Unifying Empirical and Theoretical Models of Housing Supply

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Abstract

Housing supply plays an important role in the volatility of macroeconomic cycles and the speed with which house prices respond to changes in demand, yet it is understudied in the current literature. In this paper we present and estimate a new model of the supply of residential construction that is consistent with the theoretical treatment of land development and urban growth. The model shows that new housing construction is best described as a function of changes in house prices and costs rather than as a function of the levels of those variables. Previous research that uses the price levels specification has the drawback that a one-time increase in the number of households that raises the level of real house prices leads to a permanent jump in new construction and thus an infinite increase in the stock of housing. The empirical tests of the model support our new specification, which performs better than alternative models in out-of-sample forecasts. Our estimates suggest a fairly moderate response of supply to house price changes. A 10 percent rise in real house prices leads to an 0.8 percent increase in the housing stock, which is accomplished by a temporary 180 percent increase in the average number of quarterly starts, spread over four quarters.

Introduction

Construction of new housing plays a critical role in the economy. Housing starts are more volatile than the overall economy and tend to lead recessions and recoveries. Residential construction influences overall output both directly, as construction and manufacturing employment rises with housing starts, and indirectly, through the multiplier effect and because new home buyers tend to purchase other consumer durables contemporaneously with the purchase of their house. Changes in new housing supply also affect the price of existing units, which in turn has a large influence on the wealth position of existing homeowners and helps determine housing affordability. Finally, the elasticity of supply is a key determinant of how housing prices would respond to fundamental tax reform. (See Capozza, Green, and Hendershott 1996.)

Despite its importance in the macroeconomy, empirical research on housing supply is surprisingly rare. This dearth of work is striking when compared to the extensive literature on housing demand, a discrepancy noted in housing market overviews by Olsen (1987) and Smith, Rosen, and Fallis (1988), among others. Most of the existing empirical work treats housing like other types of capital. This approach fails to recognize the defining role of land in residential development and construction. In this paper we present and estimate a model of the supply of new single-family residences that is consistent with the theoretical treatment of land development and urban growth. Unlike other empirical models, our approach is also consistent with the time series characteristics of the data. After developing and testing the model, we use out-of-sample forecasts to compare it with several alternative empirical treatments of new housing supply.

Our model of new housing supply is developed from the relationship between city size and land and housing prices found in Capozza and Helsley (1989). Housing has two components: the structure (capital), which is supplied at constant cost in the long run, and land which is inelastically supplied, even in the long run. Over time, differences in housing are solely determined by differences in land prices. In a given metropolitan area, vacant land is available at the fringe of a city, but this land is inferior to existing locations that are closer to the downtown or other suburban subcenters. Unlike other investment goods, the long run cost curve for land is upward sloping. A one-time increase in new construction leads to a permanent increase in land prices to ensure a spatial equilibrium.

House prices are a stock variable that equilibrates the total quantity of housing with the total demand for residential space. Housing starts, on the other hand, are a flow variable, representing the change in the stock of housing. Starts should be a function of other flow variables, including the change in house prices. In contrast, the standard empirical model characterizes new construction as a function of the level of house prices. This traditional specification ignores the fact that variables such as city size and the opportunity cost of new land help to determine land prices and thus housing price levels at existing locations, but have no effect on the number of new starts in the steady state.

A simple example demonstrates the intuition of treating housing starts as a function of house price changes. Imagine a city composed of a stable number of homogeneous households. If the city is not growing and housing units do not depreciate, then the housing market will be at its long run equilibrium, house prices will be constant, and housing starts will equal zero.[1]

[1]If households are heterogeneous and changing, then there can be new starts to meet the changing needs of the stable existing population. Even with positive depreciation, housing starts will just equal a

Suppose that the city has an unexpected one-time influx of population. Demand for new residences increases, land and house prices rise, new construction occurs, and the city increases in size to accommodate the new residents. At the new equilibrium, the city is physically larger. To ensure that households are indifferent between living in houses in the newer, more distant locations and existing units, the price of developed locations must rise above the level that they were before the population inflow. In the new spatial equilibrium, population is again stable and there are no expectations of further growth, so starts are again equal to zero and prices are constant, though at a higher level.

In our example, starts occur only when the city makes the transition from one equilibrium to another, a period identified by the increase in the price level. A model where starts are a function of the price level would predict a permanent increase in the number of housing starts resulting from the one-time unexpected increase in population.[2] Yet starts will increase only as needed to accommodate the new residents, a one-time event. The difference between housing starts and housing price levels is also apparent in the data on U.S. housing prices and starts shown in Figure 1. (An explanation of the data is provided below in Section IV.) Between 1987 and 1994, house prices remained above the level of earlier periods, yet starts during this period were consistently below the number of starts recorded in the late 1970s. This figure suggests the limitations of using price levels to explain housing starts. By contrast, Figure 2 shows that the

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constant percentage of the stock that does not vary each period

[2]If we allow for depreciation in the model, we can obtain a positive correlation between housing prices and starts. When the population of the city is higher, the city occupies a greater land area, so that housing prices are higher, and the stock of housing is larger. With a constant removal rate, the larger city requires a greater number of housing starts to maintain its existing stock of units. Thus starts after the increase in population would be higher than before, as would house prices.

relationship between housing starts and the change in house prices is much more stable.

Unlike the conventional treatments of housing supply, our model generates a stable measure of the true supply elasticity, the percentage change in the housing stock from a percentage change in prices. A one-time increase in house prices leads to a one-time increase in the stock of housing, because of the temporary increase in new construction. In contrast, existing research uses estimates from the housing starts function to identify a starts elasticity, the percentage change in starts caused by a percentage change in the level of house prices. With this treatment, a change in the level of house prices results in a permanent increase in new construction. Though the change in new construction is finite, the stock of housing will increase without bound as starts are higher in all future periods. Thus, a fixed starts elasticity yields an infinite supply elasticity. Our estimate of the true elasticity of supply with respect to prices is quite small because housing starts are a small percentage of the stock - annual starts are 2.2 percent of the stock.

Treating starts as a function of house price changes is also consistent with the time series properties of housing stock and prices. Previous research (for example, Holland 1991, Meese and Wallace 1994, and Rosenthal 1995) shows that the real price of existing housing is not stationary in levels (I(0)), but is instead stationary in differences (I(1)). The stock of housing is also non-stationary. Advances in time series analysis have revealed problems in estimating relationships between data series that are non-stationary. Although over short time periods or in small samples trending and stationary variables may be correlated, in the long run this correlation will disappear. Furthermore, regressions using multiple non-stationary series can lead to spurious correlations (Granger and Newbold 1974). If the stock of housing and real house prices are both stationary in differences, the proper econometric specification is to regress starts on price changes.

