find closed form solutions to the first-order conditions. The first-order conditions can, however, be totally differentiated and simultaneously solved giving comparative static results for a Nash equilibrium. This approach assumes that an interior Nash equilibrium with positive waiting times exists. Figure 2.8 illustrates a Nash equilibrium along with the associated waiting

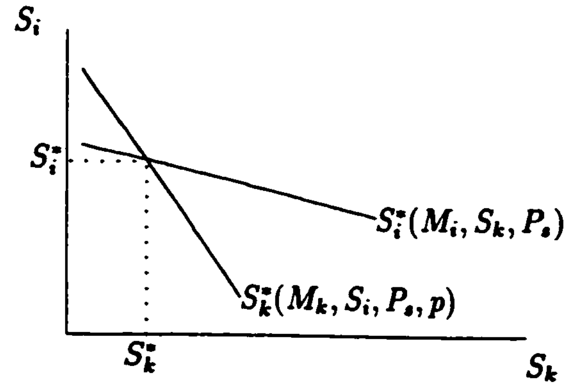

Figure 2.7: Reaction Functions

times and composite good provision.

Result 2.7.1 *When hospital k's budget is increased by one unit the total service rate will at least remain constant and at most increase by hospital k's service rate income effect.*

The proof of this result is in appendix 2.11. Equation 2.22 shows how the total service rate changes when hospital k's budget is increased. The signs of the θ and β parameters are reported in table 2.2 and were derived in section 2.6. The parameter θ_1 represents k's reaction to a unit increase in its budget, θ_4 represents k's reaction to a unit change in i's service rate and β_4 represents i's reaction to a unit change in k's service rate.

$$D_{M_k}(S_k + S_i) = \theta_1 \frac{1 + \beta_4}{1 - \theta_4 \beta_4} \tag{2.22}$$

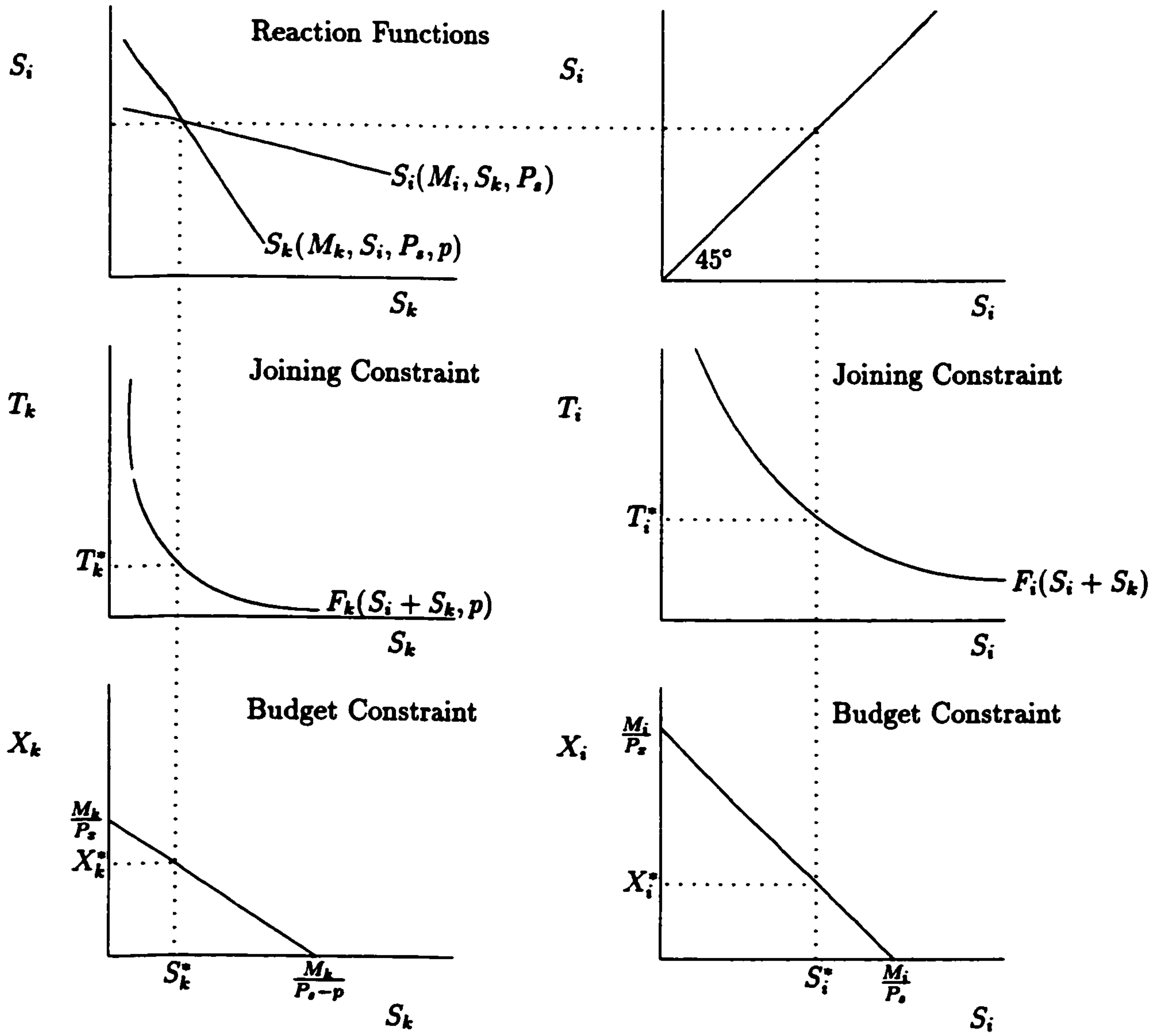

Figure 2.8: Nash Equilibrium

Hospital k's partial equilibrium response to an increase in its budget is positive. If hospital i almost completely offsets the increase in S_k and hospital k does not react, then, the change in the total service rate will be small. This is true even if k's partial equilibrium response to a unit increase in its budget is large.

In contrast, if hospital i does not offset changes in S_k the effect on the total service rate is equal to k's partial equilibrium response to a unit increase in its budget.

This result was derived under the sufficient assumptions. Under the consistent assumptions anything could happen to the total service rate when hospital k's budget is increased.

Result 2.7.2 *A large increase in the total service rate may not decrease the equilibrium waiting times much.*

A proof of this result is in appendix 2.11. Equations 2.23 and 2.24 show how the waiting times change when the total service rate changes. The sign of the term $D_{M_k}(S_k+S_i)$ was reported in the previous result. The sign of the term $D_1F_k(S_k+S_i,p)$ comes from result 2.5.3 and is a slope of the joining function.

$$D_{M_k}T_k = D_1F_k(S_k + S_i, p)D_{M_k}(S_k + S_i) \tag{2.23}$$

$$D_{M_k}T_i = D_1F_i(S_k + S_i)D_{M_k}(S_k + S_i) \tag{2.24}$$

If small changes in the waiting time attract many more patients, waiting times will not fall much even when the total service rate increases.

This result is consistent with evidence presented by Mackinnon, Smith and Dixon (1992). They observed an increase in an elective orthopaedic surgical rate which had no impact on the number of people waiting. In providing possible explanations of this result they state, "it is possible that the willingness to list patients for surgery was increased because of a perceived relaxation of pressure owing to the scheme. ... Well formulated plans can be upset by (unpredictable) events over which there is no control, or, indeed, understanding" (Mackinnon et al., 1992, p.7).

Result 2.7.3 *The direction of change in the total service rate resulting from a change in the price charged to patients depends on k's partial equilibrium response to the price change.*

The proof of this result is in appendix 2.11. Equation 2.25 represents this comparative static result. The parameter θ_3 represents hospital k's reaction to a unit increase in the price charged to patients. The parameter θ_4 represents how hospital k reacts to a change in i's service rate and β_4 represents how i reacts to a change in k's service rate. Result 2.6.4 shows that these two parameters are negative.

$$D_p(S_k + S_i) = \theta_3 \left[\frac{1+\beta_4}{1-\theta_4\beta_4}\right] \tag{2.25}$$

Result 2.6.3 demonstrated that hospital k's partial equilibrium response to a change in the price charged to patients could be positive or negative. Hospital k's partial equilibrium response to a change in p may be offset by the interaction effect between the two hospitals. The interaction effect will never be more than offsetting because neither hospital will more than offset the actions of the other.

Again, this result was derived under the sufficient conditions. Under the consistent conditions anything could happen because each hospital's response to a change in the other's service rate could be reinforcing or more than offsetting.

Result 2.7.4 *If k increases its service rate when the price charged to patients increases, the effect on the total service rate is at least zero and at most equal to k's partial equilibrium response.*

The proof of this result is in appendix 2.11. Result 2.7.4 considers the case where hospital k's partial equilibrium response to the price change is positive. If i offsets changes in S_k but k does not react, then the patient price effect on the total service rate will be very small. On the other hand, if i does not offset changes in S_k the patient price effect on the total service rate equals k's initial response to the price change.

Under the consistent conditions anything could happen as a result of the interaction between the two hospitals.

Result 2.7.5 *When the total service rate does not change in response to the price charged to patients the waiting time at k may fall. However, the waiting time at i will not change.*

Equation 2.26 shows how the waiting time at k changes when the price charged to patients increases. The term $D_p(S_k + S_i)$ comes from result 2.7.3. The terms

$D_1F_k(S_k + S_i, p)$ and $D_2F_k(S_k + S_i, p)$ come from results 2.5.3 and 2.5.5 and are slopes of the joining function.

$$D_pT_k = D_1F_k(S_k + S_i, p)D_p(S_k + S_i) + D_2F_k(S_k + S_i, p) \tag{2.26}$$

Equation 2.27 shows how the waiting time at i changes when the price charged to patients changes.

$$D_pT_i = D_1F_i(S_k + S_i)D_p(S_k + S_i) \tag{2.27}$$

This price change affects the waiting time through the hospitals' behaviour and through the behaviour of patients. Therefore, even if hospital k does not change its service rate the fact that patients who join at k face a higher price means that the waiting time at k will fall. Furthermore, if the total service rate remains constant, then changes in the price charged to patients will not affect T_i. Intuitively, the marginal individual must be indifferent between joining at i and not joining at all. The values of these two options do not change when p changes, therefore, if the total service rate is held constant the waiting time at hospital i will not change.

The following lists several possible comparative static results of the model.

- The effect of a change in hospital's k's budget on waiting times may be small if
  - k's partial equilibrium response to an increase in its budget is a small change in its service rate.
  - i offsets changes in S_k and k does not offset changes in S_i.

- Small changes in the waiting time results in a large change in the joining rate.

- Waiting times may actually increase when hospital k's budget is increased if
  - k's partial equilibrium response to an increase in its budget is a decrease in its service rate.
  - i more than offsets changes in S_k and k does not change its service rate when S_i changes.
- Increasing the price charged to patients at hospital k may not affect waiting times much if
  - hospital k does not change S_k much initially.
  - i offsets changes in S_k and k does not offset changes in S_i,
  - A decrease in waiting time results in a large change in the joining rate and the joining rate is not very price sensitive.
- Waiting times may actually increase when the price charged to patients increases if
  - S_k is initially decreased when p is increased.
  - i more than offsets increases in S_k and k does not offset changes in S_i.

2.8 Conclusions

As is probably clear by now it is difficult to suggest how a policy maker could induce the two hospitals to increase the total service rate unless one is willing to make specific assumptions about each hospital's utility function. Unfortunately, the sufficient assumptions are no more plausible than the consistent assumptions which imply that the model provides very few definitive predictions. The model suggests we should be cautious of any policy prescriptions that rely exclusively on financial incentives to bring down waiting time. Perhaps the model also serves as a challenge for economists to design better institutions for managing waiting lists.

This model predicts that if an increase in the total service rate is achieved then waiting times will fall. Increasing the total service rate may be difficult if hospitals choose to provide a lower service rate when their budget is increased. Furthermore, achieving an increase in the total service rate may require hospitals to co-operate with each other in order to overcome the externality in service rates and the incentives that hospitals impose on each other through joining constraints.

Achieving a significant decrease in waiting times will be difficult if there is a substantial increase in the joining rate in response to a decrease in waiting times. For example, patients who could benefit from elective surgery may choose to live with the problem when the waiting times are long. If small decreases in waiting times encourage many more patients to join the list, and hence increase the joining rate, then changes in total service rate will not be very effective at bringing waiting times down.

Ambiguity in the comparative static results arises in part because the second derivative of the distribution of valuations among potential joiners ($G''(V)$) is left unspecified. This seems plausible because in practice the change in the flow of potential joiners with an instantaneous valuation of V or less could be increasing or decreasing in V. Ambiguity in the results of the model also arises because there are different sets of assumptions concerning the hospital utility function that are consistent with the second order condition for a local maximum. Any one set of assumptions does not seem more plausible than the others.

The health services research literature suggests that uncertainty surrounding patient behaviour is a source of confusion and unexpected empirical results relating to waiting lists. This conjecture is consistent with the model presented here. Understanding patient behaviour is certainly valuable. However, this model illustrates that understanding the behaviour of hospitals, or other health care providing organizations, may be important as well.

Finally, this model assumes that a non-cooperative game describes the behaviour of hospitals as organizations. It is possible that in practice this non-cooperative game could be avoided through cooperative efforts which may lead to better outcomes in a market cleared by waiting lists. Perhaps there are mutually beneficial and enforceable agreements that hospitals could make that would unambiguously decrease waiting times. If this is true, governments aiming to decrease waiting times may want to avoid the unpredictability associated with the non-cooperative environment described above by creating a policy environment that fosters cooperation among health care providers.

2.9 Further Research

In practice goods could be rationed by preventing some individuals from joining a waiting list. For example, a physician playing the role of a gate-keeper to the health care system may not record the name of an elderly person on a list for a medical service. This paper has abstracted from this issue and focuses on rationing through discouraging demand by assuming that any individual can join a waiting list. Future research could extend the role of the physician as a gatekeeper to the health care system.

In this paper, order on a waiting list is maintained using a 'first come, first served' rule. In practice order could be established according to other rules. For example, order on a waiting list could be established according to patient need as judged by a physician. Furthermore, order established by any particular rule could be altered by political or financial means that would allow an individual to 'jump' in the order. Analyzing different methods of maintaining order raises issues concerning both equity and efficiency. This paper has abstracted from the issues surrounding order by assuming a 'first come first served' rule. Future research could explore the implications of alternative rules for maintaining order on a list.

This paper analyzes the situation where some of the costs are incurred when the consumer joins a waiting list and the rest of the costs, along with all of the benefits, are incurred when the consumer reaches the top of a list. In practice individuals could face many different costs and benefits whose timing could be altered by waiting times. For example, an individual who could benefit from a hip replacement may wait some time before consulting their general partitioner. They may also have to wait for an initial consultation with a specialist, for medical tests to be completed, and for the hip replacement surgery. More complicated cost and benefit scenarios could also be a topic for future research.

It is important to note that this paper compares different steady state waiting times. In the steady state an individual who chooses not to join a list will never reconsider their choice because by definition of the steady state waiting times are not changing. However, if waiting times are decreasing as the market moves from one steady state to another some individuals who have decided not to join could reconsider and join a list. This is not an issue if waiting times are increasing because any potential joiner whose condition is stable and who chooses not to join at relatively shorter waiting times will not reconsider and join when waiting times are longer. Future research could explore movements between steady state equilibria rather than simply comparing them. It would be particulary interesting to know the conditions under which a steady state can be reached at all.

It may also be informative to model the situation in which patients have no choice but to join a waiting list. In this case the joining constraint is horizontal and given a service rate at one hospital there is only one service rate at the other hospital that will result in a steady state equilibrium. Finally, future research could introduce uncertainty into the model developed in this paper.

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2.11 Appendix

By substituting k's joining constraint and k's budget constraint into k's utility function we can get an objective function that depends only on the service rate that k chooses. Equation 2.28 represents this objective function.

$$U_k(S_k, \Gamma_k - F_k(S_i + S_k, p), M_k - (P_s - p)S_k) \tag{2.28}$$

Differentiating hospital k's objective function with respect to the service rate and setting the derivative equal to zero gives the first order condition as presented in equation 2.29. The parameter P_x is normalized to one. This first order condition is written under the assumption that the optimal service rate is not equal to zero.

$$\begin{aligned}
&D_1U_k(S_k, \Gamma_k - F_k(S_i + S_k, p), M_k - (P_s - p)S_k) \\
&-D_2U_k(S_k, \Gamma_k - F_k(S_i + S_k, p), M_k - (P_s - p)S_k) \cdot D_1F_k(S_i + S_k, p) \\
&-D_3U_k(S_k, \Gamma_k - F_k(S_i + S_k, p), M_k - (P_s - p)S_k) \cdot (P_s - p) = 0
\end{aligned} \tag{2.29}$$

Differentiating the first derivative of the objective function with respect to the service rate and requiring that this derivative be less than or equal to zero gives the second order condition as presented in equation 2.30.

$$\begin{aligned}
&D_{1,1}U_k + D_{2,2}U_k[D_1F_k]^2 + D_{3,3}U_k \cdot (P_s - p)^2 \\
&-D_2U_k \cdot D_{1,1}F_k - 2D_{2,1}U_k \cdot D_1F_k - 2D_{3,1}U_k \cdot (P_s - p) \\
&+2D_{3,2}U_k \cdot (P_s - p) \cdot D_1F_k \leq 0
\end{aligned} \tag{2.30}$$

The following assumptions are sufficient to ensure that the second order condition holds. In the text of the paper I refer to these assumptions as the "sufficient assumptions".

$$D_{1,1}U_k < 0 \quad D_{2,2}U_k < 0 \quad D_{3,3}U_k < 0$$
$$D_{1,1}F_k > 0 \quad D_{2,1}U_k < 0 \quad D_{3,1}U_k > 0 \tag{2.31}$$
$$D_{3,2}U_k > 0$$

The following assumptions are consistent with the second order condition. Unlike the sufficient assumptions this set of assumptions do not ensure that the second order condition holds. In the text of the paper I refer to these assumptions as the "consistent assumptions".

$$D_{1,1}U_k < 0 \quad D_{2,2}U_k < 0 \quad D_{3,3}U_k < 0$$
$$D_{1,1}F_k > 0 \quad D_{2,1}U_k > 0 \quad D_{3,1}U_k < 0 \tag{2.32}$$
$$D_{3,2}U_k < 0$$

The first three sufficient assumptions are the same as the first three consistent assumptions. Each of these three assumptions imply that the marginal utility of a good decreases as more or the good is used. For example, if more of the composite good is used then the marginal utility of the composite good falls. The fourth sufficient assumption is the same as the fourth consistent assumption and will be discussed in detail below.

Each of the last three consistent assumptions are that the second cross partial derivatives have the opposite sign of those made under the sufficient assumptions. For example, according to the sufficient assumptions the marginal utility of the composite good increases as the service rate grows while under the consistent assumptions the marginal utility of the composite good decreases as the service rate grows. The sufficient assumptions were made because they are easy to work with and are commonly made in economics. The consistent assumptions were made because they are equally plausible and they broaden the predictions of the model substantially. The fact the consistent assumptions rule out very few predictions suggests that there is little value in considering a third set of assumptions.

Proof of Result 2.5.2

Setting V_k^m equal to V^m and $J = S_i + S_k$ and then solving equations 2.15 and 2.19 for T_k gives the joining constraint represented by equation 2.33.

$$T_k = \frac{1}{g}\ln\left(\frac{G^{-1}(N - S_i - S_k) - (c_r + p)}{c_j}\right) \equiv F_k(S_i + S_k, p) \qquad (2.33)$$

Similar steps can be applied to derive the waiting time at i function.

$$T_i = \frac{1}{g}\ln\left(\frac{G^{-1}(N - S_i - S_k) - c_r}{c_j}\right) \equiv F_k(S_i + S_k) \qquad (2.34)$$

Proof of Result 2.5.3

Differentiating the joining constraint with respect to the total service rate gives equation 2.35.

$$D_1F_k(S_i + S_k, p) = \frac{-c_jG^{-1\prime}(N - S_i - S_k)}{gG^{-1}(N - S_i - S_k) - g(c_r + p)} \qquad (2.35)$$

Setting $J = S_i + S_k$ defines a steady state. Substituting the steady state condition into equation 2.19 and solving for V^m gives $V^m = G^{-1}(N - S_i - S_k)$. A lower service rate results in a higher flow of individuals who do not join in the steady state and hence a higher marginal valuation. This means that $G^{-1\prime}(N - S_i - S_k)$ is positive, the cost of joining a list c_j is positive as well, and therefore the numerator is negative.

Using $V^m = G^{-1}(N - S_i - S_k)$ we can write the denominator of equation 2.35 as $g(V^m - c_r - p)$. The marginal instantaneous valuation must be bigger than the net cost incurred by patients when the service is received otherwise the marginal individual would be better off not joining. The decay rate g is positive by definition; therefore the denominator is positive and the joining function is downward sloping.

Proof of Result 2.5.4

Earlier in this paper it was assumed that the change in the waiting times shrinks as the total service rate grows. Here I show that this may very well be true but that that are no intuitive reasons that support, or reject, this assumption. In other words the second derivative of the joining function could reasonably be positive or negative. Differentiating equation 2.35 with respect to the total service rate gives equation 2.36.

$$D_{1,1}F_k(S_i + S_k, p) = \tag{2.36}$$
$$\frac{[G^{-1}(N - S_i - S_k) - (c_r + p)]c_j G^{-1\prime\prime}(N - S_i - S_k) - c_j G^{-1\prime}(N - S_i - S_k)^2}{g[G^{-1}(N - S_i - S_k) - (c_r + p)]^2}$$

If $G(V^m)$ were linear this second derivative of the joining function would be negative. From the above we know that $(G^{-1}(N - S_i - S_k) - c_r - p)c_j$ is positive. Therefore, if $G^{-1\prime\prime}(N - S_i - S_k)$ is sufficiently large and positive, or equivalently, $G''(V)$ is sufficiently large and negative then the second derivative of the joining function will be positive. Unfortunately there are no intuitive reasons that suggest the potential joiners value function $(G(V))$ is a particular shape apart from the fact that it is upwards sloping.

Both the sufficient and consistent assumptions assume that the second derivative of the joining function with respect to the total service rate is negative. As mentioned earlier these assumptions imply a very wide range of results and there seems to be little value in extending this further by relaxing the assumption that right hand side of equation 2.36 is positive.

Proof of Result 2.5.5

Differentiating the joining constraint with respect to the price charged to patients gives equation 2.37.

$$D_2F_k(S_i + S_k, p) = \frac{-c_j}{gG^{-1}(N - S_i - S_k) - g(c_r + p)} \tag{2.37}$$

The cost of joining a list is positive and from the discussion of equation 2.5.3 we know that the denominator is positive as well. Therefore, the change in the waiting time due to a unit change in the price charged to patients is negative.

Differentiating equation 2.35 with respect to the price charged to patients gives equation 2.38.

$$D_{1,2}T_k(S_i + S_k, p) = \frac{-c_j}{g[G^{-1}(N - S_i - S_k) - (c_r + p)]^2} \tag{2.38}$$

This cross partial derivative is negative because c_j and g are positive.

Proof of Result 2.6.1

Totally differentiating the first order condition with respect to S_k and M_k and solving for the derivative of S_k with respect to M_k gives equation 2.39.

$$D_{M_k}S_k \mid_{\bar{S}_i} = \frac{-D_{1,3}U_k + D_{2,3} \cdot U_k D_1 F_k + D_{3,3}U_k \cdot (P_s - p)}{\text{S.O.C.}_{\cdot k}} \tag{2.39}$$

The term S.O.C.$_{\cdot k}$ represents hospital k's second order condition. A bar over a variable indicates that it is fixed. According to the sufficient assumptions this derivative is positive. According to the consistent assumptions the sign of this derivative is ambiguous. For example, if $D_{1,1}U_k$, $D_{2,2}U_k[D_1F_k]^2$ and $D_2U_k \cdot D_{1,1}F_k$, (the first two terms are assumed to be negative and the third is assumed to be positive) are all a long distance from zero then the second order condition will hold. The term $D_{3,3}U_k(P_s - p)$ is also assumed to be negative and if it is a long distance from zero equation 2.39 is positive. In contrast, if $D_{3,3}U_k(P_s - p)$ is close to zero equation 2.39 is negative. If the terms $D_{1,1}U_k$, $D_{2,2}U_k[D_1F_k]^2$, $D_{3,3}U_k(P_s - p)$ and $D_2U_k \cdot D_{1,1}F_k$ are all relatively close to zero then the second order condition does not hold.

Proof of Result 2.6.2

Totally differentiating the first order condition with respect to S_k and P_s and then solving for the derivative of S_k with respect to P_s, and using equation 2.39, gives equation 2.40.

$$D_{P_s}S_k\mid_{\bar{S}_i} = \frac{D_3U_k}{\text{S.O.C.}_{\cdot k}} - S_k \cdot D_{M_k}S_k\mid_{\bar{S}_i} \tag{2.40}$$

According to the sufficient assumptions this derivative is negative. According to the consistent assumptions this derivative could be positive but only if the income effect outweighs the substitution effect.

Proof of Result 2.6.3

Totally differentiating the first order condition with respect to S_k and p and then solving for the derivative of S_k with respect to p and substituting in equation 2.40

gives equation 2.41.

$$D_pS_k\,|_{\bar{S}_i} = \frac{\begin{pmatrix} D_{1,2}U_k \cdot D_2F_k - D_{2,2}U_k \cdot D_2F_k \cdot D_1F_k \\ +D_2U_k \cdot D_{1,2}F_k - D_{3,2}U_k \cdot D_2F_k \cdot (P_s - p) \end{pmatrix}}{\text{S.O.C.}_k} - \left(D_{P_s}S_k\,|_{\bar{S}_i}\right) \tag{2.41}$$

According to the sufficient assumptions and the consistent assumptions this derivative is ambiguous. As suggested earlier the term $D_{P_s}S_k\,|_{\bar{S}_i}$ could be positive or negative which means that the left hand side of eqution 2.41 could be positive or negative as well. Under both the sufficient assumptions and the consistent assumptions the first term on the right hand side of equation 2.41 can not be signed either. Under the sufficient assumptions the second order condition holds and if the term $D_2U_k \cdot D_{1,2}F_k$ (the term is assumed to be negative) is a long way from zero the first term on the right hand side of equation 2.41 is positive. In contrast, if $D_2U_k \cdot D_{1,2}F_k$ is close to zero then the first term on the right hand side of equation 2.41 is negative.

