Journal of Housing Economics **8,** 1–25 (1999)
Article ID jhec.1999.0239, available online at http://www.idealibrary.com on IDEAL®

Housing Investment Dynamics, Period of Production, and Adjustment Costs

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This paper develops and estimates an investment model that explicitly outlines the connection between investment starts and completions, a connection that is often left vague in analyzing investment dynamics. The model uses gestation lag technology along with adjustment cost. Consequently, the model is built on dynamic marginal cost pricing considerations. The findings in this paper suggest, using the U.S. quarterly investment in single-family housing units from 1963 to 1991, that gestation lag with adjustment cost technology fits the description of the industry and potentially addresses the well known problem of the positive autocorrelation in residuals discussed in the empirical *Q*-investment and neoclassical adjustment cost literature.

Key Words: housing investment dynamics; time-to-build; adjustment cost; Q-theory.

1. INTRODUCTION

"In the study of investment behavior, the most important current problem is the integration of the time structure of the investment process into the representation of technology" (Jorgenson, 1971, pp. 1142).

That was almost 30 years ago. Still, understanding the dynamics that are inherent in the investment process is the fundamental issue in investment research. For investment models that are based on Tobin (1969) *Q* theory and Eisner and Strotz (1963) neoclassical adjustment cost, the main issue has been understanding the ways in which the dynamics enter in the translation of the demand for the

1981; Hayashi, 1982; Abel and Blanchard, 1986). These empirical investment papers consistently display positive autocorrelation of residuals in a simple regression of investment on current Q, where Q is the ratio of market to replacement values of investment goods. The display of large positive residuals implies that there are other unobserved variables, namely the past Qs, which can explain investment. Most of these papers include lagged values of Q in the empirical specifications to improve the regression, but with no theoretical justifications.

In this paper, I develop and estimate an investment model that explicitly outlines the connection between investment starts and completions, a connection that is often left vague in analyzing investment dynamics. In doing so, I provide an alternate investment technology—gestation lags[2] with adjustment cost—which is a useful extension that can potentially address the positive serial correlation problem in the empirical investment literature.[3] In the tradition of the Austrian school in their period-of-capital production theory followed by Kydland and Prescott (1982) and Taylor (1982), I use gestation lag technology for the specification of the starts–completions nexus. And, as in Topel and Rosen (1988), my model is built on dynamic marginal cost pricing considerations; "internal" adjustment costs are superimposed on the rising long-run supply price for the representative firm. However, unlike Taylor (1982), who restricts the role of prices,[4] and Topel and Rosen (1988), who exogenously include led and lagged investment in their Euler equation, I show that the future expected prices and not the current prices affect investment, and that led and lagged investment expenditure arise endogenously for the econometrics specification.[5]

To empirically show that gestation lag, along with adjustment cost, helps to explain the investment regression, I use U.S. quarterly investment in single family housing units. U.S. residential fixed investment is recognized to be an attractive candidate for studying investment behavior because of its volatility[6] and data availability (e.g., Topel and Rosen, 1988). In the next section, some facts regarding the U.S. single-family housing industry are discussed. The long pattern of capital construction lags and expectational (procyclical) investment activity are two main characteristics of the industry that could attribute to its highly volatile investment

[2]I use the terms time to build, construction lags, and gestation lags interchangeably. Gestation lags are delays in investment output.

[3]Other possible ways to address the serial correlation issue are given by Schiantarelli and Georgoutsos (1990), who use a monopolistic competition model; Schaller (1990), who also uses monopolistic competition but with heterogeneity of investment by firms; Chirinko (1993b) and Wildasin (1984), who use multiple capital inputs with differing adjustment costs technologies; and Chirinko and Schaller (1995), who look at investment equation with liquidity constraints.

[4]Abel and Blanchard (1986) and Altug (1989) also use lag technology but restrict the role of prices.

[5]A similar approach to technology is taken by Lee (1998), who analyzes investment cycles using a market equilibrium approach, and by Zhou (1994), who studies the irreversibility of investment using a log approximation method.

[6]According to the U.S. data, the U.S. fixed residential investment has the second highest standard deviation in percentage, 10.7%. (Cooley and Prescott, 1995).

behavior. The multiperiod model accommodates observed behavior by allowing the firm to have greater flexibility in its investment planning.[7] The model, moreover, has direct implications for the analysis of short and long run housing supply elasticities, as well as for the irreversibility of investment in the housing industry.

In Section 3, I describe the model. I examine a representative firm's problem of choosing the initial number of projects to be invested to maximize the present discounted value of its cash flow over an infinite horizon. I then obtain investment supply functions that are based on time-to-build with adjustment cost technology. Investment depends on housing prices. A single-period adjustment cost technology predicts that only the current price affects investment, while the time-to-build technology predicts that the expectations of future prices—with as many lags as there are lags in the technology—should affect current investment.

Section 4 contains the empirical analysis: I estimate the housing supply functions. Empirically, I find that the model of gestation lag along with adjustment cost produces higher fitted values and lower sum-of-square residuals than the single-period adjustment cost model. More specifically, a housing supply function that is estimated by instrumental variable method regression of current investment on two-period future price describes the data. Also, in this section, I estimate short and long run supply elasticities as well as the structural parameters. Concluding remarks are presented in Section 5. The data description is reported at the end of the paper separately from the main text.

2. U.S. HOUSING INDUSTRY

One of the prominent features of the U.S. housing industry is that its investment activity is expectational. The Bureau of the Census, Construction Reports C-27, estimates that one-fourth of units are built on contract and the rest for the market at large. That is, most housing construction firms do not build to order, but instead adjust housing starts and completions in relation to demand conditions and price and cost expectations. Thus, in a housing boom the completion rate may be accelerated by employing more materials and labor, etc., to ensure quick sales. And in time of recession, firms may lengthen completion lags and may reduce starts. Figure 1 displays the percentage distribution of buildings completed by number of months from start. In recessions (e.g., 1982), firms prolong the construction period by distributing projects in progress over the period, whereas in booms (e.g. 1977), they finish most of their projects within 6 months.[8]

[7]The main drawback to using only the time-to-build technology is its inflexibility; once the firm carries out the investment plan, it cannot incorporate any new information (e.g., good or bad production shocks) into the original plan.

[8]This "accordion" effect of the time-to-build period during recessions and boom's is also documented by Merkies and Steyn (1994) for the Dutch construction industry.

