Housing Markets, Local Constraints, and Monetary Policy in England

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Abstract

The UK housing market features some of the most expensive, yet smallest dwellings in Europe. Nonetheless, historically low policy rates fuel housing demand. But because incomes, regulatory and physical constraints differ across regions, so does the transmission of an aggregate policy shock. This paper investigates the response of English house prices and property sizes to a monetary policy shock, and analyzes the role of local constraints in the transmission mechanism. Using data for all residential property sales between 1995 and 2015, I present 3 main results. First, prices and transactions rise following an unanticipated cut in the policy rate, with more pronounced results for re-sales compared to first-time sales. Second, I show that the income channel plays no role in determining local differences in housing market dynamics. Finally, local planning regulations create a trade-off between higher prices and preserving property size. Thus, local policy can affect the distributional impact of monetary policy on the housing market.

1 Introduction

The UK housing market faces a dual threat from inordinate house prices combined with decreasing property size. Property in England is among the smallest and most expensive in Europe. In 2019, UK housing costs were 70% higher than the EU average, and the average housing price exceeds income by a factor of eight.[1] At the same time, the average new dwelling size in the UK is among the smallest in Europe, at only 70% of the average German dwelling (Evans and Hartwich, 2005), and while average property size in the US has increased by over 60% since the 1970s, UK homes shrunk by 20% (LABC Warranty, 2018).

National policy to address these issues are complicated by the ongoing Covid-19 pandemic. Since the onset of the pandemic, most people have been spending more time at home. As a result, the nature of housing has changed from places of shelter and relaxation to work spaces, schools and gyms. This trend has highlighted existing housing inequalities, with some residents having access to large living spaces and gardens, while others are confined to overcrowded dwellings. In addition, the pandemic has accelerated housing price growth by triggering the flight of individuals from small city apartments to suburbs, and by causing significant construction supply shortages. At the same time, policy rates are at historic lows to boost the economy, which in turn fuels housing demand.

Against this background, the goal of this paper is two-fold: First, with interest rates at historic lows, I explore the effect of an aggregate monetary policy shock on house prices and sizes. Whether monetary policy plays an important role in driving housing market dynamics has been subject to discussion at least since the housing market boom starting in the early 2000s. On the one side, research including Taylor (2007) shows that low interest rates have been associated with fueling housing booms. In contrast, Shiller (2007) argues that links between monetary policy and housing prices are weak. Intuitively, monetary policy can affect housing supply by lowering lending rates, thus encouraging new housing development projects. In addition, lower mortgage rates make housing more affordable, thereby increasing

[1] Source: Eurostat (online data code:PRC_PPP_IND), and ONS (Price to residence-based earnings ratio)

housing demand.

The second goal of the paper is to analyze the role of local regulatory and geographic constraints in the transmission mechanism of a monetary policy shock. Local differences in housing markets arise from changes in supply and demand in conjunction with local physical and regulatory constraints. Intuitively, when supply is unable to keep pace with demand, more of the shocks carry through into prices. Several papers, including Saiz (2010), Gyourko, Mayer, and Sinai (2013) and Paciorek (2013), argue the importance of local supply price elasticities in determining house price dispersion. For example, population density may reduce supply price elasticities in areas such as Greater London, while topography related constraints may affect housing supply in mountainous areas in the North or in coastal regions. In addition to physical constraints, local regulatory constraints surrounding the British planning system are often blamed for high housing price growth (e.g. Cheshire and Sheppard (2002), Evans and Hartwich (2005), Hilber and Vermeulen (2016)). The rigid planning system has historically slowed down housing development, and increased construction costs. For example Cheshire and Hilber (2008) estimate that the regulatory tax for Westminster exceeds 800% of marginal construction costs. Further, Saks (2008) finds that areas with fewer regulatory constraints experience more residential construction and smaller increases in house prices.

As monetary policy differentially affects housing prices across local authorities, it also affects the size of housing on the market. From a demand perspective, lower interest rates attract first time home buyers, who on average purchase smaller homes. Similarly, low interest rates may increase the demand for second homes, including vacation homes and investment property, which may be of different size than the primary residence. Once the increase in housing demand translates to higher prices, budget constraint home-buyers are forced to purchase smaller property. Further, rising house prices may provide an incentive for existing home owners to downsize, or realize gains by giving up owner-occupation for renting. From a supply perspective, low interest rates encourage new property developments, which tend to be smaller in size and have fewer bedrooms. As a result, smaller homes make up a larger share of the housing market. This downward trend in property size, in conjunction with rising prices, may lead to welfare losses, that become particularly concerning in times where more and more households work from home. It is the primary aim of this paper to improve the understanding of the distributional effects of monetary transmission – both along the price and size dimension – by focusing on disaggregated responses in local housing markets.

