# Modeling the supply of new residential construction for local housing markets: The case of Aberdeen, UK

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**Abstract**

Housing investment affects economic growth both directly and indirectly and so understanding the mechanisms underlying the market is of great importance. However, the demand side of the housing market is much better understood than the supply side and most of the housing supply studies are conducted at the national and regional levels even though the advantages of conducting such studies at the local level are well known among researchers. This paper employs several model specifications to estimate the supply of housing for the local housing market of Aberdeen in the UK. It is found that the local variables - changes in house prices, time on the market, planning regulation, lagged stock, and lagged and future housing starts are the main factors that influence new residential construction in Aberdeen. None of the national variables is significant confirming the need to limit housing market analysis to the local level. The price elasticities of supply estimated are in the range of 2.0 - 3.2 for housing starts, and 0.01- 0.02 for housing stock. These estimates are higher than most of the elasticities for the other UK local markets. The paper recommends more local housing market and even firm level studies to be conducted to better understand the supply of housing at the local (district) and firm levels.

**Keywords**: Housing supply, price elasticity, Aberdeen

# 1 Introduction

Housing is very important to the socio-economic development of every nation and as a result has triggered many studies into housing. Because of the importance of housing, any assumption about the price elasticity of housing supply for instance, can have great policy implications (Wigren and Wilhelmsson, 2007). As a result, it has become increasingly important to understand the mechanisms underlying the housing market.

The housing market like any other market comprises of the demand and the supply sides. The actors on the supply side of the housing market include the central government, various regional and local authority councils, real estate developers, housing associations and individuals. The actors on the demand side of the housing market also include corporate bodies, individuals etc.. House prices are determined by the equilibrium of the total quantity of housing (housing stock) and the total demand for residential space.

The demand side of the housing market is an area which is more researched than the supply side (DiPasquale, 1999). DiPasquale also notes that the empirical evidence on the demand side of the housing market is much more convincing than the small evidence we have on the supply side. Simple questions about the price elasticity of housing supply can even produce a wide range of estimates (Ball et al., 2010). The reasons for these divergent estimates may be due to a number of factors. First, the studies are conducted at the different levels of the housing market, ranging from national, regional, local and even at the micro level examining house building firms. Second, different datasets and variables are used for the empirical modelling depending on the available data and the housing market level under study. Finally, different methodological and analytical approaches are adopted ranging from reduced form equations where demand and supply housing functions are combined into a single equation, just modelling construction starts as a function of house prices and various cost shifters, to combining both approaches.

Most of the housing supply studies, particularly in the UK, are conducted at the national and in some limited cases regional levels (see for example Malpezzi and Maclennan, 2001; Tsoukis and Westaway, 1994; Bartlett, 1988) as compared to local housing market studies. Using aggregated data is a problem because it hides interesting variation in the timing of real cycles across regions and also shrouds inter-metropolitan area movements in population (Goodman, 1998). However, even though disaggregated level study is more desirable, it seems very difficult for such local level studies to be conducted. This has been attributed to lack of consistent time series data at the local levels. As a result of this, the studies conducted at the local or district levels in the UK mostly employ cross sectional data (see for example Pryce, 1999; Monk and Whitehead, 1999; Bramley, 1993a, 1993b; DeLeeuw and Ekanem, 1971; Ball et al., 2010). The problem of employing cross sectional data to estimate housing price elasticities is that when cross-sectional data is used to simulate outcomes over time, the reliability of the results will be questionable since the cross sectional data usually cover a very short period of time (Evans, 1996; Pryce, 1999) and so cannot be applied to other points in time or cannot be used to measure long run values (Bartlett, 1988). Clearly, using time-series data has an advantage in that it helps to examine elasticities over long period of time.

This paper provides further evidence about the determinants of housing construction and house price elasticity of supply in the local housing market in the UK. Unlike the previous local housing market studies in the UK which employs cross-sectional data, this study employs quarterly time-series data for a twenty-five year period. Several models are employed and both housing starts and housing stock elasticities are estimated for the various models.

The paper is structured as follows. Section 2 reviews previous housing supply studies and draws conclusions based on which the methodology of this paper is based. Section 3 discusses the statistical methods used to estimate housing supply and house price elasticities. In Section 4, the data is described and pretested. Section 5 presents and discusses the results while Section 6 concludes the paper.

## 2 Review of housing supply research

The supply of housing at any period in time comes from two main sources. The first source is new housing construction that arise as a result of the production decisions of builders of new units. New construction whether from private developers or the public sector contributes to the already existing housing stock. The second source of housing supply comes from the decisions made by housing owners and/or their agents concerning the conversion of existing stock of housing. Housing owners can for example convert two or more units into one to reduce the supply of housing. A very large single-family home can also be converted into several small apartments. Again, owners may decide to renovate an existing unit to increase the flow of housing services that are being provided by that unit or decrease the flow of housing services being delivered by an existing unit by decreasing maintenance (DiPasquale, 1999). Even though improvements to existing stock also contribute to the actual stock, in the USA for instance, new construction is the main source of additions to the existing stock (Baer, 1986).

In modeling housing supply, several variables have been used in the literature to represent housing supply. These include new construction starts, stock or changes in stock, completed houses etc. Table 1 summarises some of the recent studies about housing supply. The Table reveals that housing supply studies usually employ either total housing stock (i.e. total housing supply) or new construction starts (new units) as the dependent variable to measure housing supply, with housing construction or starts dominating. New residential construction or housing starts is the main means of moving the housing stock from one equilibrium to another following a shock in demand for housing (Baer, 1986; Mayer and Somerville, 2000). The use of housing starts is therefore more appealing in analysing the factors that determine housing supply.