Under the consistent assumptions, if $D_{2,2}U_k$ (which is assumed to be negative) is a long way from zero then the second order condition will hold and the numerator of the first term on right hand side of equation 2.41 is positive. This means that the first term is negative. In contrast, if $D_{2,2}U_k$ is close to zero and $D_{1,1}U_k$, $D_{3,3}U_k(P_s - p)^2$ (these two terms are assumed to be negative) and $D_2U_k \cdot D_{1,1}F_k$ (this term is assumed to be positive) are each a long way from zero then second order conditions are satisfied and the first term on the right hand side of equation 2.41 is positive. There are situations where the second order condition does not hold under the consistent assumtions. In summary, according to the sufficient assumptions the left hand side of equation 2.41 is between zero and minus one and according to the consistent assumptions the the left hand side of equation 2.41 could be less than minus one or greater than minus one.

Proof of Result 2.6.4

Differentiating k's first order conditions with respect to S_k and $\bar{S}_i$ and then solving for the derivative of S_k with respect to $\bar{S}_i$ gives equation 2.42.

$$D_{\bar{S}_i} S_k = \frac{\begin{pmatrix} D_{1,2}U_k \cdot D_1 F_k + D_2 U_k \cdot D_{1,1} F_k \\ -D_{2,2}U_k \cdot D_1 F_k^2 - D_{3,2}U_k \cdot (P_s - p) D_1 F_k \end{pmatrix}}{\text{S.O.C.}_{\cdot k}} \tag{2.42}$$

According to the sufficient assumptions this derivative is between zero and minus one. One way to demonstrate that the sufficient assumptions imply that the derivative is greater than minus one is to assume that the right hand side of equation 2.42 is greater than minus one, collect like terms, and then compare this finding to the sufficient assumptions. Writing down the assumption that the right hand side of equation 2.42 is greater than minus one and collecting like terms gives equation 2.43.

$$0 < D_{2,1}U_k \cdot D_1 F_k - D_{3,2}U_k (P_s - p) D_1 F_k - D_{1,1}U_k - D_{3,3}U_k (P_s - p)^2 + 2D_{3,1}U_k (P_s - p) \tag{2.43}$$

According to the sufficient conditions equation 2.43 holds. However, under the consistent conditions equation 2.43 may not hold. For example, if the first derivative of the joining function $(D_1 F_k)$ is a large amount less then zero, then equation 2.43 will be false and provided that $D_{2,2}U_k[D_1F_k]^2$ is a large amount less than zero the second order condition is satisfied.

To demonstrate that the sufficient assumptions imply that the derivative is less than zero assume that the right hand side of equation 2.42 is less than zero, collect like terms, and then compare this finding to the sufficient assumptions. Writing down the assumption than the right hand side of equation 2.42 is less than zero and simplifying the terms gives equation 2.44.

$$0 < D_{1,2}U_k \cdot D_1F_k + D_2U_k \cdot D_{1,1}F_k - D_{2,2}U_k \cdot D_1F_k^2 - D_{3,2}U_k(P_s - p)D_1F_k \quad (2.44)$$

According to the sufficient conditions equation 2.44 holds. However, under the consistent conditions equation 2.44 may not hold. For example, if the first derivative of the joining function (D_1F_k) is a large amount less than zero and $D_{2,2}U_k$ is close to zero then equation 2.44 will not hold. Provided that $D_{3,3}U_k(P_s - p)$ is a long way from zero then the second order condition holds. If the term $D_{3,3}U_k(P_s - p)$ is close to zero then the second order condition may not hold.

Proof of Result 2.7.1

To prove this result, and the following ones, I use the symbols which were defined in table 2.2. The information in table 2.2 is re-reported in table 2.3 in this section. Differentiating the two first order conditions with respect to S_k, S_i and M_k and then rearranging will give equations 2.45 and 2.46 where d represents the differential.

$$dS_k - \theta_1 dM_k - \theta_4 dS_i = 0 \quad (2.45)$$

Table 2.3: Partial Equilibrium Results Under the Sufficient Conditions

Hospital k	Hospital i
$D_{M_k}S_k \mid_{\bar{S}_i} \equiv \theta_1 \geq 0$	$D_{M_i}S_i \mid_{\bar{S}_k} \equiv \beta_1 \geq 0$
$D_{P_s}S_k \mid_{\bar{S}_i} \equiv \theta_2 \leq 0$	$D_{P_s}S_i \mid_{\bar{S}_k} \equiv \beta_2 \leq 0$
$D_pS_k \mid_{\bar{S}_i} \equiv \theta_3 \gtrless 0$	—
$D_{\bar{S}_i}S_k \equiv \theta_4 \leq 0$ and ≥ -1	$D_{\bar{S}_k}S_i \equiv \beta_4 \leq 0$ and ≥ -1

$$dS_i - \beta_4 dS_k = 0 \tag{2.46}$$

Equations 2.45 and 2.46 imply that equations 2.47 and 2.48 hold.

$$D_{M_k}S_k = \frac{\theta_1}{1 - \theta_4\beta_4} \tag{2.47}$$

$$D_{M_k}S_k = \frac{\theta_1\beta_4}{1 - \theta_4\beta_4} \tag{2.48}$$

Adding equations 2.47 and 2.48 together gives the equation 2.49 which is the one we are interested in.

$$D_{M_k}(S_i + S_k) = \theta_1 \frac{1 + \beta_4}{1 - \theta_4\beta_4} \tag{2.49}$$

Under the sufficient assumptions equation 2.49 is greater than or equal to zero and under the consistent assumptions the sign of equation 2.49 is unrestricted.

Proof of Result 2.7.2

Differentiating equation 2.33 with respect to M_k gives equation 2.23. Equation 2.24 is derived in a similar manner except p is equal to zero. Equations 2.23 and 2.24 are repeated in the next two equations.

$$D_{M_k}T_k = D_1F_k(S_k + S_i, p)D_{M_k}(S_k + S_i) \tag{2.50}$$

$$D_{M_k}T_i = D_1F_i(S_k + S_i)D_{M_k}(S_k + S_i) \tag{2.51}$$

The proof of result 2.5.3 shows that $D_1F_k(S_k + S_i, p)$ is negative. Similarly one can show that $D_1F_i(S_k+S_i)$ is negative. The proof of result 2.7.1 shows that $D_{M_k}(S_k+S_i)$ is greater than or equal to zero under the sufficient assumptions. The term $D_{M_k}(S_k + S_i)$ cannot be signed under the consistent assumptions.

Proof of Result 2.7.3

Differentiating the two first order conditions with respect to S_k, S_i and p and then rearranging will give equations 2.52 and 2.53 where d represents the differential.

$$dS_k - \theta_3 dp - \theta_4 dS_i = 0 \tag{2.52}$$

$$dS_i - \beta_4 dS_k = 0 \tag{2.53}$$

Equations 2.52 and 2.53 imply that equations 2.54 and 2.55 hold.

$$D_pS_k = \frac{\theta_3}{1 - \theta_4\beta_4} \tag{2.54}$$

$$D_pS_k = \frac{\theta_3\beta_4}{1 - \theta_4\beta_4} \tag{2.55}$$

Adding equations 2.54 and 2.55 together gives the equation 2.56 which is the one we are interested in.

$$D_p(S_i + S_k) = \theta_3 \left[\frac{1 + \beta_4}{1 - \theta_4\beta_4}\right] \tag{2.56}$$

Equation 2.56 cannot be signed under the sufficient assumptions or the consistent assumptions. Under the sufficient assumptions the term in square brackets is positive; however, θ_3 could be positive, negative or equal to zero. Under the consistent assumptions neither θ_3 or the term in square brackets can be signed.

Proof of Result 2.7.4

Under the sufficient assumptions the term in square brackets in equation 2.56 is positive. If we assume that θ_3 is also positive then the change the total service rate resulting from a change in p is positive. Under the consistent assumptions the term in square brackets cannot be signed.

Chapter 3

An Evaluation of Alternative Econometric Specifications for Estimating a Tobacco Budget Share Equation: Introduction

Tobacco consumption offers an important opportunity to investigate the relationships among the biology of addiction, consumer preferences, health and well being. Tobacco is notable because it is one of the few physically addictive goods for which large amounts of purchasing and consumption data are available.

The chronological development of this project differs from the order in which the paper has been written. I began with a cross sectional data set on tobacco expenditures, which was collected over a number of years. The objective was to estimate a tobacco budget share equation. The literature suggested three specifications that one might use to estimate a tobacco budget share equation. It was not clear which one was most appropriate. Therefore I took a step back and worked on developing an intuitively appealing tobacco purchasing model that is useful for comparing the three specifications.

A story can be a simple, though unrealistic, vehicle for gaining a concrete and intuitive understanding of complex ideas. In a similar way a behavioural model can be a vehicle for gaining a concrete and intuitive understanding of complex behaviour and the corresponding econometric specifications. In this paper I use a simple model of behaviour as a reference point for comparing three specifications. A primary objective is to identify the similarities and differences between three econometric specifications that have often been applied to tobacco data.

In the econometrics literature three specifications have been applied to cross sectional and pseudo-panel data relating to tobacco consumption. They are called the two-part specification, the sample-selection specification[1] and the double-hurdle specification. The behavioural model I develop serves as a reference point for comparing these specifications. This reference point is not neutral in that some other behavioural model may provide other useful insights and in the future other researchers may want to provide alternative behavioural models. A data set that reports expenditures on

[1]The sample-selection specification has also been called a Heckman sample-selection specification.

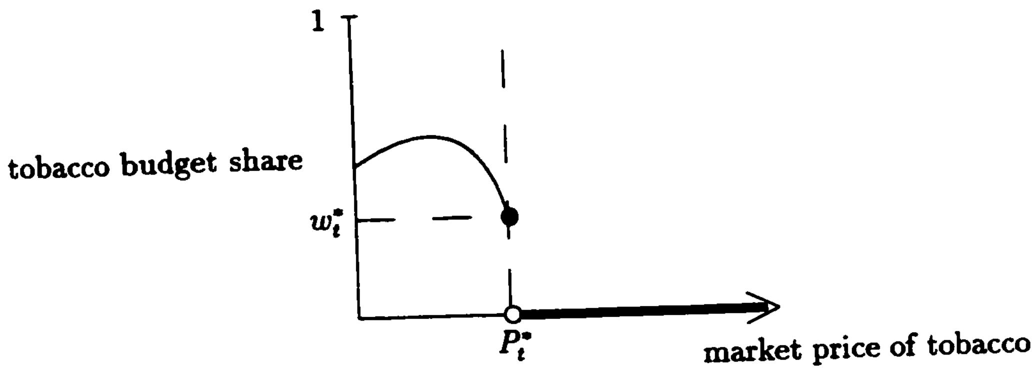
tobacco is used to compare the results obtained by applying different specifications. Because the data set reports tobacco expenditures the dependent variable is the budget share of expenditures on tobacco.

Three specifications are compared in five different ways. First I develop a behavioural model as a common underlying framework to inform the econometric specifications. I then survey the literature which compares the two-part specification to the sample-selection specification. This survey will demonstrate why it has been difficult to develop a clear understanding of the similarities and differences between these two specifications. I also review the economic literature on tobacco that compares the two-part, sample-selection and double-hurdle specifications. Next I describe a nesting structure which Yen and Jones (1996) have developed for comparing statistically specifications that have been applied to tobacco data. I then describe the data set used in the analysis, apply the tests that Yen and Jones (1996) apply and discuss the parameter estimates and policy implications obtained. The final section summarises these five comparisons.

3.1 A Behavioural Model

Analysing the relationship between tobacco purchases and a set of explanatory variables is challenging because tobacco is a physically addictive substance and there are many individuals who purchase no tobacco. Some people who purchase no tobacco would purchase some if they faced a lower market price. For these individuals it is

Figure 3.1: Tobacco budget share



plausible to suggest that tobacco enters their utility function as a good. Such individuals will take the price of tobacco as given and make choices between tobacco and other goods that are substitutes or complements. Other people view tobacco as a bad rather than a good. These people would choose to purchase no tobacco regardless of their budget constraint and the market price of tobacco products.

For those who view tobacco as a good. Figure 3.1 illustrates a plausible relationship between an individual's tobacco budget share and market prices. If the market price of tobacco is less than or equal to P_t^* then individual t will choose to purchase some tobacco. If the market price of tobacco is greater than P_t^* then individual t will choose to purchase no tobacco. The important thing to note is that at P_t^* a marginal increase in the price tobacco causes the tobacco budget share to jump from a strictly positive amount down to zero.

In order to keep things simple this model is static in that individuals choose one consumption level. This is in contrast to Becker and Murphy's model of rational addiction (1988), a seminal paper on the dynamics of tobacco consumption. One of the implications of the rational addiction model is that current tobacco consumption will depend on past and future tobacco consumption as well as past and future prices. The data employed in this paper do not report each individual's past and future tobacco consumption and the past and future prices. Therefore, a static model is presented in order to compare three specifications that can be applied to such a data set.

The sudden drop in the budget share at P_t^* allows for simple heterogeneity of preferences that would not be accounted for in a model that assumes each person's tobacco budget share is a continuous function of the market price. There is nothing unique or unusual about Figure 3.1 in that a sudden drop in the budget share at P_t^* is intuitively plausible for a wide range of goods that consumers purchase. The sudden drop in this figure accounts for the fact that groups of individuals who are very similar in terms of their explanatory variables may contain some individuals who purchase no tobacco and others who spend a strictly positive proportion of their budget on tobacco. For example, one consumer may have a reservation price that is marginally higher than market price and therefore spend a strictly positive proportion of their budget on tobacco. Another very similar consumer who faces the same market price may have a slightly lower reservation price and therefore purchase no tobacco.

A number of explanatory variables may influence whether a person purchases tobacco or not. With this in mind let $I_t^\dagger$ represent the net utility gained by individual

t when he or she purchases some tobacco[2]. The value of each $I_t^\dagger$ will not be observed in a data set. Those who purchase some tobacco will have a strictly positive $I_t^\dagger$ and those who purchase no tobacco will have a $I_t^\dagger$ that is less than or equal to zero.

The data set exploited in this study reports tobacco budget shares. Equations 3.1 and 3.2 identify the relationship between the model described above and the data set. Let w_t represent individual t's tobacco budget share. By definition

$$\text{if } I_t^\dagger \leq 0 \text{ then } w_t = 0 \tag{3.1}$$

$$\text{if } I_t^\dagger > 0 \text{ then } w_t > 0 \tag{3.2}$$

This standard economic model accounts for the fact that groups of individuals with very similar explanatory variables may consist of some people who purchase no tobacco and others who purchase a strictly positive amount.

The two-part, sample-selection and double-hurdle specifications are three different ways of accounting for the fact that there may be groups of observations in a data set that have very similar explanatory variables, with some observations reporting no tobacco expenditure and others reporting a strictly positive amount. In comparing the two-part, sample-selection and double-hurdle specifications it is valuable to recognise that some people who purchase no tobacco see tobacco as a good and others see tobacco as a bad.

[2]Davidson and MacKinnon suggest that an endogenous indicator variable may represent the sign of a net utility index (1993 p.514).

3.2 Three Specifications

The following three sub-sections describe a two-part specification, a sample-selection specification and a double-hurdle specification. The fourth sub-section discusses variations of these three specifications that have been used in the applied tobacco demand literature. The behavioural model will be used to describe each specification.

3.2.1 Two-Part

The following two equations describe a basic version of a two-part specification.

$$I_t^\dagger = x1_t \cdot \delta + \psi_t, \tag{3.3}$$

$$\ln(w_t) = \begin{cases} x2_t \cdot \theta + \mu_t & \text{if } x1_t \cdot \delta + \psi_t > 0 \\ -\infty & \text{otherwise} \end{cases} \tag{3.4}$$

The subscript t indexes each observation, there are a total of T observations. The term $x1_t$ is a row vector of observed explanatory variables for individual t and δ is an unobserved parameter vector that determines $I_t^\dagger$. The letter ψ_t in equation 3.3 is an unobserved random error term. The data set does not identify anyone's $I_t^\dagger$; however the data set does report each w_t. Equations 3.3 and 3.4 state that $I_t^\dagger$ is positive when w_t is positive and $I_t^\dagger$ is negative when w_t is equal to zero. Researchers can estimate equation 3.3 as a probit equation (Davidson and MacKinnon 1993, p.514-515) which is written as:

$$\Pr(I_t^\dagger > 0) = \Phi(x1_t \cdot \delta) \tag{3.5}$$

The left-hand side of this equation represents the probability that an individual purchases tobacco. The term $\Phi(\cdot)$ represents the cumulative standard normal distribution. This follows from assuming that ψ_t is a standard normal variate. Equation 3.4 determines the proportion of an individual's budget that is spent on tobacco if he or she purchases some tobacco. The term $\ln(w_t)$ represents the natural logarithm of the individual's observed tobacco budget share. The term $x2_t$ is a row vector of observed explanatory variables associated with individual t and θ is a parameter vector which is to be estimated. The term μ_t is an unobserved random error term. If an individual is not a tobacco purchaser then $\ln(w_t) = -\infty$ which implies that none of their budget is spent on tobacco ($w_t = 0$).

The key statistical assumptions in estimating these two equations are that $E(\mu_t \mid x1_t \cdot \delta + \psi_t > 0) = 0$ and that $(\mu_t \mid x1_t \cdot \delta + \psi_t > 0)$ is conditionally independent of the decision to purchase tobacco. It has been suggested that this specification implies sequential decision making because one can imagine that ψ_t is first realised and then depending on the value of ψ_t the random variable μ_t may be realised as well. Under the assumptions stated above, θ in equation 3.6 can be estimated consistently by ordinary least squares using only the observations with positive tobacco budget shares.

$$\ln(w_t \mid x1_t \cdot \delta + \psi_t > 0) = x2_t \cdot \theta + \mu_t \tag{3.6}$$

Mathematically the specification implies that the tobacco budget share could be greater than one. However, as very few of the observed tobacco budget shares are close to one, estimates based on this specification will suggest that this is unlikely. The two-part specification accounts for the fact that two very similar individuals, in terms of their $x1_t$ and $x2_t$ values, could be observed in the data set, one that purchases no tobacco and another that spends a high proportion of their budget on tobacco.

If in the future a change in one or more of the explanatory variables resulted in a new group of tobacco consumers who are similar to those previously observed purchasing tobacco then the conditional two-part specification may accurately identify who is likely to purchase some and who is likely to purchase a relatively large amount given that they purchase some. The two-part specification involves the conjecture that those who were observed purchasing tobacco in the past are similar to those currently purchasing tobacco. For example, if the price of tobacco dropped below the levels that had been observed in the past then the two-part specification uses the strictly positive observations to make conjectures about how much the new consumers would purchase conditional on positive purchases.

One alternative to this conjecture would be to ask each observation, how much tobacco would you purchase at each and every possible market price? Answers to this question would identify the relationship between market prices and tobacco budget shares among those who have been observed purchasing none in the past. In the absence of this question one could apply a sample-selection specification in order to address this issue.

3.2.2 Sample-Selection

Equations 3.7 to 3.9 describe a sample-selection specification.

$$I_t^{\dagger} = x1_t \cdot \delta + \psi_t \tag{3.7}$$

$$\ln(w_t^{\dagger}) = x2_t \cdot \alpha + \mu_t \tag{3.8}$$

$$\ln(w_t) = \begin{cases} x2_t \cdot \alpha + \mu_t & \text{if } x1_t \cdot \delta + \psi_t > 0 \\ -\infty & \text{otherwise} \end{cases} \tag{3.9}$$

Equation 3.7 is interpreted in the same way as equation 3.3 in the two-part specification and can be estimated as a probit equation. The probit equation can be thought of as a hurdle that must be passed before a strictly positive tobacco budget share is observed in the data. In order to link the behavioural model to equations 3.8 and 3.9 consider the following story. The letter $w_t^{\dagger}$ represents the tobacco budget share that is observed in the data set when an individual has passed the probit hurdle. Among those who purchase no tobacco the letter $w_t^{\dagger}$ represents the tobacco budget share that would have been observed if they had passed the probit hurdle.

In estimating the sample-selection specification it is often assumed that the unobserved variables ψ_t and μ_t are generated by a bivariate normal distribution with $E(\psi_t) = 0$, $E(\mu_t) = 0$, $\mathrm{Var}(\psi_t) = 1$, $\mathrm{Var}(\mu_t) = \sigma^2$ and $\mathrm{Corr}(\psi_t, \mu_t) = \rho$.

Under these assumptions, if one observed δ then one could estimate α and $\rho\sigma$ in equation 3.10.

$$E[\ln(w_t \mid I_t^{\dagger} > 0)] = x2_t \cdot \alpha + \rho\sigma \frac{\phi(x1_t \cdot \delta)}{\Phi(x1_t \cdot \delta)} + \epsilon_t \tag{3.10}$$

The term $\phi(\cdot)$ represents a standard normal density function and $\Phi(\cdot)$ represents the cumulative standard normal distribution. The term $\rho\sigma\frac{\phi(\cdot)}{\Phi(\cdot)}$ is $E(\mu_t \mid I_t^{\dagger} > 0)$, so $E(\epsilon_t \mid I_t^{\dagger} > 0) = 0$. Equation 3.7 could be estimated as a probit equation. The resulting estimates of δ could then be used to construct the term $\frac{\phi(x1_t \cdot \hat{\delta})}{\Phi(x1_t \cdot \hat{\delta})}$ for each observation with a strictly positive w_t. Equation 3.10 could then be estimated by ordinary least squares using only observations with a strictly positive w_t. This is Heckman's two step procedure[3]. Heckman's two step procedure does not produce the most accurate estimates of a sample-selection specification in that lower asymptotic variance can be achieved by a more cumbersome maximum likelihood procedure.

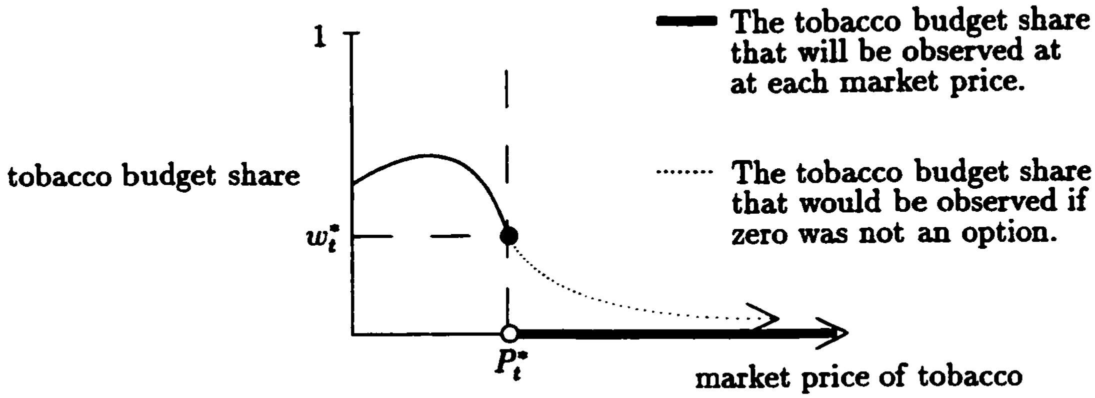
Equation 3.10 has a relatively clear intuitive interpretation. The α vector represents the unconditional relationship between $w_t^{\dagger}$ and the explanatory variables. The term $\hat{\rho\sigma}\frac{\phi(x1_t \cdot \hat{\delta})}{\Phi(x1_t \cdot \hat{\delta})}$ represents an indirect relationship between the explanatory variables and the conditional budget share. For example if the price of tobacco, represented

[3]This description of Heckman's two step procedure is taken from Greene (1993, p.711).

by one of the elements of $x2_t$, falls individuals will have incentive to increase their $w_t^\dagger$, an effect represented the corresponding α term. The lower price will also alter the value of $I_t^\dagger$ and indirectly alter the expected conditional tobacco budget share in equation 3.10 through the added regressor. The magnitude of the indirect effect will be determined by σ, ρ and δ. If the two error terms are not correlated ($\rho = 0$) then the expected value of the conditional tobacco budget shares depends only on $x2_t \cdot \alpha + \mu_t$. Equation 3.10 demonstrates that the unconditional budget share parameter estimates ($\hat{\alpha}$), the probit equation parameter estimates ($\hat{\delta}$), the estimated correlation between the twc error terms ($\hat{\rho}$) and the estimated standard deviation of the unconditional tobacco budget share random error term ($\hat{\sigma}$) can be used to examine the conditional relationship between tobacco budget shares and the explanatory variables. Under the sample-selection specification the probit equation parameters determine who is observed purchasing tobacco and hence they also determine the relationship between the strictly positive tobacco budget shares that are observed and the explanatory variables.

As mentioned earlier the two-part specification uses observations that report strictly positive tobacco budget shares to make conjectures about the relationship between the strictly positive tobacco budget shares and the explanatory variables. Equation 3.10 identifies how the sample-selection specification makes use of all observations, and the estimated correlation between the two error terms, to make conjectures about the relationship between the strictly positive tobacco budget shares

Figure 3.2: Sample-selection specification



and the explanatory variables.

