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THE DEMAND FOR AUTOMOBILES IN CANADA

Gordon H. Davies

RESEARCH PROGRAM: IMPACT OF THE PUBLIC SECTOR ON LOCAL ECONOMIES

Department of Economics
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London Ontario Canada
Discussion Paper 014

THE DEMAND FOR AUTOMOBILES IN CANADA

Gordon W. Davies

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1. **Introduction**

The objectives of this study are to assess the economic factors which affect the stock demand for automobiles in Canada and to illustrate the sensitivity of the stock demand to the variables which enter into its determination. The determination of the stock of automobiles is thought to be important because the provision of transportation infrastructure for automobile travel and of mass transit facilities must depend in part on the number of automobiles held by the public. At a time when the relative prices of various forms of energy are changing rather dramatically, it would appear to be useful to be able to assess the importance of these changes on the demand for automobiles. The existing literature which bears on these questions is relatively sparse.\(^1\) Our results suggest that the stock demand for automobiles is much more sensitive to changes in the relative price of gasoline than to other prices and incomes. Section 2 develops the specification of the equation to be estimated; section 3 deals with the problems of estimation and shows the results; section 4 concludes the paper with a discussion of the relevant elasticities.

2. **Specification**

We postulate that a consumer has a finite time period \(t = 0, \ldots, \tau\) over which the potential benefits and costs of automobile ownership are calculated. Non-ownership is assumed to involve only one alternate mode, mass transit, for which a fee of PT is charged per trip. If the consumer purchases an automobile, we assume that he takes \(N^a\) trips per year as compared with \(N^b\)
trips per year on mass transit if he does not. One part of the benefit of purchase will therefore be the savings in transit fare costs.\(^2\)

The gross benefit of automobile purchase will also be related to the time savings from trips by automobile as opposed to trips by mass transit and the comfort, flexibility, and convenience of automobile travel. This benefit is expressed as an increasing function of income because studies on the value of travel time have shown that, as income increases, commuters value their travel time at an increasing proportion of their wage rate; these studies have also shown that the total number of intraurban trips taken varies positively with income. The travel benefits from automobile purchase are expressed as \(B(Y_t)\), the average benefit per trip of travelling by automobile as opposed to by mass transit.

We assume that the individual chooses between an automobile purchase at price \(PA_0\) and investment in an asset which earns interest at rate \(r_t\). With purchase, the individual is returned the discounted value of the depreciated automobile at the end of the period, \(PA_0(1-\delta)T/(1+r_T)^T\). With non-purchase, he receives \(r_tPA_0\) in interest per period and the discounted value of the full amount \(PA_0\) at the end of the period which is \(PA_0/(1+r_T)^T\). The financial cost of the purchase is therefore

\[
PA_0 \left[\frac{1 - (1-\delta)^T}{(1+r_T)^T} + \sum_{t=0}^{T-1} \frac{r_t}{(1+r_T)^t}\right]
\]

The first term in parentheses is a factor representing the cost of depreciation and the second term represents the opportunity cost of ownership as compared to investment in a financial asset.

A further cost of automobile ownership and use is the cost of gasoline and maintenance. We assume that the quantities of gasoline and maintenance consumed per time period vary in proportion to the number of trips in that
period, by factors $k^g$ and $k^m$ respectively. These quantities have unit prices $PG_t$ and $PM_t$ associated with them respectively. Operating costs per time period therefore equal

$$N_t(k^g PG_t + k^m PM_t)$$

The consumer purchases an automobile if the present discounted value of the stream of benefits less costs of the purchase is greater than zero, which is expressed by

$$\sum_{t=0}^{\tau-1} \frac{N^a_t(B(Y_t) - k^g PG_t - k^m PM_t) + N^b_t PT_t - r_t PA_o}{(1+r_t)^t} - PA_o \left( \frac{1 - (1-\delta)^\tau}{(1+r)^\tau} \right) > 0$$