It is also clear from Table 1 that several factors affect the supply of housing. These factors can be grouped into house prices, cost of construction, interest rate,

**Table 1:** Recently published studies on housing supply

| Authors and year of publication | Period | Explained variable | Explanatory variables | Estimated sign |
|---|---|---|---|---|
| Ball, Meen and Nygaard (2010) | 1969-2007 | Changes in log of new construction | Log of housing stock | + |
| | | | Lagged changes in log of real house price | + |
| | | | Changes in short term interest rate | - |
| | | | Changes in log of construction cost | - |
| Wigren and Wilhelmsson (2007) | 1976-1999 | Log housing stock | Log of GDP | + |
| | | | Log of constrution price index | - |
| | | | Log of property price index | + |
| | | | Log of interest rate | - |
| | | | Log of consumer price index | + |
| | | | Log of price level | + |
| Neto (2005) | 1989-2005 | Housing starts | House price | + |
| | | | Real interest rate | - |
| | | | Cost of construction | - |
| | | | Urban land | + |
| | | | Rural land | + |
| Riddel (2004) | 1967-1998 | Log of residential unit stock | Price index | + |
| | | | Rate on 3-month treasury bills | - |
| | | | GDP | + |
| | | | Apartment vacancy | + |
| | | | Construction cost index | + |
| Harter-Dreiman (2004) | 1980-1998 | Log price | Log investment | + |
| Kenny (2003) | 1975-1998 | private new homes completed | Real price of new housing | + |
| | | | Real cost of construction | - |
| | | | Real interest rate | - |
| | | | Time trend | + |
| Malpezzi and Maclennan (2001) | 1850-1995<br>1889-1994 | Log price of new residential construction | Log GDP per capita | + |
| | | | Log population | - |
| | | | Log stock $(t-1)$ | + |
| | | | AR$(1)$ | + |
| Mayer and Somerville (2000) | 1975-1994 | Construction starts | Change and lagged changes in price | + |
| | | | Change in real prime rate | - |
| | | | Lagged stock | + |
| | | | Change in real material cost index | + |
| | | | Median month on the market | - |

| Authors and year of publication | Period | Explained variable | Explanatory variables | Estimated sign |
|---|---|---|---|---|
| Blackley (1999) | 1950-1994 | Real residential construction | Real price of houses | + |
| | | | Real price of construction materials | - |
| | | | Real wage | + |
| | | | Real short-term interest rate $(t-1)$ | - |
| | | | Real price of agricultural land | + |
| | | | Real price of non-residential construction | + |
| Lee (1999) | 1963-1991 | Housing investments | House price | + |
| | | | Inflation rate | - |
| | | | Real interest rate | - |
| | | | AR$(1)$ | + |
| Pryce (1999) | 1988, 1992 | Private house starts | House price | + |
| | | | Unemployment rate | - |
| | | | Land supply | + |
| | | | Percentage of residential development on land in former urban uses | - |

planning regulations and market conditions. While interest rate and cost of construction negatively affect housing starts, house prices positively affect housing starts. Also, when planning regulations are tight, less housing construction will be initiated.

There are basically two main approaches that are used to estimate the relationship between housing supply (starts) and the various determinants. In the first approach, housing supply and demand functions are combined into a single reduced form equation. In this case, the price elasticity of starts is derived from the coefficients on supply and demand shifters in the reduced form regression (Muth, 1960; Follain, 1979; Stover, 1986; Malpezzi and Maclennan, 1994). In the second approach, aggregate supply curve is directly estimated for new residences by modeling construction starts as a function of the level of house prices and various cost shifters (Poterba, 1984, 1991; Topel and Rosen, 1988; DiPasquale and Wheaton, 1994; Mayer and Somerville (2000); etc).

One of the earlier studies that empirically examine the supply side of the housing market in the US is the study by Muth (1960). Muth regresses the rate of housing construction on the relative price of housing, income and mortgage interest rate using 8-year time series data from 1922-1929 inclusive. The equation he estimates is:

$$I_t = \beta_0 + \beta_1 P_t + \beta_2 Y_t + \beta_3 R_t \tag{1}$$

where $I_t$ is the rate of housing construction, $P_t$ is the long-run equilibrium price, $Y_t$ is the per capita income and $R_t$ is the long-run equilibrium interest rate on mortgages. He finds no significant relationship between output and price. He then reverses the model with house price as the dependent variable and the rate of housing construction and the other factors as the dependent variables. Again, Muth finds no significant relationship between price and quantity in this model and so concludes that housing supply is highly elastic. The annual time series data for the only 8-year period and the use of national data may give rise to this perfectly elastic evidence (Stover, 1986). Also the use of the reduced form equation instead of modeling only the supply side is another reason for Muth's conclusion (see Topel and Rosen, 1988).

In their widely cited paper, Topel and Rosen (1988) formalize the house building firms' decision of how many new residential units to start so as to maximise their profits in the presence of adjustment costs. They hypothesize that marginal costs rise with both level of and changes in new construction activity. As a result of this, when there is a positive demand shock, the building firms lower costs by smoothing their increase in output over a number of of periods rather than building all units at a time. They estimate the model

$$I_t = \beta_0 + \beta_1 I_{t-1} + \alpha\beta_1 E_t I_{t+1} + \beta_2 P_t + \beta_3 R_t + u_t \tag{2}$$

where $E_t$ is the expectation formed at time $t$, $\alpha$ is a discount factor and the rest of the notation is obvious. $\beta_1$ reflects adjustment costs whose absence ($\beta_1 = 0$) reduces the model down to the simply supply schedule relating quantity to price.

The authors employ the instrumental variable approach to estimate Equation 2 because of the possible endogeneity of $P_t$, even though they indicate that endogeneity is unlikely to be a serious problem because investment is such a small fraction of existing stock. The instruments used include current and lagged values of interest rate, current and lagged values of income and current and lagged values of energy price index. Using quarterly data from 1963 to 1983, they find empirical evidence to support the introduction of dynamic adjustment cost aspects in housing supply models with both lagged and future starts being correlated with current period starts. They also estimate a long-run flow elasticity of 3. This approach is able to place new construction in a dynamic framework and the assumption that builders smooth production in response to shocks in demand is very intuitive. Their model is completely supply side, with all relevant demand-side information being captured in the price level of houses.

In their widely cited paper, DiPasquale and Wheaton (1994) present a stock-adjustment model in which they allow for the possibility that it takes several years for the housing market to be in equilibrium. Their stock-flow model estimates current starts as a function of the difference between desired stock and the stock in the previous period adjusted for removals. They use the current price level as a proxy for the desired stock and include an estimate of the lagged stock in their regressions. They estimate housing supply elasticity to be in the range of 1.0 and 1.4.

