# Testing the (*S, s*) Model

*By* Christopher Foote, Erik Hurst, and John Leahy*

The (*S*, *s*) model has enjoyed tremendous popularity over the past decade. It has been employed almost everywhere that discrete adjustment is observed. Today microeconomic rigidities are seen as an important influence on aggregate dynamics.

In this paper we quickly characterize the microeconomic evidence for the model. To narrow the scope of our discussion, we will focus our attention on real variables, and we will comment on price inertia where appropriate. We conclude that, in spite of its popularity, the evidence for the importance of the (*S*, *s*) adjustment is surprisingly weak. We argue that discrete adjustment is, in and of itself, of little macroeconomic interest. To be important these frictions must coordinate agents to act together, thereby exacerbating deviations from the neoclassical benchmark. To date there have been few attempts at empirically identifying such interactions.

In the last section, we present some results of our own. We test one of the main implications of (*S*, *s*) adjustment, that a greater variance in the forcing process leads to more frequent adjustment. Using data on automobiles from the Consumer Expenditure Survey, we find that more variable income leads to less frequent adjustment. We speculate that this correlation is indicative of a link between discrete adjustment and imperfect capital markets. This interaction could provide an important role for (*S*, *s*) frictions.

## I. (*S*, *s*) and Macroeconomics

The paper of Giuseppe Bertola and Ricardo Caballero (1990) spawned a large literature attempting the use of microeconomic rigidities to explain aggregate time series. This literature assumes that the neoclassical model correctly predicts an individual's frictionless optimal policy and posits a (potentially stochastic) rule by which agents react to deviations from this optimum. This rule captures the main feature of (*S*, *s*) dynamics: the greater the deviation, the greater is the likelihood of adjustment. Previous papers differ as to the control variable. They differ in their empirical specification of the unobserved frictionless optimum. Some work with microeconomic data; others fit only aggregates. All, however, share the characteristic that they attempt to explain the errors from the frictionless neoclassical model in terms of shifts in the cross-sectional distribution of individuals' deviations from their frictionless optima.

By this metric the exercise appears remarkably successful. In a number of settings (durables, investment, labor hiring and firing), taking account of distributional dynamics statistically improves the fit of the neoclassical model.

These results, however, do not imply an important macroeconomic role for these frictions. Instead, the methodology tends to produce dynamics that are but a slight twist on the neoclassical dynamics. At the individual level, the difference is bounded by the size of the nonadjustment bands. At the aggregate level, heterogeneity implies that the difference is much smaller. Rather than highlighting the importance of frictions, the methodology assigns them a secondary role. Only at turning points, when there is room for the cross-sectional distribution to shift from one side of the inaction range to the other, or when the disturbance is large, as in the example of Jérôme Adda and Russell Cooper (2000), does the model produce answers that deviate sharply from the neoclassical model. It is therefore unlikely that the introduction of frictions in this manner would alter any of the standard business-cycle statistics.

What is needed to establish the importance of (*S*, *s*) dynamics is evidence that rigidities contribute to problems in the economy. For this to

* Department of Economics, Harvard University, Cambridge, MA 02138; Graduate School of Business, University of Chicago, Chicago, IL, 60637; and Department of Economics, Boston University, Boston, MA 02215, respectively. We thank Alexander Bongartz for outstanding research assistance, and Robert Hall for insightful comments. Leahy thanks the National Science Foundation for financial support.

be the case there need to be interactions among agents that exacerbate the effects of inertia.[1] Do complementarities (Cooper and Andrew John, 1988) or informational externalities (Andrew Caplin and Leahy, 1994) allow the economy to get stuck far from the frictionless optimum? How do rigidities interact with credit-market imperfections (Christopher Carroll and Wendy Dunn, 1997) or holdup problems (Caballero and Mohammed Hammour, 1998). Answering these questions requires a better analysis of why agents adjust and how they adjust.