From this expression, the net benefits and hence the probability of ownership vary positively with income and the price of mass transit, and negatively with the price of gasoline, the price of maintenance, the price of automobiles, and the interest rate. This describes the economic factors affecting the demand for automobiles and allows us to specify the desired stock of automobiles as a function of the expected values of the independent variables, or

$$k^D_t = f(Y_t, PA_t, PG_t, PM_t, PT_t, R_t) + \varepsilon_{1t}$$

In the above, the stock of automobiles $K$ is defined to be the total stock of automobiles divided by the number of persons between 15 and 65 years of age, which is an approximation to the car-driving population. Income $Y$ is defined to be real per capita disposable income, $PA$ is an index of the purchase price of automobiles divided by the consumer price index, $PG$ is an index of the price of gasoline deflated by the consumer price index, $PM$ is an index of maintenance costs also deflated by the consumer price index,
PT is an index of the cost of the alternate mode deflated by the consumer price index, and \( R \) is the real rate of interest which is defined as the nominal rate minus the rate of change in consumer prices. The superscript \( e \) denotes the expected value of the variable. The error term \( \varepsilon_{1t} \) is assumed to be distributed normally with zero mean and variance \( \sigma^2 \).

Because the expected values are not directly observable, we assume that consumers adapt their expectations in the current period on the basis of the difference between the current value of the variable and the value which was expected to prevail in the previous period. More precisely, we postulate that

\[
(2) \quad x^e_t - x^e_{t-1} = (1 - \gamma) (x_t - x^e_{t-1})
\]

where \( x^e \) is the expected value of the independent variable and \( 0 \leq \gamma < 1 \). This may be rewritten as

\[
(3) \quad x^e_t = (1 - \gamma) x_t + \gamma x^e_{t-1}
\]

which implies that the current expected value is a simple weighted average of the actual current value and the previous expected value where the weights sum to one. The formulation also implies that the current expected value is a geometric distributed lag of the current and past actual values, that is,

\[
(4) \quad x^e_t = (1 - \gamma) (x_t + \gamma x_{t-1} + \gamma^2 x_{t-2} + \ldots).
\]

The desired stock may not be fully realized in the current period. We therefore postulate that the actual increment in the stock will be a fixed proportion \( \lambda \) of the difference between the desired stock and the existing
stock in the previous period, with a stochastic error term. Formally,

\begin{align}
K_t - K_{t-1} &= \lambda (K^D_t - K_{t-1}) + \varepsilon_{2t} \\
\end{align}

where \( 0 < \lambda \leq 1 \) and the error term \( \varepsilon_{2t} \) is distributed normally with zero mean and variance \( \sigma^2 \). Substituting equation (1) for \( K^D_t \), we have

\begin{align}
K_t &= \lambda f(Y^e_t, P^e_t, P^g_t, P^m_t, P^r_t, R^e_t) + (1 - \lambda)K_{t-1} + \lambda \varepsilon_{1t} + \varepsilon_{2t}.
\end{align}

Assuming the demand function is linear and using the expression for the expected value of each of the independent variables shown in equation (4) above allows us to write

\begin{align}
K_t &= \alpha_0 + \alpha_1 (1 - \gamma) (Y_t + \gamma Y_{t-1} + \gamma^2 Y_{t-2} + \ldots) \\
&\quad + \alpha_2 (1 - \gamma) (P^e_t + \gamma P^e_{t-1} + \gamma^2 P^e_{t-2} + \ldots) \\
&\quad + \alpha_3 (1 - \gamma) (P^g_t + \gamma P^g_{t-1} + \gamma^2 P^g_{t-2} + \ldots) \\
&\quad + \alpha_4 (1 - \gamma) (P^m_t + \gamma P^m_{t-1} + \gamma^2 P^m_{t-2} + \ldots) \\
&\quad + \alpha_5 (1 - \gamma) (P^r_t + \gamma P^r_{t-1} + \gamma^2 P^r_{t-2} + \ldots) \\
&\quad + \alpha_6 (1 - \gamma) (R_t + \gamma R_{t-1} + \gamma^2 R_{t-2} + \ldots) \\
&\quad + (1 - \lambda) K_{t-1} + \lambda \varepsilon_{1t} + \varepsilon_{2t}.
\end{align}

In (7), \( \alpha_0, \alpha_1, \ldots, \alpha_6 \) are the parameters in the demand function for the desired stock, which is assumed to be linear.