Mayer and Somerville (2000) note that the nature and supply of land makes housing construction different from other forms of investment. According to them new residential construction starts increases only as needed to accommodate the new residents, a one time-event. Mayer and Somerville (2000) therefore estimate a model similar to that of DiPasquale and Wheaton (1994) but uses changes in house prices instead of the price levels used by DiPasquale and Wheaton (1994) as shown in Equation 3

$$I_t = g[\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta R_{t-1}, \Delta C_t] \tag{3}$$

where $I$ is housing start, $P$ is house price change, $R$ is real interest rate and $C$ is the construction cost. They obtain supply elasticity of 0.08, substantially lower than that of DiPasquale and Wheaton (1994) above.

In the study by Malpezzi and Maclennan (2001), a long-term price elasticity of the supply of housing construction is estimated in the UK and USA employing the reduced price equation. Their work employ relatively long series of data. The available data they utilise in the UK covers the period 1850-1995, more than hundred and fifty years. For the US also, the data covers a period of more than a century, 1889-1994. They regress the price of new residential construction on gross domestic product (GDP) per capita, population, housing stock and an autoregressive representation. They estimate the price elasticity of supply to be approximately 0-4 and 4-13 in the UK and USA respectively. This means that the supply elasticity in the UK is far lower than that of the USA. This finding is also evidenced in Ball et al. (2010). One commonly suggested explanation for the lower price elasticity of supply in the UK is that housing supply in the UK is constrained by land availability problems due to a sluggish planning system (Ball et al., 2010; White and Allmendinger, 2003; Pryce, 1999).

Several important conclusions are drawn from the literature. First, local housing supply studies are relatively few as compared to the national and regional levels and since national supply elasticities are an aggregation of local elasticities, more and less responsive areas cannot be detected when national elasticities are estimated. This study provides further evidence about price elasticities for a local housing market.

Second, most of the local supply studies employ cross-sectional data because of the difficulty involved in gathering an appropriate time series data (see Bramley, 1993a, 1993b; Cheshire and Sheppard, 1995; Pryce, 1999; Ball et al.,2010). Cross-sectional data however, do not provide the opportunity to examine the long-run elasticities of housing supply. This study mitigates such a problem by employing time series data over a twenty-five year period.

The third issue has to do with whether house price levels or house price changes should be used in empirical modelling. The magnitude of the price elasticity of housing supply are dependent on whether changes in the variables are used or their levels are used. The price elasticities are found to be greater when changes are used than when levels are used. Even though it is possible to make a case for either or both (Ball et al., 2010), the use of changes in house prices seems to be more consistent (Mayer and Somerville, 2000).

Finally, most of the studies using the time series data employ an instrumental variable (IV) approach instead of OLS (Mayer and Somerville, 2000; Tsoukis and Westaway, 1994; Topel and Rosen, 1988; etc). This is due to the possible endogeneity between starts and both current period house prices and construction costs.

# 3 Methodology

## 3.1 The econometric model

The econometric model is based on the empirical papers examined above. Theory suggests that profit maximization aim of private real estate developers is influenced by demand (price for completed houses) and cost of construction, including the cost of land, building materials and borrowing. The basic model employed is similar to that of Mayer and Somerville (2000):

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t) \tag{4}$$

That is, current housing investment or starts ($I_t$) is expressed as a function of current and lagged changes in prices of houses and various cost shifters. Even though in most of the housing supply literature house price levels are used (see for example Muth, 1960; Follain, 1979; DiPasquale and Wheaton, 1994; etc.), the use of changes in house prices rather than levels is more intuitive (see for example Blackley, 1999; Mayer and Somerville, 2000; Hwang and Quigley 2006). This is because changes in the scale of the home building industry may entail changes in price and so housing start may be viewed as a one-time event needed to accommodate a demand shock caused by an increase (a change) in house prices. Also, starts are usually generally stationary while house price levels are not. Changes in house prices are however stationary and so it is econometrically justified and intuitive for changes in house prices to be used. This model is completely supply side with all the relevant demand side information summarised in the house price change. All the demand factors are assumed to determine the price change.

Using Equation 4 as the basic model, several specifications are estimated by including or excluding some additional housing supply variables to analyse the impact on the price elasticity. The first model to be estimated is exactly as we have in Equation 4. From the literature, we expect the sign on the change in house prices to be positive and negative for cost of construction and interest rate. In model 2, the cost of construction is excluded from the basic model in order to analyse if the cost of construction has effect on price elasticities. The reason is that most studies have found the cost of construction to have no effect on housing supply (see for example Mayer and Somerville, 2000; Topel and Rosen, 1988; Poterba, 1984).

In the third model, the average number of days properties stay on the market until they are sold is included to the basic model. This variable has been found to have a large negative impact on housing supply (see for example Mayer and Somerville, 2000; Topel and Rosen, 1988). Thus, increase in the number of days suggests to suppliers that the market is slow and so starts will be reduced. In the same way, when the number of days decreases, the signal is that the condition of the market is good and so suppliers being rational will increase starts to supply more. The model is thus,

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, \Delta T_t) \tag{5}$$

where $T_t$ is the time on the market and all the other variables are defined above.

The impact of planning regulation on housing supply is also examined in the fourth model. In doing this, the ratio of building warrants approved to the total building warrant applications made is included in the basic model. An increase in the ratio suggests that more land has been made available for development and so with all other things being equal, supply will also increase. We therefore expect a positive sign on the ratio of building warrants approved to the total building warrant applications made. The model is presented by Equation 6

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, \Delta(BWG_t/BWA_t)) \tag{6}$$

where $BWG_t/BWA_t$ is the ratio of building warrants granted to the total number of building warrant applications in the Aberdeen City district council. Planning variables have not been found in any of the national and regional models reviewed above. In the local models that use planning variables also, the dataset employed has been mainly cross-sectional covering just a few years. Employing the ratio of building warrants approved to the total building warrant applications in such a local model with about twenty-five year quarterly data is clearly a major contribution to the literature and the results will help to analyse the true impact of planning regulation in the long-run.