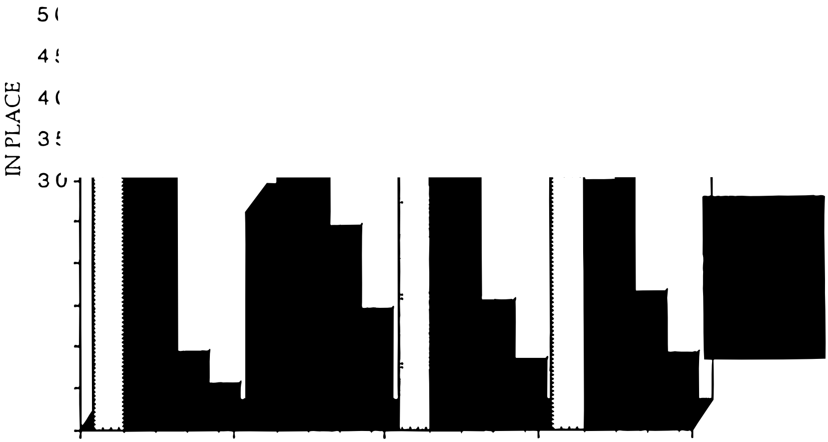
IN PLACE

TABLE I
Summary of Table S2-1: Average Number of Months from Start to Completion of New One-Family Houses, by Region and Purpose of Construction

	Region[b]				
Year[a]	United States	Northeast	South	Average unit size (sq. ft.)	Aggregate (U.S.) investment ($ billion)[c]
1971–1979	5.82	6.3	5.45	1600	44.9
1980–1989	6.37	7.04	5.68	1800	84.1
1990–1992	6.17	8.6	5.43	2100	102.1
1971–1992	6.12	7.31	5.52	1850	77.03

Source. U.S. Department of Commerce, the Bureau of the Census. Construction Reports C20, Supplement 2, *Total Time From Start of Construction to Completion of Private Residential Buildings*, and C25, *Supplement A, Characteristics of New Housing.*

[a] Although the actual estimation is done over the time period from 1963:1 to 1991:4, the years 1963–1969 could not be reported in this table since the first survey for Supplement 2 for Construction Reports C20 starts from 1971.

[b] The original survey in Table S2-1 reports other regions as well, namely, Midwest and West. Moreover, the average number of months in the table represents all purposes of construction, which include the houses built for sale, contractor-built houses, and owner-built houses.

[c] Aggregate U.S. investment refers to the actual investment in structures for single-family-unit housing.

that some firms may face liquidity constraints. But a more convincing reason for the variation of completion time from year to year is given by Bils and Kahn. They find a strong negative correlation, -0.8, between time to build and the increase in number of starts over the preceding year. This suggests that people

TABLE II
Summary of Table S2-4: Percentage Distribution of Buildings Completed by Number of Months from Start for Residential Buildings with One Unit

	Periods			
Year	3 months	6 months	9 months	12 months
1971	43	43	8	3
Cumulative	43	86	90	97
1980	27	36	19	9
Cumulative	27	63	82	91
1991	35	38	12	5
Cumulative	35	73	85	90
1971–1991	35	39	13	5.7
Cumulative	35(37.8)[a]	74(80)	87(93.9)	92.7(100)

Source. U.S. Department of Commerce, the Bureau of the Census. Construction Reports C20, Supplement 2. *Total Time From Start of Construction to Completion of Private Residential Buildings.*

[a] The numbers in brackets are adjusted upward to reach 100%.

"expect time-to-build to respond more to unexpected movements in sales and production, which are presumably better approximated by the growth in starts"[10] (Bils and Kahn, 1995, p. 21).

The actual completion time for single-family housing units is longer if one includes the planning time for land acquisitions, building permits, building itself, and other steps (i.e., preconstruction lags as well as construction lags per se). I ignore such details, mainly due to the lack of data, and focus only on investment in housing structures.[11] Consequently, I consider a housing unit to be started when excavation for the building has begun. Also by convention, one-family-unit houses are classified as completed either when all finish flooring has been installed or when the house is occupied even if flooring is not finished. One should, therefore, notice the difference between preconstruction, construction, and delivery lags. In this paper, I focus on the construction lags that are naturally associated with the flow of investment in structures. The delivery lags that I have in mind are not those due to the delays in delivering the input materials, but rather the lags that arise from not selling the finished houses immediately (postconstruction lags). I also ignore the delivery lags, although these lags may affect firms that are indebted and financial constrained.

In summary, it is clear that the time-to-build aspect of new houses is a considerable and significant part of the U.S. housing industry. Moreover, the amount of investment and the longer completion time of construction are positively correlated with boom and recession periods, respectively. With these facts in hand, it thus seems logical to explicitly incorporate both time to build and adjustment cost to capture the lengthening and shortening effects as well as the construction lags when one analyzes housing investment models.

3. SUPPLY OF NEW HOMES

Housing investment is the main series to be explained. Figure 2, which graphs annual time series of investment and of input and output prices for houses, shows that every downturn in housing investment is associated with the National Bureau of Economic Research's definition of a peak-to-trough period of the business cycle. NBER's peak-to-trough periods are highlighted over the time series in

[10]The stability in completion time is also partially due to offsetting effects between improved construction technology (shortening effect) and changing characteristics of single-family unit housing (extending effect). The "characteristics of new housing," which are defined in the Current Construction Reports C.25, *New One-Family Houses Sold and For Sale*—special supplement—and are used to calculate the hedonic housing prices have changed from 1970 to 1990.

[11]Using a calibrated real business cycle model, Christiano and Todd (1996) show that the preconstruction ("time-to-plan") period may help to account for several key features of business cycles. Their model uses a standard four-period time-to-build investment technology, where the first period is assigned as a time-to-plan stage in which only a negligible amount of resources is used.

underpinning factor of the theoretical model developed in this paper. I use annual time series of investment, input, and house prices in Figs. 2 and 3 to present clear evidence of an upward-sloping investment supply function, although quarterly data from 63:1 to 91:4 are used to estimate the detailed model. The quarterly series are too volatile seasonally to depict the salient longer term positive correlations that exist between price and investment. The time series in Fig. 2 lends informal evidence that "cyclical movements in housing construction are driven largely by demand fluctuations along a rising supply curve of new homes" (Topel and Rosen, 1988, pp. 718). Figure 2 shows that the correlation between annually detrended investment in housing structures and real price in housing is 0.79. This real price in housing is a hedonically adjusted house with 1987 characteristics deflated by the consumer price index. The comovements of a Boeckh index of construction costs, investments, and housing prices lend additional support to the hypothesis of a rising supply price (e.g., correlation values between investment and construction costs and between housing prices and construction costs are 0.77 and 0.75 respectively). The comovements of three series between 1981 and 1982, however, are not supported. I do not have any explicit economic reasons for this. Nevertheless, a more convincing upward-sloping supply function that is not affected by a time trend is presented in Fig. 3, where house prices and investments are plotted against each other.