## II. Tests of the Model

Formal tests of the (*S*, *s*) model are rare. In most cases, intermittent adjustment is taken as prima facie evidence in favor of the model. Few papers test the comparative statics of the model or test the model against well-specified alternatives that also give rise to nonlinearities, nonadjustment, and discrete adjustment. These alternatives include time-dependent rules, indivisibilities, and "one-hoss-shay" depreciation.

Those that try to test the model have been hampered by data problems. It is difficult to find a data set that tracks stocks of a variable over time in great enough detail that one can identify times of adjustment and adjustment triggers and targets, and is also rich enough to control for individual heterogeneity, test the comparative-static implications of the model, and test for other motives for adjustment.

Rarely do all the pieces fall into place. Much work has focused on automobiles. Automobiles are in principle easy to count, albeit more difficult to value. Using data from the Panel Study of Income Dynamics (PSID), Pok-Sang Lam (1991) estimates adjustment triggers and targets but does not test for any of the implications of the (*S*, *s*) model. Using data from the Consumer Expenditure Survey (CEX), Orazio Attanasio (1995) characterizes the range of inaction in automobile purchases but does not test the main comparative-static implications of the model, because he lacks a time series with which to characterize the forcing process (namely, permanent income). Janice Eberly (1994) does try to test the model's implications using data from the Survey of Consumer Finances. Unfortunately, her results are unreliable. The panel that she uses does not properly account for the sale of autos. Moreover, the date of purchase in the data was imputed, and the imputation error is correlated with the properties of the forcing process.[2]

[1] Note the contrast with the pricing literature. There, the goal is to reduce fluctuations.

## III. Some New Results

There clearly remains a need for careful analysis of the nature of microeconomic adjustment. While such a careful analysis is beyond the scope of a short presentation such as this one, we report some preliminary results on the adjustment in automobile stocks.

We focus on one implication of the (*S*, *s*) model: that an increase in the variance of the forcing process leads agents to purchase an automobile more frequently. This seems to us to be the least intuitive implication of the model. Theoretically, this result holds because agents trade off the cost of adjustment against the cost of holding the wrong amount of the durable. When the variance of the forcing process rises, agents allow both costs to rise. They spend a little bit more time away from their optimum and adjust more often.

We skirt a number of measurement issues by focusing on the implications for the frequency of purchase rather than the width of the (*S*, *s*) bands. It is relatively easy to identify dates at which consumers alter their automobile holdings. It is more difficult to identify the adjustment trigger and target.

We use the Consumer Expenditure Survey (CEX) because it contains very good data on consumer automobile holdings as well as consumer characteristics. The CEX, however, has only a very short panel, which makes it difficult to derive a measure of the variance of the forcing process. Instead of estimating the variance of income from the CEX, we estimated the variance of income from the PSID, where there is a long panel

[2] In the 1986 panel, respondents were asked whether they had purchased an automobile between 1983 and 1986, and the nominal amount that they paid for the car, but not the year of purchase. The year of purchase was then imputed using aggregate data and household characteristics. Given the effects of depreciation and inflation, mistakes in imputation are likely to be large.

available. We regressed the variance of income on a number of household characteristics, including the educational attainment of the household head, and the labor-force status of the household head. We then took the coefficients from this regression and imputed a variance of income for each household in the CEX.[3]

The first-stage regressions from the PSID appear in Table 1. The $R^2$ value is respectable, and $F$ tests indicate that the educational and occupational dummies have explanatory power. We also report results for income growth. Under the permanent-income hypothesis, predictable income growth should not affect durable purchases; in a model with liquidity constraints, however, income growth might matter. This regression fits less well, although $F$ tests still indicate that the educational and occupational dummies have explanatory power.

Table 2 presents the results of the adjustment probits from the CEX. We report the coefficients on two variables.[4] "Predicted $\sigma^2$" is the predicted variance of income using parameters from the first column ($\sigma^2$) of Table 1. "Miles" is the number of miles driven in the previous year. Some of the variables used to predict the variance of income must be excluded from the probit in order to identify the effect of income variance on the probability of purchase. The rows of Table 2 correspond to various indentifying assumptions. Coefficient estimates are in ($dF/dx$) form, standard errors are in parentheses, and all regressions are weighted.