In the next section of the paper we review existing empirical treatments of the supply of new residences. We present our formal model in Section III. In Section IV, we use national time series data from 1975 to 1994 to estimate an empirical specification of the model of new housing supply. We also use out-of-sample forecasts to show that our model fits the data better than other specifications used in DiPasquale and Wheaton (1994) and Topel and Rosen (1988). Section V concludes the paper with an agenda for future research.

II. Review of Empirical Housing Supply Research

Existing empirical studies of housing supply use two approaches to estimate the relationship between starts and house prices. In the first, housing supply and demand functions are combined into a single reduced form equation. The price elasticity of starts is derived from the coefficients on supply and demand shifters in the reduced form regression. Authors such as Muth (1960), Follain (1979), Stover (1986), and Malpezzi and Maclennan (1994) use variants of the reduced form and find no statistically significant relationship between price levels and demand measures, suggesting that the supply curve for new housing is perfectly elastic. Olsen (1987) notes that, if improperly specified, this approach can yield inconsistent coefficient estimates when both input costs and output are included as independent variables in a price equation.[3] The second method directly estimates the aggregate supply curve for new residences,

[3]Follain includes a variety of specifications, only one of which is directly affected by this criticism. Malpezzi and Maclennan structure their tests to avoid the problem altogether.

modeling starts as a function of the level of house prices and various cost shifters. This modeling of new housing supply curves (for example, Poterba 1984, 1991; Topel and Rosen 1988; and DiPasquale and Wheaton 1994) yields an upward-sloping supply curve with a price elasticity of starts that is approximately equal to 3.

In their widely cited paper, Topel and Rosen (1988) borrow from the general investment literature to estimate single-family starts using a dynamic marginal cost framework in which marginal costs rise with output and the change in output. In response to a positive demand shock, builders lower their total costs by smoothing their increase in output over a number of periods. In their empirical work, Topel and Rosen find evidence of this relationship: both lagged and future starts are correlated with current-period output. They find that the single-quarter price elasticity of starts is about one-third of the long run value.

Their model does a good job of placing development in a dynamic framework and evaluating the investment aspects of residential development. The premise of the model is that builders smooth production in response to demand shocks. However, some authors in the inventory investment literature have criticized this approach. For example, Blinder and Maccini (1991) demonstrate that actual production is typically more volatile than sales in the manufacturing sector, implying that little smoothing occurs. A similar result occurs in housing markets, where the coefficient of variation for starts is greater than that for sales of new houses (0.26 versus 0.19).

The formal presentation in Topel and Rosen does not address the role of land. Instead their treatment focuses on a model that is more appropriate for the supply of structures. Still, it is possible to interpret their empirical results as a function of the land development process. For instance, smoothing in housing starts can be caused by the time required to procure serviced land and obtain building permits, rather than by inter-temporal smoothing by builders.[4]

DiPasquale and Wheaton (1994) estimate a stock-adjustment model in which current starts are a function of the difference between desired stock and the stock in the previous period. They use the current price level as a proxy for the desired stock and an actual estimate of the lagged stock. Consistent with the above model, DiPasquale and Wheaton estimate a starts equation and find that the coefficient on prices is positive and the coefficient on lagged stock is negative. Their approach has the advantage that it recognizes the stock-flow problems that plague much of the earlier research. It has the disadvantage that the quarterly stock of housing is notoriously difficult to measure in non-Census years, because physical depreciation and removals are unobserved and not all starts are completed with the same lag.[5] Thus the variation in their lagged stock variable is almost identical to the variation in previous periods' starts. In addition, while the authors recognize the problem inherent in estimating starts solely as a function of the price level, they do not take into account the same problems in using the level of costs and interest rates.

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[4]These conditions are not strictly identical to Topel and Rosen's rising marginal costs of production. The supply of new units can become perfectly inelastic at a certain point because land ready for building is just not available, so the supply function is no longer continuously differentiable. The assumption of continuous, fully differentiable, input supply functions in the dynamic marginal cost approach may apply to a semi-mobile input like skilled labor, but can be less appropriate for a spatially fixed factor such as land. Mayer and Somerville (1996) find that production lags vary by region, with greater lags in the Northeast and the West, where land approval processes are slower, and fewer lags in the South and the Midwest.

[5]They assume constant decennial rates of removals or demolitions. The stock of housing in a given quarter is calculated by taking the stock last quarter, adding last quarter's starts, and subtracting the decennial average removal rate.

III. A Model of Residential Construction Based on Land Development

In the model that follows, new construction depends on the development of raw land. Our treatment of land development is based on Capozza and Helsley (1989) and draws heavily on the Arnott and Lewis (1979) and Wheaton (1982) models of the conversion of land to urban use. Throughout, we assume that all new construction occurs at the urban fringe. This assumption is consistent with the fact that relatively few U.S. single-family starts involve redevelopment of existing sites or occur in core urban areas.[6]

Builders convert raw land to urban use by developing the land and constructing housing on the finished lots. With fixed lot and house sizes, developers maximize profits by selecting development time t^* to convert land at location d, given agricultural land rent r_a, house rents r_h, and structure cost c_h:

$$\max_{t^*} \pi(\gamma,b) = \int_T^{t^*} r_a e^{-i(\gamma-T)} d\gamma + \int_{t^*}^{\infty} r_h(d,t) e^{-i(\gamma-T)} d\gamma - c_h e^{-i(t^*-T)}. \quad \textbf{(1)}$$

The solution to this problem is the optimal development time:

$$r_h(d,t^*) = r_a + ic_h. \quad \textbf{(2)}$$

Conversion occurs when the price of housing at a currently undeveloped location exceeds the

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[6]Among the 44 SMSAs surveyed in the 1989-91 AHS metro files, only 16 percent of units less than 5 years of age are in the SMSA's principal city. These units tend to be located in those SMSAs, such as Ft. Worth, Oklahoma City, Phoenix, San Antonio, San Diego, and San Jose, where the central city includes undeveloped land within its municipal boundary. In 18 of the 44 SMSAs, fewer than 2 percent of newer units are located in the SMSA's principal city. While new housing is also provided by the redevelopment of existing properties, this tends to occur at much higher densities and is generally not a factor for the supply of new single-family residences.

agricultural value and cost of conversion. At the fringe, land owners must be indifferent between leaving land in its existing agricultural use or developing it, so location rents must equal zero.

Applying the optimal development timing to a monocentric city allows us to develop a model of aggregate housing starts.[7] In a monocentric city all workers are assumed to work in the city center and location rents reflect commuting costs to the urban core. Equilibrium house rents depend on city size b (the distance from the core to the city border), transport cost k, structure cost, fixed lot size q, and agricultural land rent. At time T and distance d from the city center, the price of a house is given by the present discounted value of house rents:

$$p(d,T) = \int_T^{\infty} [r_a q + i c_h + k(b_t - d)] e^{-it} dt. \tag{3}$$

The first term is the rent for the land in its current use, the forgone agricultural rent. The second term is the rental value of the house's structure capital using a discount rate i. The third term is the location rent needed for a spatial equilibrium, which equals the linear transportation cost k multiplied by the distance a house is located from the urban fringe. A house that is located close to the city center will have low transportation costs and thus higher rents. At the fringe, the location rents equal zero.