3.1. The Model with Time-to-Build and Adjustment Cost

The best way to analyze the supply side of the housing market dynamics is to apply a simple but general enough model to approximate the actual function in a fairly wide range of empirical situations. In doing so, I ignore tax (Chirinko 1987), credit availability (Poterba 1984; Stein 1995), and demographic issues in housing investment (Mankiw and Weil, 1989; Poterba, 1991).

Consider a representative firm which is rationally managed in a competitive industry, so that the output price P_t is exogenous. Given that firm-level time-series data do not exist, I consider the representative firm's problem using industry-level data. The U.S. private residential construction industry can be described as being unconcentrated, with a large number of small construction firms remained stable from 1971 to 1990, and hence supporting the "price-taker" assumption.[13]

As previous research has rejected the single-period adjustment cost model, I blend the time to build with the adjustment cost to avoid the problems faced by single-period adjustment cost models. As a result, the model becomes an extension of multiperiod adjustment costs theory.[14] The adjustment process in this paper deals with changes in new investments that can only be initiated at the beginning stage of production. That is, once the production has started, the firm cannot hurry production in the original plan even if it has enough time to do so. Rather, it can only expand the whole set of production by starting a new set of investments.

The supply side of my multiperiod model begins with a construction of capital technology, in which a single-family-unit house takes two periods to build. But any fixed period of production will do. The data on the percentage distribution of buildings completed in Table I show that it is reasonable to consider a case for two-period (quarter) project, as the average completion time is 6.12 months (2 quarters). Gestation lags longer than two periods are mere extensions of the two-period model. Thus, the inclusion of longer lags does not change the essence of the issue but only adds computational complexity.

Accordingly, I assume that firms invest in projects that take two periods to complete. Following the time-to-build literature, let S_t be the number of projects started at time t, that is, projects that are two stages from completion, and let S_{t-1} be the output plan of the previous period that is in the final stage of production. Thus, stock-flow governs the capital (house) accumulation for the housing construction industry in the equation

[13]The difference in completion time, between Northeast (7.31 months) and South (5.53 months) in the period from 1971 to 1991, which is shown in Table II, is mainly due to climate difference. Quarterly investment data show clear seasonal variations: summertime construction is twice as large as in winter (this is not plotted). Thus, the regional difference in completion time cannot be attributed to heterogenous firms.

[14]The model, however, is not as "pure" as the general equilibrium multiperiod model proposed by Park (1984), who allows changes in the original plan to occur in the latter stages of production.

$$K_{t+2} = (1 - \delta)K_{t+1} + S_t \tag{1}$$

where K_t is the number of complete houses in the entire housing stock at time t. Whole housing depreciates at the rate $\delta \in (0,1)$; the depreciation rate can be thought of as the maintenance rate of houses at t. Equation (1) says that projects started today, S_t, are added to the stock of productive capital two periods later.

The firm also faces a current investment constraint. The current gross investment consists of the value put in place during different stages of production,

$$I_t = \omega_1 S_t + \omega_2 S_{t-1}, \tag{2}$$

where ω_j denotes the fraction of resources allocated to the investment projects at the jth stage from completion. In this work, ω_1 and ω_2 are taken as exogenously determined fixed parameters. Thus, the definition of ω_j implies that

$$\omega_1 + \omega_2 = 1. \tag{3}$$

Substituting (1) into Eq. (2), the gross investment expenditure in period t affects the availability of capital goods in the future. That is, total gross investment = [value put in place during the first period of projects started in the current period] + [value put in place during the second period of projects started in the previous period].

The representative firm in a competitive market generates revenues by selling the number of houses completed during time t. Consequently, the revenue function is given by $P_t S_{t-2}$, where P_t is the price of a house (i.e., the real hedonic price index for 1987 quality homes) and S_{t-2} is the number of houses started two periods ago and ready to be sold at time t (housing investment is measured in billions of 1987 dollars).

Operating costs of construction arise from purchasing inputs, I_t, and the vector of variables, Y_t, that shift the cost function. Y_t can be thought of as the cost shock. The firm's cost function has a quadratic form, so the marginal cost of installation is a linear increasing function of the level of gross investment: For $I > 0$, $C(I, Y) > 0$, $C_1(I, Y) = \partial C/\partial I > 0$, and $C_{11}(I, Y) = \partial^2 C/\partial I^2 > 0$ with $C(0) = 0$. The simplest function with these characteristics is the quadratic

$$C(I_t, Y_t) = aI_t + a_0 I_t Y_t + \frac{b}{2} I_t^2, \tag{4}$$

where b represents the adjustment cost parameter that makes marginal cost an increasing function of I_t. The costs of adjusting the capital stock increase at an increasing rate with the absolute value of the rate of expansion. The cost function in Eq. (4) is written in levels of the investment, I_t, which obviously is not homogeneous of degree one, and hence a possible source for serial correlation in investment. However, Lucas (1967a, 1967b) and Lucas and Prescott (1971) point out, in their theoretical development of the adjustment cost technology, that the firm's growth rate is independent of its size, and further, they state that from the point of view of empirical studies, the shadow price of capital has a strong positive correlation with the level of investment. Consequently, I do not use the relative investment, I_t/K_t, in my empirical work. Because of this, capital stock in my model plays no role: there is no inventory of finished homes waiting to be sold. It is, however, true that the dynamics of prices of new homes depend substantially upon the availability of existing homes in the market (Englund and Ioannides, 1997).

To address the upward trending over time in investment variable, I use detrended investment data. Also, I make the adjustment costs a function of gross investment, I_t, instead of net capital, ΔK, because the rising supply price refers to the resources needed to build new houses plus depreciation. With the adjustment cost specification above, a speedy adjustment of capital stock to the "desired" level is more costly than a slow one so long as $b > 0$. The adjustment costs employed here reflect the internal costs to the construction industry but external to firms. These are the costs which are associated with the change of capital stocks when there are technology and other supply shocks. Had the model been an aggregate one then the adjustment costs could be referred to as external costs (Mussa, 1977).

