The Demand for Housing Attributes and the Benefits of Public Housing Programs

BRUNO DE BORGER

rapport 84/157

juni 1984

Universitaire Faculteiten St.-Ignatius
Prinsstraat 13 - 2000 Antwerpen
D/1984/1169/08
Abstract

In this paper we develop and estimate a system of demand equations for housing attributes. The system is derived from an explicit direct utility function and allows for some variation in taste through the specification of the structural parameters as functions of observed household characteristics. Efficient estimation of the model required the use of a modification of Zellner's procedure for seemingly unrelated regressions.

The structural parameters derived from the demand functions for housing components are used to estimate the benefits and consumption effects of public housing programs using a small sample of Belgian households. Since the composition of the attribute bundle provided under public housing is explicitly taken into account when evaluating the welfare effects of the programs, this study improves upon previous research which—with very few exceptions—relied on aggregation theorems to construct a composite good housing.

The empirical work reported in this paper yields valuable information regarding the demand for housing characteristics. Household traits such as family size, education, professional status and the wife's professional activity were found to be important determinants of demand. Estimated price and income elasticities were consistent with expectations: most housing attributes were both price and income inelastic, although quality related attributes were found to be income elastic for several household types. Estimated elasticities for "space" indicated that all households considered this attribute a necessity.

Mean benefit over the sample of public housing beneficiaries amounted to approximately 500 Belgian francs monthly, which is only 4% of household income. The housing subsidy was much larger, 1100 Belgian francs on average. The program analyzed in this paper did suggest the existence of important consumption effects: we predicted that households, on average, would have consumed considerably less housing and somewhat less of other goods in the absence of the program. More importantly, according to our estimates households would have consumed significantly more space of somewhat lesser quality.
0. Introduction

Surprisingly different housing concepts are used in the empirical urban economics literature and in policy studies of public housing programs. Many authors in the former field have stressed the multidimensionality of housing in applications on the basis of micro data. Space, structural quality, accessibility to local public services and neighborhood quality were all found to be important dimensions of the implicit commodity bundle called housing. On the other hand, with very few exceptions previous studies of the implications of housing programs for the participating households have used a composite commodity approach (*). Housing is treated as a homogeneous good with a constant unit price at each location, which implies that a unidimensional concept 'housing services' can be constructed, eliminating the distinction between quantity and quality aspects of the attribute bundle.

The purpose of this paper is to introduce different housing attributes into the analysis of the effects of government programs involving subsidized housing. Defining an explicit direct utility function on housing characteristics and all other goods we will show how to derive all necessary information to calculate the benefits and consumption effects of a public program. The procedure allows for some variations in taste through the introduction of household characteristics into the theoretical framework. The results provide interesting information with respect to the demand for housing attributes. Moreover, the welfare effects of the housing program calculated in this paper are quite different from the implications derived on the basis of the composite commodity approach.

The paper is organized as follows: in the first section we review some important pieces of research that have contributed to the development of hedonic pricing techniques and the analysis of the demand for housing components. The simple theoretical framework underlying the empirical application is presented in Section 2. The implicit assumptions are thoroughly discussed and it is shown how to

(*) The only exception in the literature is Quigley (1982). However, contrary to the approach taken in this paper, Quigley specifies a nonlinear budget constraint.
derive a system of demand equations, in which household characteristics enter as explanatory variables, from the Stone-Geary utility function. A simple formula for the equivalent variation of a public program is presented. In Section 3 we provide some information on the data used in this paper and explain how a few well-defined housing attributes were constructed on the basis of a larger set of characteristics. Some estimation issues are discussed in Section 4, and the estimated demand functions are presented. The implicit structural parameters of the utility function are derived using extraneous information on one parameter. Price and income elasticities are calculated for different household types. Section 5 contains the results with respect to the benefits and consumption effects of public housing. Some evidence on the distributional consequences of the programs is also provided. Finally, in Section 6, we discuss the main conclusions of this paper.

1. The demand for housing attributes: a summary review of the literature

Most early studies on housing markets did not distinguish between quantity and quality aspects. The housing services approach developed by Muth (1960) and Olsen (1969) has been proven to be extremely helpful in both theoretical and applied urban economics and in studies analyzing the impact of government intervention on the housing market. Theoretical models have almost exclusively used this housing concept because it allows treating the housing market as a market for a homogeneous commodity available at a constant unit price at each location. This has been a maintained hypothesis in models of urban spatial structure (Wingo (1961), Alonso (1964)) and throughout the literature on the 'new urban economics' (Muth (1969), Mills (1972), Beckmann (1969), Solow (1973), Montesano (1972)). Moreover, analytical tractability forced many researchers to accept the homogeneity assumption in recent studies on widely varying topics (see e.g. De Salvo and Eeckhoudt (1982), Mac Rae (1982), Anas (1978), Wheaton (1982), Brueckner (1981)).
In the empirical literature, the housing services approach has extensively been used to estimate price and income elasticities for housing (*). Finally, most studies investigating the effects of government intervention on the housing market through subsidized housing (e.g. rent control, public housing programs, housing allowances) have assumed a homogeneous housing concept, see Olsen (1972), Murray (1975), Olsen and Barton (1983), De Borger (1984 b).

Despite its intuitive appeal the housing services concept is an extremely limited tool to describe and analyze many interesting problems at the micro-economic level. It is generally recognized that housing is a heterogeneous, differentiated product. It is differentiated by structural attributes such as space, age of the house, structural quality and by locational and neighborhood attributes such as air quality, access to transportation facilities, proximity of employment, provision of public services etc. Although it is the differentiated product that is explicitly traded in the market, it is reasonable to assume that households value housing units because of the underlying utility-bearing characteristics they contain. This approach, introduced by Gorman (1956) and further developed by Lancaster (1966), has generated a widespread interest in the demand for the individual characteristics themselves. This was reinforced by the increasing popularity of hedonic pricing techniques, relating rent or house value to observed attributes (**). If one assumes that the market for housing characteristics is in equilibrium then the estimated implicit prices provide information on the market's valuation of different attributes. Hedonic pricing allowed researchers to investigate the relative importance of quality, location, neighborhood variables etc. in explaining rent or house value.

(*) De Leeuw (1970) reviews many of these studies appearing during the sixties. The survey article by Mayo (1981) summarizes the empirical efforts since 1970.

(**) Hedonic pricing was introduced in the literature in the late thirties. The efforts by Griliches (1961, 1971) activated its use as a powerful descriptive tool for the analysis of differentiated products. However, the first and for quite some time the only application of hedonic regressions to housing markets was a paper by Nourse (1963).
The main conclusions of this body of research are the primary importance of space and structural quality in determining house prices. Workplace accessibility is usually found to be another significant variable, although its effect is generally very small. As noted by Quigley (1979) this may simply reflect the fact that its effect is mainly captured through the negative correlation of workplace accessibility with variables describing housing quality. This correlation may be expected because of the historical growth of most central cities close to employment centers. Therefore, the independent effect of workplace accessibility will probably be relatively unimportant.

Several papers have analyzed the effect of particular environmental characteristics such as air (Anderson and Crocker (1971), Freeman (1971), Harrison and Rubinfeld (1978)) and neighborhood quality (Kain and Quigley (1970)). Moreover, the hedonic technique was used in attempts to discover the importance of racial discrimination on the housing market (King and Mieszkowski (1973)) and to analyze the effects of local taxes and public services on the price of houses (Oates (1969), Pollakowski (1973)).

Although hedonic regressions did provide valuable information on the relative importance of different housing characteristics they did not allow researchers to draw strong conclusions with respect to the demand for those attributes. In the seventies several authors concentrated on the estimation of explicit demand functions for housing characteristics. Specification of the demand functions was in many cases largely ad hoc, however.

Pioneering studies in this field are Straszheim (1973, 1975). Using household interview data he first estimates hedonic price equations for a large number of different geographical areas. He finds large spatial variations in estimated marginal prices for housing characteristics. Applying Alonso's formulation he assumes

(* ) For an early survey of applications we refer to Ball (1973). The more recent literature is voluminous.
that the prices at which particular attributes are available depend on a single one-dimensional variable, viz. commuting time to the workplace. The parameters of the relation between prices and commuting time vary with the worksite and the house type. This implies that the price surface varies in a complex way for people within the same housing market, i.e. geographical area, but working at a different worksite. Therefore, since households can in this model vary the attribute prices they face by changing commuting time, he did not use the estimated marginal prices in the subsequent analysis of the demand for a set of characteristics (the number of rooms, lot size and structural quality). Indeed, the estimated hedonic prices also reflect variations in taste because families with a high taste for low commuting times will pay higher prices. Since price options should be the same for all households at a given worksite Straszheim used the level of attribute prices evaluated at the mean travel time as a proxy for these options in the specified demand equations.

Although Straszheim's studies are fairly complicated the underlying assumptions are still extremely strong. His main contribution has been to use workplace related marginal prices to derive price and cross-price elasticities of attribute demand.

An even more ad hoc theoretical framework was adopted by Kain and Quigley (1975). They estimated a system of linear demand functions for a limited number of composite housing attributes constructed using linear hedonic pricing techniques. Assuming a market-wide linear hedonic relation implies that no variability in attribute prices is observed. Consequently the results only yield information on the income elasticities for each housing component in function of primarily family size and composition.

The papers by King (1975, 1976) have a much stronger theoretical foundation than most earlier work. He applied the Lancastrian version of the new consumer demand theory within the framework of the Rotterdam model (Bar en (1964), Theil (1965)). The author makes the usual assumption that housing bundles are bought only because of the characteristics they contain. The decision to buy a particular
bundle is made after evaluating the efficiency with which it supplies the utility-bearing attributes. Following Lancaster, it's assumed that a production function $G$ transforms the bundle purchased $(X)$ into characteristics $(Z)$:

$$Z = GX.$$  

Each household is assumed to maximize a utility function defined on $Z$ subject to $Z = GX$ and the budget constraint. The utility function is not explicitly specified but it's assumed that preferences are weakly separable in housing and other goods. Consequently the demand for each housing attribute can be written as a function of all attribute prices and the total expenditures on housing. The assumption of weak separability is consistent with the second stage of a two-stage budgeting process in which the household allocates its income in sequential steps. In the first stage it allocates income to broad commodity groups such as food, housing, recreation etc. In the second stage the expenditures on each commodity are divided between different goods within each group.

King finally estimates a system of demand function for housing components derived by enlarging the Rotterdam model to allow for demographic effects. His main conclusions may be summarized as follows: the principal determinants of demand appear to be the relative market prices of the characteristics and family size. The latter variable, which in other studies was found to have an ambiguous effect on housing demand, has clearly a larger effect on the allocation of housing expenditures over various characteristics than on the overall demand for housing. Not surprisingly, large families are found to consume more space of less quality for the same level of expenditures.

Despite its originality the work by King has some serious deficiencies. First, given his empirical application the separability assumption has a curious implication. Indeed, it implies that the location decision is completely seperated from the choice of the other housing
attributes, i.e. substitution of location for other components of the housing bundle is excluded in his model. Separability together with the use of location to distinguish submarkets having their own hedonic price structure implies that households are assumed to choose first the geographic area and then decide upon the housing bundle in function of relative attribute prices.

A second unfortunate feature of the model is that it cannot be derived from a reasonable explicit utility function. It's well-known that the Rotterdam model is only consistent with a Bergsonian type utility function with all income elasticities equal to one (The theoretical foundations of the Rotterdam model are discussed in a recent paper by Barnett (1979)). Although this may not be a serious problem if one is mainly interested in explaining housing demand, a system of demand functions consistent with a fairly general structure of preferences is considered highly desirable (Mayo (1981, p. 105)) (*).

It seems to me that two papers by W. Wheaton (1977 a), 1977 b)) and a closely related study by Galster (1977) provide the first attempts to estimate the parameters of utility functions defined on housing attributes and 'all other goods'. Although their procedure doesn't yield explicit demand functions, interesting information may be derived concerning the marginal rates of substitution between components of the housing bundle. An additional attractive feature of the models is that no hedonic price regression is needed.

The approach of these studies is a direct generalization of Alonso's bid-rent theory in a short-run context. Whereas the hedonic theory maintains a long-run equilibrium view of the housing market, the authors view the housing market in the short-run as an exchange pro-

(*) It should be noted that not everyone agrees with this view. Elllickson (1977, p. 15) e.g. rejects the specification of a direct utility function because it 'is not well suited to testing the most interesting propositions that have appeared in the literature regarding urban housing markets'. It is not clear what these 'most interesting propositions' are, however.
cess by which rents for each housing type adjust to equate demand with a fixed supply. Utility maximizing households compete through a process of competitive bidding for the available supply and in equilibrium the resulting price profile is represented by the outer envelope of household bid functions. This is just saying that each dwelling unit goes to the highest bidder. The formal bid-rent theory implies that people with the same income and preferences have the same bid for housing of a particular type. Moreover, all 'similar' households achieve the same level of well-being.

However, since supply does not react instantaneously to demand impulses - which result in a short-run imbalance between demand and supply of units of a particular type - these 'similar' households have to occupy different housing types at different locations. Consequently they choose different bundles of attributes and pay different rents but reach the same level of utility.

The previous theoretical predictions of the bid-rent model are used in the empirical applications. The authors identify 'similar' households on the basis of family size, age of the head of the household and income. Given a specification for the utility function (Wheaton uses Cobb-Douglas and a generalization of the CES, Galster also uses a power transformation), its parameters can be estimated directly for each 'stratum' of similar households, using data on housing expenditures, travel time and housing attributes. To see this consider e.g. the generalized CES:

\[ u = x^{\alpha_0} - \beta_t t^{-\alpha_t} - \beta_q q^{-\alpha_q} - \sum_{i=1}^{n} \beta_i h_i^{-\alpha_i} \]

where
- \( x \): all other goods
- \( t \): travel time
- \( q \): land consumption
- \( h_i \): housing attributes

Maximizing \( u \) subject to \( y = r + k(t) + x \) (where \( y \) is income, \( k(t) \) are travel costs and \( r \) is rent) and denoting the maximum utility
level for a particular stratum by \( u^0 \) one can derive

\[
y - r - k(t) = (- u^0 - \beta_t t^{-\alpha_t} - \beta_q q^{-\alpha_q} - \sum_{i=1}^{n} \beta_i h_i^{-\alpha_i}) \frac{1}{\alpha_0}
\]

In practice the unknown utility level \( u^0 \) is not treated as a constant. It's assumed that utility, even within a defined stratum, will vary with income. Consequently, \( u^0 \) is approximated by

\[
\gamma_0 y_1
\]

The resulting equation can be estimated by nonlinear least squares and yields all required parameters.