In model 5, the lagged stock is introduced into the basic model to control for the role of depreciation in explaining new housing construction. If we assume a constant depreciation rate as almost all supply studies do, then starts should increase with the stock as more units depreciate and need to be replaced. We therefore expect a positive relationship between starts and lagged stock as evidenced in many of the housing supply literature (DiPasquale and Wheaton, 1994; Mayer and Somerville, 2000). The model is thus,

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, S_{t-1}) \quad (7)$$

where S$Q_{t-1}$ is the lagged of the total dwelling stock.

In the sixth model, the lagged of the dependent variable, housing starts, is introduced into the basic model to find out if the past construction starts affect the current construction starts. Like the inclusion of the stock, we expect a positive relationship between starts and lagged stock.

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, I_{t-1}) \quad (8)$$

In model seven, the adjustment cost hypothesis by Topel and Rosen (1988) is incorporated into the basic model. The assumption that marginal costs rise with both level of and changes in new construction and so building firms lower costs by smoothing their increase in output over a number of period is very intuitive and evidence of this has been found by Topel and Rosen (1988), Tsoukis and Westaway (1994), and Kenny (2003). We therefore introduce both lagged of housing start ($I_{t-1}$) and expected future housing start ($E_t I_{t+1}$) into the model. The model is presented by Equation 9.

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, (\alpha EI_{t+1} + I_{t-1})) \quad (9)$$

where $EI_{t+1}$ and $I_{t-1}$ are the future and lagged starts respectively. $\alpha$ is the discount factor which constraints the coefficients of $EI_{t+1}$ and $I_{t-1}$ to differ. Following Topel and Rosen (1988), the discount factor, $\alpha$, is taken to be 0.98.

In the eight model, all the variables with the exception of the lagged stock are included in basic model to analyse their impact on both new construction and price elasticity of supply. The lagged stock is dropped in this model so that multicollinearity problem likely to arise as a result of the inclusion of both lagged stock and lagged starts will be avoided. This model is presented by Equation 10

$$I_t = f(\Delta P_t, ..., \Delta P_{t-j}, \Delta R_t, \Delta C_t, \Delta T_t, \Delta(BWG_t/BWA_t), (\alpha EI_{t+1}+I_{t-1})) \quad (10)$$

Following Mayer and Somerville (2000), Tsoukis and Westaway (1994) and Topel and Rosen (1988), we estimate all these models using instrumental variables (IV) approach. The reason for the use of the IV approach is due to the possible endogeneity between housing starts and both current period changes in house prices and construction costs.

The endogeneity problem arises because while price and cost influence new residential construction, the price of a property and construction costs are also influenced by property supply. If more properties are supplied and demand remains the same, then prices will fall. In the same way, as more construction takes place as a result of the desire to supply more properties then there will be more demand for land, construction materials and labour; hence construction cost will increase. Therefore, when house prices and construction enter into Equation 4 using OLS, then one of the OLS classical assumptions that the variables should be linearly independent is violated and hence the results will be biased. More so, the error term will not be uncorrelated with the independent variables.

Endogeneity is however not likely to be a serious problem because housing start is just a small fraction of existing stock. The variables used as instruments to represent house price include current and lagged values of one-year libor rate to represent the user cost of capital, current and lagged changes in GDP to represent changes in income, current and lagged changes in the ratio of the volume of transactions to actual housing stock, changes in population as well as the exogenous variables. Since there is no appropriate instrument that are not correlated with housing demand to correct for the endogeneity between starts and cost of building materials, we use lagged changes in the real building materials (Mayer and Somerville, 2000).

We also include seasonal dummies and trend variable in all the regressions. The AR(1) term is also included to analyse if the disturbance terms are serially correlated.

## 3.2 Stationarity

Stationarity is a situation where the mean, variance and auto-covariance are constant over time, that is, the movement of the variable does revert to the mean (Wooldridge, 2009). When a variable is integrated of order zero, that variable is stationary. A variable that has to be differentiated once to become stationary is integrated of order one. Wigren and Wilhelmsson (2007) note that when non-stationary variables are used to perform regressions, the results become spurious. The stationary assumption of individual variable plays a crucial role in our modeling strategy and hence the official tests.

The variables are tested for stationarity using two different unit root tests, namely, the Augmented Dickey Fuller (ADF) Test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test. These two stationarity tests are employed because they make different assumption about the null hypothesis. The ADF test is a form of unit root test that has been utilised over the years to analyse whether series are stationary. This is done by testing the hypothesis that the lagged level of a variable can explain the change. We test the null hypothesis that the series are unit root. That is, $H_0 : \beta_1 = 0$. If the null hypothesis can be rejected, that is $H_1 : \beta_1 \neq 0$, then the variable is stationary. The null hypothesis of a unit root is rejected in favour of stationarity if the test statistic is more negative than the critical value (Wooldridge, 2009).

The KPSS test however is used to test the null hypothesis that an observable time series is stationary around a deterministic trend and do not have a unit root. That is, $H_0 : \beta_1 \neq 0$. The KPSS test can be estimated with or without a time trend. In this study, we estimate it without the time trend so as to enable us compare accurately the two tests. When we test both the unit root hypothesis (ADF) and the stationarity hypothesis (KPSS), we can distinguish series that appear to be stationary and series that appear to be non-stationary so as to be sure whether the series are stationary or integrated.

# 4 Data

The variables that are used for the empirical part of this paper are described in this section. The variables are housing starts ($I$), actual housing stock ($S$), house prices ($P$), cost of raw building materials ($C$), the interest rate ($R$), real gross domestic product ($Y$), time on the market ($T$), volume of housing transactions ($V$), the number of building warrant applications ($BWA$), the number of building warrants granted ($BWG$) and population ($POP$).

The housing starts variable is defined as the number of new private single-family housing starts in the Aberdeen City district council. The housing starts information is sourced from the Scottish Government Statistics. According to the Scottish Government Statistics, a dwelling is considered as started on the date that work begins on the foundations of the block of which the dwelling will form a part, and not on the date when site preparations begin.