To answer the questions at hand, I use housing price data on the universe of all residential property sales in the UK from 1995 - 2015. Unfortunately, the availability of housing price data limits the analysis to years after 1994, while the monetary policy shock series ends in 2015. The UK land registry reports transaction prices for each sale, together with information such as property type, sales date, physical location, and whether the sale was first-time or repeat. The Monetary Policy Shock series for the UK is taken from Champagne and Sekkel (2018) and aggregated to quarterly frequency. Their approach is based on the method developed by Romer and Romer (2004) and later applied to the UK by Cloyne and Hürtgen (2016). In a nutshell, the approach aims to isolate unexpected shifts in monetary policy from the systematic component in the intended policy rate driven by policymakers' response to data in their information set. Intuitively, the definition of a monetary policy shock then is the unpredictable surprise that is not taken as a response to information about current and future economic developments. As such, the approach addresses traditional endogeneity concerns stemming from i) monetary policy and other macroeconomic variables being determined simultaneously, and ii) policy makers and investors including past and current information, as well as expectations about future economic conditions in their decision (i.e. anticipation effects).

Results indicate that house prices and the number of transactions increase in the medium run, before slowly reverting to their pre-shock levels. Specifically, a 25bp decrease in the policy rate increases transactions by 1.5% after 6 quarters, and house prices by 1% after

8 quarters. Unsurprisingly, the transactions response leads the price response – in other words, demand for housing increases, triggering a rise in home values, which in turn leads to a decrease in housing transactions.

In addition, I confirm previous findings relating local regulatory constraints to higher house price growth (e.g. Hilber and Vermeulen (2016)), but also suggest that the relationship between regulatory constraints and housing markets may be more complicated. On one side, tighter regulatory constraints increase the quality adjusted price and make housing less affordable. On the other side, however, local authorities with stricter planning regulations transact relatively larger new builds as a result of a monetary policy shock. As such, planning regulations seem to create a trade off by acting as gate-keepers in line with British space standards, limiting the decline in property size.

In contrast to regulatory constraints, local differences in labor market and earning responses to a monetary policy shock are not sufficient to explain differences in local price responses. Arguably, changes to monetary policy and income are linked as monetary expansions typically increases labor and earnings. For example, Auclert (2019) shows monetary policy affects consumption through 3 channels - income, inflation, and interest rates. I account for local differences in incomes via the unemployment responses to a monetary policy shock, and I show that the unemployment channel plays no role in determining local differences in the price and size response of housing. This suggests that direct monetary policy effects via the lending rate are a more likely mechanism, compared to indirect effects via changing local labor and earnings.

Finally, I analyze price responses separately for new builds and re-sales. New builds are often of smaller size and in less central locations than their already existing counter parts. For example, the average home in 1970 was almost 84 square-meters, compared to 68 in 2010. As such, monetary policy, as well as local regulatory and physical constraints may affect the price and size of new builds differently. Results show that the price response to a monetary policy shock is more muted for new builds. Intuitively, lower policy rates provide an incentive for developers to start new housing projects. As the supply of new property in the market increases, the upward pressure in prices from the demand side gets muted. After 8 quarters, house prices of first-time sales increase by only 0.5% following an unexpected 0.25 percentage point cut in the interest rate.

Two important caveats are worth mentioning. First, the size measure is derived from the quality adjustment term of the UK house price index, and does not allow me to separate between house size changes or location changes directly. However, quality adjustments in the UK house price index occur by i) local authority, ii) new or old property, iii) ACORN area classification, and iv) property size. Thus, by looking at narrowly defined geographical regions, and separating between new builds and existing property, property size is the only remaining dimension of quality adjustment. Moreover, separating dwellings into new-builds and re-sales in combination with local factors allows me to draw some conclusions about the nature of quality changes. For example, I observe relative quality decreases in areas that have less developable land but more amenities (assuming that amenities locate near population centers). Thus, the likely quality change is along the size dimension, rather than along neighborhood characteristics. Second, I only observe completed sales. In other words, I do not observe prices and size of listed, but unsold, property, and I do not observe changes in housing demand (i.e. unsuccessful home searches) for any particular price and size type.

Nevertheless, my findings are important for policy makers for at least 3 reasons. First, aggregate policy shocks have distributional effects. Previously, literature has focused on distributional effects by income and other socio-economic characteristics (e.g. Iacoviello (2005), Mian and Sufi (2011), Auclert (2019), Cloyne, Ferreira, and Surico (2020)), but the spatial diffusion of a monetary policy shock are less understood (recent exceptions include Amarasinghe et al. (2018), Furceri, Mazzola, and Pizzuto (2019), or Pizzuto (2020)). Findings imply that monetary policy shocks decrease affordability, especially in more urbanized areas, thereby excluding many first-time buyers from owning property in these areas. Second, the UK planning system has often been criticized as being highly problematic (e.g. Cheshire and Sheppard (2002), Evans and Hartwich (2005), Hilber and Vermeulen (2016)). While I find evidence that more regulated local authorities experience higher house price growth, they also serve as gatekeepers for home size. Lastly, to the extent that exogenous factors, like distance to London or population density, are the key drivers behind local differences in price and size responses, policy can do little to address distributional effects. In contrast, if regulatory constraints affect the sensitivity of house prices and size, local policy can react accordingly. Thus, this paper informs policy by disentangling and identifying the separate impacts of different types of constraints to provide important insights into the current policy debate surrounding Britain's housing affordability and housing standard crisis.