TABLE 1—RESULTS FROM THE PSID

| Independent variable | $\sigma^2$ | $\mu$ |
|---|---|---|
| Constant | 0.113 (0.257) | −0.179 (0.147) |
| Age | 0.005 (0.022) | 0.017 (0.013) |
| $(\text{Age})^2 \times 100$ | −0.276 (0.630) | −0.448 (0.373) |
| $(\text{Age})^3 \times 10{,}000$ | 0.038 (0.059) | 0.361 (0.353) |
| Female head | −0.008 (0.009) | −0.020 (0.006) |
| Married head | −0.026 (0.007) | −0.001 (0.004) |
| Black head | 0.019 (0.008) | −0.004 (0.004) |
| Homeowner | −0.018 (0.006) | −0.009 (0.003) |
| Unemployed spouse | −0.006 (0.011) | 0.006 (0.007) |
| Education of head[a] | | |
| Less than high school | 0.019 (0.025) | −0.013 (0.005) |
| High-school graduate | — | — |
| Some college | 0.005 (0.006) | 0.000 (0.004) |
| College and above | −0.016 (0.007) | 0.016 (0.004) |
| Labor-force status or occupation of head[a] | | |
| Homemaker | 0.070 (0.025) | 0.004 (0.011) |
| In school | 0.065 (0.028) | 0.038 (0.021) |
| Disabled | 0.030 (0.021) | 0.020 (0.019) |
| Unemployed | 0.092 (0.016) | −0.002 (0.010) |
| Self-employed | 0.072 (0.013) | −0.022 (0.008) |
| Manager | −0.008 (0.011) | −0.008 (0.006) |
| Sales and craft | −0.006 (0.011) | −0.008 (0.005) |
| Farming | 0.052 (0.024) | 0.011 (0.018) |
| Laborer | −0.008 (0.011) | −0.013 (0.006) |
| Service | — | — |
| $F$ test for excluded education and occupation dummies | 16.61 ($p = 0.00$) | 7.42 ($p = 0.00$) |
| $F$ test for excluded occupation dummies only | 20.11 ($p = 0.00$) | 2.10 ($p = 0.05$) |
| $N$: | 5,186 | 4,954 |
| $R^2$: | 0.12 | 0.04 |

*Notes:* Dependent variables are $\sigma^2$, the variance of income, and $\mu$, income growth.
[a] Mutually exclusive categories.

The effect of Miles on the probability of purchase is positive, as predicted by the ($S$, $s$) model. More miles driven should indicate a greater rate of depreciation, which should lead to more frequent replacement. The effect of the variance of income is sensitive to the identifying assumption. When occupation dummies are used to identify the effect of variance, an increase in variance significantly reduces the

[3] The distribution of these characteristics is very similar in the two data sets. The main differences are that the CEX has slightly more female heads of households and fewer unemployed. The latter difference probably results from not having a good measure of unemployment in the CEX. These data are availible from the authors upon request.

[4] Coefficients on other variables are available from the authors upon request. The probit also included all of the variables in Table 1 (except those explicitly excluded), the minimum number of cars held by the household, yearly dummies, the number of interviews conducted with the family (from one to four), dummies for U.S. region (Northeast, Midwest, South, West, or rural), a dummy for MSA residence, the number of males at least 16 years old at the beginning of the survey, the change in the number of males from the first to the last interview, the number and change in females at least 16 years old, total family size, the change in total family size, the total number of wage-earners, and the change in the total number of earners.

TABLE 2—ADJUSTMENT PROBITS

| Excluded variables[a] | Predicted $\sigma^2$ | Miles |
|---|---|---|
| E and LF/O | −0.066 | 7.81 |
| | (0.072) | (2.03) |
| LF/O | −0.264 | 8.43 |
| | (0.081) | (2.03) |
| O | −0.264 | 8.45 |
| | (0.092) | (2.03) |
| E | 0.896 | 8.41 |
| | (0.212) | (2.02) |

[a] E = education, LF = labor-force, and O = occupation.