3.2. Derivation of the Supply Function

In making its supply decision, the firm maximizes the discounted present value of all future net cash flow. The firm then chooses the number of first stage investment projects S_t in the maximization problem as expressed in the equation

$$\underset{\{S_{t+\tau}\}}{\text{Max}}\; E_t \sum_{\tau=0}^{\infty} \left(\prod_{i=0}^{\tau} \beta_{t+i} \right) [P_{t+\tau} S_{t+\tau-2} - C(I_{t+\tau}, Y_{t+\tau})] \qquad (5)$$

subject to Eqs. (1), (2), and (3). $\beta = 1/(1 + r)$ is the discount factor and r is the average real interest rate. E_t denotes expectations conditional on the date t information set, which includes the past and present values of housing prices.[15] Holding the discount factor constant[16] and differentiating with respect to S_t, the supply decision rule then is

[15]I ignore the technology shock in the production and cost functions. The possible sources for uncertainty and error that I am thinking of are from differential information sets available to the econometrician and the firm, mismeasurement, and exogenous cost shifters.

[16]Although the value of expected cash flows is discounted by a time-varying rate in the objective function, I assume that the firm is owned by a risk neutral individuals. Consequently, the firm's discount factor, β, is assumed to be constant. Using a time-varying discount factor may give the firm an added instrument to hedge against either highly procyclical or countercyclical cash flows, but this is too difficult to work with empirically.

$$\beta^2 E_t(P_{t+2}) = E_t[\omega_1 C_1(I_t, Y_t) + \beta\omega_2 C_1(I_{t+1}, Y_{t+1})]. \tag{6}$$

The left-hand side of Eq. (6) is the discounted expected marginal revenue that is to be realized at the end of two periods. The right-hand side is the sum of the discounted expected marginal costs till the period before the completion date.

For gestation lag of length J (i.e., investment projects take J periods to complete), Eq. (6) simply becomes

$$\beta^J E_t(P_{t+J}) = E_t\left[\sum_{j=0}^{J-1} \beta^j \omega_{j+1} C_1(I_{t+j}, Y_{t+j})\right]. \tag{7}$$

That is, the discounted expected marginal revenue at period J equals the sum of the expected discounted marginal costs till period $J - 1$. On the other hand, if $J = 0$ then Eq. (7) simplifies to the usual adjustment cost decision rule derived from the condition that current price equals current marginal cost:[17]

$$P_t = C_1(I_t, Y_t). \tag{8}$$

The supply function for my two-period model is obtained by inverting Eq. (6) so that

$$I_t = S(E_t[P_{t+2}, I_{t+1}, Y_t, Y_{t+1}]) \quad \text{with} \quad \frac{\partial S}{\partial E_t(P_{t+2})} > 0 \tag{9}$$

Thus, the production side of the model can be simply described by combining Eqs. (1) and (9),

$$K_{t+2} = (1 - \delta)\, K_{t+1} + S(E_t[P_{t+2}, I_{t+1}, Y_t, Y_{t+1}]), \tag{10}$$

where the total number of houses in stock today equals the depreciated number of housing stocks from the period before plus the houses that were started two periods ago.

By employing gestation lags technology, the solution to the optimization problem implies that current total gross investment depends on the current expectation that is projected on J (e.g., $J = 2$ above) future price, plus the sum of expected future investment and cost shifter till $J - 1$ period. As a result, one of the features of general form of Eq. (9) is that when the time-to-build technology is used, no

[17]For a clarification, I use the term "single-period adjustment cost model" for $J = 0$. That is, $J = 0$ is meant to imply that investment projects are finished within a period rather than to unrealistically indicate they take no time to complete. Consequently, if $J = 1$, so that the output does not get realized till the next period (i.e., one-period model), then the supply decision becomes $\beta E_t(P_{t+1}) = C_1(I_t, Y_t)$. Thus, the current investment depends on the discounted one-period-ahead expected price.

more than J prespecified lags appear between the expectation operator and the housing price and $J-1$ lags with respect to investment and cost shifter in the gross investment schedule. Hence, one can see that current price P_t no longer incorporates all current and future information that is relevant for the investment decision, I_t: expectations of future prices and other variables affect current supply. This conclusion is similar to that of Englund and Ioannides (1997), who concludes that housing price, although the price of an asset, does not exhibit a random walk. Consequently, my model sheds new light on the investment process by which firms incorporate future forecasts into current information. Furthermore, it potentially addresses the positive serial correlation issue in the investment literature.

Moreover, my model is a formalization of the fact that U.S. single-family-housing investment cycles precede business cycles by at least three months. That is, although the economy might be in a recession and there may be many unsold houses, one could observe a boom in the single-family construction industry due to anticipation of an increase in future demand. Situations of excess supply in real state are not uncommon. Kling and McCue (1987) note the overbuilding phenomenon for new office building construction. They observe a high investment proceed in new office construction (around $30 billion in the first quarter of 1985) in spite of a high vacancy rate (around 16–18%). This overbuilding during recession is possible when the decisions of firms to invest depend, due to construction lags, on the future expected market price as well as on other future variables: An optimizing firm would invest to build in spite of unfavorable current economic conditions in order not to miss the forthcoming improved market conditions and benefit from them.[18]

Even with only two-period lags in construction, the supply function in Eq. (9) shows that, unlike the single-period ($J = 0$) supply function in Eq. (8), the inclusion of gestation lags allows short- and long-run differences in supply. The partial equilibrium path of two-period-lag investment supply can formalize this point:[19] Short-run supply curves are less elastic than long-run supply curves, with the elasticity increasing as time goes by.

4. ESTIMATION

The supply functions in the form of linear equations are estimated using quarterly time-series data on U.S. housing investment in structures from 1963:1

[18]Of course, the time-to-build aspect is only one of many possible explanations for this overbuilding. Poor planning on the firm's part, tax issues concerning construction, and other financial aspects of the firms could attribute to this puzzle as well.

[19]This is a partial equilibrium solution since the price is endogenous in this model. Further, the closed form of the partial equilibrium path for supply function (i.e., Eq. (10)) can be found using a lag operation as in Sargent (1987).