Current prices depend on the expected growth rate for the city g. When g is known, solving the integral in (3) yields:

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[7]General results from a polycentric city will be similar, as long as all employment centers are in the interior of the urban area. The mathematics of these solutions are substantially more complicated. As a result, we use the simpler, though less realistic, monocentric model to convey the qualitative results of this approach.

$$p(d,t) = \frac{r_a q}{i} + c_h + \frac{k(b_t - d)}{i} + \frac{kb_t g}{i(i-g)}. \quad \textbf{(4)}$$

The first three terms are the present value of the components of current rent. The last term is the present value of the expected increase in rent at location *d*. It is derived from future increases in location rents that will be needed to ensure a spatial equilibrium as the city grows at the expected rate *g*. Thus increased demand from population growth raises location rents, allowing previously undeveloped land to meet the criterion in equation (2). This new land is developed, providing residences for the increase in population.[8]

Instead of defining prices as a function of the distance from the border to the city center, we rearrange equation (4) to express the border as a function of house prices at a fixed interior location $\bar{u}$ ($\bar{u} \leq b_T$):

$$b_t = (i-g)\left[\frac{p(\bar{u},t) - c_h}{k} - \frac{r_a q}{ki} + \frac{\bar{u}}{i}\right]. \quad \textbf{(5)}$$

Next, we relate the city border to the total stock of housing.

The stock of housing units at any point in time is the sum of all housing built, with adjustments for abandonment and demolitions. When there is no undeveloped land in the city, the stock measures city size. In a circular city of radius b_t with θ radians of developed area and fixed lot size q, the total stock H_t can be described by the city's radius, the distance to the

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[8]Another strand of literature on city growth (Capozza and Helsley 1990) examines this transition as the exercise of a real option. The real option treatment of land development generally studies whether real estate prices reflect an option value (Titman 1975; Capozza and Schwann 1989; Williams 1991; and Quigg 1993), although recent work examines the implication of the real options framework for new construction (Holland, Ott, and Riddiough 1995).

boundary:

$$H_T = \frac{\pi b_t^2}{q} * \frac{2\pi}{\theta} = \frac{2\pi^2 b_t^2}{\theta q}. \qquad (6)$$

Total starts between two periods will equal the change in the city's area adjusted for lot size. To ease the exposition we assume no abandonment or demolition and that all development occurs in a smooth process with no leapfrogging. In this case, starts equal the change in the housing stock over a single time period from T-1 to T :

$$s_T = H_T - H_{T-1} = \int_{T-1}^{T} \frac{4\pi^2 b(t)}{\theta q} dt. \qquad (7)$$

Equation (7) and the characterization of the city border from (5) can be combined to express the equilibrium level of starts $s*$ as a function of prices in the two periods:

$$s_T^* = \frac{4\pi^2}{\theta q} * [F(p(\bar{u},T),c_h(T)) - F(p(\bar{u},T-1),c_h(T-1))]. \qquad (8)$$

This equation formalizes an aspect of DiPasquale and Wheaton's work. They describe starts as a function of optimal and lagged stock. These two variables are themselves functions of current and lagged prices and costs. Thus equation (8) reflects the same underlying economic and spatial factors.

If we substitute for $b(t)$ in equation (7) and then take the integral, starts in (8) are a quadratic function of $p(\bar{u},T)$ and $p(\bar{u},T\text{-}1)$. The quadratic specification is accurate when development is a smooth, continuous process around the entire ring of the city border. However, land assembly, topographical constraints, non-market uses of land, and differences in land use regulations across space all serve to prevent this pattern of development. They also make it difficult to identify the precise form of the underlying relationship between distance to the border and city population. If we assume an urban form that causes (8) to be linear in $p(\bar{u},t)$, then starts are a function of the change in house prices $\Delta p(\bar{u},t)$. Given the complications of urban space listed above, for small changes in prices approximating equilibrium starts in (8) as linear in changes in prices and costs is not unreasonable.

This model assumes perfect foresight by profit-maximizing developers and that development occurs instantaneously as needed to meet the growth in the city's population. To add realism to the model, we introduce a more complicated dynamic adjustment formula to the housing supply process. In order to supply housing, developers must first convert agricultural land to urban use as finished lots. Because of delays in the development process, developers must forecast demand several periods in advance without knowing the actual demand for new housing. Once they have produced finished lots, builders can then construct new housing. We assume that it takes one or more quarters to convert land to finished lots, but once it is converted, construction occurs instantly.[9]

The supply of finished lots, ld, in any period is a function of previous period forecasts of city growth, which are themselves a function of price and cost changes in period t-1:

$$ld_t = D(\, E_{t-1}(\Delta P_t, \Delta c_t\,)\,) = G(\, \Delta P_{t-1}, \Delta c_{t-1}\,). \qquad \textbf{(9)}$$

[9]These assumptions are reasonable, as land development is the slowest part of the supply process. Negotiating the approvals and subdivision permitting process can take up to several years in some jurisdictions. In contrast, once permits are obtained houses can be constructed in less than 60 days.

The supply of developed lots acts as a constraint on the number of houses that can be constructed, thus forming an upper bound on actual starts s_t. The number of actual starts depends on demand for new housing starts and the supply of lots:

$$s_t = \min [s_t^* , ld_t]. \qquad \textbf{(10)}$$

Incorporating (8) and (9) into (10), actual starts are a function of current and lagged price and cost changes:

$$s_t = \min[s_t^*(\Delta p_t, \Delta c_t) , ld_t(\Delta p_{t-1}, \Delta c_{t-1})] \approx J(\Delta p_t, \Delta c_t, \Delta p_{t-1}, \Delta c_{t-1}). \qquad \textbf{(11)}$$

The difficulty in identifying the exact form of the expectations process for future price changes leads us to estimate (11) in a reduced form.[10]

Though the structure of our model differs from that of DiPasquale and Wheaton, we share much in common. We formalize the interrelationship between movements in housing prices, land development, and the existing stock that is implicit in the DiPasquale and Wheaton model. Their use of lagged stock in conjunction with price level is an attempt to capture the relationship between demand for new units and the existing urban form. We achieve similar results through the use of price changes.[11] One advantage of our approach is that the specification does not

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[10]It is possible to incorporate Topel and Rosen's (1988) treatment of a rising average cost curve for housing structure into this framework. Starts would also depend on the difference between equilibrium starts and starts last period. In studying actual construction costs, Somerville (1996) finds that construction costs are endogenous, rising with increases in market activity, a result consistent with Topel and Rosen's premise.