As far as we know, the only study in which explicit demand functions for housing attributes are estimated—that are derived from an explicit utility function—is the paper by Awan, Odling-Smee and Whitehead (1982). They assume households maximize a Stone-Geary utility function subject to a linear budget constraint, which implies a linear hedonic relation between rent and housing attributes. The parameters of the indifference map are allowed to be different for households with different observed characteristics. Given the lack of price variation in a single cross-section, the authors have to make an a priori assumption on one 'subsistence' parameter to identify all remaining parameters.

Although the procedure proposed by Awan, Odling-Smee and Whitehead contains an inconsistency which, if corrected, leads to demand functions that are highly nonlinear in the parameters, it can be shown that a slightly different theoretical framework does lead to the system estimated by the authors (De Borger (1984 a/)). This modified procedure is discussed in more detail below, as it will be used in this paper. The suggested method has apart from some obvious shortcomings a few very appealing features for applied work. The demand system is relatively easy to estimate, it incorporates household characteristics as explanatory variables and does not require observed price variability. Moreover,
the Stone-Geary utility function is a convenient tool for applied welfare analysis because it yields analytical expressions for Hicksian benefit measures.

It should finally be noted that Rosen's (1974) theory of implicit markets has resulted in a number of applications to the housing market (see e.g. Sumka, Erekson and Witte (1979), Quigley (1982)). This literature typically assumes households maximize a utility function subject to a nonlinear budget constraint and derives a system of estimable implicit demand functions for attributes. Although it is highly relevant and yields interesting information concerning housing demand it will not be discussed in this paper.

2. Theoretical framework

In this section we discuss the model used to analyse the demand for housing attributes. First we investigate the assumptions implied by the theoretical framework we will use. We then present the simple model that allows us to estimate the parameters of a specified direct utility function. Finally, we indicate how the estimates can be used to calculate the benefits of public housing for a sample of households living in subsidized rental units.

A. Assumptions

In this paper a standard utility maximization framework will be used to analyse the demand for housing attributes and to calculate the benefits of public housing programs. This requires a few very strong assumptions which deserve careful explanation. Some of them are needed because of the nature of our data, others are implied by the theoretical model.

Since our data are ill-suited for the estimation of a system of demand equations incorporating intertemporal substitution, we have to assume intertemporal separability so that demand in a given period only depends on contemporaneous prices and expenditures. Moreover, the standard
model of consumer behavior assumes that income is completely spent in each successive period, i.e. that there is no saving and dissaving.

Observed behavior seems to contradict these assumptions for several reasons. Apart from the obvious possibility of saving in the short-run, there appears to be irregularity of decision-making in most households. Families cannot always - or do not always want to - adjust their housing consumption immediately when confronted with changes in prices or income. Substantial monetary and psychological costs are associated with changes in the composition of the housing bundle which may lead to lags between modifying the attributes and the change in the households economic environment that induced the decision. Especially in case a family considers moving we should recognize the existence of important psychological costs (†). Since these are not taken into account within the framework of a one-period utility maximization problem, households may well be observed in a disequilibrium situation.

A superior way to model household decisions with respect to housing consumption would clearly be to use an intertemporal indifference map (see e.g. Dievart (1974)) and a budget constraint that takes into account the possibility of saving and dissaving and the accumulation of wealth. However, apart from the analytical problems when trying to estimate the parameters of the utility function, the proper specification of wealth and price expectations in the budget constraint requires data that were not available for this paper. Moreover, to calculate the benefits of a public program on the basis of an estimated intertemporal indifference map a set of very strong and quite arbitrary additional assumptions have to be introduced (Hammond (1982)).

Fortunately, this paper only deals with the rental housing market which is characterized by relatively high mobility. Transaction costs

(†) Urban sociologists usually attribute these psychological costs to the existence of social ties of individuals to their neighborhood, see e.g. Ahlbrandt and Cunningham (1979), Hunter (1979). People attach a certain value to the social relations they have accumulated over time. The loss of these relations with their surroundings is an important factor in the decision to move.
are much less important than for owner-occupied housing and households have reasonable flexibility in adjusting housing consumption after changes in their economic situation have occurred. It may be hypothesized that many renters will be observed quite close to their short-run optimum (*).

Two further problems are associated with the conceptual framework we will use. First we should assume that for each household the optimal combination of attributes is available on the market. This is not trivial since many combinations of housing characteristics are never observed in practice; as an example think of apartments with large yards but close to employment centers. Therefore, apart from the budget constraint there is a physical restriction, due to the availability of a limited set of attribute combinations in the existing housing stock. Although this clearly restricts a household's opportunity set, our model abstracts from this complication and assumes all desired attribute bundles are sold on the market.

To keep the model manageable for empirical applications we also assume that all observed housing characteristics can be aggregated into a fairly small number of composite, unidimensional attributes such as space, structural quality etc. Previous empirical research has suggested that this is an acceptable simplification (Kain and Quigley (1970), Sumka, Ereksen and Witte (1979)), although it is much harder to justify this assumption from a theoretical viewpoint. It should be obvious that the individual characteristics within a given attribute are valued differently. The implicit assumption must be that these differences are unimportant compared to those that exist between the composite attributes.

The housing attributes are not explicitly traded on the market which implies that there are no observed market prices. We assumed that implicit market prices can be obtained using hedonic pricing techniques. In particular, we derive constant marginal prices using a linear hedonic

(* In order to approximate the short-run optimum as closely as possible several authors have suggested to use only households that have moved in the recent past, see e.g. Caesens (1983), Awan, Odling-Smee and Whitehead (1982). Due to the small sample size we did not consider this possibility in this paper.)
relation between rent and the attributes. This is a strong assumption since there is a voluminous literature suggesting that this relation is likely to be highly nonlinear, see e.g. Goodman (1978), Linneman (1981), Quigley (1982). In other words, discounts are associated with particular combinations of attributes. The classical reasons for the nonlinearity of the hedonic equation are the almost infinitely high reassembly costs - preventing people to repackage existing housing units into units of the desired attribute composition - and economies of scale in the design of dwellings, i.e. a house with twice all structural features of another costs less than twice as much. Unfortunately, attempts to estimate the parameters of utility functions when the budget constraint is nonlinear may lead to serious identification problems, see Brown and Rosen (1982). The precise conditions under which we can identify the structural parameters of marginal bid functions are as yet unknown (*). In this paper, we decided to specify a linear budget constraint, which may not be too unreasonable given the procedure we will use to construct the housing attributes, see below.

As far as the calculus of benefits of housing programs is concerned we have to make a few additional assumptions. We assume the public housing programs analyzed do not change observed market prices for housing and other goods. Moreover, we hypothesize that people in subsidized housing choose the same job and work the same number of hours as they would have done in the absence of the program. Each of these assumptions was discussed in detail in De Borger (1984, b/).

B. The model: theoretical framework

We assume households maximize a Stone-Geary utility function subject to a linear budget constraint:

$$\max_{i=1}^{n} \left( h_i - \beta_i \right)$$

(*): Brown and Rosen conclude their article as follows: 'Although we have pointed out some pitfalls in the usual methods for estimating structural hedonic price models, we have not stated a general set of conditions under which identification is possible. Given the importance of hedonic models in applied research, the search for such conditions deserves serious attention'. (p.768).
s.t. \[ \sum_{i=1}^{n} p_i h_i = y \]  \hspace{1cm} (2)

where \( h_i \), \( i=1,2,\ldots, n-1 \) are the housing attributes to be constructed
\( h_n \) : all other goods

The parameters \( \gamma_i \) are normalized so as to sum to unity i.e.
\[ \gamma_n = 1 - \sum_{i=1}^{n-1} \gamma_i. \]

Moreover, it follows from the definition of the budget constraint that the housing attributes are defined such that
\[ \sum_{i=1}^{n-1} p_i h_i = R, \]
where \( R \) is rent.

It will be indicated below how to construct the attributes consistent with this specification when using an estimated hedonic price function.

Since we do not observe price variation - the \( p_i \) are constant throughout the sample because we assume a linear hedonic relation - we have chosen the Stone-Geary indifference map because it is one of the very few utility functions of which the parameters can be estimated without observable price variation. Using this fairly simple utility function has its costs, however. It implies that all commodities are net substitutes with positive, and in practice low, cross-price elasticities.

As suggested by Deaton and Mullbauer, the linear expenditure system derived from the Stone-Geary utility function performs best when applied to broadly defined commodity utility groups where the implicit shortcomings of the model are likely to be least restrictive.

In this paper we will define a very small set of housing attributes on the basis of a larger set of observed characteristics. Even then, however, the limited substitution possibilities are somewhat unsatisfactory, especially when considering the trade-off between quality and quantity aspects of housing.
The demand functions obtained when maximizing (1) subject to (2) are as follows:

\[ h_i = \beta_i + \frac{\gamma_i}{p_i} (y - \sum_{i=1}^{n} p_i \beta_i) \]  

\[ i = 1, 2, \ldots n. \]

It's clear from this expression that the parameters \( \gamma_i \) are to be interpreted as the marginal propensities to spend on commodity \( i \). The \( \beta_i \)'s are usually interpreted as subsistence consumption of good \( i \), i.e. the minimum consumption necessary to derive positive utility, although there's no theoretical reason why all \( \beta_i \)'s should be positive. In practice, many authors have estimated linear expenditure systems yielding negative subsistence expenditures for one or more goods, especially when dealing with a limited number of goods in a model that does not allow for saving or dissaving (see e.g. H. Rosen (1978), Olsen and Barton (1983)).

The Stone-Geary indifference map is quasi-homothetic which implies that the marginal propensities to spend are constant for all households. Since we want to estimate the demand for housing attributes for different types of households, we should proceed by incorporating a set of socio-economic characteristics into the analysis. One way of doing this has been suggested by Awan, Odling-Smee and Whitehead (1982). They specified the parameters \( \gamma_i \) and \( \beta_i \) as linear, nonstochastic functions of some household traits \( x_j \):

\[ \gamma_i = c_i + \sum_{j=1}^{k} d_{ij} x_j \]

\[ \beta_i = t_i + \sum_{j=1}^{k} v_{ij} x_j \]
Incorporating these expressions into the demand functions the latter can be written as (*):

\[ h_i = (t_i - \frac{c_i}{p_i} \sum_{i=1}^{n} p_i t_i) + \frac{c_i}{p_i} y + \sum_{j=1}^{k} \frac{d_{ij}}{p_i} x_j y \]

\[ + \sum_{j=1}^{k} \frac{v_{ij}}{p_i} \left( \sum_{i=1}^{n} p_i t_i \right) - \frac{c_i}{p_i} \sum_{j=1}^{k} \frac{v_{ij}}{p_i} \left( \sum_{i=1}^{n} p_i v_{ij} \right) x_j \]

\[ + \sum_{j=1}^{k} \sum_{i=1}^{n} \frac{d_{ij}}{p_i} \left( \sum_{i=1}^{n} p_i v_{ij} \right) x_j x_i . \]

Although this may not be obvious at first sight, careful investigation of this system of demand equations reveals that empirical estimation would require a large number of both within-equation and cross-equation restrictions on the coefficients. In most cases the constraints are highly nonlinear. This does not imply, of course, that estimation is infeasible. However, some preliminary experiments indicated that obtaining the maximum likelihood estimates would be extremely costly. We therefore decided to adopt a slightly different procedure to introduce the household characteristics into the demand analysis. This method will lead to a system of equations that is much easier to estimate without imposing any intrinsically stronger assumptions on the model.

First note that the original demand functions (3) may be written as

\[ h_i = (\beta_i - \frac{\gamma_i}{p_i} \sum_{i=1}^{n} p_i \beta_i) + \frac{\gamma_i}{p_i} y \] (4)

Rather than specifying the \( \beta_i \)'s as linear functions of household characteristics we define new parameters \( z_i \):

\[ z_i = \beta_i - \frac{\gamma_i}{p_i} \sum_{i=1}^{n} p_i \beta_i \]

(* Due to an error in the original paper, these demand functions differ from those given in Awan, Odling-Smee and Whitehead (1982, p. 186). We show elsewhere that the above specification is the correct demand system, see De Borger (1984 /).
These parameters may be assumed constant for all households with a given set of socio-economic characteristics, since the implicit prices \( p_i \) are constant throughout the sample. We now specify \( \gamma_i \) and \( z_i \) as linear functions of household traits \( x_j \):

\[
\gamma_i = \gamma_{i0} + \sum_{j=1}^{k} \gamma_{ij} x_j
\]  

(5)

\[
z_i = z_{i0} + \sum_{j=1}^{k} z_{ij} x_j
\]  

(6)

Substituting (5) and (6) in (4) and imposing the budget constraint

\[
\sum_{i=1}^{n} p_i h_i = y
\]

the following system of demand equations results:

\[
h_1 = z_{10} + \sum_{j=1}^{k} z_{1j} x_j + \frac{\gamma_{10}}{p_1} y + \sum_{j=1}^{k} \frac{\gamma_{1j}}{p_1} x_j y
\]

\[
h_2 = z_{20} + \sum_{j=1}^{k} z_{2j} x_j + \frac{\gamma_{20}}{p_2} y + \sum_{j=1}^{k} \frac{\gamma_{2j}}{p_2} x_j y
\]

\[
\vdots
\]

\[
h_{n-1} = z_{(n-1)0} + \sum_{j=1}^{k} z_{(n-1)j} x_j + \frac{\gamma_{(n-1)0}}{p_{n-1}} y + \sum_{j=1}^{k} \frac{\gamma_{(n-1)j}}{p_{n-1}} x_j y
\]

(7)

\[
h_n = \frac{1}{p_n} \left( -\sum_{i=1}^{n-1} p_i z_{i0} - \sum_{i=1}^{n-1} \sum_{j=1}^{k} p_i z_{ij} x_j + (1 - \sum_{i=1}^{n-1} \gamma_{i0}) y \right.
\]

\[
- \sum_{i=1}^{n-1} \sum_{j=1}^{k} \gamma_{ij} x_j y
\]

where the final equation follows from the budget constraint.