Applying the Koyck transformation and rearranging terms permits simplification to
\[ K_t = a_0 \lambda (1 - \gamma) + a_1 \lambda (1 - \gamma)Y_t + a_2 \lambda (1 - \gamma)PA_t + a_3 \lambda (1 - \gamma)PG_t \]
\[ + a_4 \lambda (1 - \gamma)PM_t + a_5 \lambda (1 - \gamma)PT_t + a_6 \lambda (1 - \gamma)R_t \]
\[ + (1 - \lambda + \gamma)K_{t-1} - (1 - \lambda) \gamma K_{t-2} + \eta_t \]

where \( \eta_t = \lambda \varepsilon_{1t} + \varepsilon_{2t} - \gamma (\lambda \varepsilon_{1t-1} + \varepsilon_{2t-1}) \).

3. Estimation

Equation (8) presents two estimation problems. First, ordinary least squares estimates of the coefficients would be inconsistent, because of the presence of the lagged dependent variables on the right hand side. Second, because of the constraints on \( \lambda \) and \( \gamma \), the coefficient on \( K_{t-1} \) must fall in the range \( 0 \leq (1 - \lambda + \gamma) < 2 \), and the coefficient on \( K_{t-2} \) must fall in the range \( 0 \leq (1 - \lambda) \gamma < 1 \). The constraint problem may be dealt with by first writing

\[ K_t - (1 - \lambda + \gamma)K_{t-1} + (1 - \lambda) \gamma K_{t-2} + \gamma (\lambda \varepsilon_{1t-1} + \varepsilon_{2t-1}) \]
\[ = a_0 \lambda (1 - \gamma) + a_1 \lambda (1 - \gamma)Y_t + a_2 \lambda (1 - \gamma)PA_t + a_3 \lambda (1 - \gamma)PG_t \]
\[ + a_4 \lambda (1 - \gamma)PM_t + a_5 \lambda (1 - \gamma)PT_t + a_6 \lambda (1 - \gamma)R_t + \lambda \varepsilon_{1t} + \varepsilon_{2t} \]

We next define transformed variables as follows:

\[ K^*_t = K_t - (1 - \lambda + \gamma)K_{t-1} + (1 - \lambda) \gamma K_{t-2} \]

\[ \text{CON} = \lambda (1 - \gamma) \]
\[ Y^*_t = \lambda (1 - \gamma)Y_t \]
\[ PA^*_t = \lambda (1 - \gamma)PA_t \], etc.
We select the ordinary least squares estimates of the following equation, for the combination of $\lambda$ and $\gamma$ which minimizes the sum of squared residuals:

$$K_t^* = \alpha_0 \text{ CON} + \alpha_1 Y_t^* + \alpha_2 PA_t^* + \alpha_3 PG_t^* + \alpha_4 PM_t^* + \alpha_5 PT_t^* + \alpha_6 R_t^*.$$ 

All pairs of $\lambda$ and $\gamma$ were first tested for $0 < \lambda \leq 1$ and $0 \leq \gamma < 1$, by increments of .1. Two pairs of $\lambda$ and $\gamma$ minimized the sum of squared residuals in this trial: $(\lambda = .3, \gamma = 0)$ and $(\lambda = 1, \gamma = .7)$. The second trial attempted combinations of $\lambda$ and $\gamma$ for $.2 \leq \lambda \leq .4$ and $.6 \leq \gamma \leq .8$, by increments of .02. The resulting pairs of values which produce equal minimum values of the sum of squared residuals are $(\lambda = .28, \gamma = 0)$ and $(\lambda = 1, \gamma = .72)$.

The generation of two minima for the sum of squared residuals is expected, because equation (8) is overidentified in $\lambda$ and $\gamma$. Note that either pair of values for $\lambda$ and $\gamma$ generate the same numerical values for $\lambda(1-\gamma)$, $(1-\lambda+\gamma)$, and $(1-\lambda)\gamma$. The last term $(1-\lambda)\gamma$ is zero in both cases. The economic sense of the problem of overidentification is that we have postulated a structural relationship between a desired quantity and some expected quantities, neither of which can be observed. The specification also assumes a particular form of the relationship between expected and observed quantities of the independent variables and a particular form of the relationship of the desired stock to the actual. Because we have only one equation in observed magnitudes, we cannot expect the estimation to yield information about the expected and desired relationships separately; rather, the estimates produce information only on the net effect of the two processes.