[11]Complete substitution for the equilibrium stock in the DiPasquale and Wheaton starts equation results in starts as a function of the long run equilibrium price. Although this price is unobserved, it can

require the stock of housing, a variable that is observed directly only in census years. Also, the above specification shows that costs as well as prices should be included in differences.

IV. Empirical Analysis

The above model describes a supply function for new housing that is consistent with the land development process. While the model is most appropriate for a single city, the empirical work that follows uses national data. Doing so imposes the strong assumption of a single national housing market. Although this assumption is inconsistent with the reality of distinct, spatially segmented local housing markets, the vast bulk of the existing literature uses national data; using these data allows us to compare our results with existing studies of the supply of new housing. Also, several of the data series that we use are not available at the metropolitan area level.

We use the Freddie Mac repeat sales price index to measure house price movements. The Freddie Mac index has the advantage that it controls for differences in the locations of new and existing housing. As an urban area grows, new construction occurs at the fringe, which is increasingly distant from existing housing units and employment centers. With growth in the size of an urban area, the location premium (and thus the price) for existing units increases. But as equation (2) indicates, land prices at the urban fringe, where new construction occurs, remain stable, even though the fringe itself is located ever more distant from the city center.[12] In the

be expressed as a function of the current and previous period's price, which is analogous to the change in prices.

[12]Land prices may not be strictly constant because of differences over time in the opportunity cost for agricultural land and expectations of the level and variance of population and income growth.

pure form of the model, (anticipated) growth causes increases in the price of existing housing units, while the price of new units is stable. However, Topel and Rosen, like most other researchers, measure demand using a price series for new housing (Census Series C-27). Changes in the location of new housing over time mean that this price measure is biased downward, because it does not incorporate the increase in location rents (prices) inside the city as growth occurs. By measuring price changes by repeat observations of housing units at fixed locations, the repeat sales methodology of the Freddie Mac series controls for location and thus is more consistent with the theoretical model presented above.

Table 1 gives descriptive statistics for all of the variables used in the empirical work. The real house price series is calculated by taking the Freddie Mac index, which identifies quarterly changes in house prices for the years 1975 to 1994, and converting these changes to house price levels using the 1991 national hedonic house price estimated in DiPasquale and Somerville (1995).[13] Real house prices increase by an average of $224 per quarter (0.3 percent of the mean price level), with declines as large as -$2,508 and increases as high as $2,127. Most of these gains occurred in the late 1970s; real house prices leveled off in the 1980s. Housing starts also vary significantly over the cycle. Quarterly starts range from 113,600 to 449,100 (0.2 to 0.8 percent of the total stock).[14]

We use real the real prime rate to measure the cost of financial inputs to builders. Most

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[13]All dollar values are in third-quarter 1994 dollars, deflated using CPI-UX less shelter.

[14]The stock series is estimated using the starts series and the 1970, 1980, and 1990 Census counts and the 1993 American Housing Survey estimate of the number of year-round single-family residences. The inter-decennial removal rates are estimated so that starts minus total removals equals the stock in the next census year. The estimated annual rates for 1970-80, 1980-90, and 1990-93 are 0.2, 0.5, and 0.47 percent respectively. The 1990-93 rate is assumed to hold for 1993-94.

construction loans are financed at adjustable rates based on the prime rate. Any demand-side effects of changes in interest rates should be captured by the user cost, which is included as an instrument for price changes.[15]

Evidence of positive serial correlation for real house prices in the short run (Case and Shiller 1989) suggests that prices do not fully adjust to clear the housing market. In fact, time-to-sale also varies significantly at different parts of the cycle and changes in this measure can precede real price movements. For example, at the beginning of a downturn, time-on-the-market will typically rise several quarters before observed transaction prices begin to fall (Genesove and Mayer 1995). Thus, like other researchers we include in our model the lagged value of the median number of months recently sold new homes were on the market, to proxy further for demand factors that are not covered with price changes. This variable exhibits considerable variation, with a low of 3.7 months to a high of 11.6 months.

By estimating starts as a function of changes in house prices, we address the econometric problems that occur because house prices are non-stationary (Holland 1991; Meese and Wallace 1994; and Rosenthal 1995). Augmented Dickey-Fuller (ADF) tests for stationarity presented in Table 2 confirm that both starts and price changes are stationary, although the power of these tests can be quite low when samples are small (Faust 1993). These results show that the time series nature of the data is consistent with the model presented earlier.[16] Figures 1 and 2 from the

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[15]The user cost of capital can differ from the prime rate because it is based on long-term loans (home mortgages) and marginal tax rates. Interest rate spreads and marginal tax rates both vary significantly over time, so that the two series are only weakly correlated. (See Poterba 1991.)

[16]The empirical tests of the housing starts model presented above are intended to explain short-term cyclical variations in housing investment (starts), rather than the long run relationship between the housing stock and the price level. Other tests (not presented here) reject a cointegrating relationship

introduction also demonstrate this point.

The model in equation (11) requires lagged price and cost changes, but the appropriate number of lags depends on the length of time required to acquire and obtain housing permits as well as builders' expectations about changes in future house prices. (See equation (10) above.) We use the following equation, with starts as a function of current and lagged changes in house prices, real interest rates, and construction costs, along with quarterly dummies q_i and a time trend T:

$$s_t = f\,[\Delta p_t ,\ldots, \Delta p_{t-3} , \Delta r_t , \Delta r_{t-1} , \Delta c_t , q_i , T]. \qquad \textbf{(12)}$$

We use an instrumental variables estimator for (12) because of the possible endogeneity of both current period house prices and construction costs. Instruments include lagged changes in construction costs and current and lagged changes in the number of married couples, the user cost of capital, non-construction employment, and real energy prices, as well as current and lagged exogenous variables.[17]

Table 3 presents estimated coefficients from (12), along with several alternative specifications. We correct for serial correlation using an AR1 process. The Q-statistics indicate that the 95 percent chi-squared critical values are met for all regressions. The first regression is a direct estimate of equation (12). The regression yields plausible parameters; the coefficients on the current and first two lags of changes in prices and current interest rate changes are statistically different from zero at the 5 percent level.

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between the stock and the real price of housing.

[17]These instruments are similar to those used by Topel and Rosen.

Changes in house prices have the strongest effect on housing starts. In regression (1), a one-standard-deviation increase in real house prices ($943) increases aggregate starts by 18,300 units in the quarter of the increase, and by 53,800 units over the course of a year. These figures are approximately 7.0 and 20.7 percent of mean quarterly starts respectively. The alternative specifications in regressions (2) to (4) yield similar results though the aggregate effect on starts tends to be smaller; for instance, a total increase over a year of 45,200 units in regression (3).