In the next section we will introduce a stochastic component into the demand functions and discuss some estimation problems. At this moment
it suffices to investigate how the structural parameters $\beta_i$ and $\gamma_i$ can be recovered from estimates of the coefficients in (7). Obviously, the marginal propensities to spend for each household can be calculated directly using (5). Using (4) and (5) together with the definition of the $z_i$'s it is not difficult to show (*) : 

$$
\beta_i = z_{i0} + \sum_{j=1}^{k} z_{ij} x_j + \left( \sum_{i=1}^{n} p_i \beta_i \right) \left( \gamma_{i0} + \sum_{j=1}^{k} \gamma_{ij} x_j \right)
$$

for $i = 1, 2, \ldots, n-1$, and 

$$
\beta_n = \frac{1}{p_n} \left( -\sum_{i=1}^{n-1} p_i \left( z_{i0} + \sum_{j=1}^{k} z_{ij} x_j \right) + \left( \sum_{i=1}^{n} p_i \beta_i \right) \right)
$$

(1 - \left( \sum_{i=1}^{n-1} \gamma_{i0} + \sum_{j=1}^{k} \gamma_{ij} x_j \right))

Note that these expressions do not allow us to identify all $\beta_i$, since the term 

$$
\left( \sum_{i=1}^{n} p_i \beta_i \right)
$$

appears on the right-hand side. Because the demand system (7) only has (n-1) independent equations the n equations in (8) can not be solved for the n unknown $\beta_i$. The identification problem should come as no surprise because it is impossible to identify all parameters (on the basis of a single cross-section) for even the simplest version of the linear expenditure system, see e.g. Pollak and Wales (1978).

We therefore propose to use a priori information on one parameter, say $\beta_r$, to calculate all remaining $\beta_i$'s. The procedure is as follows : first we derive, using (8),

(**) The equation for $\beta_n$ is derived by summing

$$
\sum_{i=1}^{n-1} p_i \beta_i
$$

and solving the resulting expression.
\[ \begin{align*}
\sum_{i=1}^{n} p_i \beta_i &= \frac{\beta_r - \left( z_{ro} + \sum_{j=1}^{k} z_{rj} x_j \right)}{\left( \gamma_{ro} + \sum_{j=1}^{k} \gamma_{rj} x_j \right)/p} \\
\end{align*} \] (8a)

and substitute this expression back into (8) to get all subsistence parameters (\*). Since this procedure is quite arbitrary care should be taken to select 'reasonable' a priori values. Moreover, it is important to test the sensitivity of the structural parameters with respect to changes in the chosen parameter. Of crucial importance is the impact of variations in the selected a priori value for the final benefits obtained. These issues will be discussed when the empirical results are presented.

C. Calculating Benefits

We only consider Hicks' equivalent variation in this paper. This is defined as the amount we should pay a household in the absence of the program to make it as well off as under the housing program.

We have

\[ EV = e(p^0, u^S) - y^0 \] (9)

where \( e(\cdot) \) is the expenditure function
\( p^0 \) is the vector of prices in the absence of the program
\( y^0 \) is household income. It's assumed that the housing program doesn't affect income.

(\*) One can use one of the subsistence parameters for housing attributes or the parameter \( \beta_n \) for all other goods. In that case

\[ \begin{align*}
\sum_{i=1}^{n} p_i \beta_i &= \frac{p_n \left( \beta_n + \sum_{i=1}^{n-1} p_i \left( z_{i0} + \sum_{j=1}^{k} z_{ij} x_j \right) \right)}{1 - \sum_{i=1}^{n-1} \left( \gamma_{i0} + \sum_{j=1}^{k} \gamma_{ij} x_j \right)} \\
\end{align*} \]
$u^s$ is the utility level attained under the program, i.e.

$$u^s = \prod_{i=1}^{n} (h_i^s - \beta_i)^{Y_i},$$

where $h_i^s$ is the quantity of commodity $i$ consumed under the program.

Substituting (3) in (1) it is straightforward to derive the indirect utility function

$$v(p^0, y^0) = \left( \prod_{i=1}^{n} \left( \frac{\gamma_i}{p_i^0} \right) \right) (y^0 - \sum_{i=1}^{n} \left( \frac{p_i^0}{\beta_i} \right))$$

Inverting $v(p^0, y^0)$ and applying (9) we find

$$\text{EV} = \left( \prod_{i=1}^{n} \left( \frac{h_i^s}{p_i^0} - \beta_i \right)^{\gamma_i} \right) + \sum_{i=1}^{n} \frac{p_i^0}{\gamma_i} \beta_i - y^0$$

(9a)

where, as usual, $\gamma_n = 1 - \sum_{i=1}^{n-1} \gamma_i$

3. The data and the construction of the housing attributes

The data used in this paper were derived from a survey conducted in Liège, Belgium, in the early seventies. We only used the sample of households living in rental housing, which implies that we had 326 observations available for analysis. The subsamples on uncontrolled and public housing contained 261 and 65 observations, respectively. A total of 105 households reported to live in single-family housing units, whereas 221 families occupied apartments. A detailed description of the data is in De Borger (1984 b/, appendix 1).

The data include a set of variables describing the dwelling unit (such as the number of rooms, living space, construction date etc.) and a
set of variables with respect to the socio-economic characteristics of the households (such as observed wage, family size, etc.). The available information on housing characteristics is far less detailed than would be desirable. We have no variables at all describing neighborhood and environmental quality. Moreover, the data with respect to location were scarce and not very useful for the purpose of this paper. Indeed, although the data did contain some information with respect to travel costs and times for the journey-to-work, using these variables as proxies for location in hedonic price regressions is not consistent with the classical hedonic pricing theory. The hedonic equation is assumed to represent the equilibrium price profile resulting from the interaction between demanders and suppliers of housing characteristics. This implies that it should not depend on household-specific variables such as travel costs or times, which are related to the workplace of the families' working members, see S. Rosen (1974, p. 36). It is preferable, therefore, to use objective measures as proxies for location, such as e.g. distance to the C.B.D. Since such variables were not available and many authors have used travel information as a proxy for location in hedonic rent equations, we did perform some experiments along these lines. The results consistently produced insignificant coefficients, which in most cases had the wrong sign (*). In order to be consistent with the theoretical framework used in this paper and given the procedure used to construct the attributes, see below, these poor results forced us to limit the analysis to observed structural housing characteristics. Still, the information used in this paper is comparable to that in many previous studies of housing demand and observed housing components allow us to explain a reasonable proportion of the variation in rent.

To construct the housing attributes we considered three methods that have been proposed in the literature. They are basically data reduction

(*) Our failure to obtain reasonable coefficients casts some doubt on the validity of Straszheim's (1973) theory of household specific hedonic equations for our sample. This is not surprising because our sample comes from a relatively small and homogeneous urban area. The more employment is concentrated in a single zone, the better Straszheim's theory may be expected to be validated by empirical work.
techniques. That composite attributes can be constructed on the basis of a larger set of individual housing characteristics is a strong simplifying assumption, but it is almost universally accepted in the literature.

One procedure that has extensively been used to define housing components is factor analysis (see e.g. Kain and Quigley (1970), Witte; Sumka and Erekson (1979), Archer and Wilkinson (1973), King (1975)). Some authors have considered it a convenient technique to avoid multicollinearity in hedonic price regressions, others have used it to summarize a large number of characteristics, especially when some of them are defined on a very coarse measurement scale. Factor analysis constructs artificial components as linear combinations of the standardized original characteristics in such a way as to capture as much of the variance as possible. The factors are then rotated to ease their interpretation (*). Unfortunately, interpretation of the results is precisely the main weakness of the technique. How should one e.g. interpret a factor in which living area, age of the house and access to public transport have a high factor score? In many cases the factors have no clear meaning and the researcher has to use his own views - and his imagination - to attach a unique descriptive name to each of them. However, if a factor is not clearly defined its expected sign in a hedonic regression is ambiguous and estimated demand functions are difficult to interpret (**).

The sometimes arbitrary interpretation of the final factors has encouraged some authors to use a different approach. Bartik (1982) e.g. constructs the attributes using principal components, but groups the variables a priori into roughly homogeneous categories, each of which can reasonably be assumed to represent a single housing dimension. A single component is extracted from each group. Variables not belonging in any of the groups are kept separately in the analysis. Although the procedure obviously does not take into account the full set of corre-

(*) A good description of principal components and factor analysis is in Morrison (1967).

(**) An excellent illustration of these problems can be found in Awan, Odling-Smee and Whitehead (1982, p. 190 - 194).
lations between the variables, it has the advantage that the results are straightforward to interpret.

A third method was proposed by King (1976). In a critique of factor analysis he notes that 'a little thought will suggest that this mechanical technique might as readily combine as isolate specific characteristics' (p. 1086). His procedure is to first estimate a linear hedonic relation between rent and all observed housing characteristics. He assumes that the housing bundle only produces an a priori fixed number of well-defined attributes and that each individual characteristic only contributes to the production of an attribute. Each characteristic is allocated to one of the attributes. The final step is to sum all characteristics assigned to each attribute and to use the estimated hedonic prices as weights.

Note that each of the methods discussed produces housing attributes that are linear combinations of observed characteristics. Moreover, all are somewhat arbitrary and require the subjective input of the investigator (\(*\)). The implicit objectives are quite different, however. Whereas the factor analytic techniques try to capture a large proportion of the variation in the housing characteristics, King's procedure has the advantage that the attributes are constructed so that they explain exactly as much of the variance in observed rent as the complete list of characteristics (\(* \ast\)).

Considering advantages and disadvantages of the three procedures and taking into account the results of a formal factor analysis we decided to use King's method in this paper. In appendix 1 we do present the results of the other approaches and justify why they were not used for further empirical work.

\(--\)

(\(*\)) An important difference is that factor analysis requires subjective input at the interpretation stage, whereas the other procedures use the researcher's subjective information to define the attributes prior to the analysis.

(\(* \ast\)) This assumes a linear hedonic relation. Note that public housing units should be excluded when applying this method since it is based on an hedonic regression. The first two methods use the complete sample of uncontrolled and public units.
Linear hedonic regressions were estimated using all available housing characteristics (*). Separate equations were estimated for apartments and single-family housing. For many variables the raw data were used, i.e. we included the original variables as they were defined in the survey. Consequently, several variables are defined on a scale, e.g. the construction date of the unit, the story at which it is situated etc. The definition of the variables is given in table 1 a). Regression results are in table 1 b).

Most coefficients have the expected sign, although quite a few are not significantly different from zero. This is no problem for our purposes as long as the linear combinations that will define the housing attributes are highly significant. Also note that the explanatory power of the equations is comparable to that of alternative specifications used in earlier work (see De Borger 1984 b).

The allocation of individual housing characteristics to composite attributes and descriptive names for the latter are given in table 2. A first attribute was constructed as a linear combination of the number of rooms and bedrooms, the living area in m² and the variables describing additional space, OTHSPA and YARD. Not surprisingly the attribute was named 'SPACE' (**). A second attribute 'SANITARY QUALITY' was defined as a linear combination of BATHR, WC and WATER. The construction

(*) Two available pieces of information were not used in these regressions. A variable describing whether the housing unit contained a kitchen and the type of kitchen was not used because most units did have a kitchen, and the interpretation of the 'quality scale' was unclear. A variable indicating whether running water was available was not used because of a complete lack of variance.

(**) It might correctly be argued that outside space (YARD) will be valued differently and that a separate demand function for this characteristic should be estimated. However, most apartments had no outside space at all. Moreover, for single family housing the information on outside space was extremely crude. Estimation of an additional demand function for outside space yielded insignificant and nonsensical results. Therefore, we assigned YARD to the attribute 'SPACE' as a very rough indicator of lot size.
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>NUMERICAL VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTRDAT</td>
<td>Construction date of unit; classified in 4 periods</td>
<td>1 - 4</td>
</tr>
<tr>
<td>STORY</td>
<td>Story on which the unit is situated</td>
<td>0 - 5</td>
</tr>
<tr>
<td>ELEV</td>
<td>Whether or not an elevator is available</td>
<td>0 - 1</td>
</tr>
<tr>
<td>SECSYS</td>
<td>Whether or not the unit has a security system</td>
<td>0 - 1</td>
</tr>
<tr>
<td>ROOMS</td>
<td>Number of rooms</td>
<td>0 - 9</td>
</tr>
<tr>
<td>BEDR</td>
<td>Number of bedrooms</td>
<td>0 - 9</td>
</tr>
<tr>
<td>SPACE</td>
<td>Living area in m²</td>
<td>Continuous</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>Height of the rooms; classified in 4 categories</td>
<td>1 - 4</td>
</tr>
<tr>
<td>WATER</td>
<td>Whether or not hot water is available</td>
<td>0 - 1</td>
</tr>
<tr>
<td>BATHR</td>
<td>Whether or not the unit has a bathroom</td>
<td>0 - 1</td>
</tr>
<tr>
<td>WC</td>
<td>Quality indicator of the restrooms</td>
<td>1 - 6</td>
</tr>
<tr>
<td>OTHSPA</td>
<td>Availability of basement, dépositories, terrace, or a combination of two or more</td>
<td>1 - 7</td>
</tr>
<tr>
<td>YARD</td>
<td>Quality indicator of yard</td>
<td>1 - 4</td>
</tr>
<tr>
<td>CH</td>
<td>Quality indicator central heating system</td>
<td>1 - 3</td>
</tr>
<tr>
<td>LIGHT</td>
<td>Power of electrical system</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

Table 1 a): Description of regressors in hedonic rent equation (*). 