2 Empirical Analysis

2.1 Data

I use quarterly data for England from 1995 - 2015, aggregated to the local authority level (prior to April 2015).[2] Local government in England is divided into district councils, metropolitan districts, London boroughs, and unitary authorities. I geographically aggregate data from these local government areas to 324 local authorities.[3] The aggregation is necessary to ensure a sufficient number of housing transactions for each property type within a given quarter and local area. Figure 1 plots the county boundaries of these local authorities. Detailed data definitions and sources can be found in Appendix A. Table 1 lists descriptive statistics.

2.1.1 Monetary Policy Shocks

Identifying the effects of monetary policy is problematic for at least 2 reasons. First, monetary policy, interest rates and other macroeconomic variables are determined simultaneously

[2]The availability of housing price data limits the analysis to years after 1994, while the monetary policy shock series ends in 2015.

[3]There are 326 councils in England prior to April 2015. Because few housing transactions are being recorded, I exclude Isle of Scilly and the City of London.

as policy makers respond to current economic conditions. Second, policymakers, as well as other individuals, take into considerations expected future economic conditions, as well as current and past information. To address these endogeneity concerns, Romer and Romer (2004) suggest to disentangle cyclical movements in short-term interest rates from policy-makers' intended changes in the policy rate, and rid the series of policy changes that were responding to macroeconomic variables within the policymakers' information set. In a nutshell, the approach aims to isolate unexpected shifts in monetary policy from the systematic component in the intended policy rate driven by policymakers' response to information they have about the state of the economy. Cloyne and Hürtgen (2016) show that this policy shock variable is unpredictable on the basis of various macroeconomic time series for the UK and it is uncorrelated with other structural shocks.

To identify the monetary policy innovations, they use a two step procedure. In the first step, an intended policy rate is constructed by estimating the following regression:

$$\begin{aligned}\Delta i_m = \; & \alpha + \beta i_{t-d14} + \sum_{j=-1}^{2} \gamma_j \hat{y}^F_{m,j} + \sum_{j=-1}^{2} \phi_j \pi^F_{m,j} \\ & + \sum_{j=-1}^{2} \delta_j (\hat{y}^F_{m,j} - \hat{y}^F_{m-1,j}) + \sum_{j=-1}^{2} \nu_j (\pi^F_{m,j} - \pi^F_{m-1,j}) + \sum_{j=1}^{3} \rho_j u_{t-j} + \epsilon_m\end{aligned} \tag{1}$$

where the dependent variable Δi_m is measured at a meeting by meeting frequency, m, and presents the intended policy target around the policy decision. Forecast and real-time data are denoted with the subscript j indicating the quarter of the forecast relative to the meeting date. As such, $y^F_{m,j}$ ($\pi^F_{m,j}$) is the one and two quarter forecast of real GDP growth (inflation), as well as the real time backdata of the previous period and the forecast for the current period. Equation 1 further includes revisions in the forecast relative to the previous round for forecasts (e.g. $\hat{y}^F_{m,j} - \hat{y}^F_{m-1,j}$), as well as controls for recent economic conditions such as the interest rates two weeks before the meeting, i_{t-d14}, and the unemployment rates of the previous three months, u_{t-j}.

In a second step, the residuals from equation 1 are estimated and defined as the exogenous monetary policy shock measure. Intuitively, the definition of a monetary policy shock then is the unpredictable surprise that is not taken as a response to information about current and future economic developments. As such, the shock reflects an unpredictable exogenous movement in the policy rate representing a variety of factors such as deliberately induced policy surprises, or temporary shifts in the preferences of policymakers. Finally, this meeting-by-meeting measure of monetary policy shocks is aggregated to a quarterly series.

Figure 2 plots a time series of the quarterly series of exogenous policy shocks. The series is relatively volatile until 1993. This timing coincides with a regime shift in the Bank of England explicitly targeting inflation. Further, the policy making process has become more transparent during this time due to regular publications of the Inflation Report and MPC Minutes, which reduces surprise policy rate changes. In my analysis, the availability of housing price data restricts the sample period to 1995 - 2015, and thus the shift towards inflation targeting precedes the analysis.