Changes in real interest rates have a statistically significant effect on housing starts, but the effect is smaller in magnitude than that of changes in house prices. In regression (1), a one-time, one-standard-deviation (1.3 percentage points) increase in the real prime rate lowers total starts by 12,000 units, less than 5 percent of the average number of starts in a quarter. The effect is smaller, 8,000 units, in regression (3). The effect of changes in interest rates on demand for housing is captured in the price change variable; changes in the user cost is an instrument for price changes. This small direct effect of real interest rates on housing starts does suggests that much of the effect of interest rates on the housing market occurs through demand rather than supply.

As in other empirical housing supply studies, the coefficient on materials prices is not statistically different from zero. Lacking appropriate instruments at the national level that are uncorrelated with housing demand with which to correct for the endogeneity between starts and materials prices, we use lagged material prices. As demonstrated in column (2), removing the materials cost variable from the basic equation has little effect on other coefficients.

Regression (3) in Table 3 augments the basic equation with the lagged values of median time-to-sale for new homes, a non-price measure of market conditions. Consistent with the findings of both Topel and Rosen and DiPasquale and Wheaton, this variable is negative and significantly different from zero, suggesting that builders pay attention to sales rates as well as prices in deciding whether to start new homes. The inclusion of lagged time-to-sale slightly reduces the size of the coefficients on current and lagged price and interest rate changes. The coefficient on median time-to-sale in column (3) suggests that deviations in this variable have a quite large effect on new construction. A one-standard-deviation increase in the median time-to-sale lowers aggregate starts by 16,300 units, approximately 36 percent of the total effect of a one-standard-deviation change in price. Clearly, builders respond to demand factors other than price.

Lagged stock is included in regression (4) to control for the role of depreciation in explaining new construction. With a constant depreciation rate, starts should increase with the stock as more units depreciate and need to be replaced. In the other specifications we assume that this depreciation is captured by the time trend and the constant. In DiPasquale and Wheaton, lagged stock is important because it describes aspects of the land market and urban growth not fully revealed in price levels. Once we control for price changes, the coefficient on lagged stock is not statistically different from zero and including it has little effect on the results. This suggests that our approach of using price changes is successful in capturing the process of urban growth in the housing starts equation.

Like DiPasquale and Wheaton, we differentiate between the elasticity of housing supply and that of housing starts. The former describes the percentage change in the entire stock of housing, while the latter addresses the flow of new construction. Regression (1) in Table 3 generates an estimated supply elasticity of 0.08, so that a doubling of house prices would increase the entire stock by 8 percent. Our estimate is substantially lower than DiPasquale and Wheaton's estimate of 1.0-1.2. The differences results from their conclusion that only 2 percent of the difference between the optimal and existing stock of housing is made up in any given year. This finding seems quite low given the extent to which the level of housing starts can change quite rapidly in short periods. In contrast, our data suggests that the complete response of the stock to a demand shock occurs in approximately one year.

Comparing our elasticity of housing starts to existing estimates is difficult because our starts elasticity is sensitive to the period over which we aggregate starts. Here, a one-time increase in prices increases starts in the current quarter and in each of the next three quarters. Afterwards, starts return to their previous level. The percentage increase in starts in the current quarter as a result of a 1 percent increase in prices is 6.3 six times the estimate from DiPasquale and Wheaton and Topel and Rosen (1988). If the total increase in starts from a 1 percent increase in prices is measured against the mean of quarterly starts, our estimated elasticity of housing starts rises to 18.5. While large, this increase in construction is only temporary; starts return to their initial level after a year. In contrast, in the existing models starts are permanently higher because of a permanent increase in the level of construction.

Comparing our result directly with those of other researchers is difficult because of differences in the underlying models. Instead of limiting the comparison to regression coefficients, we also present out-of-sample forecasts for our model, using regression (3), and those of DiPasquale and Wheaton (1994) and Topel and Rosen (1988). Table 4 presents the estimates from each of the models using data from 1976 to 1987.[18] The coefficients from the

[18]In their papers DiPasquale and Wheaton and Topel and Rosen use different price variables and interest rate measures than we do here. To facilitate direct comparisons, all of the forecast regressions use the Freddie Mac price index.

DiPasquale and Wheaton specification are similar to those presented in their article. However, the estimated coefficients from the Topel and Rosen model appear to be less stable. In fact, the estimated coefficient on the current price level is not statistically different from zero.

Next, we use the coefficients from these estimates to develop forecasts for 1988 to 1994, which we present in Figure 3. Overall, our model performs better than those that use price levels: the standard error of our forecast is 24.2, well below that of the other two models, 32.9 for DiPasquale and Wheaton and 36.4 for Topel and Rosen. These forecasts use estimated values for lag starts, i.e. dynamic updating, rather than actual starts. The difficulty in using estimated future values for starts means that the forecast for the Topel and Rosen model in Figure 3 is based on regression (4) on Table 4 rather than on their actual specification, which is regression (3). While we cannot draw definitive conclusions from these forecasts because of the relatively small sample size and the difficulties in generating forecasts from the Topel and Rosen specification, the above results indicate that the model presented here may outperform existing treatments of housing supply.

V. Conclusion

In this paper we develop an empirical model of new single-family housing supply that reflects the role of land in producing new housing and is more consistent with theoretical treatments of urban growth than existing studies of housing supply. This approach also better reflects the time series properties of housing market data. Empirical estimates support the treatment of housing starts as a function of changes in existing and lagged house prices and costs, rather than price and cost levels. The significance of up to three lags of price changes and one lag of interest rate changes suggests that lags in the development process cause housing starts to adjust slowly to demand shocks. The importance of lags is not surprising given the time needed for land assembly, obtaining permits, and then constructing units. Consistent with other research, we find that the lagged value of expected time-to-sale has good explanatory power, which suggests that non-price measures of demand are important in explaining new construction. This outcome is certainly to be expected given the potential delays in land assembly, permitting, and construction. Finally, our model performs quite favorably when its forecasts are compared with forecasts of two other widely cited models of new housing supply.

Our estimates suggest a fairly moderate response of supply to house price changes. A 10 percent rise in real house prices leads to an 0.8 percent increase in the housing stock; this is accomplished by a temporary 180 percent increase in the average number of quarterly starts, spread over four quarters. This process highlights the difference between a housing supply elasticity and the starts elasticity found in the existing literature. Our approach shows that a one-time increase in housing prices leads to a temporary rather than permanent increase in new construction, yielding a finite supply elasticity.

While our model performs well on national data, it is ideally suited for estimating housing supply functions for individual metropolitan areas. As noted above, the level of housing prices can vary across housing markets for reasons that have little to do with the demand for new housing, including differences in population, land availability, and the expected rate of growth. Consequently, applying the conventional specification of starts as a function of the current level of house prices may generate misleading results in cross-sectional or panel analysis. By using changes in house prices instead of house price levels, our model avoids this problem.