Figure 3.2 represents the relationship between the price of tobacco and a budget share when the price of tobacco is in $x1_t$ and $x2_t$. The letter P_t^* represents the level at which a small increase in the price of tobacco, ceteris paribus, would result in the tobacco budget share jumping from a strictly positive number down to zero. If an individual faces a market price that is higher than their reservation price (P_t^*) data analysts could ask this person, "how much tobacco would you purchase if zero were not an option?" The answer to this question is not in the data set. The sample-selection specification uses all observations to make a conjecture about how much tobacco would be purchased by those who have been observed purchasing none if they passed the probit hurdle. In other words for those who were observed purchasing no tobacco the sample-selection specification involves making a conjecture about the value of their $w_t^\dagger$. This is represented by the dotted line in figure 3.2.

There are two unconditional error terms under the sample-selection specification. This implies that everyone has a $w_t^\dagger$ and the functional form of the budget share equation implies that $w_t^\dagger$ is always strictly positive.

People who were observed purchasing no tobacco and who view tobacco as a good may have more in common with those who were observed purchasing tobacco in the past than with those who view tobacco as a bad. If the price of tobacco falls a new group of people who view tobacco as a good may start purchasing some. In this case the sample-selection specification may be a good way to estimate how much people will spend on tobacco under various conditions.

Perhaps today many people view tobacco as a 'bad' rather than a 'good'. Asking these people, "how much tobacco would you purchase if purchasing none were not an option?" may be an unanswerable and irrelevant question. More important, making conjectures about how much tobacco would be purchased by those who are observed purchasing none ($w_t^\dagger$) may be misleading.

The two-part specification uses the observations reporting strictly positive budget shares to make conjectures about the relationship between strictly positive budget shares and the explanatory variables. Under the sample-selection specification one assumes that each observation has a strictly positive $w_t^\dagger$ and all observations are used to make conjectures about the relationship between the strictly positive budget shares and the explanatory variables. It is challenging to tell an intuitively appealing story about why each observation's $w_t^\dagger$ is strictly positive. The double-hurdle specification addresses this issue by allowing $w_t^\dagger$ to be strictly positive or equal to zero.

3.2.3 Double-Hurdle

The double-hurdle specification accounts for the fact that two different processes may be generating zero observations on w_t. A hurdle is synonymous with a condition. The double-hurdle specification can be viewed as an extension of a tobit specification. Therefore, it is useful to begin by describing a tobit specification.

Imagine that we have data on a dependent variable called y_t. Some of our observations on y_t are positive while others are negative. Also imagine that our plan is to estimate equation 3.11 by ordinary least squares.

$$y_t = x_t \cdot \zeta + \epsilon_t, \quad t = 1...T \tag{3.11}$$

The letter x_t is a row vector of explanatory variables, ζ is a column vector of parameters that are to be estimated and ϵ_t is a random variable. Unfortunately, before we run the regression a coding error sets all of the negative observations on y_t equal to 0. In this situation we could specify and estimate equation 3.12.

$$y_t = \begin{cases} x_t \cdot \zeta + \epsilon_t & \text{if } x_t \cdot \zeta + \epsilon_t > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.12}$$

Equation 3.12 is a tobit specification. Tobin (1958) used this specification. Consumption or expenditures observations are never negative; therefore the tobit specification may be a plausible way to account for zero observations. A tobit specification could be applied to tobacco budget share data. One shortcoming of a tobit specification is that one equation ($x_t \cdot \zeta + \epsilon_t$) plays two roles. If y_t represented tobacco budget shares the tobit specification implies the term $x_t \cdot \zeta + \epsilon_t$ determines the relationship between the explanatory variables and the probability of purchasing tobacco and it determines the relationship between the explanatory variables and the tobacco budget share.

Both the two-part and the double-hurdle specifications are an extension of the tobit specification. The two-part specification accounts for the fact that each explanatory variable could play two different roles. For example, the price of tobacco could have a strong influence on who purchases tobacco but a weak influence on the quantity of tobacco people purchase given that they purchase some. Under the double-hurdle specification the tobit specification is one of the two hurdles.

The following three equations describe a double-hurdle specification. Equation 3.13 is a probit equation and it determines who passes the probit hurdle. This is similar to the probit equation in the two-part and sample-selection specifications. The second inequality in equation 3.14 indicates that individual t has passed the probit hurdle. Equation 3.14 is a tobit equation and it determines who passes the tobit hurdle. The first inequality in equation 3.15 indicates that individual t has passed the tobit hurdle. Equation 3.15 represents the nonzero tobacco budget share that is observed if both hurdles are passed and the zero tobacco budget share that is observed if one or more of the hurdles is not passed.

$$I_t^{\dagger} = x1_t \cdot \delta + \psi_t \tag{3.13}$$

$$w_t^\dagger = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2_t \cdot \gamma + \mu_t > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.14}$$

$$w_t = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2 \cdot \gamma + \mu_t > 0 \\ & \text{and } x1_t \cdot \delta + \psi_t > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.15}$$

When I apply the double-hurdle specification I assume that μ_t and ψ_t are generated by a bivariate normal distribution with the same moment assumptions that were made for the sample-selection specification.

The following story fits well with the double-hurdle specification. In deciding how much tobacco to purchase individuals may ask themselves the following two questions. Would I like to purchase some tobacco? If the answer is yes then the probit hurdle has been passed ($I_t^\dagger > 0$). Individuals also ask themselves, what quantity of tobacco would I like to purchase? If the answer is a strictly positive amount of tobacco then the tobit hurdle is passed. Those who pass both hurdles purchase a strictly positive amount of tobacco.

Some individuals will pass the tobit hurdle but not the probit hurdle. These individuals have asked themselves, "would I like to purchase some tobacco?" and their answer is "no". If their answer had been "yes" then they would have purchased a strictly positive amount. But because the probit hurdle was not passed the observed tobacco budget share will be equal to zero and $w_t^\dagger$ represents the strictly positive tobacco budget share that would have been observed in the data if they had passed both hurdles.

Other individuals will pass the probit hurdle but not the tobit hurdle. These individuals have decided that they would like to purchase some tobacco but in choosing how much to spend on tobacco they decide to purchase none. For these individuals both $w_t^{\dagger}$ and w_t are equal to zero. Some people will not pass either hurdle. If asked "would you like to purchase some tobacco?" the answer is "no". For these people even if they had answered "yes" to the probit question in deciding how much to purchase they would have chosen to purchase none.

This story demonstrates why two hurdles must be passed before researchers observe a strictly positive tobacco budget share. The idea that there are two hurdles is plausible and it would be valuable to have a data set that indicates which hurdle each observation has passed. When a data set does not indicate which hurdles have been passed by each observation, analysts who apply the double-hurdle specification rely on the functional form of the tobit hurdle to account for the two different reasons that zeros are observed. The term $x2_t \cdot \gamma + \mu_t$ enters equations 3.14 and 3.15 four times. For those who pass the probit hurdle it determines whether or not a person would purchase tobacco and it determines how much tobacco is purchased.

In discussing the tobit specification alone Pudney argues that it, "is essentially nothing more than an ad hoc modification of the [standard] regression model, allowing it to be used in cases where there are observations 'piled up' at a limiting value (usually zero), and has no convincing foundation in behavioural theory" (Pudney 1989, p.139). Similarly the functional form of the tobit hurdle in a double-hurdle specification has no convincing foundation in behavioural theory. It is not clear why the functional form of a tobit hurdle is able to account accurately for the idea that there are two hurdles that individuals must pass before they purchase some tobacco. For example if all people who were observed purchasing no tobacco see tobacco as a 'bad' rather than a 'good' then conjectures based on a tobit hurdle may be misleading.

3.2.4 Variations

There are several variations on the three specifications that have been used to estimate tobacco demand equations or budget share equations. Hu et al. (1995) use a two-part specification to estimate the demand for cigarettes. They use a logit equation (rather than a probit equation) to estimate the probability that an individual is currently a smoker and ordinary least squares to estimate the demand equation. A recent paper by Mullahy (1998) points out that the two-part specification can be used to examine how much all people are likely to spend on tobacco unconditional on them having purchased some. He also compares the conditional two-part specification that was presented in this paper to other versions of the two-part specification. He states that, "both the algebraic and empirical results presented hear suggest that one should approach use of the standard (homoskedastic) two-part model with considerable caution in microeconometric applications where interest centers on $E[y \mid x]$

[the expected unconditional relationship between a dependent variable and a set of explanatory variables] and its associated partial effects" (Mullahy 1998, p. 279). For example the two-part specification can be used to examine how the price of tobacco is related to the probability of individuals purchasing tobacco and how the price of tobacco is related to tobacco budget shares conditional on some being purchased ($E(w_t \mid w_t > 0)$). Examining the relationship between the price of tobacco and the unconditional expected tobacco budget shares ($E(w_t)$) is not simply a matter of multiplying the probability of purchasing some by $E(w_t \mid w_t > 0)$ because the two unconditional error terms may be correlated and this correlation may depend on one or more of the explanatory variables. Mullahy 1998 demonstrates how the two-part specification can be used to examine the relationship between the price of tobacco and the unconditional expected tobacco budget shares ($E(w_t)$). Policy makers who are interested in the relationship between the total amount of tobacco that is being purchased and the price of tobacco, or other policy instruments, may be interested in these findings. Alternatively if policy makers are interested in influencing who purchases some tobacco and how much is purchased conditional on some being purchased then examining the relationship between the expected unconditional tobacco budget shares ($E(w_t)$) and the explanatory variables may not be of serious concern.

Jimenez and Labeaga (1994) apply a sample-selection specification to a system of demand equations for tobacco and alcohol. Under a sample-selection specification the error terms are usually assumed to be bi-variate normal in distribution. Unfortunately if the normality assumption does not hold then the asymptotic properties of the sample-selection estimates are poor. Recently researchers have developed semi-parametric versions of the sample-selection specification.

In the past the double-hurdle specification has been estimated under the assumption that the error terms in the two equations are independent. This assumption simplifies the computation of the double-hurdle estimates but with modern computers it is not necessary. Jones (1989a) estimates a double-hurdle specification and proposes a triple-hurdle specification. Under certain assumptions he is able to estimate the triple-hurdle specification. Yen and Jones (1996) estimate several versions of a double-hurdle specification. Their most general specification applies a Box-Cox transformation to the observed tobacco demand variable.

3.3 Synthesis

The estimates based on the conditional two-part specification use observations that report strictly positive tobacco budget shares to examine the relationship between the strictly positive tobacco budget shares and the explanatory variables. Under both the sample-selection specification and the double-hurdle specification all of the observations are used to estimate the relationship between the strictly positive tobacco budget shares and the explanatory variables. When applying the sample-selection or double-hurdle specification researchers make assumptions that allow one to estimate how much tobacco would be purchased by people who were observed to purchase none, under different conditions.

In the past little was known about the health effects of tobacco and the biology of addiction. At that time it may have been reasonable to assume that if a person started smoking they would be very similar to those who had been observed purchasing tobacco in the past. Today many more people are well aware of the health effects of tobacco and the biology of addiction and some people may consider tobacco a 'bad' rather than a 'good'. For these individuals conjectures about how much tobacco they would purchase if they purchased some ($w_i^\dagger$) may be misleading.

The budget share parameter estimates under the two-part specification identifies who is likely to have purchased a relatively large amount of tobacco during the years in which the data were collected. Researchers could use this information to focus policy recommendations on those who have purchased tobacco in the past. Tobacco policy could be revised when new data are collected and analysed.

Ideally one would like to present a model and then estimate the model. However, here I started out with three prominent specifications and I presented a model that identifies the assumptions underlying each specification. Under the two-part specification one assumes that those who have been observed purchasing tobacco in the past have much in common with those currently purchasing some. Both the sample-selection and double-hurdle specifications use all observations to estimate the relationship between tobacco budget shares and the explanatory variables. It is challenging to develop an intuitively plausible model that motivates the functional form of the equation that determines $w_t^{\dagger}$ under a sample-selection or a double-hurdle specification.

3.4 Literature Review: Econometric Specifications

There is a long-standing controversy in applied econometrics regarding the usefulness and interpretation of the two-part specification as compared to the sample-selection specification. In commenting on the sample-selection specification, Poirier and Ruud (1981) argue "that there has been confusion in the econometrics literature over switching regression models with endogenous switching, and that this confusion can cause serious interpretation problems in applied research" (Poirier and Ruud 1981, p.249). Poirier and Ruud find that it is possible "to construct two observationally equivalent models by postulating two more general models for which the data are never completely observed. Although the interpretations of the parameters in each formulation are entirely different, the observed data cannot distinguish between these two different interpretations" (p.255) Later Maddala, points out that, "because their study [Poirier and Ruud 1981] can convey misleading impressions about the practical usefulness of the models discussed in this chapter, we shall discuss the two models here" (Maddala 1983, p.283). Maddala finds that "*they* [the two models in Poirier and Ruud 1981] *are just two different ways of writing the same model. Thus there is no ambiguity of inferences*" (Maddala 1983, p.286).

Later, in a paper on this subject Maddala writes, "this issue [of observational equivalence between two different specifications] raised by Poirier and Ruud (1981) arises from their mistaken formulation of the selectivity model and a model based on conditional distribution, creating a confusion that did not exist. ... Frankly, this issue is not even worth mentioning but for the fact that it has been referred to approvingly and extensively by Duan et al. (1984, p.285-286) and can mislead researchers in the area of health economics, suggesting to them that there are serious problems with the sample-selection model" (Maddala 1985a, p.12).

A rather heated debate over comparing the two-part and sample-selection specifications continued in Duan et al. 1984 and Hay and Olsen 1984. Maddala (1985a) attempts to provide some understanding of the many differences between Duan et al. 1984 and Hay and Olsen 1984. He begins with the following, "when I first read the paper by Hay and Olsen (1984) in a recent issue of *JBES* [*Journal of Business & Economic Statistics*] I felt that the authors were quite right, and when I read the reply by Duan et al. (1984) in the same issue I felt on first reading that the authors of that paper were also quite right" (1985a, p.3). In response Duan et al. disagree with Maddala (1985a) on several points and state that, "from a policy perspective, both this exchange and our exchange with Hay and Olsen are much ado about nothing" (1985, p.19). They make this statement because one arrives at roughly the same quantitative conclusions regardless of which specification is applied to their experimental data. In a final response Maddala states, "I am sorry to note that the Rand researchers feel that my paper is "much ado about nothing." I leave it to the readers to judge it for themselves" (Maddala 1985b).

At one point during this exchange Maddala argues that a two-part specification is perhaps valid when the decision to consume a good and the decision concerning how much to consume are made sequentially and that a two-part specification is not valid for a joint decision model (1985a, p.14). Duan et al. disagree and argue that this issue is more semantic than substantive (1985, p.22). In the econometrics literature there is no clear message that the two-part specification is better than the sample-selection specification or visa-versa.

Theoretical arguments have not produced a consensus on which specification is, in general, more appropriate. In part it depends on which set of statistical assumptions are correct. For example, if we used a two-part specification to generate hypothetical data and then used the data to estimate a sample-selection specification, would the results be misleading? Alternatively, if we used a sample-selection specification to generate hypothetical data and then used the hypothetical data to estimate a two-part specification, would the results be misleading? This is called a Monte Carlo experiment. Monte Carlo evidence reported by Hay, Leu and Rohrer (1987) and Manning, Duan and Rodgers (1987) both suggest that the two-part specification performs better than the sample-selection specification even when Monte Carlo data sets are generated by a sample-selection specification. These findings seem to give strong support to the two-part specification.

A more recent paper by Leung and Yu (1996) finds that this conclusion is incorrect. The abstract in Leung and Yu begins by stating that "this paper resolves the vigorous debates between advocates of the sample selection model and the two-part model" (1996, p.196). In the introduction they provide a clear summary of this debate. Leung and Yu (1996) demonstrate that the data generating processes that were used in Hay, Leu and Rohrer (1987) and Manning, Duan and Rodgers (1987), "produces serious collinearity problems that bias against the sample-selection model. Once the design problem is rectified, the poor performance of the sample-selection specification evaporates. Our Monte Carlo results offer a more balanced view on the relative merits of the two models as each performs well under different conditions" (Leung and Yu 1996). They also point out that, "[w]hen the sample selection model is the true model, it performs substantially better than the two-part model as long as there are no collinearity problems. When the two-part model is the true model, the sample-selection model is inferior, but it is still reasonably close to the two-part model" (Leung and Yu 1996). This Monte Carlo evidence does not lend clear support to either the two-part specification or a sample-selection specification.

There is a consensus that the two-part specification is not just a special case of the sample-selection specification. Duan et al. 1984 give an example where the two unconditional error terms in a two-part specification (ψ_t and μ_t in equations 3.3 and 3.4 on page 82) are correlated (1984 p.285). After presenting this example they state "it should be noted that although the class of joint distributions just described allows dependence between η_{1i} and η_{2i}, [the two error terms in a two-part specification] the correlation coefficient ρ does not enter the likelihood function. Therefore ρ is irrelevant for the purpose of estimating the two-part model" (Duan et al. 1984, p.286). They also state that, "As the example indicates, the two-part model (either the general version or the normal version [the normal version was presented on page 82]) allows joint distributions that are different from any joint distributions available under sample selection models. Thus Hay and Olsen's allegation that the two-part model "can be interpreted as being nested in the more general sample selection models" (1984, p.279) is invalid" (Duan et al. 1984, p.286). Leung and Yu agree with this point and state that Duan et al. (1984) prove convincingly that the two-part model is not nested in the sample selection model" (1996, p.203). I have not read a paper that disagrees with this point.

There is a consensus that the two-part specification is not just a special case of the sample-selection specification even if the error terms are assumed to have a normal distribution. The assumption that two error terms are not correlated is sufficient, but not necessary, when constructing a two-part specification. This means that researchers who apply the two-part specification have not implicitly assumed that the two error terms are independent. However if researchers start out with a sample-selection specification then the two-part specification is a special case where the two error terms are independent.

3.5 Literature Review: Specifications that have been applied to Tobacco Data

Several papers on the demand for tobacco products point out the disadvantages of applying ordinary least squares or a tobit specification to tobacco data. Hu et al. (1995) and Wasserman et al. (1991) point out the disadvantages of estimating a cigarette demand equation by applying ordinary least squares. Hu et al. (1995) and Jones (1989a) point out the disadvantages of applying a tobit specification. This led Hu et al. (1995) and Wasserman et al. (1991) to a two-part specification[4]. Ohsfeldt et al. (1997) estimate "the 'participation' part of a two-part" (1997, p.526) specification. Blaylock and Blisard (1992) estimate two-part tobacco specifications that are within a system of equations that determine each individual's cigarette consumption and their self-evaluated health status.

In contrast to the papers estimating two-part specifications, Jimenez and Labeaga (1994) apply a sample-selection specification in estimating a two-equation budget share system of tobacco and alcohol. The disadvantages of applying a tobit specification lead Fry and Pashardes (1994), García and Labeaga (1996), Jones (1989a), Jones (1989b) and Yen and Jones (1996) to a double-hurdle specification. Jones 1989a also applies a triple-hurdle specification to a data set that indicates who has never purchased cigarettes, who has quit purchasing cigarettes and who is cur-

[4]Wasserman et al. (1991) also apply a Poisson specification that has not been widely applied to tobacco related data.

Table 3.1: Papers That Have Applied Two-Part, Sample-Selection and/or Double-Hurdle Specifications

Specification	Authors, Year
two-part	Blaylock and Blisard, 1992
	Hu et al. 1995
	Ohsfeldt et al. 1997
	Wasserman et al. 1991
sample-selection	Jimenez and Labeaga 1994
double-hurdle	Fry and Pashardes, 1994
	García and Labeaga 1996
	Jones 1989a
	Jones 1989b
	Yen and Jones, 1996

rently purchasing some. The data set analysed in Jones 1989a reports two different types of observations that report no cigarette consumption. Table 3.1 identifies papers that have applied the two-part specification, the sample-selection specification and or the double-hurdle specification to tobacco data. All of the papers mentioned above seem to agree that there are disadvantages associated with applying ordinary least squares or a tobit specification to tobacco data.

Jones 1989a points out that if, under a double-hurdle specification, the probit hurdle is the dominant factor in determining who purchases tobacco then the tobit hurdle is no longer relevant (p.26). If the tobit hurdle is irrelevant then the double-hurdle specification is the same as the sample-selection specification.

Garcìa and Labeaga "are interested in analysing the distinction between abstentions and corner solutions, and how relaxing specification and distributional assumptions affect the income and price elasticities" (1996, p.489). Neither the two-part nor the sample-selection specifications distinguish between tobacco abstentions and corner solutions. In contrast the double-hurdle specification allows researchers to, "jointly model, first, why one decides to be a smoker and second, the quantity one decides to consume" (Garcìa and Labeaga 1996, p.490). Garcìa and Labeaga state that the "reason for separating the decision process is: first, if an individual is a non-smoker, any value of the exogenous variables (price, income, etc.) will be irrelevant (abstentions) and, second, the individual could be a potential smoker, but for certain levels of the relevant variables he may decide not to consume (corner solutions). We can therefore, suppose a group of factors that influences the decision to smoke is different from those which determines the quantity that a potential smoker will eventually consume (although there could be variables common to both). In this sense, two 'hurdles' must be overcome before observing a positive consumption" (1996, p.491).

Garcìa and Labeaga point out that under a double-hurdle specification if everyone who passes the probit hurdle also passes the tobit hurdle then the probit hurdle is the dominant factor that determines who purchases some tobacco[5]. Garcìa and Labeaga call this special case a "Heckman's generalised sample selectivity model" (1996, p.492).

To demonstrate why a sample-selection specification is a special case of a double-hurdle specification recall the story that was used to describe a tobit spec-

[5]Garcìa and Labeaga (1996) refer to the probit hurdle as the first hurdle and they call this first hurdle dominance.

ification. Imagine the case where we start out with a data set in which some of the dependent variable observations are positive and others are negative. If before running ordinary least squares a coding error set all of the negative dependent observations equal to zero we could apply a tobit specification to this partially damaged data set. If all of the dependent variables in the original data set were strictly positive the coding error would not have been a problem and we could have applied ordinary least squares to the data set despite the coding error.

Under a double-hurdle specification there is a probit hurdle and a tobit hurdle. If a data set identified all of the people who passed the probit hurdle then we could apply a tobit specification to these observations. If everyone who passed the probit hurdle purchased a strictly positive amount of tobacco then we could apply ordinary least squares to all of the observations that passed the probit hurdle. In practice data sets identify who has purchased some tobacco and who has not. Among the zero observations data sets rarely identify who has passed the probit hurdle and failed to pass the tobit hurdle, who is passed the tobit hurdle and failed to pass the probit hurdle and who has failed to pass both hurdles. Under a double-hurdle specification if data analysts assume that the probit hurdle is the dominant hurdle (no one who passes the probit hurdle is at a corner solution according to the tobit hurdle) this implies a sample-selection specification.

García and Labeaga (1996) apply a number of statistical tests in comparing the tobit specification and different versions of the double-hurdle specification. These statistical tests clearly support a linear double-hurdle specification. They also apply a statistical test of the two-part specification as a special case of the sample-selection specification. These tests reject the two-part specification. García and Labeaga conclude that "[w]e have made use of the double-hurdle approach because of the restrictiveness embodied within the Tobit and because we believe abstentions and corner solutions are the reasons generating them [tobacco data sets] in Spanish surveys. Our results suggest that there are two decision processes and we propose these models should be estimated using a double-hurdle approach both with and without assuming independence between the errors" (1996, p.500).

Yen and Jones present a model that has a probit hurdle which consumers must pass in order to be observed purchasing some tobacco. In line with the double-hurdle specification they also allow for a latent variable that generates zero observations (1996, p.107). Yen and Jones 1996 apply a Box-Cox transformation to the tobacco budget shares in a double-hurdle specification. Yen and Jones point out that "the Box-Cox specification makes it clear that the two-part model is a potentially restrictive special case, which requires independence between the unobservable factors underlying participation and consumption ... and the correct distributional assumption for the conditional level of consumption" (1996, p.109).

Yen and Jones investigate data that include current and ex-smokers; individuals who never smoked are not included in the sample they analyse. Yen and Jones apply likelihood ratio tests in comparing a Box-Cox transformation of the dependent variable in a double-hurdle specification to twelve specifications nested within it. Some of these nested specifications are similar to the two-part, sample-selection and double-hurdle specifications presented earlier. Yen and Jones find that all of the nested specifications were rejected, "each with a p-value of less than 0.0001" (1996, p.112).

Yen and Jones "propose a model of the simultaneous decisions of whether to quit and how much to smoke which incorporates the 'fixed costs' of addiction associated with withdrawal effects" (1996, p.116). Yen and Jones conclude that the "Box-Cox specification is shown to out-perform all the nested models that have been used extensively in the empirical literature" (1996, p.116).

In summary, several papers point out the disadvantages of applying ordinary least squares or a tobit specification. This leads them to apply a two-part specification, a sample-selection specification or a double-hurdle specification. Jones (1989a), García and Labeaga (1996) and Yen and Jones (1996) encourage investigators to apply the double-hurdle specification. The idea that there are two hurdles is intuitively plausible. However, it is not clear that the functional form of a double-hurdle specification accurately accounts for the two reasons that zeros may be observed in tobacco data. Jones 1989a, Garcìa and Labeaga (1996) and Yen and Jones (1996) all develop models that underlie a double-hurdle specification. However, the models do not explain why corner solutions take the functional form of a tobit hurdle. The data sets analysed do not identify who has passed each hurdle. The double-hurdle specification relies on the functional forms of the two hurdles to account for these two types of zeros. Under the sample-selection specification there is just one hurdle. There may be several reasons, including corner solutions, that some observations do not pass this one hurdle. Similarly there may be several reasons that individuals do not pass the probit hurdle under a two-part specification.

3.6 Nesting Structure

As mentioned earlier Yen and Jones 1996 compare several specifications using likelihood ratio tests. Figure 3.3 is a tree diagram of the nesting relationship among some of these specifications. This tree diagram contains two versions of the double-hurdle specification. At the top of the tree is a double-hurdle specification where a Box-Cox transformation has been applied to the dependent variable.