The results of the estimation for either pair of $\lambda$ and $\gamma$ are identical. In the estimated equation shown as A in Table 1, all of the variables have the hypothesized signs but income and the price of maintenance are not
significant at any reasonable level when the tests for significance are
made on each of these variables independently of the significance of the
other variables. The real rate of interest was insignificant in this
equation; all the results in Table 1 accordingly use R defined as the
nominal rate of interest. The explanatory power of the model is very high
\( R^2 = .98 \) and there is no evidence of serially correlated residuals.

The consistency problem may be dealt with by assuming in equation (8)
alternatively the extreme values for \( \lambda \) and \( \gamma \), \( \lambda = 1 \) and \( \gamma = 0 \) respectively.
In either case, the coefficient \( (1 - \lambda)\gamma \) on \( K_{t-2} \) is zero and the coefficient
\( (1 - \lambda + \gamma) \) on \( K_{t-1} \) is between zero and unity. Consistent estimates of the
parameters may be obtained by the instrumental variables technique. Each
of the independent variables is an instrument for itself and the lagged
value of any one of the independent variables may serve as an instrument
for \( K_{t-1} \).

The results using \( PA_{t-1} \) as an instrument for \( K_{t-1} \) are shown as
equation B in Table 1. All of the variables have the hypothesized signs and
the coefficient on the lagged stock falls within the specified range. The
lowest significance levels are for income and the price of automobiles.
The explanatory power of the model is very high \( R^2 = .999 \) and the whole
equation is highly significant, as shown by the value of the F-statistic.

The same equation was estimated directly using ordinary least squares.
This equation is shown as C in Table 1. Again, the variables have the
hypothesized signs, with higher t-values associated with the respective
coefficients. Note also that the coefficient \( (1 - \lambda + \gamma) \) on \( K_{t-1} \) in equation C
is .727 which is close to the value of .72 generated in the iterative
procedure used for the first equation in Table 1. A consistent estimate of
this coefficient is .630 (in equation B), which implies that \( \lambda = .37, \gamma = 0 \)
or \( \lambda = 1, \gamma = .63 \).
Table 1
Empirical Results

<table>
<thead>
<tr>
<th>Eqn.</th>
<th>Dep. Var.</th>
<th>CON</th>
<th>$Y_t^*$</th>
<th>$PA_t^*$</th>
<th>$PG_t^*$</th>
<th>$PM_t^*$</th>
<th>$PT_t^*$</th>
<th>$R_t^*$</th>
<th>$R^2$</th>
<th>D.W.</th>
<th>N</th>
<th>D.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$K_t^*$</td>
<td>1.0309</td>
<td>0.04156</td>
<td>-0.001744</td>
<td>-0.004428</td>
<td>-0.001344</td>
<td>0.003614</td>
<td>-0.03355</td>
<td>0.982</td>
<td>2.47</td>
<td>23</td>
<td>6.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.237)</td>
<td>(0.884)</td>
<td>(-1.651)</td>
<td>(-5.579)</td>
<td>(-0.923)</td>
<td>(3.958)</td>
<td>(-4.273)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>$K_t^*$</td>
<td>.4150</td>
<td>0.01119</td>
<td>-0.006718</td>
<td>-0.001854</td>
<td>-0.0005961</td>
<td>0.001357</td>
<td>-0.01147</td>
<td>0.999</td>
<td>2.50</td>
<td>22</td>
<td>7.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.479)</td>
<td>(0.647)</td>
<td>(-1.174)</td>
<td>(-1.439)</td>
<td>(-1.294)</td>
<td>(1.202)</td>
<td>(-1.721)</td>
<td>(2.591)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>$K_t^*$</td>
<td>.3098</td>
<td>0.01521</td>
<td>-0.004801</td>
<td>-0.001350</td>
<td>-0.0005585</td>
<td>0.0009194</td>
<td>-0.008979</td>
<td>0.999</td>
<td>2.78</td>
<td>22</td>
<td>7.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.508)</td>
<td>(1.110)</td>
<td>(-1.446)</td>
<td>(-2.887)</td>
<td>(-1.304)</td>
<td>(2.128)</td>
<td>(-3.038)</td>
<td>(9.468)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(t-values in parentheses)
4. **Conclusions**