TABLE III
Summary Statistics for the Quarterly Data Used in the Estimation: 1963:1 to 1991:1 with 116 Quarters

Variables	Mean	Standard deviation
Investment	54.82	32.2
House price (HP)	0.921	0.07
Real interest rate (RIR)	3.402	2.02
Inflation rate (IR)	1.013	0.008
Months(M)	3.586	0.69
Consumption(C)	41.1	10.5
Family(F)	7.51 + e04	1.27 + e04
Energy(E)	0.82	0.127
Mortgage rate(MR)	9.06	2.32

Correlations

	HP	RIR	IR	M	C	F	E	MR
HP	1	0.61	0.48	0.39	−0.79	0.79	0.65	0.74
RIR		1	0.005	0.23	−0.85	0.89	0.44	0.61
IR			1	0.60	−0.09	0.15	0.31	0.38
M				1	−0.29	0.28	0.31	0.35
C					1	−0.95	−0.71	−0.79
F						1	0.52	0.70
E							1	0.87
MR								1

Note. For the definitions of these variables, see the Data Appendix.

to 1991:4. Due to the endogenity of P_t, I estimate the investment equation (9) using the instrumental variable method to address the potential zero restrictions on variables, to describe the data, and to estimate the structural parameters.

The instrumental variables include the aggregate real consumption expenditure (as a proxy for permanent income), the index of family formation, real interest rates on the first mortgage loans, and the energy price index.[20] As the summary statistics in Table III show that the listed instrumental variables are correlated with the house prices and cost shifter. The error terms appear in the linear investment equations due to the unobserved cost shifter. I use seasonally adjusted series, and both investment and price series are detrended around their means for the estimation.

I only use cost-shifting and instrument variables that are "informative" to housing investment models. The cost shifting variables that I use are the Boeckh index, prevailing wage and manufacturing wage in the construction industry, real

[20]All the instrument variables are first-differenced, except for the index of family formation, to account for nonstationarity.

interest, inflation rate, and months of median time for new houses for sale in quarter t.[21]

The real interest and expected inflation rates reflect the cost of working capital to builders, although these variables "should only affect housing starts to the extent they affect the level of house prices, and no more. Or said differently, the level of prices should be a sufficient statistic for any demand-side effects on housing starts" (Stein 1995, p. 5). The months variable reflects foregone interest costs to the builder. The amount of time that houses are on the market for sale (time-to-sale) is important because the interest costs of holding an unsold house are a major cost to builders and other house-sellers (Poterba, 1984). The cost of having too many unsold houses is informally displayed by the negative correlation between house investment and months in Fig. 4: The longer the houses are on the market, the smaller the amount of investment. Presumably, the negative correlation is due to a stoppage in cash flow. However, Stein proposes more appealing reasons for the negative correlation between "waiting time" (months variable) and house starts. He attributes one reason to the "fishing for liquidity" link: lower prices lead less liquid (or more cash-strapped) firms to fish (search) for buyers who would pay the firms' minimum costs. The second reason is the "thick markets link": lower prices lead to less trading volume, which in turn forces those sellers who do search to wait longer for a good buyer and to build less.

4.1. Zero Restrictions and Structural Parameters

The empirical form of the myopic (i.e., single-period adjustment cost: $J = 0$) supply model (7) is

$$I_t = c_0 + c_1 P_t + c_2 Y_t + \nu_t, \tag{10}$$

where

$$c_0 = -\frac{a}{b}, \quad c_1 = \frac{1}{b}, \quad c_2 = -\frac{a_0}{b}.$$

The parameters a, a_0, and b are from the cost function in (4). Unobserved cost shifters, Y_t, account for the error term, ν_t, which is assumed to be orthogonal to the observable supply and demand shifter. A positive parameter, c_1, for P_t indicates the investment supply function. The cost shift variables, Y_t, are exogenous to the firms cost function and enter the investment function negatively. If these cost shifting variables are statistically significant then one could reject the hypothesis

[21]In the final estimation, I left out the Boeckh index, and the prevailing wage and manufacturing wage in the construction industry, as they gave no statistically important effects on prices as cost shifters. Furthermore, the inflation rate being a cost shifter could be questioned, as it can be a demand shifter via nominal interest rate affecting mortgage qualification.

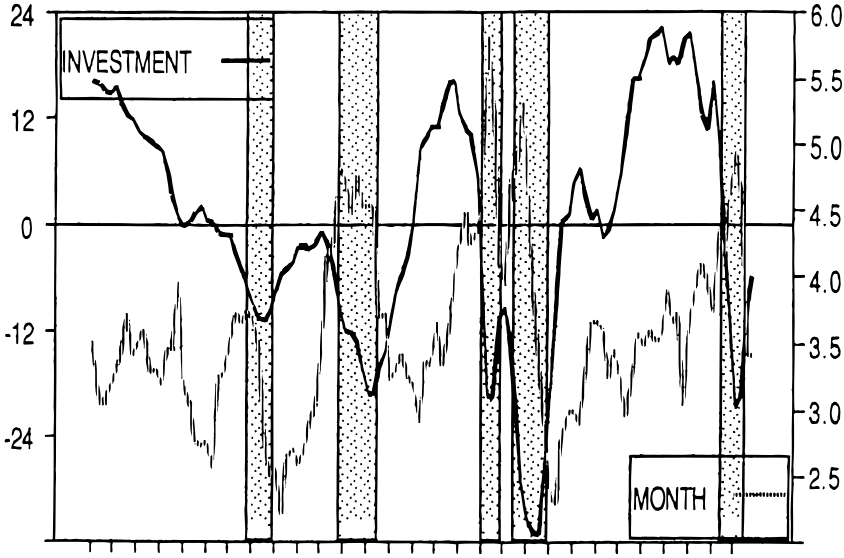
24
12
0
-12
-24
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
INVESTMENT
MONTH

TABLE IV
Instrumental Variables Estimates of Housing Investment: Adjustment Cost Model, 1963:1 to 1991:4, Single Period Project: $J = 0$, 116 Quarters

Regression equation:[a] $I^{\bullet}_t = c_0 + c_1 P_t + cY_t + v_t$ (Eq. (10))

	Intercept	P_t	Inf_t	RIR_t	M_t	AR(1)	D-W	SSR
1	143.6	168.7	−133.6	—	—	0.94	1.30	1748
	(−1.32)[b]	(3.08)	(−1.25)			(34.5)		
2	2.01	170.8	—	−2.20	—	0.99	1.38	1970
	(0.21)	(2.93)		(−1.49)		(30.7)		
3	11.1	179.1	—	—	−5.21	0.94	1.61	1443
	(1.39)	(3.60)			(−3.95)	(36.4)		
4	−102.4	173.6	−101.4	−1.95	—	0.94	1.37	1899
	(−0.87)	(3.02)	(−0.90)	(−1.31)		(32.2)		
5	−107.3	189.3	−123.6	−1.77	−5.22	0.95	1.70	1488
	(−1.02)	(3.69)	(−1.21)	(−1.31)	(−3.85)	(34.1)		