The Box-Cox double-hurdle specification is represented by equations 3.16 to 3.18.

$$I_t^{\dagger} = x1_t \cdot \delta + \psi_t \tag{3.16}$$

$$\frac{w_t^{*\lambda} - 1}{\lambda} = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2_t \cdot \gamma + \mu_t > 0 \\ \frac{-1}{\lambda} & \text{otherwise} \end{cases} \tag{3.17}$$

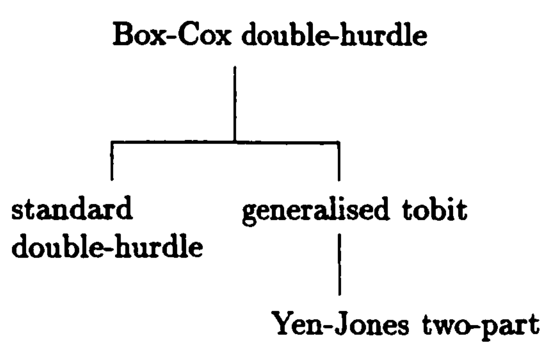
$$\frac{w_t^{\lambda} - 1}{\lambda} = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2_t \cdot \gamma + \mu_t > 0 \\ & \quad \text{and } x1_t \cdot \delta + \psi_t > 0 \\ \frac{-1}{\lambda} & \text{otherwise} \end{cases} \tag{3.18}$$

The left hand side of equations 3.17 and 3.18 is a Box-Cox transformation of the dependent variables. The letter λ is an unobserved parameter that is to be estimated. Yen and Jones state the likelihood function that is to be maximised when estimating the Box-Cox double-hurdle specification (1996, p.108).

When λ equals one equations 3.16, 3.17 and 3.18 represent what Yen and Jones 1996 call the standard double-hurdle specification. This is the double-hurdle specification that was described earlier. Yen and Jones also state that when λ equals zero this "corresponds to the Type *II* or generalised Tobit model. ...A variant on this specification is used by Fry and Pashardes to model UK [United Kingdom] household tobacco expenditure with pooled FES [Family Expenditure Survey] data. They use a logit equation for participation and the Heckman two-step estimator for the regression equation" (1996, p.109). Fry and Pashardes estimate the sample-selection specification that was presented earlier.

When λ is equal to zero the Box-Cox double-hurdle specification becomes

Figure 3.3: Nesting structure



Based on Yen and Jones (1996).

$$I_t^{\dagger} = x1_t \cdot \delta + \psi_t \tag{3.19}$$

$$\ln(w_t^*) = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2_t \cdot \gamma + \mu_t > 0 \\ -\infty & \text{otherwise} \end{cases} \tag{3.20}$$

$$\ln(w_t) = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x2_t \cdot \gamma + \mu_t > 0 \\ & \text{and } x1_t \cdot \delta + \psi_t > 0 \\ -\infty & \text{otherwise} \end{cases} \tag{3.21}$$

This is the generalised tobit specification. If everyone in the data set has passed the tobit hurdle then the generalised tobit specification can be written as

$$I_t^{\dagger} = x1_t \cdot \delta + \psi_t \tag{3.22}$$

$$\ln(w_t^*) = x2_t \cdot \gamma + \mu_t \tag{3.23}$$

$$\ln(w_t) = \begin{cases} x2_t \cdot \gamma + \mu_t & \text{if } x1_t \cdot \delta + \psi_t > 0 \\ -\infty & \text{otherwise} \end{cases} \tag{3.24}$$

This is a sample-selection specification. If some people do not pass the tobit hurdle then the generalised tobit specification findings may be different than the sample-selection specification findings. Neither Yen and Jones 1996 nor I test this restriction of the generalised tobit specification. This may be an interesting topic to explore in the future. The important thing to note is that the generalised tobit specification may lead researchers to a different set of results than the sample-selection specification.

Yen and Jones state that $\rho = 0$ under the generalised tobit specification gives "the so called 'two-part' model. This has been applied widely and is estimated as a probit equation for participation ... and conditional OLS [ordinary least squares] ... for positive observations" (1996 p.109).

If the two error terms in the generalised tobit specification are not correlated and if everyone in the data set has past the tobit hurdle then the generalised tobit specification is the same as the two-part specification that has been applied widely and was presented earlier. If there are many observations that do not pass the tobit hurdle then what Yen and Jones call a two-part specification may lead to a different set of results than the two-part specification presented earlier. Comparing the two-part specification that Yen and Jones 1996 estimate to the two-part specification presented earlier may be an interesting question to explore in the future.

In what follows I compare the Box-Cox double-hurdle, standard double-hurdle, generalised tobit and Yen-Jones two-part specifications. I do this by applying the likelihood ratio tests that Yen and Jones 1996 apply and then I compare the signs and p-values of the parameter estimates obtained by applying these four specifications. If there are a set of results that are obtained regardless of the specification applied then to some extent the policy implications arrived at may not depend on which specification researchers choose to apply.

3.7 The Data

Estimates obtained using alternative specifications are presented below. First, however, it is important to discuss the nature of the data set used for estimation. The data come from Statistics Canada's Family Expenditure Surveys. The surveys were conducted in 1969, 1974, 1978, 1982, 1984, 1986, 1990 and 1992. The data were compiled by Browning and Thomas (1994a). Browning and Thomas (1994a) also include price indices for tobacco, alcohol, and other goods. Browning and Thomas (1994b) constructed one price index for tobacco and one price index for alcohol for each region in Canada (Atlantic Provinces, Quebec, Ontario, Prairie provinces and British Columbia) and for each of the eight years. The national consumer price index for each year was copied from a University of Toronto (Ontario) web site called http://datacentre.chass.utoronto.ca:5680/cansim.search.html and added to the data set compiled by Browning and Thomas (1994a). There are 71,023 observations in the data set.

The data report each subject's total expenditure on tobacco over an entire year; the data do not follow household expenditures over time. The annual data do not distinguish between an individual who has permanently quit smoking near the beginning of a year, an individual who started smoking near the end of a year and an individual who purchases small amounts of tobacco throughout the year. In this data set these three types of observations are indistinguishable. The data set reports expenditures on all tobacco products rather than some other more narrowly defined tobacco product (for example, cigarettes only). Therefore I do not analyse how individuals choose among different tobacco products. Because the data set reports tobacco expenditures I analyse tobacco expenditure as a proportion of net income and I refer to this as a budget share.[6]

Each observation reports household expenditures. When a household has purchased some tobacco the data set does not indicate who within the household consumed the tobacco products. Theoretical models of individual behaviour are often used to analyse data; models of family behaviour are less common. There is some question as to whether one should treat households as a single decision-making unit. If members of each household are very different from each other, then a single preference function may not be capable of describing the behaviour of a household. This suggests that one should not necessarily treat each household as a single decision-making unit. The advantage of examining households that consist of one person rather than households consisting of two or more is the relatively clear relationship between a common theoretical model and the data being analysed. With this in mind, in order to explore alternative econometric specifications, I only use the household observations that report information on single individuals with no other household members. Given that single individuals with no other household members may behave differently compared to other individuals, there are limits to the generalisability of the results obtained. (In the chapter entitled, "The Determinants of Expenditure

[6]One alternative is to divide tobacco expenditures by total expenditures rather than net income. If tobacco expenditures are related to savings behaviour this would be an interesting topic to explore in the future.

on Tobacco in Canada" on pages 173 to 227 I apply one specification to household observations regardless of the number of people who are members of each household.) There are 14,137 observations that report information on households that consist of one person.

Table 3.2 reports the age range associated with each survey year. The data that were collected in 1974, 1990 and 1992 reports an age of 24 for anyone who is less than 25 years old. This same process was applied to other years but at a lower age. The observations from 1978 are the only ones that report each young person's actual age and the minimum is 17. The data that were collected in 1974, 1978, 1982, 1984, 1990 and 1992 reports an age of 76 for anyone who is older than 76. The data that were collected in 1969 and 1986 reports an age of 80 for anyone who is older than 80. Observations that do not report the actual age of an individual were dropped so that the three specifications can be compared using accurate information concerning age.

Observations with a net income that is less than or equal to zero were dropped from the analysis because they may be extreme outliers who have negative income or misreported data. A total of 25 observations were dropped for this reason. Observations that had a tobacco budget share that was greater that 100 percent were dropped because they are likely mis-reported data. A total of 5 observations were dropped for this reason. Lastly, observations for which the education information was missing were dropped. A total of 20 observations were dropped for this reason. The

Table 3.2: Age Range Reported

Survey Year	Minimum Age	Maximum Age
1969	21	79
1974	25	75
1978	17	75
1982	20	75
1984	21	75
1986	21	79
1990	25	75
1992	25	75

Table 3.3: Observations Analysed

Five steps that identify the observations analysed in this paper.	The number of observations left. after each step.
all observations	71,023
households that consist of one person	14,137
age is reported	11,876
net income greater than zero	11,851
tobacco budget share less than 100%	11,846
education information is reported	11,826
final sample	11,826

final data set consists of 11,826 observations. A total of 6,766 observations reported no tobacco expenditures (57.2%) and 5,060 observations reported positive tobacco expenditures (42.8%). Table 3.3 reports the number of observations we are left with after each data exclusion restriction was applied. Tables 3.4 to 3.6 describe each explanatory variable.

The regional indicator variables are meant to capture the fact that the regions of Canada are diverse. All regions are within Canada; the province of Ontario is the

Table 3.4: Regional indicator variables

Variable	Description
Atl	1 if they live in the Atlantic provinces, 0 otherwise
Que	1 if they live in the province of Quebec, 0 otherwise
Ont	1 if they live in the province of Ontario, 0 otherwise
Pra	1 if they live in the Prairie provinces, 0 otherwise
B.C.	1 if they live in the province of British Columbia, 0 otherwise

Table 3.5: Income, demographic and price variables

Variable	Description
ownh	1 if they own their home, 0 if they do not
lnety	natural log of net income
age	age of the individual
age2	age squared
fem	1 if the person is a female, 0 otherwise
ui	1 indicates the receipt of unemployment insurance, 0 otherwise
lptob	natural log of the price of tobacco
lpalc	natural log of the price of alcohol
lptage	lptob times age
lptage2	lptob times age squared
lcpi	natural log of the annual, national consumer price index
ed1	1 if they have less than nine years of education, 0 otherwise
ed2	1 if they have some or completed secondary school, 0 otherwise
ed3	1 if they have some post secondary, post secondary completed, or a university degree, 0 otherwise

Table 3.6: Parameters

Parameter	Description
λ	Box-Cox transformation parameter
σ	standard deviation of the error term
ρ	correlation between the two error terms

reference category. Regional dummy variables may capture regional variations in the price of tobacco. They may also reflect differences in the social acceptability of smoking across Canada. Further, the regional dummy variables may capture the effects of different provincial regulatory regimes concerning the sale and use of tobacco. In the future it may be valuable to construct indices that reflect tobacco regulations across Canada.

A home ownership variable has been found to be statistically significant in other tobacco demand equations. Perhaps people who are more concerned about the future are more likely to purchase a home and are more likely to worry about the future effects of tobacco consumption. Homeowners may also tend to be from a different socio-economic class than non-home owners and hence the two groups may have different tobacco consumption patterns. Finally, the home ownership indicator variable may be correlated with lifetime income, which in turn affects smoking behaviour.

The natural log of net income likely measures standard income effects and perhaps the effects of the social class to which an individual belongs. The age and age squared variables allow for a non-linear relationship between age and the tobacco budget share. (Possible cohort effects are discussed below.) A gender indicator variable is included to capture the fact that females may have different tobacco consumption patterns than males. It may also be that households that consist of one female often belong to a different socio-economic class than households consisting of one male. An indicator variable for the receipt of unemployment insurance could be a crude measure of stress which may influence tobacco consumption and it may also reflect the social-economic environment in which the individual lives. Becker and Murphy (1988) present a theory of rational addiction and they show how, "divorce, unemployment, and similar tension-raising events affect the demand for addictive goods" (1988, p.676). Ideally we would have a variable that reports lifetime income and this would allow us to treat home ownership as an endogenous variable rather than as an explanatory variable.

The price of alcohol is included because other studies have found that tobacco and alcohol consumption are closely related. The tobacco price variable was interacted with age and age squared in order to determine if price effects change with age. It may be that the young and the elderly have very different preferences and therefore react differently to changes in the price of tobacco; if not the price cross age variables are likely to be statistically insignificant. It may also be that individuals who have earned a certain income are likely to belong to a certain class of people, which in turn may influence their knowledge and understanding with regard to tobacco. The consumer price index is meant to measure variation in the price of other products that the individual purchases. The natural logarithm of prices and income are used as explanatory variables. This is a commonly used functional form (Greene 1993, p.144). One reason to use this functional form is that when one estimates a demand function by taking the natural logarithm of a price or income variable and the dependent variable the estimated slope coefficient can be interpreted as an estimate of demand elasticity. The natural logarithm is applied here because this is a common functional form in the economics literature. A paper by Manning lists some commonly applied reasons for choosing a log linear functional form (1998, p.284).

Education indicator variables are included because the level of education that an individual chooses may also reflect their time preferences. For example, individuals who search for a job when they are young may be less concerned about the future compared to those who choose to continue their education program in order to attain a higher paying job in the future. Given the impact of tobacco consumption on one's health in the future it may be that individuals who are less concerned about the future are more likely to purchase some tobacco. It may also be that the socio-economic group that a person belongs to influences their level of education as well as their preferences for tobacco and their appreciation of the health effects of tobacco and the physical challenge associated with quitting. Individuals who have less than nine years of education are in group number one, individual who have some, or have completed, secondary education are in group number two and those who have some post-secondary education, a post-secondary certificate or a university degree are in group number three.

It is possible that the relationship between education and tobacco consumption has changed between 1969 and 1992. Perhaps in 1969 education was an important factor in determining whether individuals were well aware of, or convinced of, the relationship between tobacco and health. The education factor may be less important in the 1990s because advertising and public education programs have made tobacco and health information relatively more available and accessible to individuals with less education. In other words people with different education levels may have more in common with each other now than they did in the past, at least with regards to knowledge of the effects of tobacco consumption; this is called a period effect.

Keeler et al. find that the effects of income on cigarette consumption are weak, insignificant and negative in spite of the fact that earlier studies found a positive income elasticity of demand for cigarettes (1993 p.12). In discussing their finding they suggest that this, "may be due to the superior education level of those in higher income groups and increased awareness of those in more educated groups as to the desirability of abstaining from smoking" (Keeler et al. 1993, p.12).

With a period effect in mind an indicator variable for the decade of the survey was crossed with the education indicator variable. The observations from 1969, 1974 and 1978 were in one group, the observations from 1982, 1984 and 1986 were in a second group and the observations from 1990 and 1992 were in a third group. Crossing the decade variables with the education variables results in 9 year/education categories. The reference category is the lowest education category crossed with observations that were collected in 1969, 1974 and 1978.

Other interaction terms between regions, the price of tobacco and years were attempted. However, the computer program was not able to find the maximum

Table 3.7: Year-Education Interaction Term Variables

Variable	Description
y7ed1	Observations collected in 1969, 1974 or 1978 and less than nine years of education (reference category).
y7ed2	Observations collected in 1969, 1974 or 1978 and have some, or have completed, secondary education.
y7ed3	Observations collected in 1969, 1974 or 1978 and have some post-secondary education, a post-secondary degree or a university degree.
y8ed1	Observations collected in 1982, 1984 or 1986 and less than nine years of education.
y8ed2	Observations collected in 1982, 1984 or 1986 and have some, or have completed, secondary education.
y8ed3	Observations collected in 1982, 1984 or 1986 and have some post-secondary education, a post-secondary degree or a university degree.
y9ed1	Observations collected in 1990 or 1992 and less than nine years of education.
y9ed2	Observations collected in 1990 or 1992 and have some, or have completed, secondary education.
y9ed3	Observations collected in 1990 or 1992 and have some post-secondary education, a post-secondary degree or a university degree.

likelihood estimates associated with each specification when these interaction terms were included. This may be because in any given year and region there is only one tobacco price index reported in this data set.

3.8 Identification

In estimating a sample-selection specification or a double-hurdle specification there is an issue concerning how one identifies the two different roles each explanatory variable plays. For example, income may affect the probability that an individual purchases tobacco and income may also affect how much tobacco an individual would purchase if they purchase some. If the same set of explanatory variables determine both the probability that an individual purchases tobacco and the amount they would purchase if they purchase some, then the functional form of each equation identifies the two different impacts of each explanatory variable. If there are explanatory variables that belong in the probit equation and do not belong in the budget share equation this to will help identify the two different roles that the other explanatory variables play.

I assume that education is related to the probability that a person purchases tobacco and that education is not related to how much one would purchase if they purchase some. Intuitively the idea is that if a consumer were to overcome the incentives to avoid addiction then education is not related to how much tobacco they would purchase.

Regressing the natural logarithm of net income on to the eight decade-education variables and a constant results in an R-squared of 0.541. This high correlation means that identifying the two sets of parameter estimates obtained by applying the sample-selection or double-hurdle specification relies in part on the difference between the functional form of the probit equation and the budget share equation.

3.9 Specification Tests

This section compares three specifications using likelihood ratio tests, the next section compares the parameter estimates based on each specification.

Table 3.8 reports the results of the likelihood ratio tests. The likelihood ratio tests strongly reject the standard double-hurdle specification and the generalised tobit specification relative to the Box-Cox double-hurdle specification. Furthermore, the Yen-Jones two-part specification is strongly rejected relative to the generalised tobit specification. The statistical tests clearly support the Box-Cox double-hurdle specification. The Yen and Jones two-part specification may arrive at a different set of results than the two-part specification presented earlier. Comparing these two two-part specifications may be an interesting topic to explore in the future.

3.10 Parameter Estimates

Tables 3.9 to 3.12 report the parameter estimates that were obtained using a software program called GAUSS. This section compares the probit equation and budget share

Table 3.8: Likelihood ratio tests for different specifications

Specifications	Test Statistics	d.f.	p
Box-Cox double-hurdle vs. standard double-hurdle	2,173	1	0.000
Box-Cox double-hurdle vs. generalised tobit	478	1	0.000
Box-Cox double-hurdle vs. Yen-Jones two-part	2,618	2	0.000
generalised tobit vs. Yen-Jones two-part	2,140	1	0.000

Note: The third column reports the degrees of freedom and the fourth column reports the p-value.

equation parameter estimates obtained using the Yen-Jones two-part, generalised tobit, standard double-hurdle and Box-Cox double-hurdle specifications. Under each of these specifications a probit equation determines who is likely to answer "yes" to the question, "would you like to purchase some tobacco?" When the answer is "yes" the budget share equation determines how much each person spends on tobacco.

Among the twenty-four probit equation parameter estimates the Atlantic, Quebec and home ownership parameter estimates each receive p-values of less than one percent in all four specifications. Table 3.13 reports likelihood ratio tests for the four probit equation age parameter estimates. These four likelihood ratio tests all have p-values of less than one percent.

The statistically significant parameter estimates suggest that those who live in the Atlantic provinces and those who live in Quebec are more likely to answer "yes" to the question "would you like to purchase some tobacco?" Furthermore, those who own their own home are less likely to answer "yes" compared to those who do not own their own home. All four specifications find that at the average tobacco price

Table 3.9: Yen-Jones two-part

Variables	Probit Equation: Estimated Coefficients	p values	Budget Share Equation: Estimated Coefficients	p values
intercept	1.023	(0.122)	3.322	(0.000)
Atl	0.113	(0.002)	0.022	(0.634)
Que	0.137	(0.000)	0.048	(0.230)
Pra	0.028	(0.254)	−0.042	(0.214)
BC	−0.019	(0.531)	−0.159	(0.000)
ownh	−0.238	(0.000)	−0.167	(0.000)
lcpi	0.444	(0.020)	0.673	(0.005)
lnety	−0.035	(0.024)	−0.778	(0.000)
age	0.075	(0.002)	0.087	(0.009)
age2	−0.001	(0.000)	−0.001	(0.001)
fem	−0.438	(0.000)	−0.121	(0.000)
ui	0.208	(0.000)	0.127	(0.001)
lptob	0.386	(0.013)	0.662	(0.000)
lpalc	−1.130	(0.000)	−0.519	(0.085)
lptage	−0.004	(0.456)	−0.008	(0.234)
lptage2	0.000	(0.182)	0.000	(0.064)
y7ed2	−0.023	(0.522)		
y7ed3	−0.192	(0.000)		
y8ed1	0.140	(0.077)		
y8ed2	0.180	(0.019)		
y8ed3	−0.146	(0.058)		
y9ed1	0.018	(0.862)		
y9ed2	−0.009	(0.922)		
y9ed3	−0.283	(0.003)		
λ			0.000	
σ	1.000		1.174	(0.000)
ρ			0.000	

Table 3.10: Generalised tobit

Variables	Probit Equation: Estimated Coefficients	p values	Budget Share Equation: Estimated Coefficients	p values
intercept	1.063	(0.049)	4.273	(0.000)
Atl	0.093	(0.003)	−0.076	(0.143)
Que	0.103	(0.000)	−0.113	(0.016)
Pra	0.019	(0.395)	−0.063	(0.111)
BC	0.000	(0.988)	−0.084	(0.083)
ownh	−0.172	(0.000)	0.193	(0.000)
lcpi	0.333	(0.039)	0.031	(0.910)
lnety	−0.078	(0.000)	−0.687	(0.000)
age	0.050	(0.026)	−0.015	(0.697)
age2	−0.001	(0.002)	0.000	(0.516)
fem	−0.400	(0.000)	0.431	(0.000)
ui	0.123	(0.000)	−0.170	(0.001)
lptob	0.255	(0.040)	0.767	(0.000)
lpalc	−0.818	(0.000)	0.199	(0.556)
lptage	−0.001	(0.864)	−0.005	(0.524)
lptage2	0.000	(0.544)	0.000	(0.514)
y7ed2	0.052	(0.002)		
y7ed3	−0.021	(0.276)		
y8ed1	0.160	(0.000)		
y8ed2	0.185	(0.000)		
y8ed3	0.047	(0.195)		
y9ed1	0.092	(0.065)		
y9ed2	0.092	(0.049)		
y9ed3	−0.031	(0.503)		
λ			0.000	
σ	1.000		1.762	(0.000)
ρ			−0.990	(0.000)

Table 3.11: Standard double-hurdle

Variables	Probit Equation: Estimated Coefficients	p values	Budget Share Equation: Estimated Coefficients	p values
intercept	0.901	(0.567)	21.723	(0.000)
Atl	0.270	(0.000)	−0.318	(0.211)
Que	0.200	(0.002)	0.044	(0.845)
Pra	0.068	(0.215)	−0.181	(0.380)
BC	0.209	(0.003)	−1.171	(0.000)
ownh	−0.297	(0.000)	−0.641	(0.000)
lcpi	0.526	(0.205)	4.067	(0.001)
lnety	0.727	(0.000)	−6.181	(0.000)
age	0.008	(0.885)	0.649	(0.001)
age2	0.000	(0.484)	−0.010	(0.000)
fem	−0.603	(0.000)	−2.049	(0.000)
ui	0.087	(0.191)	0.566	(0.014)
lptob	−0.330	(0.335)	4.005	(0.000)
lpalc	−1.601	(0.018)	−2.300	(0.152)
lptage	0.009	(0.396)	−0.043	(0.248)
lptage2	0.000	(0.529)	0.001	(0.011)
y7ed2	0.061	(0.385)		
y7ed3	−0.006	(0.960)		
y8ed1	0.153	(0.342)		
y8ed2	0.181	(0.265)		
y8ed3	−0.166	(0.317)		
y9ed1	0.063	(0.748)		
y9ed2	−0.063	(0.746)		
y9ed3	−0.366	(0.059)		
λ			1.000	
σ	1.000		6.550	(0.000)
ρ			0.093	(0.065)

Table 3.12: Box-Cox Double-Hurdle

	Probit Equation:		Budget Share Equation:	
	Estimated		Estimated	
Variables	Coefficients	p values	Coefficients	p values
intercept	1.151	(0.042)	5.809	(0.000)
Atl	0.115	(0.000)	−0.116	(0.047)
Que	0.120	(0.000)	−0.132	(0.012)
Pra	0.025	(0.292)	−0.076	(0.092)
BC	0.000	(0.999)	−0.134	(0.017)
ownh	−0.180	(0.000)	0.177	(0.000)
lcpi	0.437	(0.009)	0.057	(0.851)
lnety	−0.122	(0.000)	−1.003	(0.000)
age	0.059	(0.010)	−0.001	(0.989)
age2	−0.001	(0.001)	0.000	(0.949)
fem	−0.426	(0.000)	0.406	(0.000)
ui	0.143	(0.000)	−0.200	(0.000)
lptob	0.337	(0.010)	0.943	(0.000)
lpalc	−0.995	(0.000)	0.326	(0.395)
lptage	−0.001	(0.760)	−0.005	(0.520)
lptage2	0.000	(0.499)	0.000	(0.342)
y7ed2	0.065	(0.003)		
y7ed3	−0.019	(0.443)		
y8ed1	0.181	(0.000)		
y8ed2	0.210	(0.000)		
y8ed3	0.021	(0.670)		
y9ed1	0.123	(0.055)		
y9ed2	0.120	(0.047)		
y9ed3	−0.079	(0.191)		
λ			0.201	(0.000)
σ	1.000		1.947	(0.000)
ρ			−0.969	(0.000)

Table 3.13: Likelihood ratio tests for the statistical significance of the age parameter estimates in the probit equation

Specifications	Test Statistics	d.f.	p
Yen-Jones two-part	492	4	0.000
generalised tobit	224	4	0.000
standard double-hurdle	95	4	0.000
Box-Cox double-hurdle	259	4	0.000

Note: The third column reports the degrees of freedom and fourth column reports the p-value.