Steady-state or long run elasticities at sample means may be derived directly from the coefficients in equation A in Table 1, and indirectly from the coefficients in equations B and C in Table 1. In the latter case, we assume that \( K_t = K_{t-1} = K_{t-2} \) and transform the estimated coefficients following equation (8) in section 2. Note that either pair of \( \lambda \) or \( \gamma \) generates the same structural elasticities, because the value of \( \lambda(1-\gamma) \) is the same for either pair. Because the variables do not simultaneously take on their mean values at any one point in the sample period, and because we are interested in the effects of the exogenous variables at recent values, we show in Table 2 long run elasticities calculated at the end of the sample period (1972).

The outstanding feature of the results in Table 2 is that the absolute values of the price of gasoline and price of transit elasticities are both about double the absolute values of the other four elasticities, with the price of gasoline elasticity being slightly higher in absolute value than the price of transit elasticity. The other elasticities range from .2 to .3 in absolute value whereas the price of gasoline and price of transit elasticities range from .6 to .9 in absolute value. The evidence from this study is therefore that the total stock of automobiles held in Canada reacts quite strongly to changes in the price of gasoline energy. The purpose of this study is not to trace out the implications of this responsiveness for the allocation of resources (in particular, between public and private transportation facilities), but the established relationship between the stock, the price of gasoline, and the other variables would be relevant in assessing the long-run demands for the different types of infrastructure as well as the demands for the consumption of gasoline.
Table 2
Long Run Elasticities at Sample End Point

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Y</td>
<td>.207</td>
</tr>
<tr>
<td>PA</td>
<td>-.287</td>
</tr>
<tr>
<td>PG</td>
<td>-.720</td>
</tr>
<tr>
<td>PM</td>
<td>-.226</td>
</tr>
<tr>
<td>PT</td>
<td>.592</td>
</tr>
<tr>
<td>R</td>
<td>-.312</td>
</tr>
</tbody>
</table>
APPENDIX I

Sources of Data

K: stock of automobiles. This variable is defined as the total stock of automobiles divided by the number of people between the ages of 15 and 64 inclusive. The total stock of automobiles is total passenger car registrations (including taxis) given in the Canada Year Book, 1942 to 1974. The population aged 15 to 64 inclusive was taken from Vital Statistics, 1973.

Y: real per capita disposable income. Income is defined to be total current dollar disposable income (CANSIM Matrix No. 000557.1) divided by the total population (CANSIM Matrix No. 000060.1) and deflated by the consumer price index (CANSIM Matrix No. 000429.1), adjusted to be unity in the base year (1971).

PA: purchase price of new automobiles. This price is defined to be the automobile purchase price index (CANSIM Matrix No. 000429.1.4.1.1), deflated by the consumer price index.

PG: price of gasoline. This price is defined to be the price of gasoline index (CANSIM Matrix No. 000429.1.4.1.2.1), deflated by the consumer price index.

PM: price of maintenance. The price of maintenance series was generated from Statistics Canada price data. Prior to 1961, CANSIM data include a price of private transportation index, PO' (Matrix No. 00429.1.4.1). In general,

\[ PO' = a_0 PA' + a_1 PG' + \sum_{i=2}^{m} a_i PX'_i, \quad \sum_{i=0}^{m} a_i = 1 \]

where PA' is the nominal purchase price index for new automobiles, PG' is
the nominal price index for gasoline, and $PX_i$ ($i=2,3,\ldots,m$) are the nominal price indices for such costs as tires, batteries, insurance, and registration fees. In order to generate $PM'$, the nominal price of maintenance series, it is necessary to subtract the contributions of purchase and gasoline prices and then normalize the series so that $PM'$ and $PO'$ have the same base year. Thus,

$$PM' = \frac{PO' - a_0 PA' - a_1 PG'}{1 - a_0 - a_1}$$

From 1961 on, CANSIM lists a new price of automobile operation and maintenance index, $POM'$ (Matrix No. 000429.1.4.1.2), which includes gasoline prices as well as a number of other costs (some of which had not been included previously, such as parking), but not purchase price. Here