TABLE 3—ADJUSTMENT PROBITS CONTROLLING FOR INCOME GROWTH

| Excluded variables[a] | Predicted $\sigma^2$ | Predicted $\mu$ |
|---|---|---|
| E and LF/O | −0.221 | −0.979 |
| | (0.081) | (0.210) |
| LF/O | −0.267 | −0.097 |
| | (0.083) | (0.304) |
| O | −0.387 | −0.680 |
| | (0.118) | (0.541) |
| E | −0.269 | −1.43 |
| | (1.14) | (1.41) |

[a] E = education, LF = labor force, O = occupation.

probability of purchase. When education dummies are used to identify the effect of variance, the effect is reversed. The latter result arises because those with college educations have significantly less-variable incomes and are significantly less likely to purchase an automobile (reduced form coefficient of −0.22 with a standard error of 0.006).

We see from Table 1 that education is correlated with both a lower variance in income and a higher growth in income. We therefore control for predicted income growth in Table 3. The results are much more clear. The coefficient on the variance of income is consistently negative and of the same magnitude, although it is statistically insignificant when the education dummies are used to identify the regression.

What do we make of these results? The effect of income variance appears to be opposite that predicted by the ($S$, $s$) model. One possible explanation involves the presence of liquidity constraints and precautionary saving. Suppose that you are thinking about selling your car. You could adjust, which would deplete your holdings of liquid assets and place you at risk of a negative income shock, or you could have a bit of work done on your car and hold on to it a bit longer. The greater the variability of your income the more appealing will be waiting.

This interaction could point to an important role for discrete adjustment in aggregate fluctuations. If increases in risk or restrictions in credit cause agents to delay their purchases, this delay could lead to a large reduction in the demand for automobiles.

## REFERENCES

**Adda, Jérôme and Cooper, Russell.** "Balladurette and Jeppette: A Discrete Approach." *Journal of Political Economy*, 2000 (forthcoming).

**Attanasio, Orazio.** "Consumer Durables and Inertial Behavior: Estimation and Aggregation of ($S$, $s$) Rules." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 5282, 1995.

**Bertola, Giuseppe and Caballero, Ricardo.** "Kinked Adjustment Costs and Aggregate Dynamics," in Olivier-Jean Blanchard and Stanley Fischer, eds., *NBER macroeconomics annual 1990*. Cambridge, MA: MIT Press, 1990, pp. 237–95.

**Caballero, Ricardo and Hammour, Mohammed.** "The Macroeconomics of Specificity." *Journal of Political Economy*, August 1998, *106*(4), pp. 724–67.

**Caplin, Andrew and Leahy, John.** "Business as Usual, Market Crashes, and Wisdom After the Fact." *American Economic Review*, June 1994, *84*(3), pp. 548–65.

**Carroll, Christopher and Dunn, Wendy.** "Unemployment Expectations, Jumping ($S$, $s$) Triggers, and Household Balance Sheets," in Ben S. Bernanke and Julio J. Rotenberg, eds., *NBER macroeconomics annual 1997*. Cambridge, MA: MIT Press, 1997, pp. 165–217.

**Cooper, Russell and John, Andrew.** "Coordinating Coordination Failures in Keynesian Models." *Quarterly Journal of Economics*, August 1988, *103*(3), pp. 441–63.

**Eberly, Janice.** "Adjustment of Consumers' Durables Stocks: Evidence from Automobile Purchases." *Journal of Political Economy*, June 1994, *102*(3), pp. 403–36.

**Lam, Pok-Sang.** "Permanent Income, Liquidity, and Adjustments of Automobile Stocks." *Quarterly Journal of Economics*, February 1991, *106*(1), pp. 203–30.