Table 3.14: The age at which individuals are most likely to answer "yes" to the question "would you like to purchase some tobacco?"

Specifications	Age
Yen-Jones two-part	42
generalised tobit	42
standard double-hurdle	40
Box-Cox double-hurdle	42

index the probability of answering "yes" is a concave function of the age variable. Table 3.14 reports the age at which individuals are most likely to answer "yes". The gender parameter estimate suggests that females are less likely to answer "yes" than males.

All four specifications find that parameter estimates for the following variables are not significantly different than zero at the five percent level: the Prairie provinces (Ontario is the reference group), observed in the 1980's and have some post-secondary education, a post-secondary degree or a university degree and observed in the 1990's and have less that nine years of education (observed in 1969, 1974 or 1978 and less than nine years of education is the reference group). Overall, nine of the twenty-four probit equation parameter estimates are similar across all four specifications.

Having identified parameter estimates that have similar p-values across all four specifications, the findings that are different in some way across the specifications are identified and discussed. The Yen-Jones two-part, generalised tobit and Box-Cox double-hurdle specifications find that individuals in Ontario, the Prairies or British Columbia are the least likely to answer "yes" when asked, "would you like to purchase some tobacco?" In contrast the standard double-hurdle specification finds that those who live in Ontario or the Prairie provinces are the least likely to answer "yes" and those who live in British Columbia are more likely to answer "yes". Ontario is the reference variable and the British Columbia parameter estimate receives a p-value of 0.003 under the standard double-hurdle specification.

An increase in the consumer price index, ceteris paribus, will mean that the real price of tobacco has decreased and this will encourage consumers to consider purchasing some tobacco. All four specifications find this to be true. However, this parameter estimate is not statistically significant at the five percent level in the standard double-hurdle specification.

The probit equation net income parameter estimate has a p-value of less than five percent under all four specifications. The probit equation net income parameter estimate is positive under the standard double-hurdle specification. This suggests that people who have a relatively high level of income are more likely to consider

Table 3.15: Likelihood ratio tests for the statistical significance of the price of tobacco parameter estimates in the probit equation

Specifications	Test Statistics	d.f.	p
Yen-Jones two-part	14	3	0.003
generalised tobit	14	3	0.003
standard double-hurdle	3	3	0.357
Box-Cox double-hurdle	27	3	0.000

Note: The third column reports the degrees of freedom and fourth column reports the p-values.

purchasing some tobacco. Similarly García and Labeaga find that those with a high income are more likely to purchase tobacco (1996, p.497). In contrast to this finding the net income parameter estimate is negative under the other three specifications. This suggests that people who have a relatively low income are more likely to consider purchasing some tobacco. Similarly, Yen and Jones find that among current and ex-smokers those who are in a relatively high socio-economic group are more likely to have quit compared to those who are in a relatively low socio-economic group (1996, p.116).

In the probit equations there are three tobacco price parameters: the price of tobacco, the price of tobacco crossed with age and the price of tobacco crossed with age squared. According to the likelihood ratio tests in Table 3.15 the price parameter estimates are statistically significant in three of the specifications. They are not statistically significant under the standard double-hurdle specification.

Table 3.16 reports estimated changes in the probability of answering "yes"

Table 3.16: The change in the projected probability of answering "yes" due to a one percent change in the price of tobacco given the minimum age, the average age and the maximum age

	Minimum Age (17)	Average Age (49.8)	Maximum Age (79)
Yen-Jones two-part	0.34	0.37	0.50
generalised tobit	0.30	0.28	0.36
standard double-hurdle	-0.33	-0.44	-0.64
Box-Cox double-hurdle	0.32	0.34	0.42

in response to a one percent change in the price of tobacco products. Three of the specifications suggest that an increase in the price of tobacco is related to an increase in the probability that people will answer "yes". Perhaps provincial governments in regions where there are a large number of smokers have taken advantage of this by assigning a relatively high tax to tobacco products. The standard double-hurdle specification is the only one that arrives at a negative price parameter estimate, although it is not statistically different from zero. Fry and Pashardes also find the price of tobacco to be statistically insignificant in an equation that determines whether or not some tobacco is purchased (1994, p.513-514).

In the data set a price index was constructed for each of the five regions of Canada and for each of the eight years; this means that there were 40 price indices. Perhaps a data set that contains more accurate measures of the prices consumers face would lead to a different set of results. For example, some Canadians may avoid the Canadian tobacco taxes by purchasing tobacco in the United States. Furthermore, during some periods in which this data set was collected there was a black market for tobacco products. It is not clear what the price of tobacco was in the black market or how quantities purchased in the black market are related to the tobacco expenditures observed in the data set. It may also be that a data set that follows each individual's tobacco expenditure and the price of tobacco over time may arrive at more plausible findings with regard to the price of tobacco products.

The unemployment insurance variable in the probit equation is positive and significantly different from zero at the level of one percent in three of the specifications. Similarly Garcìa and Labeaga find that when the head of a family is unemployed this "raises the probability of smoking" (1996, p.498). Blaylock and Blisard also find that women who are unemployed are more likely to smoke than women who are employed (1992, p.433). Under the standard double-hurdle specification probit equation the p-value of unemployment insurance parameter estimate is 0.191 and, like the other specifications, this parameter estimate is positive. All four specifications suggest that those who are unemployed are more likely to answer "yes" to the probit equation question.

The year and education parameter estimates are quite different across the four specifications. At five percent none of the standard double-hurdle year-education parameter estimates are statistically different from zero. Five of them are significantly different from zero under the Box-Cox double-hurdle specification, four of them under the generalised tobit specification and three of them under the Yen-Jones two-part specification. The observations that were collected in the 1980's and report that the individual has some, or completed, post-secondary education parameter estimate is the only year-education interaction term that is statistically significant at the five percent level in three of the four specifications (observed in 1969, 1974, or 1978 and less than nine years of education is the reference group). This parameter estimate has a p-value of 0.265 under the standard double-hurdle specification.

Having discussed the probit equation parameter estimates we now move on to the budget share parameter estimates. The budget share equation determines how much tobacco will be purchased by those who answer "yes" to the question "would you like to purchase some tobacco?" Some people whose answer is "yes" will be at a corner solution and hence choose to purchase no tobacco. Others whose answer is "yes" will choose to purchase a strictly positive amount. The following compares the findings obtained through a Yen-Jones two-part specification, a generalised tobit specification, a standard double-hurdle specification and a Box-Cox double-hurdle specification.

The following identifies a set of budget share parameter estimates that are similar across the four specifications. After identifying and discussing the findings that are similar (in terms of there p-values, the sign of each parameter estimate and the size of each parameter estimate) across specifications the findings that are different across them are compared.

All four specifications find that the home ownership, net income, age, female, and price of tobacco parameter estimates receive p-values of less than one percent.

Table 3.17: Likelihood ratio tests for the statistical significance of the age parameter estimates in the budget share equation

Specifications	Test Statistics	d.f.	p
Yen-Jones two-part	57	4	0.000
generalised tobit	77	4	0.000
standard double-hurdle	151	4	0.000
Box-Cox double-hurdle	47	4	0.000

Note: The third column reports the degrees of freedom and fourth column reports the p-value.

Table 3.18: Likelihood ratio tests for the statistical significance of the price of tobacco estimates in the budget share equation

Specifications	Test Statistics	d.f.	p
Yen-Jones two-part	40	3	0.000
generalised tobit	26	3	0.000
standard double-hurdle	88	3	0.000
Box-Cox double-hurdle	413	3	0.000

Note: The third column reports the degrees of freedom and fourth column reports the p-value.

Likelihood ratio tests for the age and price of tobacco parameter estimates are in Tables 3.17 and 3.18.

Parameters estimated under the generalised tobit and Box-Cox double-hurdle specifications indicate that individuals who own their own home tend to purchase a higher amount of tobacco. In contrast, the home ownership parameter estimates are negative in the Yen-Jones two-part specification and the standard double-hurdle specification. The negative finding is similar to the findings reported in Jones 1989a.

Table 3.19: The income elasticity of tobacco products

Specifications	Income Elasticity
Yen-Jones two-part	0.22
generalised tobit	0.31
standard double-hurdle	-0.09
Box-Cox double-hurdle	0.29

Jones finds that, "home ownership reduces the probability of individuals ever smoking and of current participation, including the decision to quit, and reduces current consumption" (1989a, p.31).

The net income parameter estimates in the budget share equations are all negative. Net income is an explanatory variable and it is the denominator in the tobacco budget share variable. The income elasticity of tobacco under each specification is derived in Appendix 3. Under the Yen-Jones two-part and generalised tobit specifications the income elasticity depends on the income parameter estimate. Under the standard and Box-Cox double-hurdle specifications it depends on the tobacco budget share as well.

Table 3.19 reports an income elasticity under each specification. Under the Box-Cox and standard double-hurdle specifications the tobacco budget share is set equal to the average among the observations that report a strictly positive amount.

The standard double-hurdle income parameter estimate suggests that the income elasticity is negative. In contrast the other three specifications suggest that the income elasticity is positive.

Table 3.20: The age at which the projected quantity of tobacco purchased is at a maximum or minimum given and the sign of the second derivative of the quantity purchased with respect to age

Specifications	Age	Sign Second Derivative
Yen-Jones two-part	49	negative
generalised tobit	40	positive
standard double-hurdle	46	negative
Box-Cox double-hurdle	32	positive

Note: Both columns were calculated at the average tobacco price index.

Both the Yen-Jones two-part and the standard double-hurdle specifications find that the quantity of tobacco purchased is a concave function of age. This functional form is similar to what Blaylock and Blisard 1992 and Hu et al. 1995 find. Under the Yen-Jones two-part specification the minimum is at forty-nine years of age and under the standard double-hurdle specification the minimum is at forty-six years of age. In contrast the generalised tobit and Box-Cox double-hurdle specifications find that the quantity of tobacco purchased is a convex function. The maximum is at forty years of age under the generalised tobit specification and at thirty-two years of age under the Box-Cox double-hurdle specification.

All four specifications find that the female parameter estimates in the budget share equations are statistically significant. However the coefficients are negative in the Yen-Jones two-part specification and in the standard double-hurdle specification; in contrast they are positive in the generalised tobit specification and in the Box-Cox double-hurdle specification.

Table 3.21: The price elasticity of tobacco given the minimum age, the average age and the maximum age

	Minimum Age (17)	Average Age (49.8)	Maximum Age (79)
Yen-Jones two-part	-0.43	-0.42	0.81
generalised tobit	-0.30	-0.35	-0.31
standard double-hurdle	-0.37	-0.25	0.16
Box-Cox double-hurdle	-0.38	-0.38	-0.28

Note: Under the standard and Box-Cox double-hurdle specifications the tobacco budget share is set equal to the average among those that purchase some tobacco.

Under the Yen-Jones two-part and generalised tobit specifications the price elasticity of tobacco depends on the age variable and the three price parameter estimates. Under the standard and Box-Cox double-hurdle specifications the price elasticity of tobacco depends on the tobacco budget share and age variables as well as the three price parameters.

All four specifications find that the tobacco demand function is downward sloping at the minimum age and the average age. The Yen-Jones two-part and standard double-hurdle specifications find that the price elasticity of tobacco is positive at the maximum age. In contrast the generalised tobit and Box-Cox double-hurdle specifications find it to be negative at the maximum age. Several other papers find that an increase in the price of tobacco will decrease the quantity consumed. However, as Keeler et al. 1993 and Wasserman et al. 1991 point out there is a wide range of findings.

In all four specifications the Prairies and the price of alcohol parameter estimates have a p-value that is greater than five percent. This suggests that those who live in the Prairies spend a similar proportion of their budget on tobacco compared to otherwise similar people who live in Ontario. These findings also suggest that the price of alcohol has little influence on the quantity of tobacco people purchase.

Having identified parameter estimates that have similar p-values across all four specifications the findings that are different in some way across the specifications are identified and discussed. The British Columbia budget share parameter estimate is negative under all four specifications. Under the Yen-Jones two-part specification and the standard double-hurdle specification the British Columbia budget share parameter estimate is the only region of residence parameter estimate that has a p-value of less than one percent, Ontario is the reference group. In contrast none of the region of residence parameter estimates have p-values of less than five percent under the generalised tobit specification or under the Box-Cox double-hurdle specification.

The consumer price index parameter estimates in the budget share equations are positive in all four specifications. They have a p-value of less than one percent in the Yen-Jones two-part specification and in the standard double-hurdle specification. This plausibly suggests that an increase in the real price of tobacco encourages people to decrease how much they spend on tobacco. In the generalised tobit specification and the Box-Cox double-hurdle specification the consumer price index parameter estimates are not significantly different from zero according to the p-values.

In the budget share equations three of the unemployment insurance indicator parameter estimates have a p-value of less than one percent. Under the standard double-hurdle specification the unemployment insurance p-value is 0.014 in the budget share equation. The unemployment insurance indicator parameter estimate is positive under the Yen-Jones two-part specification and under the standard double-hurdle specification in the budget share equation. This is similar to what Garcìa and Labeaga find (1996 p.498) and it seems plausible that the stress associated with unemployment is related to an increase in the amount of tobacco purchased. It may also be that those who are most likely to become unemployed belong to a group of people who tend to purchase a large amount of tobacco. The unemployment insurance parameter estimate is negative under the generalised tobit specification and under the Box-Cox double-hurdle specification. This is also intuitively plausible in that some people who are unemployed may have experienced an unexpected decrease in their lifetime income and hence cut back on how much tobacco they purchase.

In summary, in the probit equation under all four specifications the Atlantic, Quebec, home-ownership, age and female parameter estimates have p-values of less than one percent. Under all four specifications these parameters suggest that individuals in the Atlantic provinces, Quebec, who do not own their home, are in their late thirties or early forties or are of the male gender are more likely to answer "yes" to the question "would you like to purchase some tobacco?" Apart from these findings the standard double-hurdle specification stands out as unique.

The standard double-hurdle specification is the only one that suggests those living in British Columbia are more likely to answer "yes" to the question "would you like to purchase some tobacco?" than those living in Ontario. The standard double-hurdle specification is also the only specification under which none of the year-cross-education parameter estimates have p-values of less than five percent. The standard double-hurdle specification obtains the finding that an increase in the price of tobacco likely results in fewer people answering "yes" to the question "would you like to purchase some tobacco?" This is in contrast to the probit equation parameter estimates obtained using the other three specifications. All four specifications plausibly suggest that those who are unemployed are more likely to answer "yes". However, the unemployment parameter estimate is not statistically significant under the standard double-hurdle specification. All four specifications also suggest that an increase in the consumer price index, and hence a decrease in the real price of tobacco, reduces the probability that people will answer "yes". The standard double-hurdle specification is the only one that suggests the consumer price index is not statistically significantly different from zero. In some ways the standard double-hurdle probit equation parameter estimates stand out on their own. It is not clear which set of results are the most intuitively plausible.

The Yen-Jones two-part and standard double-hurdle specifications arrive at many similar budget share finding that are in contrast to the findings obtained using generalised tobit or Box-Cox double-hurdle specifications. According to the Yen-

Jones two-part and standard double-hurdle specifications individuals who do not own their home, are in their forties or are male are less likely to be at corner solution and are likely to purchase more tobacco. In contrast according to the generalised tobit and Box-Cox double-hurdle specifications individuals who own their home, are in their twenties or seventies, or are female are less likely to be at a corner solution and are likely to purchase more tobacco. No single specification seems to arrive at a set of results that stand out as more intuitively plausible or often reported in other papers.

3.11 Conclusions

The Yen-Jones two-part specification arrives at an intuitively plausible and appealing set of results and the conditional two-part specification is clearly related to a plausible model. The two-part specification makes use of observations that report strictly positive tobacco budget shares in order to estimate the relationship between strictly positive tobacco budget shares and explanatory variables. In contrast the sample-selection and double-hurdle specifications use all of the observations in order to estimate the relationship between strictly positive tobacco budget shares and explanatory variables. The functional form of the equation that determines $w_i^\dagger$ is difficult to motivate intuitively. For these reasons I have applied the two-part specification in the Chapter 4.

If policy makers are interested in who purchases tobacco and the amount consumed conditional on some being purchased ($E(w_t \mid w_t > 0)$) then the conditional two-part specification may provide valuable information on these two separate issues. If policy makers are interested in how policies such as tobacco taxes are likely to influence the expected amount of tobacco being purchase ($E(w_t)$) in the population then the unconditional two-part specification suggested by Mullahy 1998 is one way to address this issue. The sample-selection, Yen-Jones two-part, generalised tobit and double-hurdle specifications are other options. It is challenging to present an intuitively appealing model that underlies these four specifications.

The two-part specification and the sample-selection specification have strong proponents and opponents. Recent Monte Carlo tests do not support the two-part specification over the sample-selection specification or vice-versa (Leung and Yu 1996). In estimating a tobacco budget share equation researchers could also apply a double-hurdle specification. Jones (1989a), García and Labeaga (1996) and Yen and Jones (1996) encourage investigators to apply the double-hurdle specification.

If researchers are choosing among different versions of the double-hurdle specification then the likelihood ratio tests provide good reasons to apply the Box-Cox double-hurdle specification. Comparing the Yen and Jones two-part specification to the two-part specification presented in this chapter may be an interesting topic to explore in the future.

In the future it may also be valuable to develop further behaviour models that motivate the functional form of the specifications that have been applied to tobacco data. Systematic use and further development of behavioural models may be a valuable way to compare specifications and interpret the results obtained. Such models would enable investigators to make explicit the behavioural model on which they base their work.

There are some findings that are obtained using several different specifications. Policy makers who are interested in aiming anti-smoking campaigns at a large number of tobacco purchasers may want to consider these findings. (This topic will be more thoroughly examined in Chapter 4 where the data set includes information on households consisting of one or more individuals.)

In the future it would be valuable for researchers to analyse data that follow individuals and their tobacco expenditure or consumption over time. This would identify who has made small changes in their tobacco budget share in response to changes in an explanatory variable, who is likely to quit purchasing tobacco in response to a change in an explanatory variable and who is likely to start in response to changes in an explanatory variable.

3.12 References

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3.13 Appendix 1: Other Factors That May be Related to the Results Obtained.

In this appendix I identify a number of factors that may influence the findings that investigators obtained by examining tobacco data. This section reviews fifteen papers on tobacco consumption. These papers are compared in three different ways. First the dependent and explanatory variables analysed in each paper are compared. For example, some papers analyse cigarette consumption and others analyse tobacco expenditure. Next a few explanatory variables that are in four or fewer of the fifteen papers are identified and discussed. If these variables are statistically significant or correlated with some of the other explanatory variables then they may have a strong impact on several of the results obtained. Finally, the findings with regard to the influence of tobacco prices are compared and discussed. Given all of the differences across papers in the tobacco demand literature, one might expect the tobacco demand literature to obtain a wide range of results. Despite this there are some results that are common across several papers. In Chapter 4 I estimate a tobacco budget share equation and identify a number of significant parameter estimates. A literature review in Chapter 4 also demonstrates that a number of different papers have obtained similar findings. The main goal of this appendix is to identify several factors that may influence the findings investigators obtain. This information may be valuable to those who are collecting tobacco data in the future.

Table 3.22: Dependent Variables

Dependent Variable	Authors, Year
per-capita cigarette sales	Becker et al. 1994
	Keeler et al. 1993
individual cigarette consumption	Blaylock and Blisard, 1992
	Chaloupka, 1991
	Hu et al. 1995
	Jones 1989a
	Ohsfeldt et al. 1997
	Wasserman et al. 1991
	Yen and Jones, 1996
real household expenditure on tobacco	Fry and Pashardes, 1994
	García and Labeaga 1996
	Labeaga 1993
	Hu et al. 1995
	Jimenez and Labeaga 1994
aggregate quarterly tobacco budget shares	Jones, 1989c
annual measures of cigarette expenditure	Jones 1989b

Table 3.22 identifies five dependent variables that have been used in economics papers on tobacco. Nine of the papers analyse dependent variables that are a measure of cigarette consumption (Becker et al. 1994, Blaylock and Blisard 1992, Chaloupka 1991, Hu et al. 1995, Jones 1989a, Keeler et al. 1993, Ohsfeldt et al. 1997, Wasserman et al. 1991, Yen and Jones 1996). Becker et al. 1994 and Keeler et al. 1993 analyse per capita cigarette sales. Among these nine papers seven of them analyse the cigarette consumption of individual consumers. For Jones (1989a) and Yen and Jones (1996) each observation was collected at one point in time. However, the data set identifies individuals who had quit smoking in the past and who had never smoked. This information identifies two different types of zeros in tobacco data sets. Hu et al. 1995 analyse data that came from a survey which asks individuals who have smoked at least 100 cigarettes if they currently smoke, and if so, the number of cigarettes smoked per day. This may be a valuable way to distinguish between those who have consumed a small amount of tobacco and those that are physically addicted to tobacco.

Six of the fifteen papers analyse tobacco expenditure rather than the number of cigarettes smoked (Fry and Pashardes 1994, García and Labeaga 1996, Jimenez and Labeaga 1994, Jones 1989b, Jones 1989c, Labeaga 1993). Fry and Pashardes 1994, García and Labeaga 1996, Labeaga 1993 and Jimenez and Labeaga 1994 analyse real household expenditure on tobacco. Jones 1989c analyses aggregate quarterly budget shares for tobacco and Jones 1989b analyses annual measures of cigarette expenditure and participation rates. Jones also emphasises the distinction between per capita and per smoker consumption.

In discussing tobacco dependent variables Jones points out that, "with expenditure data it is often argued that differences in quality and characteristics will be reflected in market prices, and that expenditure can therefore be viewed as a quality-adjusted measure of consumption. This is clearly not the case with the crude measure of number of cigarettes smoked, which makes no allowance for the size, flavour, and tar content of the cigarettes" (1989a, p.30). He also points out that, "with data based on expenditure diaries, completed over a limited number of days, there are problems of infrequency of purchase, purchases that are actually consumed by other members of the household, and unrepresentative or exceptional purchases" (1989a, p.30). On this same topic Yen and Jones point out that, "unlike an expenditure variable, [a measure of cigarette consumption] does not control for the price or quality of cigarettes smoked. However as a measure of 'typical' consumption, it is less likely to suffer from the problems of infrequency of expenditure and recall and response bias that are likely to arise in expenditure surveys. It can also be argued that the typical number of cigarettes is better suited for analysis of the interaction between smoking and health" (1996, p.110).

In summary, nine of the papers analyse cigarette consumption and six of the papers analyse tobacco expenditure. In the future it may be interesting to examine one data set that reports a measure of cigarette consumption and a measure of tobacco expenditure.

Table 3.23: Explanatory Variables Used in Selected Studies

Explanatory Variables	Authors, Year
health status	Blaylock and Blisard, 1992 Jones, 1989a Hu et al. 1995 Yen and Jones, 1996
height-weight	Blaylock and Blisard, 1992 Hu et al. 1995 Yen and Jones, 1996
physical activity	Blaylock and Blisard, 1992 Hu et al. 1995
attitude towards health risk of smoking	Jones 1989a
border prices	Becker et al. 1994 Chaloupka, 1991
regulation index	Keeler et al. 1993 Ohsfeldt et al. 1997 Wasserman et al. 1991

How a dependent variable is measured is one issue that may influence the results. The set of explanatory variables that are examined may also influence the results that investigators obtain. Most of the papers reviewed here include the price of tobacco products, income and age as explanatory variables. The main purpose of this appendix is to identify a number of factors that may influence the results obtained. Therefore I identify a few explanatory variables that appear in four or less of the fifteen papers reviewed.

The first four explanatory variables listed in table 3.23 have been used to identify the relationship between tobacco and health. The other two explanatory variables in table 3.23 contain information that tobacco policy makers may find valuable.

Health status is an explanatory variable in four papers. Blaylock and Blisard "develop and estimate a model that postulates a simultaneous relationship between a person's self-evaluated health status and whether or not they currently smoke" (1992, p.429). In their introduction Blaylock and Blisard point out that, "the health of an individual in our models is gauged by the person's own self-rating. This variable is obviously a broad indicator that does not account explicitly for smoking related illnesses. It may also differ from a medical evaluation. However, we believe that in the context of a model of subjective individual choice, such as the economic models we develop, a self-evaluated health rating is preferred to a clinical judgement" (1992, p.429). The health status variable is assigned a one when an individual indicates her health is good or better and is assigned a zero otherwise. Jones 1989a has a health status indicator variable that has a value of one when an individual rates his or her health status over the last year as good and a value of zero otherwise. Hu et al. 1995 have a set of explanatory variables that indicate whether each person's health status is excellent, good, fair or poor. Yen and Jones 1996 have a binary variable that indicates a disability or a long term illness. Yen and Jones 1996 also have variables that indicate lung function and cardiovascular condition. There are many ways to measure health and this information may be valuable in explaining how health and tobacco consumption may be related.

Blaylock and Blisard 1992, Hu et al. 1995 and Yen and Jones 1996 apply a weight-height index. In Blaylock and Blisard 1992 this index equals each person's weight (lbs.) divided by their height (inches). Hu et al. 1995 and Yen and Jones 1996 apply the Quetelet Index as an explanatory variable[7]. The Quetelet Index is equal to the person's weight in kilograms divided by their height in meters squared. This measure was used to identify individuals who are obese. It may be that individuals who are overweight have different preferences for tobacco compared to those who are not overweight or it may be that people who consume tobacco have different preferences for food or physical activity. This topic raises an interesting question concerning the biology of addiction, health status and consumer preferences.