2.1.2 House Prices and Sales

Housing data comes from the UK Land Registry and includes the universe of residential property sales since 1995. In addition to sales price and date, the data include information on whether or not the dwelling is a first time sale, and the property type (e.g. detached house or flat). Since the data are at the individual transaction level, the housing sales variable is based on the total number of transactions that occur during a quarter and within a local authority. To eliminate some of the noise that stems from low housing sales in some quarters and local authorities, I follow Cloyne, Ferreira, and Surico (2020) and smooth both the house price and transactions series with a backward-looking (current and previous three quarters) moving average.

The housing price series is the UK house price index by location and quarter from the UK Land Registry in 2015 British Pounds. In contrast to the raw housing price data, this index takes into account changes in the composition of housing to allow only pure price changes to feed into the measurement of house price inflation. In other words, the UK HPI is mix adjusted to allow for differences between houses sold in different periods, for example the type or size of property.[4]

Figures 3 and 4 show the mean, median and standard deviation band of the average quality-adjusted housing price and average number of sales across local authorities in a given quarter (in logs), respectively. Sales have been increasing since the bust of the housing bubble, which is also reflected in an increase in home prices. The mean and median of both series track closely together. While the dispersion of sales across local authorities has remained largely constant since 1995, house price dispersion has been increasing in recent years.

Figure 5a shows this dispersion in the form of annualized house price growth rates between 1995 and 2015 for 324 English local authorities. The average growth rates range from just over 1% to 2.7%, with a thick right tail. These differences in long-run growth rates led to a widening gap in the price of housing between the most expensive local authorities and the average ones. For example, the average home sold in Kensington and Chelsea exceeded a price of over 2 million British Pounds, compared to the English median price of 240,000. Of course, housing in Kensington and Chelsea is exceptional even by international standards. However, house values display large dispersion on the lower end of the distribution. For example, the average home in Burnley sold for just under 100,000 British pounds ($130,000), which is low for UK standards, but high in international comparison. Figure 5b plots the distribution of log house prices in 1995 and 2015. Compared to 1995, the average house price in 2015 is significantly higher, with some of the most affordable local authorities in 2015 being priced similar to the most expensive local authorities in 1995 (in 2015 British Pounds). In addition, the distribution of prices has become significantly wider, highlighting again the increasing inequality of housing affordability across local authorities.

Table 1 shows that the quality adjusted price of new dwellings is on average 23,000

[4]see www.gov.uk for details.

pounds higher compared to re-sales, but new dwellings make up only 10% of all transactions. Unsurprisingly, property in Kensington and Chelsea is, on average, least affordable. The average dwelling sells for a quality adjusted price of 1.3 million pounds (2.1 million pounds raw transaction price).

2.1.3 Property Size

I derive the property size measure from the UK house price index. Specifically, the UK Land Registry defines the quality adjusted price index as

$$PI_{i,t} = \left(\frac{\Pi_{j=1}^{n} p_{jt}^{1/n}}{\Pi_{j=1}^{n} p_{j2015}^{1/n}} \right) exp[\hat{\beta}(\bar{x}_{2015} - \bar{x}_t)] \tag{2}$$

where $PI_{i,t}$ is the price index in local authority i at time t. The first term in the index is the ratio of simple (unweighted) geometric sample means of house prices in period t relative to base period (2015), where p_{jt} denotes the transaction price of house j at time t. The second term is an adjustment for changes over time in the composition of houses from hedonic regressions. The matrix x includes i) local authority of the property, ii) property status by new sale vs repeat sale, iii) ACORN area classification, and iv) property size.[5]

To fix ideas, suppose that x only consists of one variable, house size. If average house sizes are the same in period t as in the base period (2015), then the price index value is just the ratio of geometric means. If average house size has fallen from period t to the base period (so that the second term in parenthesis is negative), then the average price in the current year is increased to reflect the decrease in house size. The proper interpretation of the price index is thus the relative change in the price, not of a house, but the price of a square foot of a house; i.e. the price of a house of standard size.

I use this index and divide it by the simple (unweighted) geometric sample means of house prices from the raw data, after deflating by the UK CPI to transform prices to 2015 British

[5]Appendix 4 contains more information regarding the construction and definition of the quality adjusted house price index in equation 2. Also see https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-RA-12-022 for additional details.

Pounds. Specifically, in this step I construct the first term of equation 2, $\left(\frac{\Pi_{j=1}^{n} p_{jt}^{1/n}}{\Pi_{j=1}^{n} p_{j2015}^{1/n}}\right)$, from the raw data by hand, and divide equation 2 by this self-constructed (unadjusted) house price index to get

$$\frac{PI_{i,t}}{\left(\frac{\Pi_{j=1}^{n} p_{jt}^{1/n}}{\Pi_{j=1}^{n} p_{j2015}^{1/n}}\right)} = exp[\hat{\beta}(\bar{x}_{2015} - \bar{x}_t)] \tag{3}$$

To ease the interpretation of the Quality measure, I take logs of equation 3 and multiply with minus one to get

$$Quality_{i,t} = \hat{\beta}(\bar{x}_t - \bar{x}_{2015}) \tag{4}$$

Note that this quality measure compares housing features in period t and locality i to housing features in the base period, 2015, in the same locality. Therefore, this measure accounts for structural differences in home features across districts. For example, housing in densely populated London may be smaller, on average, than housing in the less densely populated North West. The measure in equation 4 is not comparing the evolution of housing features to another locality, or the UK average. Instead, the measure compares housing features in locality i in 2015 to housing features in the same locality a few years earlier.