[a] I = investment, P = house price, Inf = inflation rate, RIR = real interest rate, M = months.
[b] The numbers in parentheses are the t-statistics. The dependent variable is quarterly single family housing investment in structures. P_t is the hedonic price index for new, 1987 quality single family homes sold in quarter t. Real rate_t is the real interest rate from 3 months U.S. government Treasury Bills. $\mathrm{Inflation}_t$ is the rate of inflation calculated from the C.P.I. Months_t is the median time on the market since the beginning of construction for houses that are for sale in quarter t. All data are seasonally adjusted. Variables used as instruments are current and lagged values of aggregate real consumption expenditure (as a proxy for permanent income), an index of family formation, interest rates on the first mortgage loan, and an energy price index.

affects housing price. Consequently, movements in housing prices do not necessarily follow a random walk. Various unit root tests on P_t and investment, I_t, indicate the inconclusive result that they both are integrated of order one. Since the estimation procedure is an instrumental variable method, I use the weighing matrix of Hansen (1982) to correct for inefficiencies in estimated coefficients due to heteroskedasticities and serial correlation when estimating (10).[22]

Regressions in Table IV—the single-period adjustment cost model—show that all the estimates have the expected signs. The estimated coefficients on price indicate positive supply responses to changes in the housing price. The implied supply elasticity at sample means ranges between 3.05 and 3.44 and averages 3.19. The implied internal adjustment parameter, b, for different regression specifications is obtained by taking the inverse of the estimated coefficient on price: They range from 0.0053 to 0.0069 with the average of 0.0056. These adjustment cost values are low due to a scaling effect. The main results from Table IV, however, are in line with previous empirical (single-period adjustment cost) investment literature's findings: Even after correcting for first-order serial correlation, the Durbin–Watson statistics for Eqs. 1 to 5 (1.30, 1.38, 1.61, 1.37, and 1.70, respectively) show that these regressions produce large positive residuals.

[22]I used four lead and lagged periods to create the weighting matrix.

Empirical results in Table IV suggest that, although the current housing price is statistically significant, it alone is not a sufficient statistic for the investment supply model. Cost-shifting variables such as the months are statistically significant in explaining the investment function. Looking at regression 4 in Table IV, when both the inflation and real rates are included as cost shifters, both rates are statistically insignificant and hence they do not statistically reflect the cost of working capital to builders. This belief is further supported in regressions 1 and 2: A regression either with the inflation or with the real rate as the only cost shifter is statistically insignificant. On the other hand, the months variable seems to be the most relevant cost shifter in explaining the investment: When the months variable is included in regressions (e.g., in regression 3 and 5), the D–W statistics become higher, and the sum of squared residuals is lower.[23]

The general stochastic empirical form of the Euler equation (9) is[24]

$$I_t = \alpha_0 + \alpha_1 E_t(P_{t+J}) + \alpha_2 Y_t + \sum_{k=1}^{J-1} \gamma_k E_t(I_{t+k}) + \nu_t, \tag{11}$$

where J indicates the number of gestation lags and

$$\alpha_0 = -\frac{a(\sum_{j=1}^{J} \beta^{j-1}\omega_j)}{\omega_1 b}, \quad \alpha_1 = \frac{\beta^J}{\omega_1 b}, \quad \alpha_2 = \frac{a_0}{b}, \quad \gamma_k = \frac{\beta^k \omega_{k+1}}{\omega_1}.$$

E_t is an expectation operator given period t information, β is a discount factor, and ω_i is the fraction of expenditure on the projects during different stages of production. To estimate Eq. (11), I replace $E_t(P_{t+j})$ and $E_t(I_{t+j})$ with their realizations P_{t+j} and I_{t+j}. For gestation lags of 2 periods (i.e., $J = 2$), Eq. (11) is then written as

$$I_t = \alpha_0 + \alpha_1 P_{t+2} + \alpha_2 Y_t + \gamma_1 I_{t+1} + \nu_{1t}, \tag{12}$$

where

$$\alpha_0 = -\frac{a(\omega_1 + \beta\omega_2)}{\omega_1 b}, \quad \alpha_1 = \frac{\beta^2}{\omega_1 b}, \quad \alpha_2 = \frac{a_0}{b}, \quad \gamma_1 = \frac{\beta\omega_2}{\omega_1}.$$

The error term, ν_{1t}, is a composition of other error terms stemming from $E_t(P_{t+2})$ and $E_t(I_{t+1})$: $\nu_{1t} = \nu_t - \alpha_1\varepsilon_{P(t+1)} - \gamma_1\varepsilon_{I(t+1)}$, where $\varepsilon_{P(t+2)} = P_{t+2} - E_t(P_{t+2})$ and $\varepsilon_{I(t+1)} = I_{t+1} - E_t(I_{t+1})$. Along with P_{t+2}, I_{t+1} is also endogenous

[23]A similar conclusion is stated by DiPasquale and Wheaton (1994) and Topel and Rosen (1988) in their studies of the U.S. housing market.

[24]This is true for $j = 1,2,3,\cdots$. This is the one of the main points in Hansen's Generalized Methods of Moment estimation procedure, (Hansen, 1982).