Physical activity is an explanatory variable in two of the fifteen papers. In the model that Blaylock and Blisard present physical activity is an explanatory variable used to examine the inter-relationship between health and smoking. The physical activity variable, "equals 1 if female's usual level of physical activity at job/house is heavy, equals 2 if moderate, equals 3 if light, [and] equals 4 if none (bedridden/confined to wheelchair)" (Blaylock and Blisard 1992, p.431). Hu et al. 1995 make use of a leisure time physical activity variable. This variable was, "categorized into four levels using Center for Disease Control calculations: 1) none (no exercise during the last month), 2) irregular (less than three times a week and/or less than twenty minutes per occasion), 3) regular (at least three times a week for at least twenty min-

[7]The Quetelet Index is also known as the Body Mass Index.

utes each occasion), and 4) meeting 1990 objectives (regular exercise which involves large muscle groups in dynamic movement performed at an intensity of 60 percent or greater of an individual's cardiorespiratory capacity)" (Hu et al. 1995, p. 9).

Two explanatory variables in Jones 1989a reflect each person's attitude towards the health risk of smoking. A variable called smoke-risk is assigned a value of 1 when an, "individual gives an unqualified yes to the question 'do you think that smoking can damage people's health' " (Jones 1989a, p.31). A variable called smoke-drink is assigned a value of one when an "individual believes that smoking is more harmful than drinking" (Jones 1989a, p.31). In discussing these variables Jones points out that there are two ways to interpret the statistical findings. It could be that people who believe that smoking results in a relatively small change in the probability of suffering from ill health are more likely to start smoking. It could also be that after becoming addicted to tobacco individuals convince themselves that there is a relatively small risk of suffering from the health effects of smoking. Most economics papers on tobacco do not have an explanatory variable that indicates people's attitude concerning the health risk of smoking.

In summary health status, height-weight, physical activity and attitudes towards the health risk of tobacco may all be valuable for exploring the relationship between tobacco consumption and health status.

The prices of cigarettes within a few geographic regions are explanatory variables in two papers. Three indices that measure the incentive to smuggle cigarettes throughout the United States are explanatory variables in Becker et al. 1994. One index measures the incentive to smuggle cigarettes from the three states where almost all of the cigarettes are produced in the United States (Kentucky, Virginia or North Carolina)(Becker et al. 1994, p.402). Another index measures the incentive to export cigarettes to a neighbouring state and a third index measures the incentive to import cigarettes from a neighbouring state. Keeler et al. 1993 analyse data that report cigarette consumption in California. They have an explanatory variable that indicates the cigarette tax rate in California divided by the average cigarette tax rate in two adjacent states (Oregon and Arizona) where the cigarette tax rate, and hence the price of cigarettes, is much lower (Keeler et al. 1993, p.9).

A regulation index is an explanatory variable in three of the fifteen papers. Keeler et al. state that there are, "two important reasons for including regulation in our analysis: the first is to contribute evidence on its effects, and the second is to provide accurate estimates of price elasticity, which could be substantially biased if the regulatory variable is excluded" (1993, p.2). The regulation index in Keeler et al. "reflects the per cent of the state's population living in at least one jurisdiction subject to a local smoking ordinance, controlling for the severity of the ordinance" (1993, p.10). Ohsfeldt et al. 1997 finds that, "state laws restricting smoking have no apparent effect on ST [smokeless tobacco] use" (p.525). Wasserman et al. 1991 make use of, "information on whether and, if so, when a particular state enacted a law that restricted smoking in each of the following places: public buses and trains, elevators, indoor recreational or cultural facilities, retail stores, restaurants, schools, health care facilities (e.g., hospitals and nursing homes), public meeting rooms, libraries, rest rooms, waiting rooms, public work-sites, private work-sites, and 'other' public places (e.g., jury rooms, halls and stairs, polling places, and prisons). Additionally we determined whether laws were enacted that restricted the sale or distribution of cigarettes to minors" (p.48). This data set was collapsed into a regulation index for each state. Each state was assigned a 1, 0.75, 0.50, 0.25 or 0 depending on the regulations in each state. Tobacco regulations may vary across the provinces in Canada and in the future it may be interesting to explore this issue.

Most of the papers reviewed in this appendix have the price of tobacco as an explanatory variable. With this in mind the following summarises the price findings that the twelve tobacco demand papers report.

Twelve out of the fifteen papers reviewed in this section include a tobacco-related price as an explanatory variable. The price of cigarettes is not an explanatory variable in Jones (1989a), Yen and Jones (1996) or Blaylock and Blisard (1992).

Fry and Pashardes found that the price of tobacco did not have a statistically significant effect on the probability of household purchasing tobacco. In discussing this they point out that, "it is possible that household data obscure the effect of price changes when one adult gives up smoking in a household of other smokers. For this reason we also estimated the probability of purchase using single-adult households only. Again prices were found to be insignificant" (1994, p.513). Fry and Pashardes conclude that the, "demand [for tobacco] is price inelastic" (1994, p.515).

García and Labeaga 1996 estimate a number of different household price elasticities and they find that, "the most sensitive households to price changes are those whose head is illiterate, unemployed or young. The positive own price elasticity for households of high levels of education has been estimated [to be] not significantly different from zero" (1996, p.499). Based on a two-part specification Hu et al. find a price elasticity of -0.33 for each individual's smoking participation and -0.22 for the amount of cigarettes consumed by individual smokers (1995, p.7). Jimenez and Labeaga 1994 find that the household tobacco price parameter estimates in a tobacco budget share equation are positive and less than one. Based on these estimates they find that the own price elasticity of tobacco is between zero and minus one and statistically significant at the five percent level. Jones (1989c) finds that the UK aggregate own price elasticity of tobacco is negative and less than minus one. Ohsfeldt et al. find that higher smokeless tobacco excise tax rates, "are associated with a reduction in the likelihood of use of ST [smokeless tobacco] products among males in the USA" (Ohsfeldt et al. 1997, p.529). They also find that, "higher cigarette taxes are associated with greater snuff use among males, holding ST tax rates and other factors constant" (Ohsfeldt et al. 1997, p.529).

By applying the two-part specification Wasserman et al. find, "that price changes have their greatest effect on the decision to become a smoker rather than on the number of cigarettes smoked, given that one has chosen to smoke" (1991, p.60).

In discussing the two-part results they state that, "the total price elasticity estimates from the two-part model are very close to the generalised linear model estimates. Thus, the price elasticity estimates appear insensitive to the statistical method used to model cigarette demand" (Wasserman et al. 1991, p.60). The results of applying the two-part specification to teenage smoking data show that price does not have a statistically significant effect on whether a teenager smokes or not, and when they do smoke, the price does not have a statistically significant effect on how much they smoke (Wasserman et al. 1991, p.60).

Based on a pseudo-Poisson (or generalised linear) specification Wasserman et al. (1990) find that, "the adult results indicate that the price elasticity of demand is unstable over time, ranging from 0.06 in 1970 to −0.23 in 1985." They also find that teenage price elasticity does not differ statistically from the adult price elasticity (Wasserman et al. 1990, p.43) These elasticities do not distinguish between how the price of tobacco influences whether one smokes or not and how much one smokes. Wasserman et al. suggest that, "a substantial portion of the difference between our price elasticity estimates and the higher estimates found in other studies can in all likelihood be attributed to our inclusion of the regulation index " (1990, p.61). The regulation index is a variable between zero and one and it reflects the number of public places in which people are allowed to smoke. "Given the positive correlation between prices and regulations, the earlier studies may have been biased upward due to the omission of regulations from their models" (Wasserman et al. 1990, p.61).

In their introduction Keeler et al. point out that there is, "a wide range of estimates of the effects of price (and, implicitly, taxation) on cigarette consumption" (1993, p.2) and as suggested earlier they point out that estimates of price elasticity could be substantially biased if there are no regulatory variables. Keeler et al. report results from a number of different estimates, some of which include a time trend. In interpreting their results they, "prefer to emphasise the results without [the time trend] given its intercorrelation with regulatory and price changes, and given its lack of theoretical meaning" (1993, p.11). In the conclusion section of the paper the authors state that they, "estimate that the demand elasticity was in the range of −0.5 to −0.6 in the long run" (1993, p.17). They also point out that, "for example, if one assumes no rational addiction, the most plausible specification (including regulation as an explanator) yields a price elasticity of demand of −0.5. If one assumes rational addiction, under the most plausible specification (again including regulation as an explanitor), one finds a price elasticity of demand of −0.4 in the short run and −0.6 in the longer run" (1993, p.17).

Labeaga finds that households react to changes in the price of tobacco with a time lag (1993, p.111). There is mixed evidence concerning the relationship between tobacco price sensitivity and education (1993, p.109). The author ends the paper by stating, "that the price of tobacco (or taxes on tobacco) could be an effective instrument in reducing consumption, at least for some groups in the population and it could, at the same time, help to minimise the social cost of tobacco smoking" (1993, p.111).

Becker et al. "find that a 10-percent permanent increase in the price of cigarettes reduces current consumption by 4 percent in the short run and by 7.5 percent in the long run. In contrast, a 10-percent increase in price for only one period decreases consumption by only 3 percent. In addition, a one period price increase of 10 percent decreases consumption in the previous period by approximately 0.6 percent and decreases consumption in the subsequent period by 1.5 percent. These estimates illustrate the importance of the intertemporal linkages in cigarette demand implied by addictive behaviour" (1994, p.396). This is an interesting finding because most of the data that have been analysed in the past, and the data analysed in this paper, do not report the past and future prices for each observation.

Chaloupka estimates demand equations separately for samples based on age and education. He finds that current cigarette consumption is, "significantly negatively related to the current price of cigarettes. Similarly, when included, past and future prices generally have the anticipated positive effect on current consumption, albeit at somewhat lower significance levels. In most models including both the lagged and led price of cigarettes, the coefficient on past price is larger in magnitude than the coefficient on future price, except for the sample of current smokers, as predicted by the model" (Chaloupka 1991, p.735). He also finds that, "past and future consumption both have significantly positive effects on current consumption" (Chaloupka 1991, p.735). "The estimated long-run price elasticity of demand for the full sample ranges from −0.36 to −0.27" (Chaloupka 1991, p.735). He also reports that, "estimated long-run price elasticities of demand for the sample of current and former smokers range from −0.48 to −0.35. Finally, the estimated long run price elasticity of demand for cigarettes by current smokers, based on estimates consistent with the predictions of the Becker-Murphy theoretical model, ranges from −0.46 to −0.35. The similar ranges for the samples of current and former smokers and current smokers only suggest that the price increase is effective in reducing cigarette consumption by smokers rather than by inducing smoking cessation" (Chaloupka 1991, p.735). Jones finds that, "participation may be less sensitive to price changes than smokers' demand, with an estimated elasticity of participation of −0.192 and of demand of −0.307" (1989b, p.139).

The price of tobacco products is an explanatory variable in most of the papers reviewed. Wasserman et al. point out that "[e]stimates of the price elasticity of demand for cigarettes vary considerably" (1991, p.44) and that the "broad range in price and income elasticity estimates appears to be attributable to differences in both data and estimation techniques" (1994, p.44). The relationship between the price of tobacco and the demand for tobacco depends in part on the age and education of those who are observed and on the years in which the data set was collected. Furthermore the price of tobacco may be correlated with other explanatory variables such as regulation indices. Tobacco price findings may also depend on the specification that is applied to a data set.

The main topic of this paper is to compare three different specifications that have been used to analyse tobacco consumption. This appendix demonstrates that choosing to apply particular specifications is one issue among several that may influence the results that are obtained. The way in which tobacco consumption is measured, the explanatory variables that are used to analyse tobacco consumption and the functional form researchers apply to the explanatory variables are three other reasons that may influence findings. The list of unusual explanatory variables may be valuable information for those collecting data in the future. If statistically significant explanatory variables are correlated with each other then excluding one of them may have an impact on several of the parameter estimates that researchers obtain. In the future, Canadian data that report the price of tobacco in the United States may be valuable for exploring the relationship between tobacco taxes in Canada and the quantity of tobacco consumed. Identifying the relationship between tobacco regulations and tobacco consumption may also be valuable information in developing tobacco policies.

3.14 Appendix 2: Papers That Have Applied Becker and Murphy's Model of Rational Addiction.

Becker and Murphy (1988) is a seminal paper on the theory of rational addiction. Becker and Murphy point out that, "[p]eople get addicted not only to alcohol, cocaine, and cigarettes but also to work, eating, music, television, their standard of living, other people, religion and many other activities" (1988, p.676). Becker and Murphy state that, "[i]n our theory of rational addiction, "rational" means that individuals maximise utility consistently over time, and a good is potentially addictive if increases in past consumption raise current consumption" (1988, p.694). Becker et al. (1994), Chaloupka (1991), Keeler et al. (1993) and Labeaga (1993) are four papers that apply specifications based on Becker and Murphy's model of rational addiction to tobacco data.

Applying Becker and Murphy's model of rational addiction requires that each individual or household be followed over time. Chaloupka analyses data that were constructed by asking individuals about their current and past cigarette consumption. Labeaga (1993) analyses data that follow households over time. Each household's annual expenditure on tobacco was reported over six years (Labeaga 1993, p.107). Becker et al. (1994) analyse data that report USA state wide annual per capita cigarette consumption. Annual cigarette consumption in fifty states was reported for thirty-one years (Becker et al. 1994, p.402). Keeler et al. (1993) analyse data that report monthly adult per capita cigarette consumption in California. Monthly cigarette consumption in California was reported for ten years (Keeler et al. 1993 p.7). The specification applied in Keeler et al. is unique in that it applies, "an econometric model of cigarette demand that is different from previous models in that it is econometrically tailored to the situation: the count nature of cigarette consumption data; the autocorrelation of monthly cigarette consumption data; and the endogeneity of cigarette prices in the model" (1993, p.2). Unfortunately data that report individual information over time is not widely available. With this in mind Chaloupka points out that, "imposing a 100 percent rate of depreciation results in the exclusion of past and future prices from the demand equation" (1991, p.733) and that "making this assumption does not, however, imply that smoking is not addictive since past, current, and future consumption are still expected to be complements" (1991, p.733). This provides an interesting link between specifications that are based on Becker and Murphy's model of rational addiction (1994) and specifications that that have been used to analyse data that do not report individual information over time.

Becker and Murphy's model of rational addiction suggests that, "the level and path of prices ... affect the likelihood of becoming addicted" (1988, p.694) and that past tobacco consumption, current tobacco consumption and plans for future tobacco consumption are complementaries. Most tobacco data sets do not follow subjects over time. For this reason the model presented in this paper does not introduce the concept of time. In the future Becker and Murphy's model may be widely applied to cross sectional tobacco data and data that report each individual's tobacco consumption over time.

3.15 Appendix 3: Income Elasticity, Changes in the Quantity of Tobacco Purchased Due to Changes in Age and the Price Elasticity of Tobacco.

The budget share equation in the Box-Cox double-hurdle specification is

$$\frac{\left(\frac{P_t \cdot Q_t}{M_t}\right)^{\lambda-1} - 1}{\lambda} = \beta_0 X_t + \beta_1 A_t + \beta_2 A_t^2 + \beta_3 \ln(P_t) + \beta_4 A_t \ln(P_t) + \beta_5 A_t^2 \ln(p_t) + \beta_6 \ln(M_t) \tag{3.25}$$

The left hand side of equation 3.25 represents a Box-Cox transformation of individual t's tobacco budget share. The letter P_t represents the market price of tobacco that individual t faces, Q_t represents the quantity of tobacco purchased by individual t and M_t represents individual t's net income. β_0 is a row vector of unobserved parameters and X_t is a matrix of explanatory variables. β_1, β_2, β_3, β_4, β_5 and β_6 are unobserved parameters. Short forms for each of the age, price and income explanatory variables are in Table 3.24.

The income elasticity of tobacco products under a double-hurdle specification is

$$\frac{M_t}{Q_t}\frac{dQ}{dM} = 1 + \left(\frac{P_t Q_t}{M_t}\right)^{-\lambda} \beta_6 \tag{3.26}$$

Table 3.24: Short Forms for the Age and Price Variables

Variable	Description
A	age of the individual
A^2	age squared
$\ln(P)$	natural log of the price of tobacco
$\ln(M)$	natural log of net income

Under the standard double-hurdle specification λ is equal to one and the income elasticity is

$$\frac{M_t}{Q_t}\frac{dQ}{dM} = 1 + \left(\frac{P_t Q_t}{M_t}\right)^{-1} \beta_6 \tag{3.27}$$

Under the Yen-Jones two-part and generalised tobit specifications λ is equal to zero and the income elasticity is

$$\frac{M_t}{Q_t}\frac{dQ}{dM} = 1 + \beta_6 \tag{3.28}$$

Equation 3.29 represents a change in the quantity of tobacco purchased due to a change in age under a Box-Cox double-hurdle specification.

$$\frac{dQ_t}{dA_t} = \left(\frac{P_t \cdot Q_t}{M_t}\right)^{1-\lambda} \left(\frac{M_t}{P_t}\right) [\beta_1 + 2\beta_2 A_t + \beta_4 \ln(P_t) + 2\beta_5 A_t \ln(P_t)] \tag{3.29}$$

Under the standard double-hurdle specification λ is equal to one and a change in quantity due to a change in age is

$$\frac{dQ_t}{dA_t} = \left(\frac{M_t}{P_t}\right) [\beta_1 + 2\beta_2 A_t + \beta_4 \ln(P_t) + 2\beta_5 A_t \ln(P_t)] \tag{3.30}$$

Under the Yen-Jones two-part and generalised tobit specifications λ is equal to zero and a change in quantity due to a change in age is

$$\frac{dQ_t}{dA_t} = \left(\frac{P_t \cdot Q_t}{M_t}\right)\left(\frac{M_t}{P_t}\right)[\beta_1 + 2\beta_2 A_t + \beta_4 \ln(P_t) + 2\beta_5 A_t \ln(P_t)] \tag{3.31}$$

Under each of the four specifications the quantity of tobacco purchased is at a maximum or a minimum with respect to age when

$$\beta_1 + 2\beta_2 A_t + \beta_4 \ln(P_t) + 2\beta_5 A_t \ln(P_t) = 0 \tag{3.32}$$

Under the Box-Cox double-hurdle specification the second derivative of the quantity of tobacco with respect to age is

$$\frac{d^2Q_t}{dA_t^2}\Big|_{\frac{dQ_t}{dA_t}=0} = \left(\frac{P_t \cdot Q_t}{M_t}\right)^{1-\lambda}\left(\frac{M_t}{P_t}\right)[2\beta_2 + 2\beta_4 \ln(P_t)] \tag{3.33}$$

Under the standard double-hurdle specification the second derivative of quantity with respect to age is

$$\frac{d^2Q_t}{dA_t^2}\Big|_{\frac{dQ_t}{dA_t}=0} = \left(\frac{M_t}{P_t}\right)[2\beta_2 + 2\beta_4 \ln(P_t)] \tag{3.34}$$

Under the Yen-Jones two-part and generalised tobit specifications the second derivative of the quantity with respect to age is

$$\frac{d^2Q_t}{dA_t^2}\Big|_{\frac{dQ_t}{dA_t}=0} = \left(\frac{P_t \cdot Q_t}{M_t}\right)\left(\frac{M_t}{P_t}\right)[2\beta_2 + 2\beta_4 \ln(P_t)] \tag{3.35}$$

Under all four specifications the sign of the second derivative of the quantity of tobacco with respect to age depends on the sign of $2\beta_2 + 2\beta_4 \ln(P_t)$. The estimates of β_2 and β_4 can be used to examine whether the quantity of tobacco purchased is a concave or convex function of the age variable. Equation 3.32 can be used to estimate the age at which the quantity of tobacco is maximised or minimised.

Under the Box-Cox double hurdle specification the price elasticity of tobacco is

$$\frac{P_t}{Q_t}\frac{dQ_t}{dP_t} = \left(\frac{P_t Q_t}{M_t}\right)^{-\lambda} [\beta_3 + \beta_4 A_t + \beta_5 A_t^2] - 1 \tag{3.36}$$

Under the standard double-hurdle specification the price elasticity of tobacco is

$$\frac{P_t}{Q_t}\frac{dQ_t}{dP_t} = \left(\frac{P_t Q_t}{M_t}\right)^{-1} [\beta_3 + \beta_4 A_t + \beta_5 A_t^2] - 1 \tag{3.37}$$

Under the Yen-Jones two-part and generalised tobit specifications the price elasticity of tobacco is

$$\frac{P_t}{Q_t}\frac{dQ_t}{dP_t} = [\beta_3 + \beta_4 A_t + \beta_5 A_t^2] - 1 \tag{3.38}$$

In the Parameter Estimates section the equations derived in this section were used to examine the income elasticity, the relationship between tobacco purchasing and age and price elasticity.

Chapter 4

The Determinants of Expenditures on Tobacco in Canada: Introduction

All people who purchase tobacco in Canada receive a warning of the health effects of tobacco. For example some packages of cigarettes read, "Smoking can kill you, Health Canada" and others read "Cigarettes cause fatal lung disease, Health Canada". Tobacco companies are limited as to how they can advertise their products and are required to disclose information on the health effects of tobacco.

Canadians are also exposed to U.S. health warnings concerning tobacco. For instance, on the last page of a recent issue of *Glamour* there is a cigarette advertisement that says "Virginia Slims. It's a woman thing" (October 1998). There is also a picture of a beautiful woman. In the bottom left corner of the advertisement a U.S. health agency states, "SURGEON GENERAL'S WARNING: Quitting Smoking Now Greatly Reduces Serious Risks to Your Health" (*Glamour*, October 1998). Similarly, on the back of a magazine called *G.Q.* there is a handsome cowboy and a package of Marlboro cigarettes. The following warning appears in the bottom left hand corner of this advertisement: "SURGEON GENERALS WARNING: Cigarette Smoke Contains Carbon Monoxide" (*G.Q.*, October 1998).

In contrast to advertisements that encourage tobacco purchasing, doctors' offices and television stations often present anti-tobacco advertising and advice. Pictures of people in anti-smoking advertisements often illustrate that tobacco products can adversely affect how one looks.

In Canada tobacco products are sold in drug stores, grocery stores, corner stores and stores that specialise in selling tobacco products. In order to purchase tobacco legally one must be at least 18 years old. When people do purchase tobacco there are federal and provincial sales taxes that must be paid. Once one has purchased tobacco there are many places such as hospitals, buses, aeroplanes, offices, restaurants and schools where people are not allowed to smoke.

In Canada, and in other countries and in both the private and public sectors there is clearly a tobacco battle. One side makes use of the young and beautiful to encourage people to purchase their product. The other side discourages the consumption of tobacco through restricting where tobacco can be consumed, restricting the use of tobacco, taxes, providing information on the health effects of tobacco consumption and restricting advertisements.

This paper takes a step back from this battle in order to address two questions. Who in Canada purchases tobacco and among those who do, who purchases a relatively large amount? This paper provides new estimates of these factors exploiting micro-level data on tobacco expenditures in Canada for the period 1969-1992.

A large number of econometric studies on tobacco consumption and smoking analyse data from the United States (Becker et al. 1994, Blaylock and Blisart 1992, Chaloupka 1991, Hu et al. 1995, Keeler et al. 1993, Keeler et al. 1996, Ohsfeldt et al. 1997, Wasserman et al. 1991), the United Kingdom (Fry and Pashardes 1994, Jones 1989a, Jones 1989b, Jones 1989c, Yen and Jones 1996) and from other countries such as Spain (García and Labeaga 1996, Jimenez and Labeaga 1994, Labeaga 1993). Auld 1998 is a working paper on wages, alcohol and smoking in Canada. Some of these papers find that people who own a home, people who have a relatively high level of education and people who are employed are less likely to purchase tobacco (or a particular tobacco product) and among those who purchase some tobacco, they tend to purchase less.[1]

In this paper a two-part specification economic model is presented and used to analyse a Canadian data set. This model is used to interpret the empirical findings. Observations on household tobacco expenditure (including some households that con-

[1]For a detailed literature review concerning these findings see section 4.6 on page 219 (Appendix: Comparison of Results from Other Studies).

sist of just one individual) are analysed in order to examine the policy implications of the empirical findings. The main purpose is to identify the factors associated with the probability that a household purchases tobacco and the factors associated with decisions regarding how much tobacco is purchased by households who purchase some. This information might be helpful in formulating tobacco tax policies, tobacco regulation policies and anti-smoking campaigns.

4.1 The Data

The data analysed in this paper come from Statistics Canada's Family Expenditure Surveys conducted in 1969, 1974, 1978, 1982, 1984, 1986, 1990 and 1992 and were compiled by Browning and Thomas (1994a). Browning and Thomas also include price indices for tobacco, alcohol, and other goods. A tobacco price index and an alcohol price index were constructed by Browning and Thomas (1994a) for each geographic area in Canada and for each year.

Each household's expenditure on tobacco over one year is reported in this data set. The data set does not identify who, within each household, consumes the tobacco. Four types of explanatory variables are available in the data set: pecuniary variables, variables that identify who lives within each household, variables that indicate where a household lives and when they were observed and an employment status variable. After defining and describing each variable, the number of observations with missing information are identified.

The following variables may be relevant to household expenditure on tobacco products. The price of tobacco, the price of alcohol, household income, homeownership and the general price level for consumer goods are all pecuniary variables that may affect household expenditure on tobacco. The price of alcohol is included because other papers point out that tobacco and alcohol consumption may be closely related. On this topic Ohsfeldt et al. (1997, p.528) conclude that, "cigarette use and beer are substitutes" on the other hand Jones (1989c, p.99) concludes that, "although the cross-price elasticities [between smoking and drinking] should not be treated with too much confidence, they do provide tentative evidence of complementarity between the two activities". Choosing how much tobacco to purchase may also be influenced by household income. The household income variable could reflect standard income effects but could also be associated with the social class to which a household belongs. Perhaps those who belong to a particular social class have similar preferences for tobacco. In addition to a household's current income, their past and future income may influence their expenditure on tobacco. Data on each household's past income and expected future income is not available. However, a household's past and expected future income may be correlated with a homeownership indicator variable. People who are more concerned about the future may also be more likely to purchase a home and more likely to worry about the future effects of tobacco consumption. Alternatively, homeowners may tend to be from a different socio-economic class than non-home owners and hence the two groups may have different tobacco consumption patterns. The Canadian annual Consumer Price Index measures the general price level.