To continue the example from above: If x only consists of one variable, house size, then β in the equation is likely positive (larger houses are typically associated with higher prices; see equation 7 in the appendix). Thus, if the average dwelling in locality i is larger in 2015 relative to previous periods, $t = 1995, ..., 2014$, then *Quality* is negative. In contrast, if dwelling size decreased over the sample period (i.e. size in $t = 1995, ..., 2014$ exceeds size in 2015), *Quality* becomes positive. Figure 6a plots the time series of equation 4. The Quality measure is positive in 1995, implying that quality within each district have, on average, declined between 1995 and 2015. In addition, Figure 6b shows the evolution of housing quality separately for new buildings and re-sales. The quality of new builds was relatively constant between 1995 and 2001, then declined rapidly until 2009, and has remained relatively constant since 2009.

Since I aggregate homes to narrow geographic areas, and separate transactions into new-builds and resales, property size is the only remaining dimension of quality adjustment. I therefore interpret the quality variable in equation 4 as changes to property size. This is consistent with reports from LABC Warranty (2018) that suggest that average home size has decreased by 8% over the last 2 decades. To verify the size interpretation of the quality variable, I use survey data from the UK Household Longitudinal Study (Understanding Society) for the period 1995 - 2015. Among other variables, the survey asks households the number of rooms in their home, whether the home is rented or owner-occupied, and when the house was purchased.

First, I restrict the sample to owner-occupied homes, and calculate the average price of these homes in the survey, separately for each purchase year. Figure 7a shows that the survey prices of homes purchased in a given year closely track the evolution of prices from all property sales in the UK Land Registry (Figure 4). The average price from the survey and Land Registry are 204,000 and 206,000 (in 2015 British Pounds), respectively, with a correlation of 0.94.

Second, I plot the average number of rooms of owner-occupied homes in the survey, for each purchase year. Figure 7b in the Appendix displays a similar downward trend as the quality variable in Figure 6a. The average number of rooms decreases until 2010 and remains relatively constant thereafter. Specifically, over just one decade, the average UK living room size has decreased by 14%, the average kitchen decreased by 8%, and the average number of bedrooms fell by 12% to less than 3 bedrooms per home. The correlation between the quality measure in equation 4, and number of rooms is 0.75. Thus, the fewer rooms in a dwelling, the lower the quality of a home.

Lastly, I compare the quality measure to overcrowding data from the Eurostat data base. A person is considered as living in an overcrowded household if the household does not have at its disposal a minimum number of rooms.[6] Figure 7c shows an increase in the

[6]For details, see Eurostat Online Data Code: ILC_LVHO05D

percentage of the population living in an overcrowded household. The correlation between the quality measure in equation 4, and overcrowded households is -0.87. In other words, the higher the percentage of overcrowded households the lower the quality of a home. These correlations suggest that the quality measure in equation 4 is indeed closely related to more traditional dwelling size variables like overcrowding and the number of rooms per owner-occupied dwelling.

2.1.4 Local Factors

To examine the role of local factors in determining the price and size response to a monetary policy shock, I collect data on four variables. First, I take the distance between the centroid of a local authority and Trafalgar Square in the heart of London. Intuitively, monetary policy may have a stronger and more immediate impact in London relative to more distant, rural areas. For example, Holly, Pesaran, and Yamagata (2011) show that house price shocks to London are propagated contemporaneously and spatially to other regions with delay. On average, local authorities are 150km from London, with Northumberland in the North East being the furthest at 430km.

Second, I use a measure for the share of developed land in a local authority. However, the share of developed land is arguably endogenous. For example, more desirable places attract more individuals and will thus have less developable land. Therefore, I follow Hilber and Vermeulen (2016) and use historic population density in 1911 as a proxy for the share of developed land. The population density in 1911 will be indicative of early forms of agglomeration and should be strongly correlated with the share of developed land 100 years later. Intuitively then, areas with more developed land have less space available for new housing projects, which in turn would lead to stronger house price responses. The correlation between 1911 population density and share of developable land is 0.6, where Islington (a London Borough) has historically had the highest population density at over 22,000 people per square km. So while population density in 1911 is correlated with the contemporaneous share of developed land, I would not expect historic density to directly (other than through land scarcity) explain changes in contemporaneous house prices.