TABLE V
Instrumental Variables Estimates of Housing Investment: Time to Build with Adjustment Cost Model, 1963:1 to 1991:4, One Period Projects: $J = 1$, 116 Quarters

Regression equation: $I^{\bullet}_t = \alpha_0 + \alpha_1 P_{t+1} + \alpha_2 Y_t + v_{1t}$ (Eq. (11))

	Intercept	P_{t+1}	Inf_t	RIR_t	M_t	AR(1):μ	D-W	SSR
6	−196.5	161.7	−186.2	—	—	0.94	1.45	1723
	(−1.70)	(3.06)	(−1.65)			(33.8)		
7	−2.22	137.8	—	−0.98	—	0.93	1.33	1943
	(−0.23)	(2.62)		(−0.66)		(28.7)		
8	12.7	176.1	—	—	−5.61	0.94	1.70	1442
	(1.53)	(3.75)			(−4.06)	(33.4)		
9	−181.6	157.5	−173.9	−0.43	—	0.95	1.43	1831
	(−1.52)	(2.91)	(1.50)	(−0.27)		(31.8)		
10	−206.9	195.9	−215.9	0.09	−5.81	0.95	1.96	1482
	(−1.88)	(3.90)	(−2.03)	(0.06)	(−4.09)	(34.7)		

and correlated with the composite error term. The lagged supply and demand shifter become valid instruments for P_{t+2} and I_{t+1} by assuming that $E_t(X_{t-j}\nu_t) = E_t(Y_{t-j}\nu_t) = 0 \ \forall\ j > 0$. Under rational expectations, ε_{t+1}'s are orthogonal to the period t information set. But the composite error covariance at lag 1 in Eq. (12) is nonzero, $E_t(\nu_{1t}\nu_{1t-1}) = E_t(\nu_t\nu_{t-1}) - \alpha_1 E_t(\nu_t\varepsilon_{P(t)}) - \gamma_1 E_t(\nu_t\varepsilon_{I(t)}) = 0$,[25] since $E_t(\nu_t\varepsilon_{P(t)})$ and $E_t(\nu_t\varepsilon_{I(t)})$ are both positive. If ν_t is AR(1) with parameter μ, then

$$E_t(\nu_{1t}\nu_{1t-j}) = \mu^{j-1}\, E_t(\nu_{1t}\nu_{1t-1}). \tag{13}$$

In calculations of standard errors for the instrumental variables estimates of Eq. (12), the errors are allowed to follow (13), where a consistent estimate of μ in (13) is used to form the error covariance matrix in Eq. (12).

Table V gives the regression results for one lag ($J = 1$) and Table VI summarizes the results when two lags ($J = 2$) are used. Some of the estimates in Tables V and VI do not support the theory and provide little help in explaining the model. For example, the coefficients on some of the cost shifters are positive and statistically significant. This is especially true for two lags (Table VI). Further, some of the regressions (e.g., regressions 11, 12, and 14) in Table VI indicate weak empirical support for the finding that future housing prices are statistically significant in explaining for current investment. From my model, one would

[25]I thank Jan Brueckner for bringing to my attention that Eq. (11) can also be written in terms of the lags rather than the leads in investments. That is, take $J - 1$ lags on Eq. (11) and express the equation in terms of I_t: $I_t = \lambda_0 + \lambda_1 E_t(P_{t+1}) + \lambda_2 Y_t + \sum_{k=1}^{J-1} \lambda_k I_{t-k} + \hat{v}_t$, where $\hat{v}_t = v_t/\gamma_{J-1}$, $\lambda_0 = -\alpha_0/\gamma_{J-1}$, $\lambda_1 = -\alpha_1/\gamma_{J-1}$, $\lambda_2 = -\alpha_2/\gamma_{J-1}$, $\lambda_k = -\gamma_k/\gamma_{J-1}$ for $k = 1, \ldots, J - 2$. The investment in lag form reduces the number of instrument variables that are being used to estimate the equation. However, in the actual estimation, I use Eq. (11) instead of the lag form.

TABLE VI
Instrumental Variables Estimates of Housing Investment: Time to Build with Adjustment Cost Model, 1963:1 to 1991:4, Two Period Projects: J = 2, 116 Quarters

Regression equation: $I^{\bullet}_t = \alpha_0 + \alpha_1 P_{t+2} + \alpha_2 Y_t + \gamma_1 I_{t+1} + v_{1t}$ (Eq. (11))

	Intercept	I_{t+1}	P_{t+2}	Inf_t	RIR_t	M_t	AR(1): μ	D-W	SSR
11	−207.4	0.96	20.2	203.4	—	—	0.88	1.65	973
	(−3.27)	(9.20)	(1.08)	(3.25)			(18.3)		
12	−3.28	0.91	30.8	—	0.47	—	0.89	1.53	1062
	(−0.96)	(8.18)	(1.58)		(0.81)		(18.5)		
13	7.74	0.89	37.6	—	—	−2.77	0.91	1.33	972
	(1.73)	(6.40)	(1.93)			(−3.31)	(21.5)		
14	−226.7	0.96	19.2	219.3	0.82	—	0.89	1.66	954
	(−3.52)	(9.11)	(1.00)	(3.47)	(1.47)		(19.6)		
15	−201.9	0.86	25.8	203.4	0.79	−2.53	0.91	1.50	873
	(−3.26)	(7.38)	(1.76)	(3.36)	(1.43)	(−3.16)	(22.4)		

surmise that the future housing price is a good indicator for present investment. Regressions, however, indicate that it is rather the months and the one-period-ahead investment which can explain current investment. And this conclusion is insensitive to the length of gestation lags. Purely looking at the fit of the models, the regressions with three gestation lags ($J = 3$) give lower residual sums of squares than one or two lags (this is not reported). But the statistically insignificant coefficients on three-periods-ahead investment and price suggest that the supply function with three lags is overspecified.

In my judgment, the best estimate of the supply function is either regression 13 or 15 in Table VI. It seems that the inclusion of the months variable is crucial in explaining investment, regardless of the length of the gestation lag. The statistical significance of the months in every regression suggests that time to sale has a large effect on new construction and delay effects cannot be interpreted as forgone interest costs alone. These findings suggest that a simple aggregate homogeneous auction model does not fully describe the housing market, even when expectations are formed rationally (i.e., perfect foresight). This last interpretation gives enough reasons to look at other theories that address the independent correlation between time to sell and new construction.

The supply response to housing price in the short and long runs is analyzed by focusing only on the regressions that include the months variable. To calculate the long-run supply elasticities, I take the ratio $\alpha_1/(1 - \gamma_1)$ calculated from the coefficients in regressions 11 and 15 to be the long-run price response. The calculated average long-run supply elasticity then is 6.07, which is almost twice as large as the calculated average short-run elasticity of 3.19.[26] The implied adjustment cost parameters for a two-period-lag investment range from 0.05 to 0.1. These values are calculated by fixing $\beta = 1$ and $\omega_1 = 0.5$ and then recovering b (the adjustment cost parameter) from the estimated coefficients on P_{t+2} in Table VI. The implied values for b are much larger than the single-period values, which range from 0.0056 to 0.0069. Larger adjustment parameter values for longer gestation period suggest that the impact of adjustment costs on supply decisions is large. Thus, these parameters indicate that adjustments are spread over a long period of time.