The age, gender and education of each household member may influence their household's expenditure on tobacco. This information is only reported for the head and spouse, if one exists, in each household[2]. The age of each household's head may be an important explanatory variable if households whose head is young have a different point of view, level of knowledge or set of preferences, with regard to the relationship between health, addiction and tobacco consumption compared to households whose head is old. There may also be a cohort effect. Perhaps within each year households with an older head have a different number of friends, neighbours or working companions who smoke compared to households with a younger head. For these same reasons the spouses' age is included as an explanatory variable.

In the data set there are gender indicator variables for households that have a head but no spouse. There is also an indicator variable for married couples; the married couples indicator variable is the reference category for the two single head of household gender variables. In other words, the single male variable (households whose head is a male and there is no spouse) and the single female variable (households whose head is a female and there is no spouse) indicate how their tobacco budget shares compare to households that consist of a head and a spouse.

Education indicator variables are included because the level of education that

[2]In some years there is age and gender information for household members other than the spouse and head (Browning and Thomas 1994). Rather than dropping a year or more of observations, these variables were not used in this paper.

the head of a household chooses may reflect time preferences. For example, individuals who search for a job when they are young may be less concerned about the future compared to those who choose to continue their high school, college or university education. Given the impact of tobacco consumption on future health, individuals who are less concerned about the future may be more likely to purchase some tobacco. It may also be that those who were less successful in school at a young age will have lower incomes in the future and live more stressful lives, which may encourage them to consume tobacco. The education variables may also affect their understanding and appreciation of the health effects of tobacco or be a proxy for each family's socio-economic status. Education indicator variables for the spouse are included for the same reasons.

The number of people within a household may be related to tobacco expenditure. Having more people in a household requires more food, and other goods. Given budget constraints the number of people in each household may influence how much a family spends on tobacco. People who purchase no tobacco may also avoid living in a household that consists of one or more smokers. Furthermore tobacco consumption by the head and/or spouse of a household may encourage their sons and daughters to consume tobacco. Five dummy variables indicate the number of people in each household.

Thus far the pecuniary and intra-household variables have been defined and discussed. Other factors that may be related to tobacco purchasing are the region in which the household lives, the decade they were observed in and their employment status.

Perhaps individuals who smoke encourage others to smoke and non-smokers encourage others to quit or never start. Provincial laws and regulations may affect smoking behaviour. In the data set there are five Canadian region of residence variables; the province of Ontario is the reference category. The other regions are the Atlantic provinces, Quebec, the Prairie provinces and British Columbia.

For several reasons the demand for tobacco products may have changed over time. In this paper there are three decade indicator variables. These variables may reflect how peoples' understanding of the relationship between tobacco consumption and health has changed over time. They may also reflect how laws concerning where tobacco can be smoked and tobacco advertising have changed over time. Furthermore they may reflect changes in the difference between the price of tobacco in Canada and the price of tobacco in the United States of America. For example the price of cigarettes in Buffalo relative to the price of cigarettes in Southern Ontario in 1982 differs from the relative price of cigarettes in Buffalo in 1992. All else equal this difference in the price of cigarettes may influence how much money households in southern Ontario spend on tobacco. Lastly it may be that society's views regarding tobacco have changed over time and each household may be influenced by these mores. Ideally one would have variables that clearly reflect each of these issues, but in their absence, the decade indicator variables may be a useful proxy.

One last explanatory variable is an indicator variable for the reception of unemployment insurance within a household. Perhaps households that suffer a decrease in their current income due to a change in their employment status adapt by enjoying more tobacco despite its future health effects. This may be particularly true for households that have a strong preference for employment. Alternatively there may be an unemployment cohort effect. The unemployment variable may identify a group of people who are more likely purchase a relatively large amount of tobacco. If there is an unemployment cohort effect, it is possible that a change in employment status has little influence on tobacco expenditures.

In summary, there are four types of explanatory variables: pecuniary variables, variables that identify who lives within each household, variables that indicate where a household lives and when they were observed and an unemployment indicator variable. Table 4.1 assigns an abbreviation to each explanatory variable.

There are 71,023 observations in the data set. Among these observations some information is missing. The following identifies observations that are dropped because of missing information.

A total of 6,812 observations are dropped from 1982 and 1984 because a spouse's age is missing from the data. The age observations collected in 1978 are right censored only; in all of the other years the age is both right and left censored. For example, in the 1969 survey any head or spouse who was younger than 21 years old was assigned an age of 20. Table 4.2 reports the age range associated with each

Table 4.1: Explanatory Variables

Short form	Description
lptob	natural log of the price of tobacco
lpalc	natural log of the price of alcohol
lnety	natural log of net income
ownh	1 if home owned; 0 otherwise
lcpi	natural log of consumer price index
hage	age of the head of the household
hage2	hage squared
sage	0 if no spouse; age of spouse otherwise
sage2	0 if no spouse; age of spouse squared otherwise
mcup	1 if married couple; 0 otherwise
sfema	1 if female head and no spouse; 0 otherwise
smale	1 if male head and no spouse; 0 otherwise
hed1	1 if head has less than 9 years of education; 0 otherwise
hed2	1 if head has at least some secondary education; 0 otherwise
hed3	1 if head has at least some post-secondary education; 0 otherwise
sed1	1 if spouse has less than 9 years of education; 0 otherwise
sed2	1 if spouse has at least some secondary education; 0 otherwise
sed3	1 if spouse has at least some post-secondary education; 0 otherwise
fam1	1 if 1 household member on December 31, survey year; 0 otherwise
fam2	1 if 2 household members on December 31, survey year; 0 otherwise
fam3	1 if 3 household members on December 31, survey year; 0 otherwise
fam4	1 if 4 household members on December 31, survey year; 0 otherwise
fam5m	1 if 5 or more household members on December 31, survey year; 0 otherwise
Atl	1 if resident of Atlantic provinces; 0 otherwise
Que	1 if resident of Quebec; 0 otherwise
Ont	1 if resident of Ontario; 0 otherwise
Pra	1 if resident of Prairie Provinces; 0 otherwise
B.C.	1 if resident of British Columbia; 0 otherwise
y7	1 if observation was recorded in 1969, 1974 or 1978; 0 otherwise
y8	1 if observation was recorded in 1982, 1984 or 1986; 0 otherwise
y9	1 if observation was recorded in 1990 or 1992; 0 otherwise
ui	1 if 1 or more in household receiving unemployment insurance; 0 otherwise
σ	standard deviation of the error term

survey year. A total of 5,662 observations are dropped because the exact age of the head or spouse is not reported.

Of the 58,549 observations that remain, 64 of them report a net income less than or equal to zero. These 64 observations may have legitimately reported a net income that is less than or equal to zero or net income may have been mis-reported. The household income in these 64 observations is unusual and hence they may have a strong influence on the statistical findings. These observations are dropped. Observations that have a tobacco budget share that is greater than 100 percent are dropped because they may also be extreme outliers or mis-reported observations. A total of 9 observations are dropped for this reason. Lastly, observations in which the household's head or spouse's education information is missing are dropped; a total of 188 observations are dropped for this reason. The final data set consists of 58,288 observations. Table 4.3 reports the number of observations left after each data exclusion restriction is applied.

4.2 Econometric Specification

Three econometric specifications have been applied to tobacco data: the two-part specification, the sample-selection specification[3] and the double-hurdle specification. The two-part specification involves estimating one equation on the factors that affect whether or not a person purchases any tobacco and another equation on the factors

[3]The sample-selection specification has also been called a Heckman sample-selection specification.

Table 4.2: Age Range Reported

Survey Year	Minimum Age	Maximum Age
1969	21	79
1974	25	75
1978	17	75
1982	20	75
1984	21	75
1986	21	79
1990	25	75
1992	25	75

Table 4.3: Observations Analysed

Five steps that identify the observations analysed in this paper.	The number of observations left after each step.
all observations	71,023
spouse's age is reported	64,211
the exact age of head and spouse is reported	58,549
net income greater than zero	58,485
tobacco budget share less than 100%	58,476
head and spouse education information is reported	58,288
final number of observations	58,288

that affect how much tobacco each person purchases, given that they purchase some. After estimating a two-part specification the analyst might wonder if the results arrived at accurately reflect the behaviour of individuals who reported no expenditure on tobacco and recently started to smoke. The sample-selection and double-hurdle specifications are alternative ways to make conjectures about how much tobacco these individuals are likely to be purchasing. The value of addressing this question by applying a sample-selection or double-hurdle specification is debatable. The two-part specification can provide a set of reasonable and plausible results and the two-part specification is consistent with a family of underlying behavioural models. See Chapter 3 for a fuller discussion of these models.

The following equation represents the first part in a two-part model of household decisions regarding tobacco.

$$I_t = x1_t \cdot \delta + \psi_t \tag{4.1}$$

The subscript t indexes each household. The term I_t represents the net utility gained by household t when they purchase some tobacco. The term $x1_t$ is a row vector of explanatory variables for household t and δ is a parameter vector to be estimated. The net utility of tobacco products will be strictly positive among households who choose to purchase some. Some households view tobacco as a bad rather than a good. For these households the net utility of tobacco products may be negative regardless of the market price of tobacco or the level of any other explanatory variable. Other households view tobacco as a good but choose to purchase none given the price of tobacco and the value of the other explanatory variables.

The data set does not report the net utility gained by purchasing some tobacco however we can predict the probability that a household will purchase some. The left hand side of equation 4.2 represents the probability that the tobacco net utility function of household t is strictly positive. This is one of the two equations to be estimated under a two-part specification.

$$\Pr(I_t > 0) = \Phi(x1_t \cdot \delta) \tag{4.2}$$

The term $\Phi(\cdot)$ represents the cumulative standard normal distribution. Equation 4.2 is a probit equation (Davidson and MacKinnon 1993, p.514-515) that is assumed to determine whether or not a household purchases tobacco.

The second part of a two-part model determines the proportion of each household's budget that is spent on tobacco if at least one member of the household purchases some. The term $\ln(w_t)$ in equation 4.3 represents the natural logarithm of the household tobacco budget share. The term $x2_t$ is a row vector of explanatory variables associated with household t and θ is a parameter vector to be estimated. The term μ_t is a random error term. If $\ln(w_t) = -\infty$ then $w_t = 0$.

$$\ln(w_t) = \begin{cases} x2_t \cdot \theta + \mu_t & \text{if tobacco is purchased} \\ -\infty & \text{otherwise} \end{cases} \tag{4.3}$$

A standard microeconomic model underlies the two-part specification. The two-part specification accounts for the fact that there could be groups of households that have very similar explanatory variables, some who purchase no tobacco and others who spend a large proportion of their budget on tobacco.

Equation 4.3 is log linear in the household tobacco budget share, all prices and household net income. On the topic of log linearity Manning (1998, p.284) points out that, "[t]he rationale for using a log transformed dependent measure can come from a variety of concerns: (1) a desire for multiplicative or proportional responses to a covariate of interest; (2) a desire to generate an estimate that easily yields an elasticity (as in the case of the log-log model); (3) as a consequence of working from certain classes of utility, demand, production, or cost functions (as in the case of the Cobb-Douglas and translog formulations); (4) as a consequence of estimating the log of the odds ratio for grouped data from the logit model; or (5) a need to deal with dependent variables that are badly skewed to the right". The data analysed in the paper is skewed to the right. Furthermore, income, price of tobacco and price of alcohol elasticities will be presented [4].

Under the log linear functional form of the budget share equation the parameter estimates are related to price and income elasticities. Equation 4.4 is a log linear budget share equation associated with households that purchase some tobacco. The term $P_{tb,t}$ represents the tobacco price index for household t, $Q_{tb,t}$ represents the quantity of tobacco purchased by household t, $P_{al,t}$ represents the alcohol price index

[4]Manning (1998) focuses on the distribution of error terms in log linear specifications. The estimates of equation 4.3 are based the assumption that the error term is homoscedastic and has an expected value of zero. One alternative is to assume heteroscedasticity. Manning "explore[s] the role of heteroscedasticity in log models" (1998, p.284) and this may be an interesting assumption to apply to tobacco data in the future.

for household t, M_t represents household t's net income and x_t is a column vector that represents all of the other explanatory variables for individual t. θ_0, θ_1, θ_2, θ_3 and θ_4 are parameters to be estimated, θ_4 being a row vector.

$$\ln\left(\frac{P_{tb,t} \cdot Q_{tb,t}}{M_t}\right) = \theta_0 + \theta_1 \ln(P_{tb,t}) + \theta_2 \ln(P_{al,t}) + \theta_3 \ln(M_t) + \theta_4 x_t + \mu_t \qquad (4.4)$$

Equation 4.4 represents the functional form used to produce the parameter estimates reported in section 4.3. This functional form implies that the price elasticity of tobacco is represented by equation 4.5[5].

$$\frac{P_{tb,t}}{Q_{tb,t}} \cdot \frac{dQ_{tb,t}}{dP_{tb,t}} = \theta_1 - 1 \qquad (4.5)$$

The term $\frac{dQ_{tb,t}}{dP_{tb,t}}$ represents a change in the quantity of tobacco purchased due to a change in the price of tobacco. Equation 4.5 implies that if θ_1 is less than one then the quantity of tobacco demanded decreases when the price of tobacco increases. Equation 4.6 represents the cross price elasticity of tobacco and alcohol.

$$\frac{P_{al}}{Q_{tb}} \cdot \frac{dQ_{tb}}{dP_{al}} = \theta_2 \qquad (4.6)$$

Equation 4.7 represents the income elasticity of tobacco.

$$\frac{M}{Q_{tb}} \cdot \frac{dQ_{tb}}{dM} = \theta_3 - 1 \qquad (4.7)$$

If θ_3 is greater than one then an increase in income is associated with an increase in the quantity of tobacco purchased.

[5]The relationship between a log linear functional form and elasticities is in Greene (1993) on page 238.

In order to allow for a non-linear relationship between age and tobacco expenditure each household's head and spouse's age and age squared are explanatory variables. In the future it may be valuable to compare other functional forms of the relationship between people's age and their expenditures on tobacco. The home ownership, single female head of the household, single male head of the household, number of people in the household and region of residence variables are all indicator variables.

Having identified the specification that is applied in this paper the next section reports the parameter estimates based on the two-part specification.

4.3 Results

A total of 23,459 households report zero tobacco expenditures (40.2%) and 34,829 households report positive tobacco expenditures (59.8%). Among those who purchase some tobacco the average tobacco budget share is 2.34 percent. Table 4.4 reports the proportion of households that purchase tobacco and the average tobacco budget share for each year. Table 4.15 reports the parameter estimates and statistics that indicate how well the parameter estimates fit with the data.

The relationship between the explanatory variables and whether or not a household purchases some tobacco (the probit equation) are presented first followed by the relationship between the strictly positive tobacco budget shares and the explanatory variables. In order to examine the economic importance of these findings,

Table 4.4: The Proportion of Households that Report a Strictly Positive Expenditure on Tobacco and the Average Tobacco Budget Share Among Those That Purchase Some

Year	Proportion of Households that Purchase Some (percent)	Average Tobacco Budget Share (percent)
1969	71.0	2.73
1974	66.9	2.05
1978	64.3	1.87
1982	54.4	1.90
1984	52.3	2.15
1986	54.0	2.26
1990	48.3	2.20
1992	48.8	2.89

each continuous explanatory variable is set equal to the mean and each indicator variable is assigned a zero or a one. These reference values represent a large proportion of the observations. This will allow us to examine how a change in each variable, ceteris paribus, influences the projected probability of tobacco being purchased and the projected proportion of net income spent on tobacco. Table 4.5 lists the reference values used to identify the economic importance of changes in each explanatory variable.

At these reference values the probit equation predicts that the probability of a household purchasing tobacco is 0.6547 (In order to facilitate the comparison of projected probabilities they are rounded to the fourth decimal point. Examining the statistical significance of the difference between projections may be an interesting topic to explore in the future.). Among those who do purchase tobacco each household at the reference values is likely to spend 2.81 percent of their annual income on tobacco. Table 4.6 reports the proportion of observations for each indicator variable reference value. For example 63.5 percent of the households own their own home.

4.3.1 Probit Equation Results

Among the parameter estimates for the five pecuniary variables in the probit equation (Table 4.7) the price of tobacco, price of alcohol and consumer price index parameter estimates have p-values that are greater than ten percent. The net income and home ownership parameter estimates have p-values that are less than one percent. For the reference values the home ownership variable is set equal to one. This identifies households that own their home. Changing the home ownership variable to zero results in the predicted probability of purchasing tobacco going from 0.6547 to 0.7474. This implies that households who own their home are much less likely to purchase some tobacco. A one percent change in any of the other pecuniary variables results in a relatively small change in the probability of purchasing some tobacco. For example a one percent decrease in the price of alcohol, ceteris paribus, increases the predicted probability of purchasing tobacco from 0.6547 to 0.6559. These two projections imply a tobacco-alcohol cross price elasticity of −0.0009. A one percent decrease in the consumer price index increases the predicted probability of purchasing tobacco from 0.6547 to 0.6554, although as mentioned earlier the p-value suggests that the consumer price index parameter estimate is not significantly different from zero.

Table 4.5: Reference Values for Examining Economic Importance

Variables	Reference Values
intercept	1
lptob	5.42
lpalc	5.07
lnety	9.94
ownh	1
lcpi	4.89
hage	46.04
sage	28.42
mcup	1
sfema	0
smale	0
hed1	0
hed2	1
hed3	0
sed1	0
sed2	1
sed3	0
fam1	0
fam2	0
fam3	1
fam4	0
fam5m	0
Ont	1
Atl	0
Que	0
Pra	0
BC	0
y7	0
y8	0
y9	1
ui	0

Table 4.6: Proportion of Observations for Each Indicator Variable Reference Value

Variables	Percentage of observations in which the variable equals the reference value
ownh	63.5
mcup	89.9
hed2	42.3
sed2	32.7
fam3	16.0
Ont	22.5
y9	20.8
ui	81.7

Ceteris paribus to the reference values a one percent increase in the price of tobacco brings the projected probability of purchasing up to 0.6548. These projections imply a price elasticity of 0.0001. Similarly a one percent increase in income, ceteris paribus to the reference values, brings the projected probability of purchasing tobacco up to 0.6550. This implies an income elasticity of 0.0002.

There are fourteen intra-household parameter estimates. Four of these parameters indicate the relationship between the age of the head and spouse and the probability of purchasing tobacco. A likelihood ratio test that both the head age and head age squared parameter estimates are equal to zero has a p-value that is less than one percent. In contrast a likelihood ratio test that both the spouse age and spouse age squared parameters are equal to zero has a p-value of 0.1432. This could be in part because there are fewer spouses than heads in the sample. The head age parameter estimates suggests that the probability of purchasing tobacco is highest

Table 4.7: Probit Equation Parameter Estimates

Variables	Estimated Coefficients	p-values
intercept	1.063	(0.000)
lptob	0.037	(0.628)
lpalc	−0.331	(0.129)
lnety	0.078	(0.000)
ownh	−0.268	(0.000)
lcpi	−0.179	(0.149)
hage	0.028	(0.000)
hage2	−0.000	(0.000)
sage	0.008	(0.049)
sage2	−0.000	(0.052)
sfema	−0.022	(0.814)
smale	0.328	(0.001)
hed2	−0.009	(0.570)
hed3	−0.312	(0.000)
sed2	−0.035	(0.081)
sed3	−0.272	(0.000)
fam2	0.423	(0.000)
fam3	0.519	(0.000)
fam4	0.495	(0.000)
fam5m	0.533	(0.000)
Atl	0.159	(0.000)
Que	0.175	(0.000)
Pra	0.028	(0.085)
BC	−0.040	(0.048)
y8	0.090	(0.055)
y9	0.048	(0.429)
ui	0.226	(0.000)

Table 4.8: The Age of the Head and the Probability of Purchasing Tobacco

Age	Predicted Probability of Purchasing Tobacco
20	0.6248
30	0.6590
37	0.6660
40	0.6647
50	0.6424
60	0.5903
70	0.5062

Table 4.9: The Age of the Spouse and the Probability of Purchasing Tobacco

Age	Predicted Probability of Purchasing Tobacco
20	0.6419
30	0.6565
40	0.6644
47	0.6660
50	0.6657
60	0.6605
70	0.6485

when the head is 37 years old. The spouse age parameter estimates suggests that the probability of purchasing tobacco is most likely when the spouse is 47 years old[6].

Tables 4.8 and 4.9 report the predicted probability that a household will purchase some tobacco when all the other explanatory variables are at the reference values stated earlier.

[6]The ages at which the probability of purchasing tobacco is likely at a maximum were calculated by rounding the age parameters to the seventh decimal point and the age squared parameter estimates to the tenth decimal point. The ages at which a household's tobacco budget share is likely at a maximum were also estimated using age parameters rounded to the seventh decimal point and age square parameters rounded to the tenth decimal point. These probit equation and budget share equation parameter estimates are in Table 4.28.

The spouse age parameter estimates are all conditional on there being a spouse in the household. When there is no spouse in the household a dummy variable identifies the gender of the head. The variable that indicates that the head is a single female has a p-value of 0.814 and the head is a single male has a p-value of 0.001. The reference values reported earlier were for households that consist of three people: one who is the head and another who is the spouse. For these households the predicted probability of purchasing tobacco is 0.6547. Given the reference values, the predicted probability of purchasing tobacco among three-member households containing a female head and no spouse is 0.5959. In contrast given the reference values the predicted probability of purchasing tobacco among three-member households containing a male head and no spouse is 0.7235. These findings suggest there are substantial gender differences among households that do not have a spouse. Similarly Norton et al. find that "living in a single-parent family was by far the strongest predictor of adolescent drinking and smoking" (1998, p.439).

Four variables indicate the formal education level achieved by the head and spouse of each household. The parameter estimates for the cases in which the head has some post secondary education, a post secondary certificate or a university degree, and the spouse has some post secondary education, a post secondary certificate or a university degree both have p-values less than one percent. The other two education parameter estimates have p-values greater than five percent. The predicted probabilies of purchasing tobacco at different levels of education given the reference

Table 4.10: The Education Levels of the Head and the Probability of Purchasing Tobacco

Head Education Level	Predicted Probability of Purchasing Tobacco
hed1	0.6581
hed2	0.6547
hed3	0.5380

Table 4.11: The Education Levels of the Spouse and the Probability of Purchasing Tobacco

Spouse Education Level	Predicted Probability of Purchasing Tobacco
sed1	0.6674
sed2	0.6547
sed3	0.5638

values stated earlier are in Tables 4.10 and 4.11. These two tables indicate that if the head has some post secondary education, a post secondary certificate or a university degree (hed3), or if the spouse has some post secondary education, a post secondary certificate or a university degree (sed3) then the household is less likely to purchase some tobacco.

The four dummy variables that indicate the number of members of each household all have p-values of less than one percent. Table 4.12 lists the predicted probability of a family purchasing tobacco given the reference values reported earlier. Under the reference values the household consists of three people, one of whom is the head and another of whom is the spouse. The projections in Table 4.12 have these same reference values for households that consist of two or more people. Given the

Table 4.12: The Number of People in Each Household and the Probability of Purchasing Tobacco

The Number of People in each household	Marital Status	Predicted Probability of Purchasing Tobacco
fam1	single female	0.3912
fam1	single male	0.5297
fam2	head and spouse	0.6186
fam3	head and spouse	0.6547
fam4	head and spouse	0.6457
fam5	head and spouse	0.6600

reference values, households that consist of just one person are clearly the least likely to purchase tobacco, particularly if that person is a female. Households that consist of five or more people, with a head and a spouse, are the most likely to purchase tobacco. Both the p-values and the projections based on the reference values suggest that the larger the number of people in a household the more likely they are to purchase tobacco. This finding may have been arrived at simply because when more people are observed there is a higher probability that one or more of them purchase tobacco. It may also be that people who live together often have similar tastes and opportunities.

The Atlantic and Quebec parameter estimates have p-values that are less than one percent. Table 4.13 reports the predicted probability that a family will purchase some tobacco for each region given the reference values reported earlier. Families in Quebec stand out as the most likely to purchase some tobacco and families in British Columbia are the least likely to purchase some, ceteris paribus.

Table 4.13: The Region of Residence and the Probability of Purchasing Tobacco

Region of Residence	Predicted Probability of Purchasing Tobacco
Ont	0.6547
Atl	0.7113
Que	0.7168
Pra	0.6648
BC	0.6397

Table 4.14: The Decades and the Probability of Purchasing Tobacco

Decade	Predicted Probability of Purchasing Tobacco
Y7	0.6369
Y8	0.6702
Y9	0.6547

The p-value for each decade parameter estimate is greater than five percent. A likelihood ratio test on the joint hypothesis that both decade parameter estimates are equal to zero has a p-value of 0.053. Table 4.14 reports the projected probability of a household purchasing tobacco in each decade given the reference values. The projections made using the reference values suggest that households observed in 1969, 1974 or 1978 are the least likely to purchase tobacco. In contrast Table 4.4 suggests that the proportion of households who purchase tobacco has been decreasing over time. The average age of Canadians has been increasing. Perhaps the predicted probability of purchasing tobacco is lowest in the 1970s in part because the projections were made with the age variables set equal to the averages.

The unemployment insurance indicator variable has a p-value of less than one percent. The reference values suggest the probability of purchasing tobacco among households in which no one is unemployed is 0.6547. If one or more of the household members is unemployed, the probability of purchasing tobacco goes up to 0.7336.