Third, I use the refusal rate for minor housing projects as a proxy for the supply elasticity. In contrast to distance to London and population density in 1911, this variable can be directly influence by policy. According to Hilber and Vermeulen (2016) the high real house price growth in the UK over the last 40 years may be linked to the British planning system. For example, Cameron, Muellbauer, and Murphy (2006) suggests that a lack of house building in conjunction with strong demand growth as a major driver of house price appreciation. The refusal rate of minor projects is defined as the share of applications for residential developments of less than 10 dwellings that is refused by a local authority in any quarter. Thus, local authorities with a tighter planning system should be subject to a lower housing supply elasticity, which in turn would lead to higher house price responses. However, regulatory restrictiveness is likely endogenous. One concern is that refusal rates are higher during boom periods when housing demand and prices are high. Further, more projects may apply during boom periods, overwhelming the planning authority. To address this issue I follow Hilber and Vermeulen (2016) and use the average refusal rate over the entire period I have data for (1979 - 2015) to limit co-movements between price and refusal rate fluctuations. Surprisingly, London Boroughs make up both the most and least restrictive localities. Kensington and Chelsea, and Lewisham only refuse 15% of proposed projects, while Redbridge, Harrow, and Hillingdon refuse almost 50%.

Lastly, local authorities may not only display different price responses due to differences in local housing supply factors, but also due to differences in demand factors. For example, as a response to a monetary policy shock, local income may respond differently based on their distance to London or industrial composition. Furceri, Mazzola, and Pizzuto (2019) show larger contractionary effects of monetary policy tightening in US states with higher manufacturing share, and smaller firms. In addition, Auclert (2019) shows the importance of income as a transmission mechanism of monetary policy. Unfortunately, England does not report local incomes at a quarterly frequency. Thus, I use local unemployment rates as a proxy for local authority incomes. Intuitively, areas with a stronger reduction in unemployment due to a monetary policy shock should experience a larger increase in house prices.

2.2 Empirical Specification

Let s_t denote the magnitude of an exogenous shock to monetary policy in period t as described in Section 2.1.1. The interest lies in estimating how local housing markets respond over time to policy shocks. In my baseline analysis, I estimate dynamic response functions using Jorda's local projections method:

$$y_{i,t+h} = \beta_i^h s_{t-1} + b_1^{'} \tilde{s}_t + b_2^{'} \tilde{y}_{it} + t_t + q + v_{i,t+h} \tag{5}$$

where $\tilde{s}_t^{'} = [s_{t-2}...s_{t-5}]$, $\tilde{y}_t^{'} = [y_{t-1}...y_{t-5}]$, $h = 1, ..., H$ is the forecast horizon, and β_i^h is the set of impulse responses as a function of h for each i. The variables t and q denote a linear trend and quarter dummies, respectively. I estimate the model separately for each local authority, which yields a distribution, across i, of the dynamic responses. I then use these responses in a second step cross-sectional regression to identify how they are affected by local factors.

In equation 5, y is a place holder for four variables used to estimate four separate models. First, let y denote, respectively, the backward-looking (current and previous three quarters) moving average of i) the quality-adjusted average transaction price in local authority $i = 1, ..., 324$ during time period $t = 1995Q1, ..., 2015Q4$, ii) housing sales in a given local authority and quarter, and iii) housing size (see equation 4)

Furthermore, I use the unemployment rate in a given local authority and quarter as the dependent variable. From this last regression, I calculate the average response of unemployment to a monetary policy shock over an 8 quarter horizon and use this variable in the cross sectional regression as described below. Intuitively, $\frac{1}{H}\sum_{h=1}^{H} \beta_i^h$ measures, for each local authority, how strongly unemployment responds, on average, to a monetary policy shock over an 8 quarter horizon. Then, local authorities that experience a stronger change in unemployment from a monetary policy shock might also experience larger changes in house prices. Figure 8 plots the impulse responses of unemployment, β_i^h, for each local authority and $h = 1, ..., 8$. As expected, unemployment, on average, decreases following a 25 basis point cut in the policy rates, with some variation across local authorities.

Next, I collect the 324 sets of local impulse response functions from equation 5, and run the following cross sectional regression separately for each horizon $h = 1, ..., 8$

$$\beta_i^h = \alpha_1 Refusal_i + \alpha_2 PopDens_i + \alpha_3 Unemp_i + \alpha_4 Dist_i + Region_i + e_{i,t} \tag{6}$$

where β_i^h is either the impulse response of i) house prices ii) house transactions or iii) size. $Refusal_i$, $PopDens_i$, and $Dist_i$ are the refusal rate for minor projects, 1911 Population Density, and Distance to London as described in Section 2.1.4, respectively. The variable $Unemp_i$ is the average response of unemployment in each local authority to a monetary policy shock over an 8 quarter horizon, $Unemp_i = \frac{1}{H}\sum_{h=1}^{H} \beta_i^h$. $Region$ is a dummy variable indicating a local authority's region. Equation 6 therefore indicates if local authorities with tighter regulatory and physical constraints show stronger housing market responses to a monetary policy shock.