The house price series is measured as an index (constant quality). The house prices are sourced from the Aberdeen Solicitors' Property Centre (ASPC) together with the characteristics of the properties transacted. Using this dataset, we are able to construct constant-quality house price indices for the period under study using the explicit time-variable hedonic model. The base period for the index is the first quarter of 1986 (1986Q1=100). The raw building material cost index is also sourced from the Building and Construction Information Service (BCIS) department of the Royal Institution of Chartered Surveyors (RICS). Even though this is published at the national level, we expect the material costs to be similar in the entire UK. Both the housing price index series and the raw building material cost index series are transformed from nominal to real values based on the retail price index (RPI). The RPI is sourced from the Office of National Statistics (ONS).

The next variable we describe is the interest rate. This is defined as the nominal three month Treasury Bill rate and it is sourced from the Office of National Statistics. The real gross domestic product variable is defined as the real gross domestic product in Scotland. Since GDP is not consistently available at the local level for the time period employed for this analysis, the regional values are used to represent the local area. Since this variable does not enter Equation 4 directly but rather as an instrument together with other variables, it is not likely to bias the results. The GDP information is also sourced from the Office of National Statistics. The GDP variable is measured in pounds sterling and in nominal terms but it is transformed to real values using the RPI. Population is defined as the number of people within the Aberdeen City district council. The population figures are sourced from the General Register Office for Scotland.

The time on the market is the average number of days properties in Aberdeen stay on the market per quarter before they are eventually sold. This variable is calculated as the difference between the date the properties are advertised and the date they are actually sold. Both the advertisement and sold dates are sourced from the ASPC dataset. The volume of transactions is also sourced from the ASPC dataset and it is defined as the number of properties that are sold every quarter in Aberdeen. The ratio of the volume of transactions to the actual building stock is used as an instrument since it gives the signal of demand and hence house price. The building warrant applications are the number of building applications made by private developers to start new housing development in Aberdeen. The building warrant granted on the other hand are the number of building warrants approved by the city council to private developers. These information are sourced from the Aberdeen City Council (ACC). The ratio of BWG to BWA is used to analyse the impact of planning regulation on housing supply.

Table 2 presents the summary statistics of the variables. The dataset comprises of quarterly data of these variables and covers the period from the first quarter of 1986 to the fourth quarter of 2010 (1986Q1- 2010Q4), that is, a 25 year period or a total of 100 quarters. From the Table, the average starts in Aberdeen is 173 every quarter with the minimum and maximum starts being 1 and 590 respectively. The standard deviation is about 124, which is almost 72% around the mean value,

**Table 2:** Summary statistics of data

| Variables | Unit | Average | Min. | Max. | Std. Dev. |
|---|---|---|---|---|---|
| Starts | Number | 172.89 | 1 | 590 | 124.35 |
| Stock | Number | 96055.87 | 89093 | 102570 | 4078.229 |
| Property price index rate of change | Percentage | 0.95 | -6.64 | 6.27 | 2.38 |
| Material cost index rate of change | Percentage | 1.09 | -1.03 | 4.41 | 1.16 |
| Retail price index | Percentage | 3.52 | -1.38 | 10.43 | 2.09 |
| Interest rate | Percentage | 6.40 | 0.39 | 14.50 | 3.40 |
| Gross domestic product growth rate | Percentage | 1.36 | -2.55 | 3.74 | 0.90 |
| Population growth rate | Percentage | 0.01 | -0.36 | 0.47 | 0.22 |
| Time on the market | Number of days | 108.54 | 36.11 | 215.41 | 44.40 |
| Volume of transactions | Number | 1115.73 | 567 | 1712 | 243.02 |
| BWA | Number | 580.05 | 1 | 1244 | 349.91 |
| BWG | Number | 537.33 | 0 | 1220 | 334.54 |

meaning a very high volatility. The average number of housing stock in Aberdeen is also about 96,056. That is, housing starts are only about 0.18% of the existing stock, far less than approximately 2% reported from other studies. The reason for this small starts in Aberdeen may be attributed to the fact that most of the new developments take place at the outskirts of Aberdeen where land is more available and these areas are governed by the Aberdeenshire Council and so are excluded from the study.

From the table, the average percentage rate of change in house prices in Aberdeen is about 0.95% per quarter with the minimum and maximum rate of change being -6.64% and 6.27% respectively. The rate of change of building material cost is about 1.09% every quarter. The minimum and maximum rate of changes are -1.03% and 4.41% respectively. The rate of change of PPI seems more volatile than the MCI with their standard deviations being 2.38% and 1.16% around their means respectively. The average inflation rate is also 3.52% with a standard deviation of 2.09%.

# 5 Empirical Results

## 5.1 Pre-test (stationary test) of the data

Table 3 presents the results obtained from the two stationarity tests, namely the Augmented Dickey-Fuller (ADF) test and the KPSS test. The table shows that generally most of the variables are not stationary when they are in levels. The variables that are stationary in levels according to both tests are housing starts and the ratio of volume of transactions to the stock. The real gross domestic product is also stationary in levels using the ADF test but it is integrated in order one when the KPSS test is used.

The variables, real property price index, real material cost index, nominal interest rate, population, time on the market and the ratio of building warrants granted to building warrant applications are integrated in order of one according to both the ADF and the KPSS tests. That is, these variables are only stationary when their changes rather than levels are used. This means that when these variables are employed in their levels rather than changes to do the regressions, then they will be inconsistent since starts are stationary in their levels.

While stock is integrated in order of one according to the KPSS test, it is not stationary even by differencing or taking its trend using the ADF test. A similar finding is reported by Mayer and Somerville (2000) using the ADF test. To ensure consistency with the other variables, integration order of one reported by the KPSS is accepted for the dwelling stock variable. In general, both the ADF and the KPSS produce similar.