(*) For more detailed information, see De Borger (1984 b/, appendix 1).
<table>
<thead>
<tr>
<th></th>
<th>Apartments</th>
<th>Single-family Housing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>t-value</td>
</tr>
<tr>
<td>CONSTANT</td>
<td>-1.881</td>
<td>-3.81</td>
</tr>
<tr>
<td>CONSTRDAT</td>
<td>1.243</td>
<td>1.39</td>
</tr>
<tr>
<td>STORY</td>
<td>0.860</td>
<td>0.89</td>
</tr>
<tr>
<td>ELEV</td>
<td>11.140</td>
<td>4.86</td>
</tr>
<tr>
<td>SECSYS</td>
<td>0.080</td>
<td>1.03</td>
</tr>
<tr>
<td>ROOMS</td>
<td>0.169</td>
<td>1.17</td>
</tr>
<tr>
<td>BEDR</td>
<td>2.742</td>
<td>2.35</td>
</tr>
<tr>
<td>SPACE</td>
<td>0.068</td>
<td>1.96</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>-0.002</td>
<td>-0.09</td>
</tr>
<tr>
<td>WATER</td>
<td>2.631</td>
<td>1.68</td>
</tr>
<tr>
<td>BATHR</td>
<td>4.363</td>
<td>2.35</td>
</tr>
<tr>
<td>WC</td>
<td>0.352</td>
<td>0.64</td>
</tr>
<tr>
<td>OTHSPA</td>
<td>0.773</td>
<td>0.19</td>
</tr>
<tr>
<td>YARD</td>
<td>0.127</td>
<td>0.143</td>
</tr>
<tr>
<td>CH</td>
<td>2.902</td>
<td>2.61</td>
</tr>
<tr>
<td>LIGHT</td>
<td>0.271</td>
<td>0.22</td>
</tr>
</tbody>
</table>

\[ R^2 = 0.669 \quad \text{RSS} = 8663.72 \]

\[ R^2 = 0.524 \quad \text{RSS} = 10939.18 \]

Table 1 b): Regression results hedonic rent equation
date of the unit, the indices for the heating and electrical system and the variable HEIGHT were grouped in an attribute 'STRUCTURAL QUALITY'. Inclusion of the latter as a descriptor of structural quality was suggested by the strong correlation of this variable with the construction date of the unit. This correlation is probably due to the historical evolution of building styles, causing the average height of rooms to be less in more recently constructed units. Note that the impact of HEIGHT on the attribute is extremely small anyway.

<table>
<thead>
<tr>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>CONSTRDAT</td>
<td>ROOMS</td>
<td>ELEV</td>
</tr>
<tr>
<td>BATHR</td>
<td>LIGHT</td>
<td>BEDR</td>
<td>STORY</td>
</tr>
<tr>
<td>WATER</td>
<td>CH</td>
<td>SPACE</td>
<td>SECSYS</td>
</tr>
<tr>
<td></td>
<td>HEIGHT</td>
<td>YARD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OTHSPA</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Definition of the attributes

Finally, a fourth attribute was constructed to capture the remaining characteristics that are only defined for apartments. The interpretation of the attribute is not entirely clear, although the importance of the characteristics in the hedonic equation implies that it cannot be deleted from further consideration. The included housing components give some crude information on the situation of the apartment building that is not captured by the other attributes. Their performance in the hedonic suggests that they are positively valued in the market. Although the variables ELEV and PARLO may be considered quality aspects, it is harder to explain why people would be willing to pay for living above ground level. A possible explanation is that STORY is correlated with unobserved characteristics and captures their effect on rent. Candidates include e.g. quiet, the value of the possibly better view, etc.
To some extent STORY may even capture some effects of location because high-rise apartment buildings are usually located close to city centers. Empirical results obtained further in this paper will hopefully provide some additional insight on how to interpret this fourth attribute.

Two final points should be made. First, the defined attributes are at best descriptive. It is obvious that one could think of many other, but unfortunately unavailable, housing characteristics that would fit in under the attribute names. Moreover, due to data limitations the constructed attributes do not exhaust all possible dimensions of housing. Location and neighborhood variables are only captured in as far as they are correlated with included characteristics. Second, the allocation of characteristics to attributes is quite arbitrary, though we think not unreasonable. It should be stressed that the impact of the characteristics whose allocation is questionable (e.g. HEIGHT, YARD) on the final attribute is small. Consequently, possible misallocations will probably have minor effects on the subsequent demand analysis.

4. Estimating the demand for housing attributes

For estimation purposes a stochastic component should be introduced into model (7). As in much of the existing literature on systems of demand equations we just added a disturbance term \( u_j \) to each equation. The disturbances are assumed to have mean zero and constant variance. They are included in the model to capture two quite distinct stochastic phenomena. First, households with the same observed socio-economic characteristics will choose different quantities of housing attributes and other goods due to variations in taste. It is implicitly assumed that taste variations that are not captured by the variables in the equations are uncorrelated with the observed household characteristics. Second, even if all similar households had the same preferences they would demand different quantities because of disequilibrium errors. Households face different circumstances and have varying abilities to
maximize short-run utility, as postulated by the model.

It is assumed that the joint impact of these two random processes and possible measurement errors cause the observed demands of households with the same observed characteristics to be randomly distributed around the predicted values. Moreover, it is hypothesized that the resulting stochastic fluctuations can be represented by additive disturbances. Since economic theory provides little or no guidance with respect to the specification of the error structure of econometric demand models, this assumption was maintained for convenience.

Several techniques are available for the actual estimation of the system of demand equations. An acceptable procedure seems to be to estimate the demand for housing attributes by applying ordinary least squares to each equation separately. The estimated coefficients uniquely determine the parameters in the final equation for all other goods, since these are just linear combinations of the parameters in the first \((n-1)\) equations. Although this procedure would yield unbiased and consistent estimates of all parameters in the system we have some additional information that can be used to gain efficiency. Indeed, we know that imposing the budget constraint on the system introduces a set of cross-equation restrictions on the coefficients. Moreover it implies singularity of the variance-covariance matrix of the disturbances, because the errors in different equations should sum to zero, i.e.

\[
\sum_{i=1}^{n} u_i = 0.
\]

Note, however, that if the budget constraint is to be satisfied total expenditures on all housing attributes should equal observed rent. Due to the constant and the residual in the hedonic regressions, total expenditures on the attributes defined in table 2 do not equal rent. In order to exploit the singularity of the variance-covariance matrix and to obtain more efficient parameter estimates we constructed an additional housing attribute 'ALL OTHER CHARACTERISTICS', defined as the difference between observed rent and the total expenditures on the
attributes listed in table 2. The introduction of this artificial attribute, suggested by Ellickson in a different context (Ellickson (1977)), guarantees that the budget constraint is satisfied. It should be stressed that its only purpose is to allow us to implement a superior estimation procedure. We will not engage into speculation concerning the interpretation of the demand for this composite attribute. It may be assumed to represent all unobserved housing characteristics including location and neighborhood effects, insofar as the latter are not taken into account already through their correlation with included housing characteristics (*).

An efficient procedure to estimate the system of demand equations - enlarged to include the demand for 'ALL OTHER CHARACTERISTICS' - is to use a modification of Zellner's (1962) method for seemingly unrelated regressions. The method involves two steps: first estimate the n equations, imposing the relevant constraints on the coefficients, by ordinary least squares. Second, use the estimated variance-covariance matrix of the first stage to apply generalized least squares to the system, of which one equation is deleted to account for the singularity of the true variance-covariance matrix of the disturbances. This procedure is invariant to which equation is deleted prior to the second stage (Berndt et al. (1974)). The efficiency gain over ordinary least squares may be substantial if the error terms of different equations are highly correlated and if the explanatory variables in different equations are not highly collinear (**).

Although the theory developed in this paper results in a particular functional form for the demand equations, it does not provide any information concerning the proper set of explanatory variables to use.

(*: Although Ellickson's results are consistent with such an interpretation, he notes that the defined variable 'is the sort of construct that can easily improve the performance of a model in an entirely spurious fashion by introducing an identity through the back door' (p. 54). This is no problem for our study where the variable is precisely introduced to ensure that the budget identity holds.

(**) In our empirical application the set of explanatory variables will not be the same in all equations, see below.
To select the final set of household characteristics we performed some preliminary regressions using all available information that was thought to be relevant. The variables used were intended to capture some effects of family size, income, education, professional status and whether the wife had some professional activity. They are, as usual in empirical work, only crude proxies for the underlying characteristics they are trying to measure. Variables that did not have a significant impact on any of the attributes were dropped from further consideration. Moreover, it should be indicated that inclusion of education and professional status variables for both husband and wife lead to poor estimation results, largely due to collinearity problems. In each case, only one proxy was used. The household characteristics appearing in the final model are listed below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH12, CH3+</td>
<td>Dummy variables equal to 1 if the household contains 1 or 2, 3 or more children, respectively.</td>
</tr>
<tr>
<td>ED1, ED2</td>
<td>Dummy variables describing the wife's educational achievement. ED1 = 1 if highest educational attainment was a high school degree. ED2 = 1 if highest educational attainment was a higher degree (e.g. a university degree).</td>
</tr>
<tr>
<td>INCOME</td>
<td>household income, monthly.</td>
</tr>
<tr>
<td>PROCLM</td>
<td>Dummy variable equal to one if husband is white-collar.</td>
</tr>
<tr>
<td>PRACTW</td>
<td>Dummy variable equal to one if wife has some professional activity.</td>
</tr>
</tbody>
</table>

We also left the final specification largely to be determined by the data. Several points should be made, however. First, for a general structure of preferences one would expect that a particular household characteristic would affect the demand for all commodities. Within the framework of the Stone-Geary indifference map, however, it is by no means impossible that a given household trait influences the demand for some housing attributes but not for others. This appears to be quite reasonable for the application considered in this paper.
It is e.g. conceivable that family size is an important determinant of the demand for space, but that it has no significant effect on the demand for quality related attributes.

Second, model (7) implies that household characteristics may affect the demand for a particular attribute through the marginal propensity to spend, \( \gamma_i \), and through their effect on the parameter \( z_j \), defined as a function of \( \gamma_i \) and the subsistence parameters \( \beta_j \). In practice, many household traits were significant while their cross-product was not, and vice versa. In the final specification we allow variables to affect demand only via \( \gamma_i \) or \( z_j \)(*). A household characteristic that only influences \( z_j \) will have an impact on the estimated subsistence parameter \( \beta_j \) without affecting \( \gamma_i \).

Third, the criteria used to select the final specification took into account the constraints imposed by the theory developed in this paper. This is important because the Stone-Geary indifference map does not allow inferior goods. This implies that the \( \gamma_i \) should be nonnegative for all households and for all goods, since \( \gamma_i < 0 \) would violate the concavity of the utility function.

It might correctly be argued that the selection of the final equations was largely ad hoc. Still we believe that our strategy was not unreasonable insofar as we took into account statistical considerations as well as consistency with the theory. It should be stressed that the qualitative results derived further in this paper (e.g. the calculus of benefits) depend in no substantial way on the exact specification of the demand functions for housing attributes.

The regression results are presented in tables 3 a) and b) for apartments and single-family housing, respectively. They were obtained

(* This is not only theoretically possible and desirable from the viewpoint of statistical precision, it also makes intuitively sense in many cases. For example, it would not be surprising to find that family size has an impact on the demand for space via \( z_j \) but not via \( \gamma_i \). This would just suggest that this variable influences the subsistence level, but that it has no additional effect on the marginal propensity to spend.
using the modified Zellner procedure previously discussed. Consider the demand for attributes in the apartment equations. Most coefficients are significant (*) and the explanatory power of the regression is satisfactory, taking into account the use of cross-section data (**). Income, education and professional status are the main determinants of the demand for sanitary and structural quality. Family size and income are the most important variables explaining the demand for space and apartment type. Education does affect the marginal propensity to spend on these attributes. Note that households in which the wife has some professional activity have a lower demand for apartment type, and, not surprisingly, for space. Finally, we observe that education, professional status and the wife's professional activity affect demand mainly via the parameters $\gamma_i$, whereas family size influences the demand for space and apartment type through the subsistence parameters $\beta_j (***)$.

As expected, the interpretation of the demand function for 'all other characteristics' is unclear. Apart from income all household characteristics enter the equation with a negative sign which is not very consistent with an interpretation of the attribute as a composite of mainly locational and neighborhood effects. The attribute does appear to be a normal good for all household types.

Unfortunately, the results with respect to the demand for single-family housing, reported in table 3 b), are far less satisfactory. Although the explanatory power of the estimated relations is comparable to that of the apartment regressions, only a relatively small number of explanatory variables turned out to be statistically significant. In particular, neither PROCLM nor PRACTW

(*) Obviously, these results were obtained after some 'regression fishing' since the true model is unknown. Therefore, the t-statistics are likely to be upward biased, see e.g. Leamer (1983) or Lovell (1983).

(**) The explanatory power is comparable to that reported in Awan, Odling-Smee and Whitehead (1982). It is well known that equations derived from the Rotterdam model usually perform better (in terms of $R^2$), see e.g. King (1976).

(***) When interpreting these results please keep in mind the rather crude definition of the housing attributes.
<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
<th>ALL OTHER CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>- 0.611 (-3.12)</td>
<td>4.333 (4.12)</td>
<td>5.549 (5.18)</td>
<td>- 0.088 (-1.02)</td>
<td>- 10.210 (-1.26)</td>
</tr>
<tr>
<td>CH 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH 3+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED1</td>
<td>4.938 (2.64)</td>
<td>4.709 (2.61)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED2</td>
<td>6.177 (3.51)</td>
<td>4.544 (2.67)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROCLM</td>
<td></td>
<td>1.584 (3.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INCOME</td>
<td>0.036 (5.08)</td>
<td>0.022 (3.95)</td>
<td>0.0055 (2.01)</td>
<td>0.039 (3.74)</td>
<td>0.065 (3.86)</td>
</tr>
<tr>
<td>ED1 * INCOME</td>
<td>- 0.028 (-3.03)</td>
<td>- 0.021 (-2.43)</td>
<td>0.0051 (1.89)</td>
<td>0.0087 (1.71)</td>
<td>- 0.0114 (-1.41)</td>
</tr>
<tr>
<td>ED2 * INCOME</td>
<td>- 0.031 (-3.83)</td>
<td>- 0.016 (-2.07)</td>
<td>0.0057 (2.95)</td>
<td>0.0063 (1.95)</td>
<td>- 0.0022 (-1.26)</td>
</tr>
<tr>
<td>PROCLM * INCOME</td>
<td>0.010 (3.49)</td>
<td></td>
<td>- 0.003 (-2.29)</td>
<td>- 0.019 (-2.65)</td>
<td>- 0.007 (-1.82)</td>
</tr>
<tr>
<td>PRACTW * INCOME</td>
<td>- 0.004 (-2.97)</td>
<td></td>
<td></td>
<td></td>
<td>- 0.011 (-2.50)</td>
</tr>
<tr>
<td>R²</td>
<td>0.395</td>
<td>0.373</td>
<td>0.263</td>
<td>0.256</td>
<td>0.177</td>
</tr>
<tr>
<td>n</td>
<td>159</td>
<td>159</td>
<td>159</td>
<td>159</td>
<td>159</td>
</tr>
</tbody>
</table>

Table 3a: Regression results apartments (t-statistics in parentheses)
<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL OTHER CHARACTERISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPACE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSTANT</td>
<td>5.10823 ( 4.18)</td>
<td>4.90057 ( 3.32)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH12</td>
<td>13.592 ( 3.14)</td>
<td>5.39948 ( 2.703)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH3+</td>
<td>0.740 ( 1.63)</td>
<td>2.24566 ( 1.63)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED1</td>
<td>1.461 ( 2.23)</td>
<td>0.0076 ( 2.93)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED2</td>
<td>0.0074 ( 2.85)</td>
<td>0.0074 ( 1.54)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INCOME</td>
<td>0.0074 ( 2.93)</td>
<td>0.0113 ( 2.18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRACTN</td>
<td>0.0074 ( 2.93)</td>
<td>0.0072 ( 1.92)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.425</td>
<td>0.223</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3b: regression results single-family housing (t-statistics in parenthesis)
were found to have an effect on the demand for sanitary and structural quality. Qualitatively, the results for apartments and single-family housing are quite similar, however. The figures in table 3 b) imply that income and the education proxies are the main determinants of quality demand whereas family size, the wife's professional activity, income and to some extent education influence the demand for space. Note that the difference between the coefficients of the education proxies is surprisingly large which suggests that, for our sample, better education does not affect demand in a monotonic fashion. We are unable to offer an intuitive argument to explain this finding (x).