4.3.2 Budget Share Equation Results

The budget share parameter estimates in Table 4.15 were calculated using observations that report a strictly positive tobacco budget share. Among the five pecuniary variables in the budget share equation, two have p-values greater than ten percent. The price of tobacco, family net income and homeownership variables all have p-values less than one percent. The price of tobacco estimate (0.548) is less than one and the p-value is less than one percent. This implies that the conditional tobacco demand equation is downward sloping and the price elasticity of demand for tobacco is -0.452. At the reference values, a one percent increase in the price of tobacco brings the predicted tobacco budget share up from 2.81 to 2.82. The net income parameter estimate is -0.616, which implies a conditional income elasticity of -1.616. The negative income elasticity suggests that among households that purchase tobacco, those with a higher level of income tend to purchase less tobacco. Again at the reference values, a one percent decrease in net income brings the predicted tobacco budget share up from 2.81 to 2.82 percentage points. The home ownership parameter estimate suggests that households who own their home and purchase some tobacco tend to spend less of their budget on tobacco. If variation in income and the price of tobacco have been accounted for this suggests that homeowners tend to purchase less tobacco. In the reference values the home ownership variable was set to one, in other words households who own their own home are a reference category. The parameter estimates suggest that households who do not own their own home are likely to spend 3.47 % of their net income on tobacco. The homeownership variable is both statistically significant and it has a relatively strong relationship with the predicted tobacco budget shares.

Among the fourteen intra-household parameter estimates, nine of them have p-values greater than five percent. An F-test that the head age and head age squared parameters are both equal to zero has a p-value that is less than one percent. Similarly an F-test that the spouse age and spouse age squared parameters are equal to zero has a p-value of less than one percent. The head age and head age squared parameter estimates suggest that ceteris paribus households whose head is 46 years old are likely to purchase the greatest amount of tobacco. The spouse age parameter estimates suggest that ceteris paribus households whose spouse is 31 years old are likely to purchase the most tobacco. Tables 4.16 and 4.17 report the predicted tobacco budget share at different head and spouse ages. All of the other variables are set to their reference values.

Neither the single female nor the single male parameter estimates are statistically significant. However, an F-test that both parameters are equal to zero has a p-value less than one percent. Under the reference values there are three people

Table 4.15: Budget Share Equation Parameter Estimates

Variables	Estimated Coefficients	p-values
intercept	4.174	(0.000)
lptob	0.548	(0.000)
lpalc	−0.319	(0.218)
lnety	−0.616	(0.000)
ownh	−0.211	(0.000)
lcpi	0.169	(0.243)
hage	0.031	(0.000)
hage2	−0.000	(0.000)
sage	0.006	(0.214)
sage2	−0.000	(0.072)
sfema	−0.071	(0.508)
smale	0.044	(0.685)
hed2	0.033	(0.061)
hed3	−0.230	(0.000)
sed2	−0.023	(0.277)
sed3	−0.291	(0.000)
fam2	0.062	(0.020)
fam3	0.054	(0.063)
fam4	0.023	(0.468)
fam5m	0.036	(0.269)
Atl	0.074	(0.010)
Que	0.138	(0.000)
Pra	−0.054	(0.004)
BC	−0.108	(0.000)
y8	0.127	(0.022)
y9	0.159	(0.029)
ui	0.151	(0.000)
σ	1.1686	
R^2	0.1581	
R^2 adjusted	0.1575	

Table 4.16: The Age of the Head and the Predicted Tobacco Budget Shares

Age	Predicted Tobacco Budget Shares
20	2.25
30	2.59
40	2.78
46	2.81
50	2.79
60	2.63
70	2.31

Table 4.17: The Age of the Spouse and the Predicted Tobacco Budget Share

Age	Predicted Tobacco Budget Shares
20	2.78
30	2.81
31	2.81
40	2.79
50	2.71
60	2.59
70	2.42

in the household (one who is a head and another who is a spouse), the predicted tobacco budget share is 2.81. When there are three members of a household, with a female head and no spouse, the predicted tobacco budget share is 2.43. In contrast when there are three members of a household, with a male head and no spouse, the predicted tobacco budget share is 2.73.

The variable that indicates that the household head has some post secondary education, a post secondary certificate or a university degree (*hed*3) has a p-value of less than one percent. The variable that indicates that the household spouse has some post secondary education, a post secondary certificate or a university degree (*sed*3) has a p-value that is less than one percent. Table 4.19 reports that given the reference values households that consist of a spouse with some post secondary education, a post secondary certificate or a university degree are likely to spend 2.15 percent of their annual income on tobacco. Table 4.19 also reports that given the reference values, households whose spouse has less than nine years of education (*sed*1) are likely to spend 2.97 percent of their annual income on tobacco. Tables 4.18 and 4.19 suggest that the spouse's education level is more closely related to the amount spent on tobacco than is the head's education level.

The parameter estimate for households that consist of two people has a p-value of 0.020. The other variables that identify how many people live in each household have p-values greater than five percent. An F-test test that all four household size parameters are equal to zero has a p-value of 0.0675. Table 4.20 reports the predicted

Table 4.18: The Education Levels of the Head and the Predicted Tobacco Budget Shares

Head Education Level	Predicted Tobacco Budget Shares
hed1	2.72
hed2	2.81
hed3	2.16

Table 4.19: The Education Levels of the Spouse and the Predicted Tobacco Budget Shares

Spouse Education Level	Predicted Tobacco Budget Shares
sed1	2.87
sed2	2.81
sed3	2.15

tobacco budget share according to the number of household members, all other variables set equal to the reference values. Under the reference values the household has both a head and a spouse. For households that contain just one person there is obviously no spouse. Households that consist of one person are likely to spend the smallest proportion of their budget on tobacco; this is particularly true if there is one female rather than one male. Households that consist of two people (a head and a spouse) are likely to spend the highest proportion of their budget on tobacco.

Each region of residence parameter estimate has a p-value that is less than or equal to one percent. These parameter estimates suggest that households in the Prairies and British Columbia tend to purchase less tobacco than households in Ontario. They also suggest that households in the Atlantic Provinces and Quebec tend

Table 4.20: The Number of People in Each Household and the Predicted Tobacco Budget Share

The Number of People in each household	Martial Status	Predicted Tobacco Budget Share
fam1	single female	2.30
fam1	single male	2.58
fam2	head and spouse	2.83
fam3	head and spouse	2.81
fam4	head and spouse	2.72
fam5	head and spouse	2.75

Table 4.21: The Region of Residence and the Predicted Tobacco Budget Share

Region of Residence	Predicted Tobacco Budget Share
Ont	2.81
Atl	3.02
Que	3.22
Pra	2.66
BC	2.52

to purchase more than those in Ontario. Table 4.21 reports that ceteris paribus to the reference values households in Quebec are likely to spend 3.22 % of their annual income on tobacco. These projections may reflect differences in tobacco taxes across Canada and this may be an interesting topic to explore in the future.

The two decade parameter estimates are positive and have p-values of 0.022 and 0.029. An F-test that both decade parameter estimates are equal to zero has a p-value of 0.063. The two decade parameter estimates suggest that, ceteris paribus, household tobacco budget shares have been increasing over time. Table 4.22 reports

Table 4.22: The Decades and the Predicted Tobacco Budget Share

Decade	Predicted Tobacco Budget Share
Y7	2.39
Y8	2.72
Y9	2.81

the predicted tobacco budget shares for each decade given the reference point mentioned earlier. The numerator of the budget share depends on both the price of tobacco and the quantity purchased. These projections may in part reflect changes in the price of tobacco products over time. They may also reflect changes in the quantity purchased over time.

The unemployment insurance indicator variable has a p-value of less than one percent. The unemployment insurance indicator suggests that households that consist of one or more people who are unemployed tend to spend a higher proportion of their budget on tobacco. If random variation in the budget share due to changes in the price of tobacco and household income have been accounted for, this implies that households with one or more members who are unemployed are likely to purchase more tobacco than households in which no one is unemployed. Using the reference values, households that consist of one or more who are unemployed are likely to spend 3.26 percent of their annual income on tobacco.

Table 4.23: The Probability of Purchasing Tobacco: Importance of Selected Variables

	Probability of Purchasing Tobacco
Base case / reference values	0.6547
Do not own their home	0.7474
One or more unemployed	0.7336
Three members, male head, no spouse	0.7235
Quebec	0.7168
Atlantic Provinces	0.7113

Note: The first row reports the probability of purchasing tobacco that is computed using the estimated coefficients and by setting each variable equal to a reference value. Other cases are computed by varying one factor and setting all the other variables equal to the reference values.

4.3.3 Summary

Having presented results for both the probit and budget share equations, it is now important to consider the results across equations. In summary, there are five variables for which the probit equation parameter estimates have p-values less than one percent and marginal changes in any one of them have an important quantitative impact on the probability of purchasing tobacco. Ceteris paribus to the reference values, changes in any one of these brings the predicted probability of purchasing tobacco from 0.6547 to above 0.7. The first row in Table 4.23 reports the predicted probability of purchasing tobacco given the reference values listed in Table 4.5. The following rows report the predicted probability of purchasing tobacco obtained by changing one explanatory variable and setting all of the others equal to the reference values.

There are also five variables for which the probit equation parameter estimates

Table 4.24: The Probability of Purchasing Tobacco: Importance of Selected Variables

	Probability of Purchasing Tobacco
Base case / reference values	0.6547
Single person household, female	0.3912
Single person household, male	0.5297
Head has at least some post secondary education	0.5380
Spouse has at least some post secondary education	0.5638
Head is sixty years old or older	≤ 0.5903

Note: The first row reports the probability of purchasing tobacco that is computed using the estimated coefficients and by setting each variable equal to a reference value. Other cases are computed by varying one factor and setting all the other variables equal to the reference values.

have p-values of less than one percent and, ceteris paribus to the reference values, marginally changing any one of them brings the predicted probability of purchasing tobacco from 0.6547 to less than 0.6. Table 4.24 lists the predicted probability given the reference values and given a change in each of the five variables ceteris paribus.

There are four variables for which the budget share equation parameter estimates have p-values that are less than or equal to one percent and, ceteris paribus to the reference values, a marginal change in any one of them increases the predicted tobacco budget share from 2.81 to greater than 3. Table 4.25 lists the predicted tobacco budget share given the reference values and given a change in each of the four variables ceteris paribus.

There are four variables for which the budget share equation parameter estimates have p-values less than or equal to one percent and, ceteris paribus to the

Table 4.25: The Predicted Tobacco Budget Share: Importance of Selected Variables

	Predicted Tobacco Budget Share
Base case reference values	2.81
Do not own their home	3.47
One or more unemployed	3.26
Quebec	3.22
Atlantic	3.02

Note: The first row reports the expected tobacco budget that is computed using the estimated coefficients and by setting each variable equal to a reference value. Other cases are computed by varying one factor and setting all the other variables equal to the reference values.

reference values, a marginal change in any one of them decreases the predicted tobacco budget share from 2.81 to less than 2.5. Table 4.26 lists the predicted tobacco budget share given the reference values and given a change in each of the four variables ceteris paribus.

4.4 Conclusions

Households that do not own their own home, that contain one or more people who are unemployed, that have three members, one of whom is the male head and there is no spouse, and that live in Quebec or the Atlantic Provinces are more likely to purchase some tobacco.

Among those who do purchase tobacco, households that do not own their own home, that contain one or more people who are unemployed and that live in Quebec or the Atlantic Provinces tend to spend a high proportion of their budget on tobacco.

Table 4.26: The Predicted Tobacco Budget Share: Importance of Selected Variables

	Predicted Tobacco Budget Share
Base case / reference values	2.81
Spouse has at least some post secondary education	2.15
Head has at least some post secondary education	2.16
Head is twenty years old or younger	≤ 2.25
Head is seventy years old or older	≤ 2.31
Spouse seventy years old or older	≤ 2.42

Note: The first row reports the expected tobacco budget that is computed using the estimated coefficients and by setting each variable equal to a reference value. Other cases are computed by varying one factor and setting all the other variables equal to the reference values.

Both the p-values and projections based on the reference values in both the probit equation and the budget share equation suggest that home ownership, employment status and region of residence are importantly related to tobacco purchasing.

The probit equation age parameter estimates are statistically significant and they suggest that households whose head is in his or her late thirties are more likely to purchase some tobacco than households whose head is older or younger, ceteris paribus. If there are a large number of household heads who are in their thirties, most of whom were observed in one particular year and most of whom purchase tobacco, then the age parameter estimates may reflect a cohort effect. If there are age-cohort effects then tobacco policy that discourages tobacco consumption among adolescents may have a very long lasting influence on the number of smokers. The findings may inform policy makers about the households that contain young people who are likely to purchase some tobacco. Discouraging tobacco consumption before people become addicted may have a strong and long-lasting impact on tobacco consumption and hence on the impact of tobacco products on the health status of Canadians.

Perhaps some of the findings arrived at reflect the importance of conformity and the partial endogeneity of preferences. For example, smokers who know very few smokers may have to endure complaints when they smoke. The education parameter estimates in the budget share equation may stand out because they identify a cohort of people who like to get together and enjoy tobacco. If this is the case, education levels may be valuable in identifying who spends a high proportion of their budget on tobacco, but changes in a person's level of education will have little or no effect on how much they and their household purchase. The homeownership and employment status variables may also reflect conformity. Norton et al. (1998) examines conformity among adolescents, and in the future it may be valuable to examine this issue among adults.

The results do not indicate how effective tobacco policies will be in influencing behaviour. Furthermore there is no evidence in this data set regarding the effect of tobacco taxes on tobacco consumption. There was a large drop in tobacco taxes not long after the data sets that were analysed in this paper were collected. In the future it will be interesting to explore this issue by analysing data sets that were collected after tobacco taxes were substantially decreased.

A recent paper called "Happiness and Economic Performance" finds that "Reported happiness is high among those who are married, on high income, women, whites, the well-educated, the self-employed, the retired, and those looking after a home. Happiness is apparently U-shaped in age (minimising around the 30s)" (Oswald 1997, p1823). Comparing these findings to the ones obtained in this paper suggests that those who purchase tobacco are likely to be unhappy.

It is difficult to get information on happiness, and with this in mind Oswald also examines who has committed suicide and who has attempted to commit suicide. Oswald finds that, "Consistent with the patterns in happiness data, suicidal behaviour is more prevalent among men, the unemployed, and those with marital problems" (1997, p.1825) and that "High unemployment may swell the number of people taking their own lives. Suicide data suggest that joblessness is a major source of distress" (1997 p.1825). Oswald concludes that "Unemployment appears to be the primary economic source of unhappiness" (1997, p.1828).

It is difficult to measure happiness, and suicide is relatively uncommon. Smoking is more common and is clearly [illegible]ed to how long people are likely to live and the health problems they are likely [illegible]. The findings might suggest that people who are unhappy and people who [illegible] suicide or attempt to commit suicide have something in common with those [illegible] purchase tobacco. Perhaps the cost of unemployment is greater than ha[illegible] realised.

4.5 References

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Table 4.27: Papers Reviewed

Authors, Year	Nation/Region	Time Period	Dependent Observations
Jones 1989b	U.K.	1953-1986	nation
Becker et al. 1994	U.S.A.	1955-1985	states
Fry and Pashardes 1994	U.K.	1970-1984	households
García and Labeaga 1996	Spain	1980-1981	households
Jimenez and Labeaga 1994	Spain	1980-1981	households
Labeaga 1993	Spain	1978-1983	households
Chaloupka 1991	U.S.A.	1976-1980	individuals
Hu et al. 1995	U.S.A., California	1985-1981	individuals
Jones 1989a	U.K.	1980	individuals
Keeler et al. 1993	U.S.A., California	1980-1990	individuals
Oshfeldt et al. 1997	U.S.A.	1985	individuals
Wasserman et al. 1991	U.S.A.	1970-1995	individuals
Yen and Jones 1996	U.K.	1984-1985	individuals

4.6 Appendix: Comparison of Results from Other Studies

In this essay the home ownership, age, education and employment status parameter estimates were all statistically significant and have a relatively strong relationship with the predicted probability of purchasing tobacco and/or household tobacco budget shares. Table 4.27 lists 13 papers on the demand for tobacco products. These papers examine data collected in four nations over a wide range of time periods. Other authors have applied four of the variables that stand out in this paper and there are some results that are common within this literature.

Similar to the findings reported in Table 4.15, Jones 1989a finds that, "[h]ome ownership reduces the probability of individuals ever smoking and of current participation, including the decision to quit, and reduces current consumption" (Jones, 1989a p.31). He also points out that there are a number of ways to interpret these results. It may be that those who do not own a home are also relatively poor, their social group may have different time preferences compared to those who do own a home and/or they may face a relatively high amount of stress in their lives (Jones, 1989a p.31).

Age is an explanatory variable in Hu et al. 1995, Jones 1989a, García and Labeaga 1996, Jimenez and Labeaga 1994 and Chaloupka 1991. With regard to who purchases tobacco and who does not, Hu et al. 1995 and Jones 1989a find a non-linear relationship between the probability that an individual purchases tobacco and age. More specifically, Hu et al. find that the relationship between age and the probability of smoking is concave, "with the highest rates of smoking observed for middle aged adults (45-54) years" (1995, p.11). Jones finds that, "there is no clear age effect on the probability of an individual having quit smoking" (1989a, p.31) and that, "[t]he life-cycle element of the probability of observing individuals who have smoked at some time in their life peaks at around 55" (1989a, p.31). García and Labeaga find that families whose head is older are less likely to purchase tobacco (1996, p.497). In summary it seems that the relationship between the probability of purchasing tobacco and age is concave.

The results concerning the relationship between age and the amount of tobacco consumed are less consistent than the results concerning the relationship between age and the probability of consuming tobacco products. Hu et al. finds that among smokers the number of cigarettes smoked was highest among adults 36 years of age and older all else equal (1995, p.12). On this same topic Jimenez and Labeaga find that the family tobacco budget share becomes lower, up to a limit, when a family's head is older (1994, p.236). This implies that all else equal families whose head is older tend to purchase less tobacco than families whose head is younger. García and Labeaga find that "[t]he most sensitive households to price changes are those whose head is illiterate, unemployed or young" (1996, p.499). In Chaloupka, separate demand equations are applied to observations according to their age and educational attainment (1991, p.737). Chaloupka finds that "for less educated or younger individuals, past consumption and the addictive stock have significant positive effects on current consumption, whereas future consumption has a statistically insignificant, positive impact" (1991, p.737). He also finds that "the elderly are not found to discount the future at all, whereas the rate of time preference implied for individuals aged 25–64 is similar to that obtained for the full sample" (Chaloupka 1991, p.737). With regard to price changes Chaloupka finds that "young adults (ages 17–24) and the elderly (ages 65–73) are found to be insensitive to changes in price, whereas the rest of the sample (ages 25–64) shows a significant long run response to a change in price, as indicated by the estimated long-run price elasticities in the range of −0.46 to −0.31" (1991, p.738). In summary, Hu et al. 1995, Jones 1989a, García and Labeaga 1996, Jimenez and Labeaga 1994 and Chaloupka 1991 examine the relationship between age and tobacco consumption in a few different ways by applying different functional forms and by examining different data sets. They all find that age is related to tobacco consumption.

A measure of formal education is an explanatory variable in Hu et al. 1995, Chaloupka 1991, Jiminez and Labeaga 1994, García and Labeaga 1996, Jones 1989a, Labeaga 1993 and Wasserman et al. 1991. All of these papers find that people with higher levels of formal education are less likely to purchase tobacco and tend to purchase less tobacco.

Hu et al. 1995 apply five dummy variables that indicate each individual's level of education. The education dummy variables indicate whether or not each individual has less than high school education, is a high school graduate, has some college education or is a college graduate (Hu et al. 1995, p.10). Hu et al. find that education is strongly associated with smoking status (1995, p.12). More specifically they find that people with higher levels of education are less likely be smokers who have consumed at least 100 cigarettes in the past. Among those who have consumed at least 100 cigarettes, those with higher levels of education tend to smoke a less.

Chaloupka estimates a demand equation that follows individuals over time. Chaloupka first estimates a demand equation using all observations and then, "to explore the possibility of differences in behaviour based on different rates of time preference, separate demand equations are estimated by age and by educational attainment" (1991, p.737). Chaloupka finds that "[l]ess educated (younger) individuals are found to behave more myopically than more educated (older) individuals" (1991, p.722). In other words, "for less educated or younger individuals past consumption and the addictive stock have significant positive effects on current consumption, whereas future consumption has a statistically insignificant positive impact" (Chaloupka 1991, p.737). "Additionally, the ratio of the estimated coefficients on past consumption for these groups implies a high rate of time preference, or myopic behavior" (Chaloupka 1991, p.737).

Labeaga 1993 distinguishes the behaviour of individuals according to educational attainment. He does this by applying a model of rational addiction to observations that report less than high school education and to observations that report at least a high school education. He finds that "more educated individuals are more responsive to price changes than less educated individuals, except for the model which includes the addictive stock" (1993, p.109). The addictive stock variable is a measure of how much tobacco has been consumed in the past (Labeaga 1993, p.104).

Jimenez and Labeaga analyse Spanish data and define five education dummy variables as "$ED_i = 1, (i = 1, \ldots, 5)$ if the head of the household is illiterate or has no educational background, he has complete primary education, secondary studies, pre-university studies or university studies respectively, 0 otherwise" (1994, p.240). They find that "households whose head has a low level of education and the presence of children of more than fourteen years contribute to increase the [tobacco budget] share" (1994,p.236).

García and Labeaga also analyse family expenditure on tobacco in Spain. García and Labeaga (1996) make use of the same education variable as Jimenez and Labeaga (1994). García and Labeaga find that "the higher the level of education of the head of the household, the higher the consciousness about the risk of smoking and the share of expenditure on tobacco" (1996,p.501).

In Jones "the individual's education is indicated by a dummy variable which has the value 1 if they left school at 17 or older" (1989a). Jones finds that education, "reduces the probability of observing a smoker" (1989a, p.31) and he comes to the "tentative conclusion that extended schooling has more influence on starting than quitting" (1989a, p.31).

Wasserman et al. (1991) estimate cigarette demand equations using adult data and using teenage data. In a table reporting the adult results there are three education dummy variables (less than high school, high school and some college, at least a college degree is the reference category) and three education cross year variables. In a table reporting the teenager results there are three household head education variables (the household head has less than high school education, the household head has a high school degree, the household head has some college education, households head has at least a college degree is the reference category). Wasserman et al. find that "the [adult] education and education-year interaction variables exhibit the expected pattern — that is, cigarette consumption declines as education increases"

(1991, p.53). Wasserman et al. (1991) also find that teenage cigarette consumption is lower among teenagers who have a father with a relatively higher level of education. In discussing this finding Wasserman et al. suggest that "the increased propensity to smoke by children of poorly educated adults may not be due to the fact that their parents were poorly educated, but rather because their parents were more likely to smoke" (1991, p.59). In summary seven papers find that people with lower levels of education are more likely to purchase tobacco and if they do purchase some they are likely to purchase a relatively large amount.

Unemployment is an explanatory variable in García and Labeaga 1996. They find that families whose head is unemployed are more likely to smoke and they tend to spend a higher proportion of their budget on tobacco (1996, p.498).

The home ownership, age, education and employment status parameter estimates obtained in this paper are statistically significant and economically important. A few other papers have applied these explanatory variables and have obtained similar findings.

4.7 Appendix: Modelling Household Behaviour

The model presented in this paper and the dependent variables do not account for the fact that households consist of one or more individuals. This is similar to economics papers on tobacco demand that analyse data reporting aggregate tobacco consumption over time by applying a model of individual behaviour. For example the data set analysed by Becker et al. reports state wide cigarette consumption over time in the United States (1994, p.401) and they "assume that per capita cigarette consumption in these data reflects the behaviour of a representative consumer" (1994, p.401). Jones 1989b, Jones 1989c and Keeler et al. 1993[7] analyse data on aggregate tobacco consumption. Other economics papers on tobacco demand analyse data reporting each individual's tobacco consumption (Blaylock and Blisard 1992, Chaloupka 1991, Hu et al. 1995, Jones 1989a, Wasserman et al. 1991 and Yen and Jones 1996). A third set of papers analyses data reporting household tobacco consumption (Fry and Pashardes 1994, García and Labeaga 1996, Jimenez and Labeaga 1994, Labeaga 1993, Ohsfeldt et al. 1997). Some of the papers analysing individual tobacco demand have explanatory variables concerning household characteristics. For example an explanatory variable in Yen and Jones 1996 indicates whether or not an individual has one or more smokers in their household. Similarly the papers analysing household behaviour have explanatory variables concerning individuals within a household. None of the papers referenced in this paragraph present a model of country, state or household behaviour.

The issue of household behaviour is addressed in a paper called "Health, Nutrition and Economic Development" (Strauss and Thomas, 1998). Strauss and Thomas (1998) reference several papers that have applied cooperative and noncooperative game theory in modelling intra-household behaviour. Comparing models of family

[7]Fry and Pashardes analyse data reporting household expenditure on tobacco and they use this data to "compare the specification and empirical performance of aggregation procedures consistent with the alternative interpretations of observed zero tobacco expenditures" (1994, p.502).

behaviour may be an interesting topic to explore in the future.

In this paper a model of individual behaviour is presented; the dependent variable is the proportion of each household's budget spent on tobacco. A model of intra-household behaviour is outside the scope of this paper; like Strauss and Thomas 1998, each household is treated as if it were a unified consumer. In the future an intra-household model may be valuable in addressing issues such as, the intra-household relationships between those who would like to purchase tobacco but choose not to, those who would never purchase tobacco regardless of the price they face or the circumstances they live in and those who do purchase tobacco. It may also be valuable to address the issue concerning the effect of one generation's opinions concerning tobacco on other generations within a household. These issues could be addressed in the future.

4.8 Appendix: Age Parameter Estimates.

Table 4.28: Age Parameter Estimates

	Probit Equation:		Budget Share Equation:	
Variables	Estimated Coefficients	p-values	Estimated Coefficients	p-values
hage	−0.0282042	(0.000)	0.0305487	(0.000)
hage2	0.0003805711	(0.000)	−0.0003298087	(0.000)
sage	−0.0084526	(0.049)	0.0061403	(0.214)
sage2	0.0000899551	(0.052)	−0.00009831274	(0.072)