In future research we hope to use this model to estimate housing supply functions for different metropolitan area markets. Cross-sectional supply functions would allow us to study the effects of factors such as government building restrictions and the opportunity cost of vacant land on the price of housing and on the speed with which quantity supplied responds to demand shocks. Differences across markets in the elasticity of supply and the speed of adjustment may well explain why prices are higher and real estate cycles seem to be more pronounced in markets such as California and the Northeast, where development restrictions are tighter and buildable land within a reasonable commute to the downtown is scarce.

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Table 1- DESCRIPTIVE STATISTICS

Variable	Mean	Standard Deviation	Minimum	Maximum
Stock (000)				
Level	59851	4443	51481	67166
Changes - Analogous to Starts				
Starts (000) - Not Seasonally Adjusted				
Level	263.4	69.5	113.6	449.1
Starts (000) - Seasonally Adjusted				
Level	259.9	52.5	137.4	371.2
Real House Price				
Level	84154	5714	72706	93305
Changes	224	943	-2508	2127
Real Prime Rate				
Level	4.66	2.93	-1.67	11.02
Changes	0.08	1.32	-4.82	5.61
Estimated User Cost				
Level	9.87	1.55	7.35	13.69
Changes	-0.01	0.34	-1.00	0.84
Median Months to Sale - New Homes				
Level	6.68	1.66	3.70	11.60
Changes	-0.11	2.15	-6.90	4.70
Real Material Price Index				
Level	0.97	0.06	0.87	1.08
Changes	-0.002	0.011	-0.023	0.026
Employment Excluding Construction (000)				
Level	105467	10489	87127	122567
Changes	421	612	-1644	1820
Married Couples (000000)				
Level	50.07	2.07	46.83	53.15
Changes	0.08	0.83	-0.05	0.37
Real Energy Price Index				
Level	0.830	0.114	0.692	1.067
Changes	0.000	0.031	-0.090	0.081

Notes:
Stock is constructed from the decennial census. Quarterly figures are calculated using housing starts and an implied decennial removal rate. Consequently changes in the stock is identical to starts with constant decennial trends. The real house price series is constructed using the Freddie Mac repeat sales price index and the 1991 estimated national hedonic price level from DiPasquale & Somerville (1995). The user costs series is calculated with DiPasquale & Wheaton's (1994) methodology: the marginal tax rate is for the typical first-time home buyer and property taxes are assumed to be 1.8 percent.

Table 2 - AUGMENTED DICKEY FULLER TESTS

Variable	Estimated Alpha	ADF T-Statistic	Reject Unit Root	ADF Probabilty	ADF Lags
Stock					
Level	1.001	0.749		0.991	5
Changes - Analogous to Starts					
Starts					
Level	0.735	-3.312	**	0.013	5
Real House Price					
Level	0.970	-1.417		0.574	4
Changes	0.571	-3.139	**	0.024	3
Real Prime Rate					
Level	0.832	-2.131		0.232	2
Changes	-0.349	-5.087	***	0.001	2
Estimated User Cost					
Level	0.951	1.470		0.470	3
Changes	0.477	2.977	**	0.037	3
Median Months to Sale - New Homes					
Level	0.715	-2.506		0.114	3
Changes	-0.571	-4.481	***	0.001	3
Real Material Price Index					
Level	0.957	-2.245		0.146	3
Changes	0.170	-3.445	***	0.010	2
Employment Excluding Construction					
Level	1.000	-0.024		0.956	4
Changes	0.704	-2.833	*	0.054	3
Married Couples					
Level	0.990	-2.128		0.233	4
Changes	0.508	-4.264	***	0.010	3
Real Energy Price Index					
Level	0.959	-1.239		0.656	3
Changes	0.325	-3.465	***	0.009	2

Notes:
Reject the null hypothesis of a unit root (that alpha = 1) at the following levels of significance: *** = 1% level, ** = 5% level, * = 10% level. All tests are two-sided ADF tests with seasonal dummies included in the regression. The Freddie Mac repeat sales index begins in 1975; to allow for consistent lags across variables, unit root test are imposed for the years 1977-94. With the exception of stock, including a trend does not alter the results. Changes in the detrended stock are nearly identical to the level of starts. By construction, the stock series equal the sum of starts minus a decennial trend removal rate.

Table 3 - REGRESSION RESULTS (1975-94)

Variable	Regr. (1)	Regr. (2)	Regr. (3)	Regr. (4)
Change in Price	0.0194	0.0176	0.0177	0.0189
	0.0091	0.0089	0.0092	0.0087
Change in Price (-1)	0.0196	0.0192	0.0156	0.0159
	0.0047	0.0047	0.0049	0.0048
Change in Price (-2)	0.0134	0.0132	0.0129	0.0129
	0.0043	0.0043	0.0040	0.0040
Change in Price (-3)	0.0047	0.0045	0.0017	0.0017
	0.0051	0.0051	0.0048	0.0048
Change in Real Prime Rate	-4.85	-4.88	-3.67	-3.49
	2.44	2.37	2.32	2.33
Change in Real Prime Rate (-1)	-4.16	-4.33	-2.38	-2.24
	2.50	2.47	2.40	2.41
Starts (-1)				
Stock (-1)				0.0012
				0.0019
Median Months on Market Until Sold - New Homes (-1)			-9.79	-9.33
			4.72	4.57
Change in Real Building Material Cost Index	-98.5		-19.4	14.7
	377.7		373.8	372.2
Time Trend	-0.053	-0.066	-0.228	
	0.438	0.437	0.368	
Constant	208.2	209.2	309.2	356.8
	45.8	45.6	63.9	133.9
Number of Observations	76	76	76	76
Regression Type	AR-IV	AR-IV	AR-IV	AR-IV
Adjusted - R sq	0.81	0.81	0.82	0.86
Log Likelihood	-352.5	-351.9	-348.3	-349.1
Estimated AR1 Rho	0.67	0.67	0.60	0.60
Q-Statistic(4)	6.34	7.47	5.71	5.31

Notes:
Standard errors are in parentheses. All regressions use seasonally unadjusted series and include quarterly dummies. Instruments are used for current changes in real house prices and building material costs. Instruments for current changes in real house prices are current and lagged values of changes in non-construction employment, real energy prices, mortgage rates, and the number of married couples. We use lagged changes in the real building materials price index to instrument for changes in real materials prices. The IV-AR regressions also include lagged values of all exogenous variables as instruments.