More interesting than the regression results are their implications for the structural parameters \( \gamma_i \) and \( \beta_i \) and the economic properties of demand. First consider the marginal propensity to spend. The \( \gamma_i \)'s for sanitary and structural quality decrease with the education variables. In the case of apartments they also increase with the dummy variable relating to professional status. Both for apartments and single-family housing the \( \gamma_i \) for space increases with education. Since education appears to be the main source of variation in the marginal propensities to spend for all attributes, we present in table 4 the mean \( \gamma_i \)'s for households at different levels of education. The results clearly illustrate our previous remarks. Note that a nontrivial fraction of additional income would be spend on sanitary and structural quality. The marginal propensity to spend on space is relatively small, especially for households living in apartments. The values obtained for 'all other characteristics' indicate further that a major proportion of the marginal propensity to spend on housing can be attributed to this composite good, especially in the case of single-family units. This is hardly surprising because the attribute accounts for a large fraction of the variation in observed rent, as suggested by the coefficients of determination in the hedonic price regressions reported in

(x) Please note that the only reason why the household characteristics were included in the demand functions was to allow for some differences in tastes. Whatever the results for the education proxies turn out to be, no judgment with respect to the causal relation between a household's behavior and education is implied.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Families ED0</th>
<th>All Families ED1</th>
<th>All Families ED2</th>
<th>All Families</th>
<th>Apartments ED0</th>
<th>Apartments ED1</th>
<th>Apartments ED2</th>
<th>Single-Family Housing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanitary Quality</td>
<td>0.041 (0.012)</td>
<td>0.030 (0.013)</td>
<td>0.033 (0.014)</td>
<td></td>
<td>0.031 (0.011)</td>
<td>0.016 (0.007)</td>
<td>0.015 (0.006)</td>
<td>0.008 (0.003)</td>
</tr>
<tr>
<td>Structural Quality</td>
<td>0.036 (0.009)</td>
<td>0.026 (0.006)</td>
<td>0.026 (0.009)</td>
<td></td>
<td>0.031 (0.011)</td>
<td>0.016 (0.007)</td>
<td>0.015 (0.006)</td>
<td>0.008 (0.003)</td>
</tr>
<tr>
<td>Space</td>
<td>0.002 (0.005)</td>
<td>0.003 (0.004)</td>
<td>0.006 (0.006)</td>
<td></td>
<td>0.005 (0.003)</td>
<td>0.012 (0.005)</td>
<td>0.015 (0.006)</td>
<td>0.008 (0.003)</td>
</tr>
<tr>
<td>Apartment Type</td>
<td>0.029 (0.008)</td>
<td>0.036 (0.011)</td>
<td>0.033 (0.012)</td>
<td></td>
<td>0.092 (0.034)</td>
<td>0.055 (0.022)</td>
<td>0.076 (0.035)</td>
<td>0.081 (0.033)</td>
</tr>
</tbody>
</table>

Table 4: Mean marginal propensities to spend on housing attributes for different household types (standard errors in parentheses).

*(*) Standard errors were calculated at the mean of the explanatory variables for each household type using the expression in Mood and Graybill (1963, p. 211).
Finally observe that the mean marginal propensity to spend on housing (i.e. $\Sigma \gamma_i$) equals approximately 0.13 and 0.15 for apartments and single-family units, respectively. Then values come close to previous results obtained using a quite different procedure (De Borger (1984)).

Closely related to the parameters $\gamma_i$ are the income elasticities for housing attributes $\varepsilon_{yi}$. It follows from the demand functions (3) that

$$\varepsilon_{yi} = \frac{\gamma_i}{p_i} \frac{Y}{h_i}$$

Results are presented in table 5, again for different values of the education variables. The figures in table 5 are mean income elasticities for households of different types, where the individual elasticities were calculated using observed consumption and income levels. This should be kept in mind, because on average households in the categories ED1 and ED2 have higher incomes and consume more of most housing attributes, especially the quality indicators.

In general the mean income elasticities are fairly small. However, the demand for sanitary quality in the case of apartments turns out to be income elastic on average, although the estimates strongly vary with education. The demand elasticities for the quality attributes tend to be substantially larger for households for which both ED1 and ED2 are zero. If we associate low income elasticities with necessities and take into account that the results were evaluated at observed consumption and income levels then this finding is not implausible. Also note that the income elasticity of the demand for space is small for all household types and tends to increase slightly with education(*). Not surprisingly all household types seem to treat space as a necessity.

Finally, the demand for 'apartment type' is income elastic for all households. This is somewhat surprising: although it is reasonable

(*): All conclusions are obviously conditional on the fact that the Stone-Geary is the 'true' representation of preferences. In particular, qualitatively different implications might be derived from an estimated Cobb-Douglas demand system.
<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDO</td>
<td>2.186</td>
<td>0.444</td>
<td>0.122</td>
<td>1.713</td>
</tr>
<tr>
<td>ED1</td>
<td>0.577</td>
<td>0.119</td>
<td>0.228</td>
<td>2.011</td>
</tr>
<tr>
<td>ED2</td>
<td>0.342</td>
<td>0.131</td>
<td>0.257</td>
<td>1.823</td>
</tr>
<tr>
<td>All families</td>
<td>1.510</td>
<td>0.317</td>
<td>0.169</td>
<td>1.799</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th>apartments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDO</td>
<td>0.782</td>
<td>0.514</td>
<td>0.049</td>
<td>----</td>
</tr>
<tr>
<td>ED1</td>
<td>0.258</td>
<td>0.268</td>
<td>0.154</td>
<td>----</td>
</tr>
<tr>
<td>ED2</td>
<td>0.476</td>
<td>0.503</td>
<td>0.191</td>
<td>----</td>
</tr>
<tr>
<td>All families</td>
<td>0.628</td>
<td>0.455</td>
<td>0.095</td>
<td>----</td>
</tr>
</tbody>
</table>

|               |  |  |  | single-family housing |

Table 5: Income elasticities of the demand for housing attributes
to assume that some of the characteristics included in this attribute are 'luxury' items (SECSYS, ELEV), this is not at all obvious for the story on which the unit is located. We indicated before that the positive market valuation of this characteristic in the hedonic may be due to its correlation with unobserved attributes such as quiet, proximity to the city center, etc. Moreover, in our sample the variable 'STORY' correlates positively with at least one aspect of structural quality, because high rise apartment buildings were an average constructed relatively recently. Although these remarks do not suffice to explain the results obtained, they do help to understand them.

As previously discussed we had to make an a priori assumption on one of the subsistence parameters \( \beta_r \) to identify all remaining \( \beta_i \)'s. Different results will be obtained when using a priori information on subsistence levels for different attributes or when varying the \( \beta_r \) for a particular attribute. A series of difficult problems arises: first, how to choose the attribute for which a priori information will be used. Second, how to determine a reasonable value for the chosen alternative. Third, how sensitive are the over-all results with respect to the particular choice being made.

For most attributes it is very hard to come up with reasonable a priori values for the \( \beta_r \) for different types of households. As far as the subsample of households living in apartments is concerned the most natural approach seems to be to use a priori assumptions on subsistence consumption of 'apartment type', because this attribute is always nonnegative and its physical minimum at zero may be an acceptable quantity for many households. If the housing unit is situated on ground level and the apartment complex does not have an elevator nor a security system then the value of the attribute equals zero. Moreover, 0 was the sample minimum for all 9 household types considered which provides additional justification for using it as the subsistence parameter. Theoretically speaking the sample minimum is a consistent, although obviously not unbiased, estimator of the subsistence parameter in the population if the latter contains at least one household at subsistence.
Applying expressions (8 a)) and (8) we obtained the results summarized in table 6. Since the estimated $\beta_i$ for all attributes except 'apartment type' vary both with family size and education we present mean results for 9 household types (†). Although some of the subsamples are very small, given a total sample size of 159 observations, we believe that presentation of our findings for different types of households clarifies the effect of the socio-economic characteristics (‡).

Although the absolute values of the $\beta_i$'s are difficult to interpret their variation with household characteristics is consistent with a priori expectations. The subsistence levels of sanitary and structural quality increase strongly with education and vary (i.e. increase) only slightly with family size. For space we find exactly the opposite result: the $\beta_i$ is substantially larger for families with children while it does not vary much with the education variables. The estimated $\beta_i$ for 'all other characteristics' is obviously always negative due to the procedure used to construct this attribute.

As suggested before, one should not take the estimated subsistence expenditures on 'all other goods' and total subsistence expenditures

$$\sum_{i=1}^{n} p_i \beta_i$$

too literally. The former even turns out to be negative for households without children. Moreover, we would expect on average a much larger value for

$$\sum_{i=1}^{n} p_i \beta_i$$

than the estimated sample mean of 2100 Belgian francs reported in table 6. The reasons for these unexpected results are well established

(‡) Each row in table 6 corresponds to a particular household type e.g. CHO - ED1 corresponds to households without children in which the wife's final educational attainment was a high school degree (i.e. ED1 = 1).

(‡ ‡) The sample sizes range from as few as 7 observations to a maximum of 45.
<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
<th>ALL OTHER CHARACTERISTICS</th>
<th>ALL OTHER GOODS</th>
<th>TOTAL SUBSISTENCE EXPENDITURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO-ED0</td>
<td>-0.477</td>
<td>5.150</td>
<td>5.560</td>
<td>0</td>
<td>-10.010</td>
<td>3.534</td>
<td>3.844</td>
</tr>
<tr>
<td>CHO-ED1</td>
<td>4.354</td>
<td>10.142</td>
<td>5.572</td>
<td>0</td>
<td>-10.100</td>
<td>-7.172</td>
<td>2.885</td>
</tr>
<tr>
<td>CHO-ED2</td>
<td>5.587</td>
<td>10.255</td>
<td>5.575</td>
<td>0</td>
<td>-10.063</td>
<td>-8.290</td>
<td>3.152</td>
</tr>
<tr>
<td>CH12-ED0</td>
<td>0.246</td>
<td>5.513</td>
<td>7.013</td>
<td>0</td>
<td>-9.410</td>
<td>21.118</td>
<td>25.030</td>
</tr>
<tr>
<td>CH12-ED1</td>
<td>4.553</td>
<td>10.448</td>
<td>7.089</td>
<td>0</td>
<td>-10.029</td>
<td>6.701</td>
<td>19.411</td>
</tr>
<tr>
<td>CH3+ - ED0</td>
<td>0.857</td>
<td>5.888</td>
<td>8.582</td>
<td>0</td>
<td>-8.915</td>
<td>32.513</td>
<td>40.122</td>
</tr>
<tr>
<td>CH3+ - ED1</td>
<td>4.795</td>
<td>10.662</td>
<td>8.713</td>
<td>0</td>
<td>-9.848</td>
<td>19.340</td>
<td>34.859</td>
</tr>
<tr>
<td>CH3+ - ED2</td>
<td>5.936</td>
<td>10.676</td>
<td>8.752</td>
<td>0</td>
<td>-9.440</td>
<td>19.135</td>
<td>36.256</td>
</tr>
</tbody>
</table>

Table 6: subsistence parameters apartments (×).

(×) Because the β₁ were calculated using a highly nonlinear expression of the regression coefficients no attempt was made to approximate their standard error. Previous research suggests, however, that the sampling variability of the subsistence parameters is usually large.
in the literature (*). They are, among others, the fact that the model does not take into account saving and dissaving, so that the $\beta_i$ are at best to be interpreted as subsistence consumption out of current income. Several authors have even argued that, given the framework used in this paper, the $\beta_i$ should merely be interpreted as parameters that allow a more general indifference map than the Cobb-Douglas. Observe, however, that $\Sigma p_i \beta_i$ strongly increases with family size while the effect of education is less pronounced.

We are now in a position to derive the price elasticities of the demand for housing attributes ($\varepsilon_{p_i}$) implied by the estimated system. Using (3) and some algebra we find

$$\varepsilon_{p_i} = - \left( \frac{\gamma_i (y - \Sigma_{j=1}^{n} p_j \beta_j) + \gamma_i p_i \beta_i}{\gamma_i (y - \Sigma_{j=1}^{n} p_j \beta_j) + p_i \beta_i} \right)$$ \hspace{1cm} (10)

Since all $\gamma_i > 0$ the price elasticity for a particular attribute will only be greater than 1 in absolute value if its subsistence parameter $\beta_i$ is negative. Results are summarized in Table 7. Note that the price elasticity for 'apartment type' equals -1 for all households due to the a priori assumption that its subsistence parameter is zero. All other attributes are price inelastic on average. None of the elasticities is very sensitive to family size, but they vary strongly with education. These findings are hardly surprising given the estimated income elasticities, since one should not forget that for the Stone-Geary utility function price and income elasticities are 'roughly proportional' (Deaton and Muellbauer (1980, p. 66)).