$$POM' = b_1 PG' + \sum_{i=2}^{n} b_i PY_i', \quad \sum_{i=1}^{n} b_i = 1$$

In this case,

$$PM' = \frac{POM' - b_1 PG'}{1 - b_1}$$

In addition to the existence of two different $PM'$ indices (pre- and post-1961), the weights ($a_i$ and $b_i$) do not remain constant over the complete sub-periods. To generate a consistent series for $PM'$ we weighted the components using, arbitrarily, alternatively the 1967 and 1973 weights, as specified by Statistics Canada, Retail Prices and Living Costs Service Bulletin, Catalogue 62-005, Volume 3, No. 3, 1974. The series using the 1967 weights revealed a discontinuity between 1960 and 1961. For this reason, and because the index using the 1973 weights performed better in the regressions, the results shown in the text use the 1973-weighted series (deflated by the consumer price index).
PT: price of local transportation. The index has two components -- the price of mass transit and the price of taxis. The source is CANSIM (Matrix No. 000429.1.4.2.1). This series is also deflated by the consumer price index.

R: interest rate. We experimented alternatively with the average end-of-month chartered bank prime business loan rate (CANSIM Matrix No. 002560.20) and the Canada Savings Bond first coupon rate (CANSIM Matrix No. 002560.4). To express these rates in real terms, we simply subtracted the rate of change in the consumer price index.
FOOTNOTES

*This research was funded by General Motors Corporation which does not bear responsibility for, or necessarily endorse, the views expressed in this paper. The author wishes to thank David Bellhouse, Ake Blomqvist, Robin Carter, MarkFrankena, Walter Haessel, and James Melvin for useful comments and discussions while the research was in progress. Also, Rob Porter was the efficient research assistant who also made a number of useful comments and suggestions on the work. The content of this paper remains the responsibility of the author.

Cragg and Uhler (1970) review the studies on the demand for automobiles published to 1970 and present empirical results of a model using U.S. survey data, but there are no published studies of the direct determinants of the total stock demand for automobiles using Canadian data. Blomqvist and Haessel (1976) investigate the determinants of the stock demand for automobiles in different age and size categories. Wilton (1972) presents a simultaneous equation model of the automobile industry which includes a behavioral equation for the dollar value of retail sales of automobiles. The Bank of Canada RDX2 econometric model contains a behavioral equation for consumer expenditure on motor vehicles and parts and a definitional equation for the constant dollar value of the stock of motor vehicles held by consumers (Bank of Canada, 1976, pp. 83 and 86). Similarly, CANDIDE 1.2M at the Economic Council of Canada uses behavioral equations to determine various types of expenditures on automobiles, in constant dollars. Also, an estimated definitional equation determines total passenger car registrations (CANDIDE Project, 1976, block 2, equations 28, 29, 31, 32, and 60). Finally,
there is one published study (Gaudry, 1975) on the choice of mode in a
Canadian city, Montreal; Frankena (1975) discusses other studies and related
issues in Canadian urban areas; and Frankena (1976) presents a small
simultaneous equation model of the determinants of urban bus travel using
cross-section data for twenty-eight Canadian cities.

2 We are implicitly assuming that the prices of different modes of
interurban and rural travel do not affect the demand for automobiles,
although our formulation conceptually allows these relative prices to affect
the choice of mode for any given rural or interurban trip. This specification
is based on two observations: (1) much interurban travel is simply not
practical by automobile (long distance and intercontinental) and (2) automo-
bile is the only practical mode for most rural travel.

3 The above approach was suggested by an equation in Fairhurst (1975,
p. 193). The formulation of the model which follows in this section draws
on the discussion of adaptive expectation and stock adjustment models in
Kmenta (1971, pp. 473-487). Also, Kmenta (1971, pp. 479-480) suggests the
method of instrumental variables used in section 3 of this paper.

4 Note that we may form a quadratic in γ or λ from the coefficients
on K_{t-1} and K_{t-2} but the solution of this quadratic necessarily gives complex
roots, because of the restrictions on γ and λ.
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