3 Results

This section reports heterogeneity across local authorities in the response of prices, transactions, and size to a monetary policy shock. Property size is defined as in equation 4, in other words, it measures the average size of a dwelling in local authority, i, in period t relative to 2015 in that same local authority. In all cases, I estimate the responses to a 25 basis point cut in the policy rates.

3.1 Impulse Responses of Prices, Transactions, and Property Size

Impulse responses are based on the benchmark specification in equation 5 using the backward-looking (current and previous three quarters) moving average of the i) quality-adjusted price, ii) number of housing transactions, and iii) property size as the dependent variable. Figure 9a shows the response of quality adjusted house prices over an 8 quarter horizon. Prices are initially unaffected by a drop in the interest rate, but start to increase 5-6 quarters after the shock. After 8 quarters, house prices increase by 1% following an unexpected 0.25 percentage point cut in the interest rate. Intuitively, lower interest rates increase economic activity and incomes, and lowers mortgage rates. As a result, demand for housing increases, which in turn drives up prices. In line with this argument, transactions are initially unaffected by a drop in the interest rate (Figure 9b), but start to increase 3-4 quarters after the shock. Note how the increase in transactions leads the price response. In other words, following a cut of the policy rate, housing demand (transactions) increases, which in turn results in rising house prices. After 6 quarters, when prices start to significantly increase, transactions start to decline again. At its peak, transactions increase by 1.5% following an unexpected 0.25 percentage point cut in the interest rate.

In contrast to prices and transactions, the size response to a monetary policy shock is insignificant over the 8 quarter horizon and slightly inverse-U shaped (Figure 9c). In other words, following a monetary policy shock in period t, the size of sold homes increases relative to the 2015 level in a given locality for about 5 quarters, before reverting back to their pre-shock levels. This response is entirely driven by existing homes being re-sold in the market, with significant effects 4 to 6 quarters after the shock (Figure 10f). In contrast, the average response of new builds is noisy but flat (Figure 10e).

Similar to property size, the price and transactions response of new builds is more muted than the responses of re-sales. Intuitively, lower policy rates provide an incentive for developers to start new housing projects. As the supply of new property in the market increases, the upward pressure in prices from the demand side gets muted. After 8 quarters, house prices of first-time sales increase by only 0.5% following an unexpected 0.25 percentage point cut in the interest rate (Figure 10a).

Figures 10c and 10d show the sales response for new dwellings and re-sales, respectively. The response of new dwellings is much noisier relative to the response of re-sales. While I observe a slight increase in transactions of new builds 3-4 quarter after a monetary policy shock, the effect remains insignificant for all horizons. In contrast, I observe a statistically significant increase in the sales of older property after 3 quarter. This finding, together with the price response of new builds, appears puzzling. If lower policy rates provide an incentive for developers to start new housing projects, which in turn reduces the upward pressure in prices from the demand side, why is there no significant increase in the number of transactions of new builds? To answer this questions, Figure 11 plots the impulse responses of a monetary policy shock on UK-wide industrial production, unemployment, the household variable mortgage rate, housing projects started, and housing projects completed. The first 3 variables show the expected response. However, while the number of new buildings started increases temporarily, the policy shock has no effect on new buildings completed, and therefore the number of homes transacted. In other words, an increase in the construction of new housing following a monetary policy shock keeps the upward pressure on prices low, while at the same time keeps transactions unaffected because of the significant time delay between planning, starting, and finishing a new construction project.[7]

3.2 Effect of Local Factors on Prices, Transactions, and Property Size

Figure 12 plots the coefficients from equation 6 for each forecast horizon, using the impulse responses from equation 5 of i) all property prices to a monetary policy shock (Figure 12a), ii) all property transactions (Figure 12b), and iii) dwelling size (Figure 12c) as dependent variable.

First, distance to London seems to matter: Areas further away from London experience

[7]According to the National Custom and Self Build Association it takes about two years to build a home, from planning the project to moving in.

a larger increase in house prices after 8 quarters. This is consistent with research by Holly, Pesaran, and Yamagata (2011) who show that house price shocks occur outside of London with a delay. Further, distance to London plays a role in the transaction response of a policy shock. This effect is persistent, and in contrast to the price response, manifests in the short run. Specifically, areas that are further away from London experience a stronger increase in housing transactions. Finally, transacted homes in local authorities close to London tend to be bigger 7 periods after the policy shock.