Although making an a priori assumption with respect to 'subsistence' expenditures on 'apartment type' seemed to be the most natural alternative, it was obviously a largely arbitrary decision. It is necessary to evaluate the subsistence parameters $\beta_i$ and the price elasticities under alternative assumptions to get an idea of the sensitivity of the

(*): For a summary of the main arguments see De Borger (1984 b)).
results. A first indication may be derived from the following algebraic results, calculated on the basis of equations (8), (8a) and (10):

\[
\frac{\delta (\sum_{i=1}^{n} p_i \beta_i)}{\delta \beta_r} = \frac{1}{\gamma_r} \gamma_r
\]

\[
\frac{\delta \beta_i}{\delta \beta_r} = \frac{\gamma_i}{\gamma_r}
\]

\[
\frac{\delta \varepsilon p_i}{\delta \beta_r} = \frac{(\frac{\gamma_i}{\gamma_r} (1 - \gamma_i))}{\gamma_i (y - \sum_{i=1}^{n} p_i \beta_i) + p_i \beta_i}
\]

We would expect - given the numerical values estimated for the marginal propensities to spend on the housing attributes - that the estimated total subsistence expenditures would be extremely sensitive to changes in $\beta_r$. The effect on all subsistence parameters is positive. Moreover, the use of an upward biased value for $\beta_r$ results in an upward biased estimate of the price elasticity.

These algebraic findings suggest that using a priori information on alternative subsistence expenditures will have a substantial impact on the results. To illustrate the sensitivity of our estimates we think the most honest way of proceeding is to present some summarizing results obtained under alternative a priori assumptions. Therefore, we consecutively calculated all subsistence parameters and price elasticities using a priori information on different housing attributes.

Unfortunately, the only procedure to come up with a priori values for subsistence levels that are not completely arbitrary is to use the sample minimum for different household types. Considering the regression results of table 3 a) and previous estimates (see table 6) it was assumed that subsistence expenditures for space only depend on
<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO - EDO</td>
<td>-1.103</td>
<td>-0.416</td>
<td>-0.08</td>
<td>-1</td>
</tr>
<tr>
<td>CHO - ED1</td>
<td>-0.301</td>
<td>-0.021</td>
<td>-0.236</td>
<td>-1</td>
</tr>
<tr>
<td>CHO - ED2</td>
<td>-0.215</td>
<td>-0.135</td>
<td>-0.281</td>
<td>-1</td>
</tr>
<tr>
<td>CH12 - EDO</td>
<td>-0.945</td>
<td>-0.330</td>
<td>-0.06</td>
<td>-1</td>
</tr>
<tr>
<td>CH12 - ED1</td>
<td>-0.342</td>
<td>-0.020</td>
<td>-0.204</td>
<td>-1</td>
</tr>
<tr>
<td>CH12 - ED2</td>
<td>-0.197</td>
<td>-0.117</td>
<td>-0.220</td>
<td>-1</td>
</tr>
<tr>
<td>CH3+ - EDO</td>
<td>-0.808</td>
<td>-0.301</td>
<td>-0.060</td>
<td>-1</td>
</tr>
<tr>
<td>CH3+ - ED1</td>
<td>-0.365</td>
<td>-0.019</td>
<td>-0.172</td>
<td>-1</td>
</tr>
<tr>
<td>CH3+ - ED2</td>
<td>-0.288</td>
<td>-0.112</td>
<td>-0.198</td>
<td>-1</td>
</tr>
<tr>
<td>All families</td>
<td>-0.687</td>
<td>-0.234</td>
<td>-0.126</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 7: Mean price elasticities for housing attribute demand (apartments)
family size, whereas those for quality were expected to vary mainly with education. The observed pattern of sample minima for the 9 household types defined in table 6 was largely consistent with this assumption. The sample minima used as a priori information for each of the attributes were as follows:

<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDO</td>
<td>0.704</td>
<td>4.415</td>
<td>CH0</td>
</tr>
<tr>
<td>ED1</td>
<td>2.112</td>
<td>7.713</td>
<td>CH12</td>
</tr>
<tr>
<td>ED2</td>
<td>4.742</td>
<td>9.227</td>
<td>CH3+</td>
</tr>
</tbody>
</table>

Using the sample minimum to approximate the unknown \( \beta_i \) parameter has its obvious problems, however. Although the sample minimum would be a consistent estimator of subsistence expenditures in the population if there were no saving and dissaving, this may not be the case when these assumptions are inappropriate (\( \star \)). More importantly, the sample minimum for different household types does not necessarily give a clear picture of how the \( \beta_i \) vary with household characteristics because the observed variation may be partly due to differences in mean income. However, the regression results and our previous estimates reported in table 6 are consistent with the overall pattern of the sample minima.

Using the observed sample minima as a priori information for one attribute at a time we obtained the results summarized in tables 8 and 9. Since the variation with household characteristics is quite similar to that presented in table 6 we only give mean values for the \( \beta_i \) and the mean estimated price elasticities. Moreover, in order to facilitate the comparison with the results obtained when using a priori information on \( \beta_i \) for 'apartment type' the latter are reproduced in the final row of the tables. The figures clearly illustrate the sensitivity of the \( \beta_i \),

(\( \star \)) It might be argued that, even if the \( \beta_i \) were to be interpreted as subsistence consumption, the sample minimum is an upward biased estimator for the population minimum. Note, however, that the latter is probably a worse estimator for the subsistence parameter in a particular household stratum, since variations in taste within each group imply that the true individual parameter will fluctuate randomly around the unique \( \beta_i \) for each stratum.
the price elasticities and especially

\[ \sum_{i=1}^{n} p_i \beta_i \]

to the choice of different a priori values. The estimate of total 'subsistence' expenditures is even negative in 3 out of 4 cases. This is also true for the \( \beta_i \) corresponding to 'sanitary quality' and 'apartment type' in some cases.

Although the numerical values for \( \beta_i \) and \( p_i \) vary substantially with the particular assumptions made, the qualitative results concerning the effect of household characteristics are not at all affected (\( \star \)). It is clear, however, that we should investigate the sensitivity of the benefits calculated on the basis of the estimated Stone-Geary parameters, given the observed variation in table 8. This will be accomplished in the next section.

We finally turn rather briefly to the results for the subsample on households living in single-family units. Since for none of the attributes a 'natural' value for \( \beta_i \) can be imagined, we again used the sample minima for different household types as a priori information on one subsistence parameter at a time. Unfortunately, the pattern of the sample minima for 'space' was unacceptable for this purpose, as it strongly decreased with family size. Given this erratic pattern we decided to concentrate on the results obtained when a priori information on the quality attributes was used (\( \star \star \)). The observed sample minima for different household types were as follows:

<table>
<thead>
<tr>
<th></th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>E00</td>
<td>6.886</td>
<td>5.843</td>
</tr>
<tr>
<td>ED1</td>
<td>12.659</td>
<td>8.846</td>
</tr>
<tr>
<td>ED2</td>
<td>12.659</td>
<td>8.846</td>
</tr>
</tbody>
</table>

(\( \star \)) Tables analogous to table 6 and 7 for each of the alternatives considered are available.

(\( \star \star \)) Observed sample minima are obviously extremely sensitive to the presence of outliers in the sample. Therefore, we did try some educated guesses for the \( \beta_i \) corresponding to space, unfortunately with very poor results.
### Table 8: mean subsistence parameters under different a priori assumptions (apartments)

<table>
<thead>
<tr>
<th>A PRIORI ASSUMPTION ON SUBSISTENCE EXPENDITURES</th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
<th>ALL OTHER CHARACTERISTICS</th>
<th>ALL OTHER GOODS</th>
<th>TOTAL SUBSISTENCE EXPENDITURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRUCTURAL QUALITY</td>
<td>- 0.906</td>
<td>5.980</td>
<td>5.58</td>
<td>- 6.114</td>
<td>- 17.59</td>
<td>- 149.74</td>
<td>- 162.15</td>
</tr>
<tr>
<td>SPACE</td>
<td>- 0.691</td>
<td>5.694</td>
<td>6.428</td>
<td>- 2.909</td>
<td>- 14.883</td>
<td>- 75.35</td>
<td>- 81.07</td>
</tr>
</tbody>
</table>

### Table 9: mean price elasticities under different a priori assumptions (apartments)

<table>
<thead>
<tr>
<th>A PRIORI ASSUMPTION ON SUBSISTENCE EXPENDITURES</th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>APARTMENT TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANITARY QUALITY</td>
<td>- 0.727</td>
<td>- 0.261</td>
<td>- 0.204</td>
<td>- 1.276</td>
</tr>
<tr>
<td>STRUCTURAL QUALITY</td>
<td>- 1.172</td>
<td>- 0.390</td>
<td>- 0.312</td>
<td>- 2.022</td>
</tr>
<tr>
<td>SPACE</td>
<td>- 1.308</td>
<td>- 0.452</td>
<td>- 0.225</td>
<td>- 1.749</td>
</tr>
<tr>
<td>APARTMENT TYPE</td>
<td>- 0.687</td>
<td>- 0.234</td>
<td>- 0.126</td>
<td>- 1</td>
</tr>
</tbody>
</table>
Using these values as extraneous information, in both cases we obtained results for the estimated $\beta_i$ and the implied price elasticities that varied strongly with education and family size, sometimes in a very unexpected and inconsistent way (\*). Although it is possible that these findings are partly due to the use of biased a priori information, we believe they are mainly attributable to some peculiar characteristics of our sample. In particular, from a technical viewpoint the wild variation in the $\beta_i$'s and especially in

$$\sum_{i=1}^{n} p_i \beta_i$$

is a direct consequence of the large difference in the regression coefficients of ED1 and ED2 in table 3 b). We were unable to offer an intuitive explanation for that finding.

Below, we only present the mean estimated subsistence parameters and price elasticities for the whole sample households in single-family housing, because the size of the subsamples defined in table 6 were extraordinary small in most cases (6 out of 9 household types contained less than 10 observations). Moreover, some $\beta_i$ varied mainly with education, whereas others fluctuated with family size (\* \*). The results are in tables 10 and 11. The two alternative a priori assumptions yield on average fairly similar results. Concerning the estimate for

$$\sum_{i=1}^{n} p_i \beta_i$$

the same remarks might be made as in the apartments case. Also note that the price elasticities for the quality attributes are on average

\*(\*) Sometimes the mean value for $\beta_1$ for households of type ED0 was higher than for families of type ED1, but lower than the mean corresponding to households in stratum ED2. An extreme example was the result for 'total subsistence expenditures'. The mean values for households of type ED0, ED1 and ED2 were 4800, -19000 and 13000 Belgian francs, respectively.

\*(\*) Of course, fully detailed tables with results are available.
### Table 10: Mean 'subsistence' parameters $\beta_i$ (single-family housing)

<table>
<thead>
<tr>
<th>A PRIORI ASSUMPTION</th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
<th>ALL OTHER CHARACTERISTICS</th>
<th>ALL OTHER GOODS</th>
<th>TOTAL SUBSISTENCE EXPENDITURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_i$ SANITARY QUALITY</td>
<td>9.102</td>
<td>7.428</td>
<td>14.474</td>
<td>-25.005</td>
<td>-0.418</td>
<td>5.580</td>
</tr>
<tr>
<td>$\beta_i$ STRUCTURAL QUALITY</td>
<td>8.398</td>
<td>6.996</td>
<td>14.491</td>
<td>-26.125</td>
<td>-4.178</td>
<td>-0.418</td>
</tr>
</tbody>
</table>

### Table 11: Mean price elasticities (single-family housing)

<table>
<thead>
<tr>
<th>A PRIORI ASSUMPTION</th>
<th>SANITARY QUALITY</th>
<th>STRUCTURAL QUALITY</th>
<th>SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_i$ SANITARY QUALITY</td>
<td>-0.337</td>
<td>-0.346</td>
<td>-0.104</td>
</tr>
<tr>
<td>$\beta_i$ STRUCTURAL QUALITY</td>
<td>-0.399</td>
<td>-0.392</td>
<td>-0.104</td>
</tr>
</tbody>
</table>
much higher than for space.

The extremely wild and inconsistent variation of the results with household characteristics implies that we do not have very much confidence in the estimated $\beta_i$ parameters for single-family units. Although the $\beta_i$ may also have huge standard errors so that the variation in point estimates may be statistically unimportant, we did decide to concentrate on the subsample of households living in apartments for the remainder of this paper. This seems justified, given our previous results and the fact that almost all public housing beneficiaries (59 out of 65) in the sample were living in apartments.

5. Benefits and Consumption effects

In this section we report the calculated benefits and consumption effects of public housing for the small sample of public tenants contained in our data. As indicated before, since over 90% of households in the program lived in apartments and the estimated indifference maps for families in single-family housing were extremely sensitive to the a priori assumption with respect to one of the subsistence parameters, we decided to base all calculations on the subsample for apartments only.

An important potential problem should be pointed out. The benefits and consumption effects for people in public housing will be calculated using indifference maps estimated on the basis of a sample households living in uncontrolled housing. This implies the possibility of selection bias to the extent that people in public housing have systematically different preferences, defined over housing attributes and other goods, than households with the same observed characteristics in uncontrolled housing. Although it is not straightforward to suggest a convincing argument why this would be the case, the possi-
bility of selection bias cannot be denied (\(\star\)). Although we considered Heckman's (1979) method to account and correct for selection bias, data limitations precluded its application (\(\star \star \)). As far as we know there exists only one recent study that calculated benefits of a public housing program and corrected for selection bias. Olsen and Bierman (1982) found evidence of the presence of bias, but correction of the bias resulted in an estimate of mean benefit which differed by less than 5\% of the uncorrected value. This suggests that selection bias does not necessarily have a significant effect.

(\(\star\)) It has been suggested that households in public housing would have a stronger taste for housing because the programs distort consumption towards more housing. More specifically, it might be argued that program participants have a stronger taste for quality and less for space because public housing programs appear to offer more quality and less space as compared to the average consumption of similar households in uncontrolled housing, see below. Several reasons why this type of reasoning is not a convincing argument for the presence of selection bias are given in De Borger (1984 b) or Olsen and Barton (1983).