Table 4 - FORECAST REGRESSIONS (1976-87)

Variable	Regr. (1)	Regr. (2)	Regr. (3)	Regr. (4)
Change in Price	0.001			
	0.011			
Change in Price (-1)	0.009			
	0.007			
Change in Price (-2)	0.015			
	0.006			
Change in Price (-3)	0.001			
	0.006			
Price Level		0.0034	0.0005	0.0001
		0.0013	0.0004	0.0006
Starts (-1)				0.455
				0.100
Starts (-1) + .98*Starts(1)			0.386	
			0.041	
Starts(1)*.98				0.253
				0.161
Stock (-1)		-0.0066		
		0.0025		
Change in Real Prime Rate	-4.14			
	3.36			
Change in Real Prime Rate (-1)	-4.43			
	3.61			
Real T-Bill		-4.34		
		2.26		
Expected Real T-Bill (-1)			-3.16	-4.66
			1.28	1.82
Change in Employment		0.042		
		0.007		
Expected Inflation (-1)			-0.221	-1.552
			1.085	1.650
Median Months on Market Unt	-20.5	-23.8	-13.0	-13.2
Sold for New Homes Sold (-	7.9	3.6	3.4	3.8
Constant	376.7	501.9	70.9	140.6
	69.5	93.1	46.3	93.7
Model Type	Price Changes	DiPasquale & Wheaton	Topel & Rosen	Topel & Rosen
Number of Observations	47	48	48	48
Regression Type	IV-AR	OLS	IV-AR	IV-AR
Adjusted - R sq	0.80	0.93	0.92	0.92
Durbin Watson	2.08	1.72	2.75	2.69

Notes:
Standard errors are in parentheses. All regressions use seasonally unadjusted series and include quarterly dummies. Instruments are used for current real house price variables and in the Topel & Rosen regressions for both lagged and future starts. The instruments are similar to those used in Table 3. The regressions replicating Topel & Rosen's model use their instruments, with the addition of lagged median months on market.