## 5.2 Regression results

Table 4 presents the results obtained from the empirical modeling. The first column in the table shows the variables included in the models. The lags are chosen to be

**Table 3:** Unit root tests for stationarity

| Variables | | ADF | | KPSS | |
|---|---|---|---|---|---|
| | | T-statistics | Integration order | T-statistics | Integration order |
| STARTS | | | I(0) | | I(0) |
| | Level | -5.867*** | | 0.390 | |
| STOCK | | | | | I(1) |
| | Level | -1.323 | | 0.869*** | |
| | Change | -2.100 | | 0.372* | |
| REAL PROPERTY PRICE INDEX | | | I(1) | | I(1) |
| | Level | -0.028 | | 0.832*** | |
| | Change | -8.299*** | | 0.077 | |
| REAL MATERIAL COST INDEX | | | I(1) | | I(1) |
| | Level | -0.818 | | 0.876*** | |
| | Change | -10.369*** | | 0.127 | |
| NOMINAL NTEREST RATE | | | I(1) | | I(1) |
| | Level | -0.992 | | 0.709** | |
| | Change | -8.815*** | | 0.051 | |
| REAL GROSS DOMESTIC PRODUCT | | | I(0) | | I(1) |
| | Level | -5.823*** | | 0.877 | |
| | Change | | | 0.561* | |
| POPULATION | | | I(1) | | I(1) |
| | Level | -0.258 | | 0.816*** | |
| | Change | -3.109 | | 0.485* | |
| TIME ON THE MARKET | | | I(1) | | I(1) |
| | Level | -1.697 | | 0.775*** | |
| | Change | -9.048*** | | 0.079 | |
| RATIO OF VOLUME TO STOCK | | | I(0) | | I(0) |
| | Level | -4.336*** | | 0.204 | |
| RATIO OF BWG TO BWA | | | I(1) | | I(1) |
| | Level | -2.332 | | 0.528** | |
| | Change | -15.683*** | | 0.108 | |

We reject the null hypothesis of a unit root using the ADF test, and reject the null hypothesis of stationarity using the KPSS test at the following levels of significance: *, **, *** representing 10%, 5% and 1% level respectively.

sufficient to remove any autocorrelation in the models. The table shows that serial correlation is absent in all the models as the coefficient of AR(1) is not significant on a 5% level for any of the models. Columns two to nine also show the estimated coefficients from the eight models.

The first model is a direct estimate of Equation 4. The model produces an R-squared of approximately 24% with the current changes in house prices, changes in house prices in the fourth lag and the constant term being statistically significant on a 5% level. The changes in house prices however have the greatest impact on house prices with a coefficient of 3.7% in the current period and 3.6% in the last four quarters. Changes in interest rate also have a negative but insignificant effect on housing starts at the current period. Even though it is not significant, the negative sign is expected and consistent with the previous literature as discussed above. It should be noted here that interest rate does not only affect housing supply but housing demand as well. The impact of changes in interest rate on housing demand is captured in the price change variable since current changes and lagged changes in the one-year libor rate are used as instruments for price changes. Thus, the insignificant effect of interest rate on housing starts suggests that much of the effect of interest rate on the housing market occurs through demand rather than supply. Like the changes in interest rate variable, the changes in the real cost of building materials is also not significant. The insignificancy of the real cost of building materials is evidenced in a number of empirical studies (see Topel and Rosen, 1988; DiPasquale and Wheaton, 1994; Mayer and Somerville, 2000).

Because changes in the real cost of building materials are not significant in the first model, we exclude it in the second model to see if that will have any impact on the results. The results from model 2 indicate that even though the changes in raw building material cost do not have any impact on the first model, excluding it from the model do have an effect on the results, with the coefficient of the current changes in house prices increasing from 3.7% to 5.7% but the last four quarters house price changes decreasing from 3.6% to 3.1%. Thus, if indeed private developers do not face construction cost, then following an increase in house prices, they will increase supply more than they would have done if they face construction costs. The coefficient estimates on the changes in interest rate however are similar, have the expected sign and are still not significant. To ensure consistency, the changes in the raw cost of building materials are included in models 3 to 8.

In the third model, we estimate Equation 5 by adding changes in the time on the market variable to the basic equation in order to examine the impact that the number of days properties stay on the market until they are sold have on new housing starts. Table 4 shows that by including this variable, the R-squared increased to 28% and the time on the market have a negative significant effect on housing supply. When the changes in the time on the market increases by 1%, all other things being equal, housing starts fall by some 1.7%. This negative sign is expected because when the time on the market increases, it sends a signal to builders that demand is slow and since the builders are rational and wants to maximise profit, they will reduce new construction. The magnitude is however smaller as compared to some national studies in the USA like Topel and Rosen (1988), DiPasquale and Wheaton (1994) and Mayer and Somerville (2000). The changes in house prices in periods $t$ and $t-4$ are still statistically significant on a 5% level.

The impact of planning regulation on housing supply is examined in model 4 by adding the changes in the ratio of building warrants approved to the total number of building applications to Equation 4. The results from model 4 shows that inclusion of the variable increases the R-squared to 32% and planning regulation have a significant positive effect on housing starts. With a 1% increase in the changes in the ratio of building warrants approved to building warrant applications, housing starts increase in the Aberdeen City district council by approximately 0.03%. This positive impact is not surprising because an increase in the changes in the ratio means that more land has been made available to private developers for development and hence housing starts will increase. The impact of planning regulation on housing starts is also evidenced in a number of local studies in the UK (see for example, Bramley,