(\(\star \star \)) The procedure requires the estimation of a probit model to explain the probability of participation in the program on the basis of the sample of eligible households, and use this information to construct an additional explanatory variable in each demand equation. The significance of the latter is then interpreted as an indication of the presence of selection bias. Note that the validity of this procedure is based on some very stringent assumptions. First, it is assumed that the equations are correctly specified. If not, the significance of the correction variable may be due to the fact that it captures some of the nonlinearities of the true underlying model. Consequently significance is not a sufficient condition for selection bias under these circumstances. Moreover, the disturbances are assumed to be normal. Heckman's method has been shown to be extremely sensitive to even 'modest departures from normality' (Goldberger (1983, p. 79)). Finally note that even if the normality assumption is satisfied the significance of the correction variable is not a necessary condition for the presence of bias. Indeed, in practice some multicollinearity is likely to exist because the variable is constructed as a nonlinear function of the explanatory variables already included in the equation. This may lead to an insignificant coefficient even in the presence of selection bias.
on mean benefit (*)).

In the previous section the parameters of the Stone-Geary utility function were consecutively calculated using a priori information on one subsistence parameter. Although we believe that the results obtained when using the subsistence value for 'apartment type' as extraneous information are most reliable, we did calculate benefits for each of the four alternatives considered in order to get an idea of the sensitivity of the results with respect to the assumptions made. Note, however, that benefit formula 9 a) implies that for all attributes \((h_i^S - \beta_i)\) should be nonnegative, otherwise benefits are undefined, as is the utility level reached under the program. No matter which \(\beta_i\) was used as extraneous information this condition was violated for several households. In most cases, space was the attribute causing the problem. Deleting households for which 

\[(h_i^S - \beta_i) < 0\]

from the sample is undesirable for several reasons. First it would reduce an already very small sample of households in public housing. Moreover, households for which consumption of an attribute is less than estimated subsistence are likely to have true benefits below average. Deleting these families from the sample might in fact bias our estimate of mean benefit upward. We therefore set 

\[(h_i^S - \beta_i) = 0\]

if the restriction \(h_i^S - \beta_i \geq 0\) was violated (**).

\[(*)\] An equally serious potential bias in the estimate for mean benefit is due to using the same indifference map for all households with the same set of observed characteristics. The nonlinearity of the benefit formula implies that aggregation bias is likely. Unfortunately, unless the true utility function were known for each individual household, this type of bias cannot be avoided.

\[(**)\] This procedure is not as unreasonable as it might seem. The estimated \(\beta_i\) are 'representative' for households with given characteristics. The true parameter for each household will obviously fluctuate around this value due to taste differences that are not captured by observed family traits. If the Stone-Geary is the correct specification of preferences then it is clear that this true parameter \(\beta_i\) cannot be greater than \(h_i^S\) for any household. Moreover, since in most cases the violation of the restriction was slight and previous studies have indicated that the sampling variability of estimated subsistence parameters is large the estimate \(h_i^S - \beta_i\), though negative, may not have been significantly different from zero.
Results are summarized in table 12. Benefits are on average very small for each of the four alternatives considered. Mean benefit only amounts to approximately 500 Belgian francs per month, less than 4% of average household income. This value is smaller than the estimate obtained for the same sample but using a composite commodity approach (see De Borger (1984 b)). Although we are convinced that this finding is no coincidence but has a theoretical explanation, this matter will not be analyzed in this paper, which is already sufficiently voluminous.

Mean benefit does not seem to be very sensitive to alternative a priori assumptions. Since benefits vary strongly over the sample this does not imply that individual benefit estimates are insensitive. Calculating the correlation coefficients between the benefit series obtained under different a priori assumptions, we found the results reported in table 13. Benefits are clearly not totally insensitive to the use of various extraneous parameter values, although all series correlate reasonably well.

An alternative way to investigate the sensitivity of the calculated equivalent variation $EV$ with respect to the extraneous subsistence parameter, say $\beta_r$, is to consider $\frac{\delta EV}{\delta \beta_r}$.

Differentiating expression 9 a), using the results

$$\frac{\delta}{\delta \beta_r} \sum_{i=1}^{n} p_i \beta_i^{2} = \frac{1}{\gamma_r}$$

and

$$\frac{\delta \beta_i}{\delta \beta_r} = \gamma_i,$$

and taking into account that $p_i = 1$ ($\forall i$), we derive after some algebra
### A Priori Assumption on Subsistence Consumption

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartment Type</td>
<td>4.428</td>
<td>5.24</td>
</tr>
<tr>
<td>Sanitary Quality</td>
<td>4.562</td>
<td>6.18</td>
</tr>
<tr>
<td>Structural Quality</td>
<td>5.112</td>
<td>5.27</td>
</tr>
<tr>
<td>Space</td>
<td>4.671</td>
<td>5.48</td>
</tr>
</tbody>
</table>

Table 12: Mean benefit and observed standard deviation ($10^2$ Belgian francs per month)

<table>
<thead>
<tr>
<th></th>
<th>Apartment Type</th>
<th>Sanitary Quality</th>
<th>Structural Quality</th>
<th>Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartment Type</td>
<td>1</td>
<td>0.91</td>
<td>0.82</td>
<td>0.87</td>
</tr>
<tr>
<td>Sanitary Quality</td>
<td>0.91</td>
<td>1</td>
<td>0.83</td>
<td>0.86</td>
</tr>
<tr>
<td>Structural Quality</td>
<td>0.82</td>
<td>0.83</td>
<td>1</td>
<td>0.82</td>
</tr>
<tr>
<td>Space</td>
<td>0.87</td>
<td>0.86</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Correlation coefficients of benefits calculated under alternative a priori assumptions.
\[
\frac{\delta EV}{\delta \beta_r} = - \frac{1}{\gamma_r} \left\{ \left( \prod_{i=1}^{n} \left( \frac{h_i^s - \beta_i}{\gamma_i} \right) \right) \left( \sum_{i=1}^{n} \left( \frac{\gamma_i^2}{h_i^s - \beta_i} \right) \right) \right\} + \frac{1}{\gamma_r}
\]

(11)

where as usual
\[
\gamma_n = 1 - \sum_{i=1}^{n-1} \gamma_i.
\]

It is easy to show that the effect of a change in $\beta_r$ on calculated benefits is zero if the bundle offered under the housing program is situated on the income-consumption path. In that case we have, see equation (3)
\[
\psi_{i} h_i^s - \beta_i = \gamma_i \left( y - \sum_{i=1}^{n} \beta_i \right)
\]

Consequently,
\[
\frac{\delta EV}{\delta \beta_r} = - \frac{1}{\gamma_r} \left\{ \left( y - \sum_{i=1}^{n} \beta_i \right) \left( \sum_{i=1}^{n} \gamma_i \right) \right\} + \frac{1}{\gamma_r} \left( y - \sum_{i=1}^{n} \beta_i \right)
\]

= 0.

 Evaluated over the complete sample of public housing tenants the expression \{\} in equation (11) was always greater than one, ranging from 1.003 to 1.075 with mean 1.023. This implies that
\[
\frac{\delta EV}{\delta \beta_r} < 0
\]

for all cases which is consistent with a priori expectations. The magnitude of the effect depends on $\gamma_r$. Using the subsistence parameter for 'apartment type' as extraneous information, e.g., we found
\[
\frac{\delta EV}{\delta \beta_r}
\]

to be - 0.35 on average, ranging from - 0.04 to - 2.19.
This suggests that benefits will be quite sensitive to biased a priori information for some households, depending upon their consumption bundle and indifference map parameters, but that on average the effect of a unit change in $\beta_r$ on benefits is far below unity. The relatively small variation in mean benefit under widely varying a priori assumptions is consistent with this conclusion and supports the view that our estimate of mean benefit is relatively stable.

The consumption effects of the program do not depend on the chosen $\beta_i$. Interesting results are summarized in table 13. We compare three different bundles of attributes and other goods: the bundle observed under the program, the quantities of housing attributes and other goods that the program participant would consume in the absence of the program and the commodity bundle that would emerge if we would replace the program with a system of unrestricted cash grants with the same market value. Obviously, the latter two consumption bundles have to be predicted using the estimated system of demand equations. In the case of a cash grant system with the same total market value as the housing program the consumption of commodity $i$, say $h_{i}^{cg}$, is predicted as

$$h_{i}^{cg} = z_i + \gamma_i (y + S)$$

where $S$ is the subsidy, i.e. the difference between the market rent of the public housing unit and the rent actually paid. The market rent was predicted on the basis of the hedonic equation previously estimated.

Means and standard deviations are presented in table 13. Although these numbers have no normative implications they do provide relevant information with respect to the change in consumption pattern caused by the introduction of the housing program. Moreover, they yield some insight regarding the differential effect of a cash grant system versus subsidized housing. It is well known that many economists, especially supporters of neoclassical economic theory, are strongly in favor of direct transfers in the form of unrestricted grants, because such a system would allow consumers to optimally allocate their increased in-
come among different goods. On the other hand, the classical argument in favor of public housing is that increased consumption of the subsidized good generates a variety of positive externalities. In order for this argument to have some possible validity to justify the existing system, it should obviously be the case that 'better' housing is consumed under the program as compared to the cash grant-system.

We predicted that households would consume more of both housing and other goods under the public housing program than in its absence. However, the increase in housing consumption is not at all equally distributed among different attributes. In particular, our results suggest that households would consume less quality (SANITARY QUALITY, STRUCTURAL QUALITY, APARTMENT TYPE) and more space without the program. Although the provision of more housing is one of the main goals of the program, we see no reasonable rational for providing relatively small units of higher than average quality. It is not obvious why 'decent' housing should have these characteristics.

The subsidy $S$ was calculated to be 1092 Belgian francs per month on average, which corresponds to approximately 7.5% of mean monthly household income. Note that the subsidy is twice as large as benefit which is consistent with substantial consumption effects. In particular, replacing the public program with a system of cash grants with the same market value would reinforce the tendency towards consumption of more space of somewhat lesser quality. Moreover, a substantial fraction of the subsidy would be spend on nonhousing goods. Note that households on average would consume slightly more other goods and less housing as compared to the public program. If sufficient empirical evidence could be obtained that suggests the existence of positive externalities associated with the participants' increased housing consumption under the program, this result might be used as an argument in favor of the continuation of the existing system. Whether the composition of the housing bundle under the program is preferable to that under a cash grant system, is largely a matter of taste.

We finally provide at least some evidence on the distributive effects of the program. The standard procedure is to regress the calculated
<table>
<thead>
<tr>
<th></th>
<th>Consumption under the program</th>
<th>Predicted consumption in the absence of the program</th>
<th>Predicted consumption when replacing the program with a cash grant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td><strong>σ</strong></td>
<td><strong>Mean</strong></td>
<td><strong>σ</strong></td>
</tr>
<tr>
<td><strong>SANITARY QUALITY</strong></td>
<td>6.512</td>
<td>4.893</td>
<td>5.253</td>
</tr>
<tr>
<td><strong>STRUCTURAL QUALITY</strong></td>
<td>9.676</td>
<td>8.363</td>
<td>8.570</td>
</tr>
<tr>
<td><strong>SPACE</strong></td>
<td>7.363</td>
<td>8.684</td>
<td>8.737</td>
</tr>
<tr>
<td><strong>APARTMENT TYPE</strong></td>
<td>6.245</td>
<td>3.815</td>
<td>4.166</td>
</tr>
<tr>
<td><strong>ALL OTHER ATTRIBUTES</strong></td>
<td>-1.881</td>
<td>-2.832</td>
<td>-2.239</td>
</tr>
<tr>
<td><strong>ALL OTHER GOODS</strong></td>
<td>127.132</td>
<td>121.209</td>
<td>130.565</td>
</tr>
<tr>
<td><strong>TOTAL HOUSING VALUE</strong></td>
<td>27.920</td>
<td>22.923</td>
<td>24.487</td>
</tr>
</tbody>
</table>

Table 13: Comparison of consumption of attributes and other goods under alternative regimes: mean and standard deviation (monetary values are in $10^2$ Belgian francs per month)
benefits to a set of household characteristics that are considered to be highly relevant when judging the distributional impact of a public program (see e.g. Murray (1975), Olsen (1972)). It is assumed that the sign, the magnitude and the standard errors of the estimated coefficients yield information with respect to the distribution of benefits over the sample. The coefficient of determination of the regression is supposed to indicate the extent to which households with the same observed characteristics receive equal benefits. Note that this procedure is not very satisfactory, because the desired variation of benefits with household characteristics is again largely a matter of taste. Although most people would agree that benefits should be negatively related to income and, given official program objectives, a positive 'relationship' with family size is to be expected, there is probably no consensus on these 'desired' program characteristics (\*). Moreover, it should be stressed that the method only provides information on the distribution of the monetary value of the program over the sample. It does not necessarily give a clear picture of how households' valuation of the program (in utility terms) varies with their characteristics, due to the impossibility of interpersonal utility comparisons.

Calculated benefits only varied significantly with family size and, to some extent, with income and age. All other household traits, such as education and professional status, turned out to be irrelevant. This is hardly surprising since there seems to be no obvious reason why benefits would be affected by these variables. Using the benefits calculated on the basis of a priori information on 'apartment type' as the dependent variable the following results emerged (t-statistics in parentheses):

\[
\text{Benefit} = -8.85 - 0.0245 \, \text{(INCOME)} + 0.157 \, \text{(AGE)} \\
\quad (-1.37) \quad (-1.167) \quad (0.946)
\]

\[
+ 14.411 \, \text{(CH12)} + 13.479 \, \text{(CH3+)} \quad R^2 = 0.33 \\
\quad (4.205) \quad (3.652)
\]

Very similar results were obtained for all other benefit series. Moreover, introducing nonlinear specifications did not improve the

(\*) For more discussion of this point see De Borger (1984 b)).
results and did not change the basic implications to be derived from these equations. Benefits are clearly substantially higher for households with children. Note, however, that no difference is observed for households with different numbers of children. Although the coefficients are not significant at the usual significance levels there is some slight evidence that benefits increase with age and, more importantly, decrease with income. The absence of a strong negative relation between benefits and income was also observed in earlier work, using a quite different approach, and it was suggested that the program rules applied in practice may be largely responsible for this finding. (De Borger 1984 b)).