The noticeable findings in this empirical section are as follows. An addition of expected investments (from time-to-build technology) to a supply equation increases the quality of the fit and decreases the positive serial correlation. The short-run are less elastic than the long-run supply elasticities. The data cannot support the single-period adjustment cost theory ($J = 0$) that current period housing price alone is a sufficient statistic for the investment supply model. Rather, it is the expected future price and investment, along with the cost-shifting variables such as the months and inflation rate, that can explain the current investment supply function. Further, among the cost shifters, the months variable, the median time on the market for new houses for sale in quarter t, is a crucial indicator in explaining new construction.

5. CONCLUSION

This paper develops and estimates an investment model that explicitly outlines the connection between investment starts and completions, a connection that is often left vague in analyzing investment dynamics. In doing so, I provide an alternate investment technology—gestation lags with adjustment cost—which is a useful extension that can potentially address the positive serial correlation problem in the empirical investment literature.

Empirically, I investigate a supply-determined model of U.S. investment in single-family-dwelling housing units. The evidence suggests that models of gestation lag with adjustment cost technology contribute to understanding housing investment cycles and shed light on investment behavior in general. More specifically, at least two lags are important in explaining quarterly housing investment. This result is statistical evidence which supports the conclusion that on the average it takes 6.12 months to complete a single-family-unit house. The findings

[26]The long-run elasticity of 6.07 is larger than Topel and Rosen's value of 2.76. This discrepancy in the long-run elasticity values is also found by Malpezzi (1996). Using longer data set, he calculates that for the prewar United States, the implied price elasticity from the flow models is between 11 and 18, postwar it is between 9 and 16.

in the paper suggest that time-to-build with adjustment cost technology provides a partial answer to the great cyclical fluctuation in housing investment. Further, the investment model in the paper shows that the inclusion of lags in empirical investment models need no longer be *ad hoc*.

Every estimated equation in the paper suggests that one cannot accept the supply theory: The housing price alone is not a sufficient statistic for the investment supply function. On the short- and long-run supply elasticities, I find that the long run is twice as elastic as the short run. My model shows that a consistent finding of a long lag in response cannot be simply attributed to incorrect expectations or lack of knowledge on the firm's part.

Investment with lags, further, could provide one of the causes of overbuilding in the construction industry. In my model, the solution to the optimization problem implies that current total gross investment depends on the current expectation that is projected onto J future price and other future variables: No more than prespecified J lags appear between the expectation operator and the housing price. This result formalizes the stylized fact that housing investment cycles lead business cycles. That is, according to my model, a housing investor invests with respect to the future price expectation in spite of current economic conditions in order to reap the benefits from favorable future market conditions. Bar-Ilan and Strange (1996) also show that under uncertainty—due to lags in investment—and for some parameter values "optimizing investors might choose to develop in spite of unfavorable current conditions in order not to be out of the market if it improves" (p. 620).

The estimates of my partial equilibrium investment model suggest deficiencies in explaining the residential housing market. The estimates of structural parameters and short- and long-run supply elasticities are not robust to different choices of instrumental variables. Thus, a precise set of cross-equation restrictions on parameters is needed: A close look at the demand side of the housing market as well as at the heterogeneity of firms is needed. Furthermore, a robust finding of a strong negative effect of the median time for a new house to be sold on new construction cannot be taken as an "independent" effect. It is possible to develop a model to address the "months" effect. If "the months" is considered to be the postconstruction lag, analogous to the gestation lag, one could endogenize the time-to-sell effect.[27]

DATA APPENDIX

Time series data used in the paper are seasonally adjusted, quarterly from 1963:1 to 1991:4 with 1987 = 100 as a base year, and from the following sources.

[27]In the spirit of Christiano and Todd, one could of course endogenize all the lags (e.g., time to plan (preconstruction lags), time to build (construction lags), and time to sell (delivery lags)) by prespecifying different fractions of investment for different stages of production.

New single-family housing prices: The price data were obtained from a survey conducted by the Bureau of the Census since 1963 for new single-family homes actually sold during the period. The index refers to characteristics of a standard 1987 quality house as obtained from a hedonic regression of actual price data on a vector of house characteristics in each year. Source: U.S. Bureau of the Census, New One-Family Houses Sold and for Sale (Construction Reports, Ser. c25). For the Citibase code: HNPRR.

Boeckh cost index: A weighted average of construction input prices for small residential structures. Source: U.S. Department of Commerce, Bureau of Industrial Economics, Construction Review. This series is reported bimonthly. Consequently, linear interpolation is performed in order to obtain monthly data. This monthly series is then transformed into a quarterly series.

Nominal interest rates: 3 months U.S. government Treasury Bills. Source: Board of Governors of the Federal Reserve System. Also reported in the Federal Reserve Bulletin, T 1.35. For the Citibase code: FYGN3.

Mortgage interest rates: Data are combined weighted averages of interest rates on conventional first mortgage loans for the purchase of new single-family homes. They are confined to loans originated directly (rather than by correspondents) and are compiled from data received through the cooperation of a representative sample of four major types of lenders in the U.S. These lending institutions are savings and loan associations, mortgage companies, mutual savings banks, and commercial banks. Source: Office of Thrift Supervision (OTS); the same data can be found also in Business Statistics, The Biennial Supplement to the Survey of Current Business.

Investment: Fixed Residential Investment in single family structures. Source: U.S. Bureau of Economic Analysis, The National Income and Product Accounts of the United States. Citibase code: GFIRSQ (unit: billion dollars).

Consumption: Aggregate real consumption expenditures. Source: U.S. Bureau of Economic Analysis, The National Income and Product Accounts of the United States. Citibase code: GDPQ (unit: billion dollars).

Months: Median number of months of new houses on market, start to sale (# of months). Source: U.S. Department of Commerce, Bureau of the Census, or U.S. Department of Housing and Urban Development. New one-family houses sold and for sale. Also reported in Construction reports:C25. Citibase code: HNMM.

Consumer Price Index: Urban consumers price index for all items. Source: U.S. Department of Labor, Bureau of Labor Statistics. Citibase code: PUNEW.

Energy Price Index: Urban consumers energy price index. Source: U.S. Department of Labor, Bureau of Labor Statistics. Citibase code: PU803.

Families: The number of households. This includes the related family members and all unrelated persons who share the housing unit. Source: U.S. Department of Commerce, Bureau of the Census, The Current Population Survey. Citibase code: POH (units: thousands).

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