Figure 1

Single Family Starts vs. Prices

Seasonally Adjusted Starts & Constant Quality Real House Prices

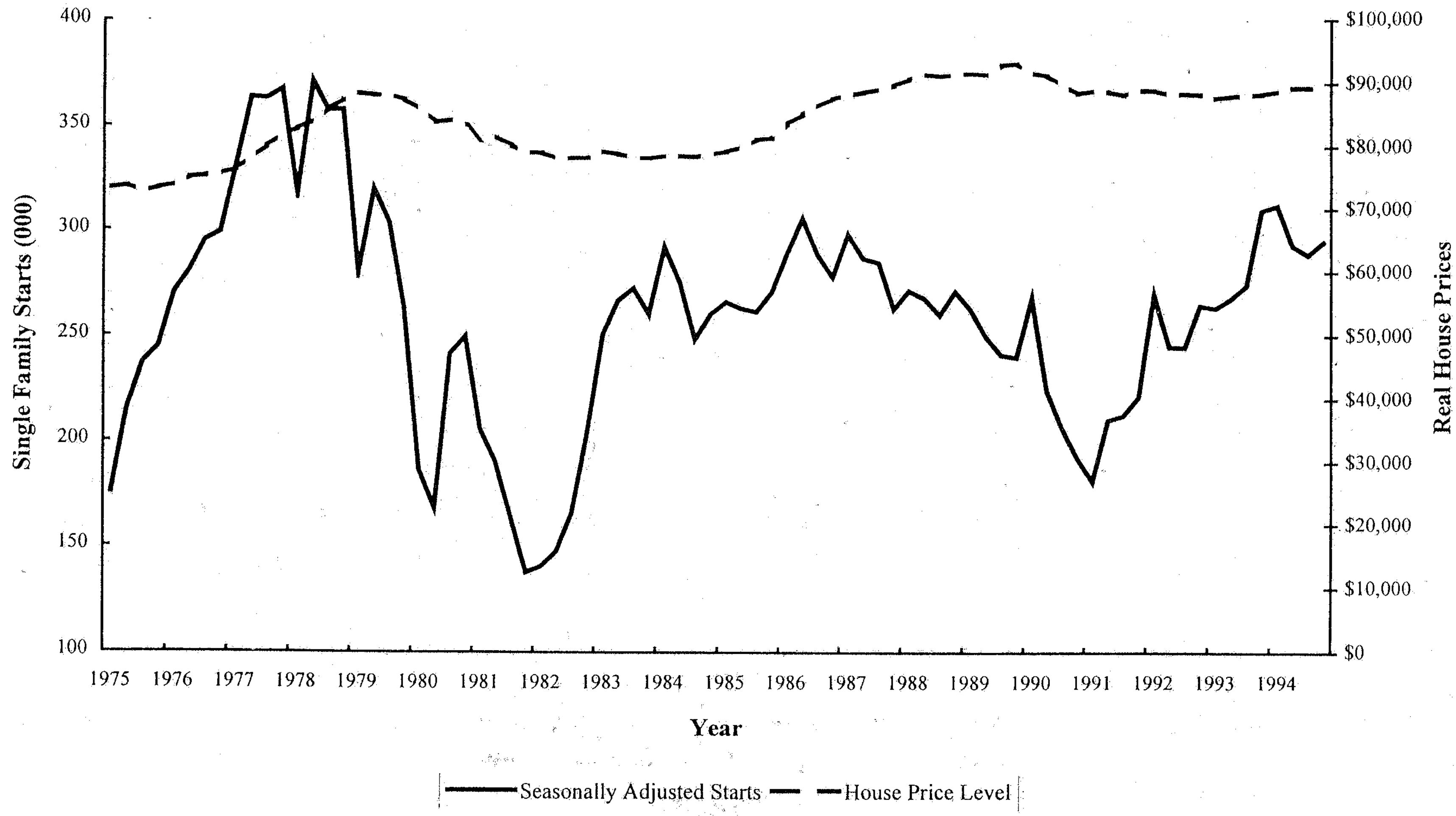


Figure 2

Single Family Starts vs Change in Prices

Seasonally Adjusted Starts & Constant Quality House Prices

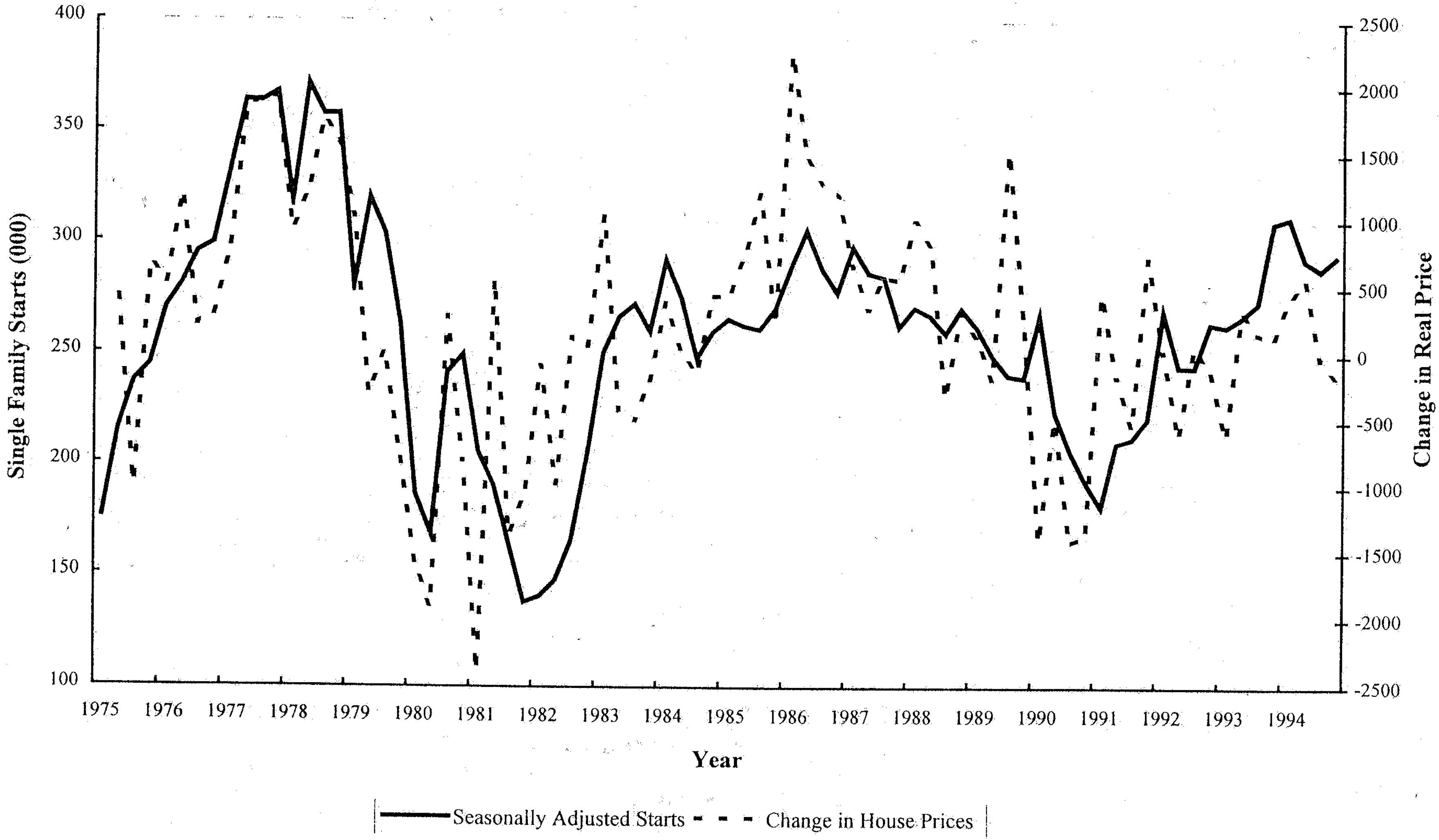
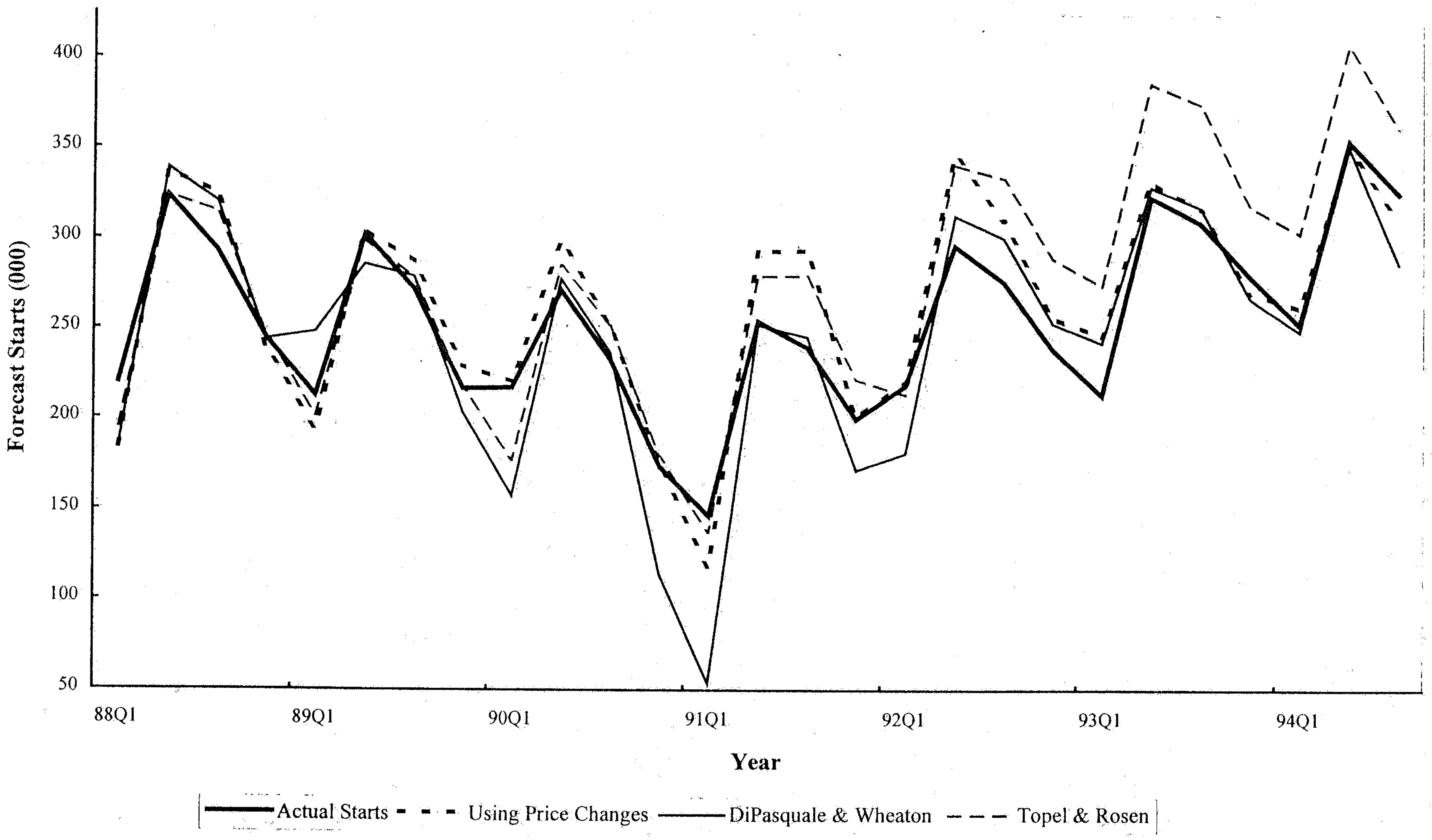


Figure 3

Forecast vs. Actual Starts

Comparing Out of Sample Starts Forecasts



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