6. Summary and conclusion

In this paper we estimated a system of demand equations for housing attributes and all other goods, derived from the Stone-Geary utility function. The attributes were constructed on the basis of a larger set of observed housing characteristics using hedonic pricing techniques. The parameters of the utility function were allowed to vary with household characteristics so as to account for some differences in taste.

A modification of Zellner's procedure for seemingly unrelated regressions was used to estimate the demand system. The sample was derived from a household survey conducted in the early seventies in Liege, Belgium. Although a priori information on one 'subsistence' parameter was needed, we were able to identify all remaining structural parameters of the utility function on the basis of the estimated demand functions. The results were subsequently used to analyze the benefits and consumption effects of public housing programs.

The estimation results suggested the importance of household characteristics in explaining the demand for housing attributes. Proxy variables for education, income, professional status and the wife's
professional activity significantly affected the demand for sanitary and structural quality. Family size and to some extent education were found to be important determinants of the demand for space. In general, we estimated the marginal propensity to spend on housing quality to decrease with education and increase with the dummy variable for professional status. The marginal propensity to spend on space was found to be higher for households at a higher educational level. The mean marginal propensity on all housing goods was estimated to be 0.13 and 0.149 for households living in apartments and single-family housing, respectively.

Not surprisingly, income and price elasticities showed a similar pattern of variation with household characteristics as the marginal propensities to spend. Consistent with expectations quality related attributes were in general more elastic, or less inelastic, than the demand for space, which is clearly considered a necessity by all families. Apart from the income elasticities for 2 quality attributes in the apartment sample all elasticities are less than one in absolute value.

Calculated mean benefit amounted to approximately 500 Belgian francs per month, which is only 4% of household income. This result was found to be relatively stable under alternative extraneous assumptions. We estimated the subsidy, defined as the difference between the market value of the public housing unit and the rent paid under the program, to be 1100 Belgian francs per month on average.

The consumption effects of the program were not trivial, however. On average we predicted that households consumed 22% more housing and 5% more other goods than they would have consumed in the absence of the program. The increase in housing consumption was not evenly distributed over all attributes. Under the program households on average consumed significantly less space (15%) and more quality than they were predicted to consume without the program. Comparing the existing system with an unrestricted cash grant with the same market value we found that households would consume slightly more other goods
and less housing with the cash grant. However, they would spend significantly more on space and less on quality.

The benefits were found to be higher for households with children than for those without. They did not monotonically increase with family size, however. Although there was some slight evidence that benefits declined with income and increased with age, more empirical work is needed to justify this conclusion.
Appendix A: Alternative approaches to the construction of housing attributes

In this paper the housing attributes were constructed using a regression procedure suggested by King (1976). In this appendix we report the results of two other methods proposed in the literature and try to justify why the regression approach was considered to be the most reasonable alternative, given the available data.

The most widely used procedure is factor analysis, which takes account of the correlations between all included variables. The correlation matrix of the fifteen housing characteristics available for analysis is shown in table A1 (*). Not surprisingly the variables STORY, ELEV and SECSYS are closely related. The same holds for the set of quality indicators BATHR, WATER, CH, WC, CONSTRDAT, LIGHT and HEIGHT, and for the space descriptors SPACE, ROOMS and BEDR. Most other intercorrelations are unimportant.

Five factors accounted for 70% of the total variance (**). In table A2 we present the final factor loadings. The results may be summarized as follows. The first factor mainly captures the variation in STORY, ELEV and SECSYS. Given the additional high loadings of the age of the housing unit and the quality of the heating system it is probably appropriate to interpret it as a quality indicator, although its composition is not entirely clear. Factor 2 mainly consists of the space variables but again CH loads quite high as well. The third and fourth factor are both primarily composed of different quality indices. Again, it is hard to provide a summarizing attribute name to describe these factors. Factor five finally is almost uniquely determined by OSPACE, a variable which has only a very weak relation with observed rent.

(*) The matrix was calculated using the total sample, including both apartments and single-family housing. Correlation matrices for both housing types separately showed the same overall pattern.

(**) Factors were derived using all observations and an orthogonal (varimax) rotation technique. Results based on the subsamples for apartments and single-family housing and results obtained after oblique rotation were qualitatively very similar. Note that only factors with eigenvalues of at least 0.8 were taken into account.
<table>
<thead>
<tr>
<th>BATHR</th>
<th>WATER</th>
<th>STORY</th>
<th>ELEV</th>
<th>SECSYS</th>
<th>CONSTRDATE</th>
<th>CH</th>
<th>WC</th>
<th>LIGHT</th>
<th>ROOMS</th>
<th>BEDR</th>
<th>SPACE</th>
<th>OSPACE</th>
<th>HEIGHT</th>
<th>YARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.499</td>
<td>0.129</td>
<td>1</td>
<td></td>
<td>0.551</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.139</td>
<td>0.307</td>
<td>0.551</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STORY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0290</td>
<td>0.630</td>
<td>0.674</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELEV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.341</td>
<td>0.284</td>
<td>0.630</td>
<td>0.674</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SECSYS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.415</td>
<td>0.277</td>
<td>0.262</td>
<td>0.381</td>
<td>0.479</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSTRDATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.502</td>
<td>0.401</td>
<td>0.056</td>
<td>0.243</td>
<td>0.296</td>
<td>0.426</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.437</td>
<td>0.465</td>
<td>0.049</td>
<td>0.174</td>
<td>0.235</td>
<td>0.361</td>
<td>0.236</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIGHT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.397</td>
<td>0.276</td>
<td>0.172</td>
<td>0.177</td>
<td>0.191</td>
<td>0.410</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROOMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.156</td>
<td>0.136</td>
<td>-0.370</td>
<td>-0.103</td>
<td>-0.141</td>
<td>-0.180</td>
<td>0.289</td>
<td>0.180</td>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEDR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.199</td>
<td>0.134</td>
<td>-0.322</td>
<td>-0.042</td>
<td>-0.071</td>
<td>-0.059</td>
<td>0.313</td>
<td>0.216</td>
<td>0.025</td>
<td>0.643</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPACE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.265</td>
<td>0.238</td>
<td>-0.253</td>
<td>-0.049</td>
<td>-0.077</td>
<td>-0.096</td>
<td>0.331</td>
<td>0.247</td>
<td>0.172</td>
<td>0.559</td>
<td>0.588</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSPACE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.041</td>
<td>0.034</td>
<td>-0.176</td>
<td>-0.133</td>
<td>-0.136</td>
<td>-0.039</td>
<td>0.066</td>
<td>0.083</td>
<td>-0.043</td>
<td>0.079</td>
<td>0.153</td>
<td>0.142</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEIGHT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.442</td>
<td>-0.388</td>
<td>-0.133</td>
<td>-0.185</td>
<td>-0.153</td>
<td>-0.632</td>
<td>-0.338</td>
<td>-0.263</td>
<td>-0.284</td>
<td>0.028</td>
<td>0.034</td>
<td>0.034</td>
<td>0.179</td>
<td></td>
</tr>
<tr>
<td>YARD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.032</td>
<td>-0.068</td>
<td>-0.398</td>
<td>-0.305</td>
<td>-0.327</td>
<td>-0.199</td>
<td>-0.041</td>
<td>-0.005</td>
<td>-0.057</td>
<td>0.183</td>
<td>0.198</td>
<td>0.239</td>
<td>0.183</td>
<td>-0.132</td>
</tr>
</tbody>
</table>

Table A1: Correlation matrix housing characteristics
<table>
<thead>
<tr>
<th></th>
<th>FACTOR 1</th>
<th>FACTOR 2</th>
<th>FACTOR 3</th>
<th>FACTOR 4</th>
<th>FACTOR 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTRDAT</td>
<td>0.317</td>
<td>0</td>
<td>0</td>
<td>0.743</td>
<td>0</td>
</tr>
<tr>
<td>SECSYS</td>
<td>0.794</td>
<td>0</td>
<td>0</td>
<td>0.314</td>
<td>0</td>
</tr>
<tr>
<td>STORY</td>
<td>0.788</td>
<td>-0.309</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ELEV</td>
<td>0.784</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>YARD</td>
<td>-0.351</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ROOMS</td>
<td>0</td>
<td>0.856</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BEDR</td>
<td>0</td>
<td>0.854</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SPACE</td>
<td>0</td>
<td>0.750</td>
<td>0.372</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LIGHT</td>
<td>0</td>
<td>0</td>
<td>0.813</td>
<td>0</td>
<td>-0.251</td>
</tr>
<tr>
<td>BATHR</td>
<td>0</td>
<td>0</td>
<td>0.649</td>
<td>0.543</td>
<td>0</td>
</tr>
<tr>
<td>WATER</td>
<td>0</td>
<td>0</td>
<td>0.639</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CH</td>
<td>0.271</td>
<td>0.445</td>
<td>0.505</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.807</td>
<td>0</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.728</td>
<td>0</td>
</tr>
<tr>
<td>OSPACE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.939</td>
</tr>
</tbody>
</table>

Table A2: Sorted rotated factor loadings (*)

(*) To facilitate interpretation, loadings less than 0.25 have been replaced by zero. Variance proportions were 2.829, 2.499, 1.951, 1.80, and 1.328, respectively.
It was indicated in the text that one of the main advantages of King’s procedure was precisely that the constructed attributes explained as much of the variation in rent as the set of original housing characteristics. Since the factors are linear combinations of the latter we can compare the residual sum of squares (RSS) of a hedonic equation estimated on the five factors with the RSS of the hedonic reported in table 1 b) in the text. A standard F-test is appropriate to test for the significance of the increase in RSS. The estimated equations for apartments and single-family housing are as follows (t-statistics in parenthesis):

**Apartments**

\[
\text{RENT} = 0.82 + 3.243 \text{ FACTOR 1} + 1.843 \text{ FACTOR 2} + 2.663 \text{ FACTOR 3} + 4.221 \text{ FACTOR 4} + 0.213 \text{ FACTOR 5} \\
(3.45) (2.88) (3.14) (2.98) (3.55) (0.63)
\]

\[
R^2 = 0.602 \quad \text{RSS} = 10428.33
\]

**Single-family housing**

\[
\text{RENT} = 0.341 + 1.281 \text{ FACTOR 1} + 3.682 \text{ FACTOR 2} + 3.441 \text{ FACTOR 3} + 4.811 \text{ FACTOR 4} + 1.382 \text{ FACTOR 5} \\
(3.24) (1.68) (3.28) (5.22) (2.23) (1.17)
\]

\[
R^2 = 0.436 \quad \text{RSS} = 12958.18
\]

Note that the fifth factor is insignificant in both equations. To test the significance of the increase in RSS as compared to the hedonic on the full set of housing characteristics the appropriate statistics are

\[
F_1 = \frac{(10428.33 - 8663.72)/10}{8663.72/147} = 2.99
\]

\[
F_2 = \frac{(12958.18 - 10939.)/7}{10939/87} = 2.29
\]

for apartments and single-family housing, respectively. Both indi-
cate a significant increase in the residual sum of squares at the 5% level. Given this result and the interpretation problems associated with the factors it seemed reasonable not to consider them for further analysis.

A second procedure suggested in the literature is to assign the characteristics a priori to a particular attribute and to extract one or more principal components from each group of variables. Using the same grouping as in the regression approach we obtained the results summarized in table A3. A single component captures between 47% and 76% of the variance in the included variables. Also note the almost equal weights of the characteristics in the components, except for space.

Again we estimated hedonic equations and tested the significance of the residual sum of squares. The regression results were:

apartments

\[
\text{RENT} = 1.24 + 2.848 \text{ PC1} + 2.485 \text{ PC2} \\
(3.31) \quad (3.70) \quad (2.91) \\
+ 5.714 \text{ PC3} + 3.469 \text{ PC4} \\
(6.89) \quad (3.85)
\]

\[
R^2 = 0.642 \quad \text{RSS} = 9376.74
\]

single-family housing

\[
\text{RENT} = 0.186 + 5.663 \text{ PC1} + 3.384 \text{ PC2} \\
(3.26) \quad (3.38) \quad (2.33) \\
+ 4.168 \text{ PC4} \\
(2.73)
\]

\[
R^2 = 0.493 \quad \text{RSS} = 11648.04
\]

Not surprisingly, the increase in RSS in this case is insignificant. The test statistics are

\[
F_1 = \frac{(9376.74 - 8663.72)/11}{8663.72/147} = 1.10
\]

\[
F_2 = \frac{(11648.04 - 10939)/9}{10939/87} = 0.63
\]
<table>
<thead>
<tr>
<th>Component Description</th>
<th>Component Definition</th>
<th>% Variance of the original variables explained by the principal component</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC 1 Sanitary Quality</td>
<td>0.420 WATER + 0.472 BATHR + 0.393 WC</td>
<td>0.603</td>
</tr>
<tr>
<td>PC 2 Structural Quality</td>
<td>0.469 CONSTRDAT + 0.495 CH + 0.478 LIGHT - 0.382 HEIGHT</td>
<td>0.589</td>
</tr>
<tr>
<td>PC 3 Apartment Type</td>
<td>0.374 STORY + 0.383 ELEV + 0.399 SECSYS</td>
<td>0.761</td>
</tr>
<tr>
<td>PC 4 Space</td>
<td>0.367 SPACE + 0.419 ROOMS + 0.410 BEDR + 0.103 YARD + 0.025 OSPACE</td>
<td>0.468</td>
</tr>
</tbody>
</table>

Table A3: principal component results on a priori grouped variables (*).

(*) The score coefficients used to define the principal components are given for the standardized variables, mean zero and standard deviation one.
which are both statistically insignificant at the 5% level.

This second procedure is not only conceptually very similar to the regression approach, it also explains rent almost equally well. Although some experiments were done using the attributes defined in table A3, we believe the most natural procedure — which many econometricians would suggest, given the limited number of observed housing characteristics — to construct the attributes was the regression method proposed in the text. Admittedly, the choice is somewhat arbitrary.
References:


15. CAESENS, T.B., Hedonic Price Theory and Consumer Demand in Urban Housing Markets, University of Antwerp, UFSIA, April 1983.


40. LEAMER, E., Let's take the Con out of Econometrics, American Economic Review, 1983.