**Table 4:** Empirical regression results using the IV approach

| | Models | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $\Delta P_t$ | 3.6968 | 5.7094 | 5.4268 | 5.2192 | 3.9785 | 3.6356 | 3.4829 | 5.3031 |
| | (1.98)** | (2.02)** | (2.51)** | (1.99)** | (2.36)** | (2.01)** | (2.06)** | (1.96)** |
| $\Delta P_{t-1}$ | 1.7094 | 1.6492 | -0.4917 | 1.6041 | 1.3144 | -0.2992 | -1.4057 | -2.9000 |
| | (0.37) | (0.36) | (-0.10) | (0.34) | (0.28) | (-0.27) | (-0.35) | (-0.69) |
| $\Delta P_{t-2}$ | 5.3569 | 6.0152 | 2.5728 | 5.4101 | 4.9309 | 4.9858 | 3.6417 | 1.3381 |
| | (1.13) | (1.36) | (0.55) | (1.14) | (1.03) | (2.12)** | (1.98)** | (2.02)** |
| $\Delta P_{t-3}$ | 6.2540 | 5.6949 | 6.0439 | 6.0250 | 5.8211 | 3.1606 | 2.5399 | 2.5240 |
| | (1.34) | (1.25) | (1.34) | (1.30) | (2.04)** | (0.72) | (0.62) | (0.63) |
| $\Delta P_{t-4}$ | 3.6430 | 3.1235 | 2.8725 | 3.4056 | 3.2141 | 1.2568 | -0.9240 | -1.3906 |
| | (2.08)** | (1.98)** | (1.97)** | (2.01)** | (1.68) | (0.28) | (-0.22) | (-0.34) |
| $\Delta R_t$ | -0.1450 | -0.1401 | -0.1451 | -0.1489 | -0.1421 | -.0825 | -0.1486 | -0.1506 |
| | (-1.13) | (-1.11) | (-1.16) | (-1.16) | (-1.09) | (-0.67) | (-1.31) | (-1.36) |
| $\Delta R_{t-1}$ | 0.1679 | 0.1834 | 0.1478 | 0.1747 | 0.1728 | 0.2041 | 0.2448 | 0.2246 |
| | (1.27) | (1.41) | (1.16) | (1.32) | (1.29) | (1.65) | (1.11) | (1.90) |
| $\Delta C_t$ | 4.3465 | | -6.2964 | 4.0002 | 4.6270 | -.8823 | -2.0332 | -11.1866 |
| | (0.39) | | (-0.46) | (0.36) | (0.42) | (-0.08) | (-0.21) | (-0.94) |
| $\Delta T$ | | | -1.7470 | | | | | -1.4722 |
| | | | (-1.97)** | | | | | (-1.99)** |
| $\Delta(BWG_t/BWA_t)$ | | | | 0.0324 | | | | 0.2290 |
| | | | | (2.06)** | | | | (2.46)** |
| $Q_{t-1}$ | | | | | 8.2431 | | | |
| | | | | | (2.41)** | | | |
| $S_{t-1}$ | | | | | | 0.3422 | | |
| | | | | | | (3.42)** | | |
| $\alpha ES_{t+1}+S_{t-1}$ | | | | | | | 0.3085 | 0.2948 |
| | | | | | | | (5.04)** | (4.83)** |
| Constant | 5.6451 | 5.6402 | 5.6349 | 5.6411 | 130.2937 | | 2.1874 | 2.3393 |
| | (26.66)** | (26.72)** | (27.41)** | (26.55)** | (4.58)** | | (3.05)** | (3.30)** |
| AR(1) | 0.3289 | 0.3409 | 0.3259 | 0.3301 | 0.3158 | 0.0092 | -0.2798 | -0.2438 |
| | (1.29) | (1.43) | (1.25) | (1.30) | (1.13) | (0.09) | (-1.78) | (-1.39) |
| $\bar{R}^2$ | 23.63% | 24.26% | 28.18% | 32.46% | 22.06% | 32.88% | 42.37% | 47.08% |

Note: The $t-$values are in parentheses and ** shows significancy on a 5% significant level. The dependent variable is the logarithm of quarterly single-family housing starts. Seasonal dummies and trend variable are included in all regressions. They are however insignificant and so are not reported in the table.

1993a, 1993b; Cheshire and Sheppard, 1995; Pryce, 1999; etc.). In the national studies examined, this variable has been ignored despite its significance as evidenced in this results. This is because planning is more localised and differs from one district council to the other. The impact of planning regulation on housing construction is more appropriate to be examined at the local level and this provides more support for housing studies to be conducted at the local levels rather than the national and regional levels. Again, the changes in house prices in periods $t$ and $t-4$ are still statistically significant on a 5% level.

In model 5, we include lagged stock to Equation 4 in order to control for the role of depreciation in explaining housing starts. As already indicated, starts should increase with stock as more units depreciate and need to be replaced assuming depreciation rate is constant. The results show that the previous period's housing stock does have a significant effect on housing starts but also reduces the model's explanatory power to 22%. A 1% increase in the previous quarter's housing stock increases the current period's housing starts by about 8%, all other things being equal. In all the other models, we assume that the time trend and the constant successfully capture the effect of depreciation (see Mayer and Somerville, 2000). The change in house prices in period $t$ is still significant but instead of period $t-4$ as found in the first four models, the price changes in period $t-3$ is now significant with the other lagged periods being insignificant.

In the sixth model, we estimate Equation 8 where the lagged value of the starts variable is added to Equation 4. As expected there is a positive significant relationship between the current starts and the lagged starts with a 1% increase in the lagged starts increasing the current starts by approximately 0.34%. Again, the change in house prices in period $t$ is still significant and that of period $t-2$ is also significant.

In model 7, the adjustment costs hypothesis by Topel and Rosen (1988) is tested with Equation 9 with the local data by including an addition of both the previous period's and next period's new construction, $EI_{t+1}+I_{t-1}$, to Equation 4. The results show that the inclusion of the variable increases the explanatory power of model one to a little over 42% and an increase in $EI_{t+1}+I_{t-1}$ do have a positive impact on the current period's construction starts. When $EI_{t+1}+I_{t-1}$ increases by 1%, the current period's housing starts increases by 0.31%. This positive effect is consistent with the finding by Topel and Rosen (1988) and suggests that the adjustment cost hypothesis is significant in building activities. That is, marginal costs rise with both level of and changes in new construction activity and so following a positive demand shock, the building firms lower costs by smoothing their increase in output over a number of periods rather than building all units at a time. The changes in house prices in periods $t$ and $t-2$ are still significant.

Finally in model 8, all the variables from each of the previous seven models, except the lagged stock variable, are included to estimate housing starts. The lagged stock is excluded so that multicollinearity problem likely to arise as a result of the inclusion of both lagged stock and lagged starts will be avoided. The inclusion of price changes together with the time trend and the constant term are assumed to successfully control for the role of depreciation. That is we estimate Equation 10. The model produces the highest explanatory power of about 47%. The results show that the changes in house prices in periods $t$ and $t-2$, the current period's time on the market, the ratio of building warrants granted to building warrant applications, the previous period's and next period's new construction are all statistically significant on a 5% level. Changes in the raw cost of building materials and interest rate still remain insignificant. Since the significant variables are all local variables, it is suggesting that local factors do influence housing starts at the local level than national variables.

### 5.3 Price elasticities of supply

The price elasticity of supply estimated from the eight models are presented in Table 5. Like DiPasquale and Wheaton (1994) and Mayer and Somerville (2000), there is a distinction between the price elasticity of housing stock and that of housing starts. The formula for the price elasticity is presented in Equation 11

$$PES = \frac{\partial I}{\partial P} \cdot \frac{P}{I} \tag{11}$$

where $PES$ is the price elasticity of supply, $\partial I$ is the change in housing starts, $\partial P$ is the change in price. $P$ and $I$ are as defined above but they represent the mean values. As a convention, when the price elasticity of supply is greater than one, ($PES > 1$), then supply is sensitive to price changes and so supply is elastic. However, when $PES < 1$, then supply is not sensitive to price changes and so it is not elastic. Also, when $PES = 1$, then supply is unit elastic, with a unit increase in house prices producing the same unit increase in supply. $PES = 0$ means that supply is fixed and does not respond to changes in price.

Table 5 shows that the price elasticities of starts range from 2.0 to 3.2 depending on the model used. That is a 10% increase in house prices increases housing starts by between 20% and 32%. These supply elasticities are within the 0-4 range of supply elasticities found by Malpezzi and Maclennan (2001) for the UK market. They are also similar to the supply elasticities estimated by Ball et al. (2010). Comparing to the other local market supply elasticities, the supply elasticities for the Aberdeen local authority district are higher than the 0.29 for the Birmingham market but similar to the 3.11 for the Worcester market estimated by Bramley (1993a, 1993b). The results are also higher than the supply elasticities of 0.58 in 1988 and 1.03 in 1992 estimated by Pryce (1999) for 162 local authority districts in England.

The model that produces the highest price elasticity of supply is the second model. This is not surprising because the second model assumes that private devel-

**Table 5:** Price elasticities of supply in Aberdeen

| | Price elasticities of supply | |
|---|---|---|
| Models | starts | stock |
| 1 | 2.1 | 0.02 |
| 2 | 3.2 | 0.02 |
| 3 | 3.1 | 0.02 |
| 4 | 2.9 | 0.02 |
| 5 | 2.2 | 0.02 |
| 6 | 2.1 | 0.01 |
| 7 | 2.0 | 0.01 |
| 8 | 3.0 | 0.01 |

opers are not faced with construction cost. If this is to be the case, then a little shock in demand will see a large change in new construction. In this case, 1% increase in house price will increase new construction by 3.2%. On the contrary, in model 1, where we assume that private developers are faced with construction cost, the same 1% change in house prices increases new construction by only 2.1%.

Model 6 which assumes that private developers face adjustment cost produces the lowest supply elasticity. This is also expected because when there is a demand shock and private developers face adjustment cost, in order to maximise their profits, they will have to spread construction over many periods and hence the small starts elasticity of only 2.0.

In estimating the stock elasticities however, the $I$ is replaced by $S$, the average number of stock. Since housing stock is stable in the short-run and changes only after some time, the coefficients of changes in the current and lagged values of house prices are summed up to replace $\partial I$ in estimating the stock elasticities. The results from Table 4 show that it takes about five quarters (one year, three months) for the housing stock to move following a demand shock, and then returns to equilibrium. The price elasticity of stock ranges from 0.01 to 0.02 meaning that a 10% increase in house prices would increase the entire stock by between 0.1% to 0.2%. The stock elasticities seem relatively small as compared to the starts elasticities but given that starts are a small percentage of the stock, only 0.18%, the results are not surprising.

# 6 Conclusion

This paper has examined the determinants of new residential construction and has estimated the price elasticity of supply for the housing market of the Aberdeen local authority district council. Eight different models are estimated using the instrumental variable (IV) approach, with the basic model treating single family housing starts as a function of the changes in the current and lagged values in house prices, raw building material costs and interest rate.

The other variables included in the other models include the number of days property stay on the market until they are sold (time on the market) as a measure of the condition of the local housing market, changes in the ratio of building warrants granted as a measure of the effect of planning regulations on housing supply, the previous total dwelling stock as a control variable for depreciation, lagged and future changes in single family housing starts to measure the adjustment cost model propose by Topel and Rosen (1988).

It has become clear from the empirical results that serial correlation is absent in all the eight models. It is also found that changes in house prices, time on the market, planning regulation, lagged stock, and lagged and future housing starts are the main factors that influence new residential construction in Aberdeen. Changes in house prices have a large positive coefficient of about 3.7% in the basic model in the current period and coefficient of about 3.6% in the previous fourth quarter.

Also, when time on the market increases by one day, housing starts also decrease by 1.7%. Changes in the ratio of the building warrants granted to the building warrant applications made also have a positive effect on housing starts, with a 1% increase in the ratio, increasing starts by approximately 0.03%. The results also show that when the previous period's single family housing starts increase by 1%, all other things being equal, the current period's single family housing starts increase by almost 0.34%. The adjustment cost hypothesis by Rosen and Topel (1988) is also found to significantly influence housing starts with a 1% increase in the lagged and future housing starts increasing current starts by approximately 0.3%.

The changes in raw building material costs and interest rates are found to be insignificant in all the models. These variables are national variables and so suggest that when modeling the local housing market, local variables are more useful than the national variables. These influential local variables would not be measured properly or would be ignored entirely when the national or regional housing markets are modelled. That is, it is more suitable and better to conduct housing studies at the local levels because important local factors that are specific to specific local markets would be shrouded when national and regional markets are used.

The price elasticities of supply estimated are in the range of 2.0-3.2 for housing starts, and 0.01-0.02 for housing stock. The starts elasticities are within the range of supply elasticities for few local housing markets but on average, higher than most of the local housing markets elasticities in the UK. Thus, private developers in Aberdeen respond more to a change in house prices by initiating new construction than most of the local authority districts in the UK.

More housing supply studies are needed especially in the UK. These studies should however be conducted at the local level and the dataset should be time series instead of cross-sectional. In this case, the long-run relationship between housing supply and its determinats could be explored further and house price elasticity of supply could be estimated for the other housing markets. Also, the inclusion of planning variables in examining the determinants of housing supply should be encouraged since this is expected to differ from one local area to the other.

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