Second, changes to local unemployment rates following a monetary policy shock do not significantly affect a local authority's house prices. Intuitively, one might expect that, as unemployment rates in some districts decline stronger (and incomes rise faster) following a monetary policy shock, house prices in these areas increase faster due to increasing demand. While results imply a tendency for this inverse relationship between unemployment and house price response, the effects remain insignificant at each horizon. This finding is related to Auclert (2019), who shows that changes to income, inflation and interest rates affect consumption after a monetary policy shock. While I confirm that monetary policy affects unemployment (and therefore income), the income channels does not significantly increase house prices. Note that these findings do not necessarily contrast the results in Hilber and Vermeulen (2016). Their paper shows how an increase in income increases demand for houses and prices, particularly in areas with tighter planning regulation. My findings merely suggests that changes in income due to a monetary policy shock are not sufficient to increase house prices. One reason for this may be that changes to unemployment and income due to monetary policy are transitory and therefore do not affect long term financing decisions.

Somewhat surprisingly, Figure 12b shows that areas with less of a decline in unemployment following a monetary policy shock experience a stronger rise in housing transactions. The effect grows over the 8 period horizon but remains statistically insignificant. Intuitively, one would expect housing transactions to increase with income and employment. However, a lower increase in a local authority's economic activity following a monetary policy shock compared to the rest of the country may also imply that people switch jobs and move, downsize or rent (maybe as a result of early retirement). These factors would trigger an increase in houses on the market. Comparing Figures 13c and 13d support this hypothesis. If existing homeowners in less economically active local authorities decide to sell their homes, I should observe that the overall effect of transactions is entirely driven by re-sales, with no significant effect in the market of new builds.

Third and last, local authorities with more inelastic housing supply show stronger price responses to a monetary policy shock. Specifically, local authorities that refuse a larger share of minor development projects are subject to larger price increases. The effect becomes significant after 1 quarter and is strongest after 6 quarters. On average, a one percentage point increase in the refusal rate increases the price response to a monetary policy shock from $\beta = 0.42$ to $\beta = 0.43$. In other words, after 6 quarters, house prices increase by 0.43%, instead of 0.42%, following an unexpected 0.25 percentage point cut in the interest rate in local authorities with a one percentage point higher refusal rate. Population density has a similar effect as the refusal rate, however, the effect seems more persistent and does not fall off after 6 quarters.

As expected, local authorities with more stringent planning regulations in place (as measured by the refusal rate of minor projects), are subject to a weaker sales response following a monetary policy shock. This effect occurs with a delay, remains persistent beyond 8 quarters, but is not statistically significant at any horizon. In contrast, local authorities with higher population density experience a more pronounced increase in sales as a result of a monetary policy shock. Again, this effect occurs with a delay, but remains persistent and statistically significant after 8 quarters. Interestingly, Figures 13c and 13d imply different effects of population density for new builds and re-sales. Areas that are more densely populated are expected to have a larger stock of existing homes, thereby reducing the need for new construction. At the same time, more densely populated areas have less developable land available, thereby reducing the ease of developing new property in an empty space.

Consistent with this argument, results indicate that areas with higher population density experience a stronger increase in the transactions of older homes, while the same areas see sales of new builds decline in the long run.

Further, Figure 13e implies local authorities with stricter planning regulations transact relatively larger new builds immediately following a monetary policy shock. This suggests that planning authorities act as gate-keepers limiting the fall in property size. However, the resulting implications for home-owners are, per se, unclear. On the one hand, holding prices constant, ensuring that dwelling sizes are in line with British space standards is welfare improving, especially as more people tend to work from home. For example, under the 2015 space standard, a new one bed, one person flat would have to be a minimum of $37m^2$ while a three bed, five person home would be a minimum of $93m^2$ (Crosby, 2015). However, more than half of new homes being built do not meet these standards. On the other hand, tighter planning regulations raise the implicit cost of construction. As a result, construction companies may respond by only putting larger, more profitable projects forward. This would exclude new home-owners from entering the market.

In contrast to new builds, Figure 13f implies that the size of already existing homes is affected by population density, but not by the local authority's planning regulation. Specifically, re-sales in more populated areas tend to be bigger relative to their 2015 level 3-5 quarters after a monetary policy shock. This finding can be explained by a faster size decrease of new builds in densely populated areas that enter the housing market again a few years later as re-sales. Consider two housing pools of already existing homes on the market – one in 2010 and the other in 2015. The first housing pool of re-sales consists of homes built prior to 2010. The second housing pool of re-sales consists of homes built prior to 2015, including homes that were built in 2010 and before. If, on average, houses built between 2010 and 2015 were significantly smaller than property built before 2010, then average property size of already existing homes on the market in 2015 is smaller compared to 2010. Moreover, if this decrease in property size happened faster in areas that are more densely populated, we would observe larger housing in period $1994 < t < 2015$ relative to 2015 in areas that are more densely populated – which is what the result above suggests.

Can data confirm the plausibility of this mechanism? Urbanization has long put pressure on densely populated areas to reduce property size, as more people have to be cramped into tighter spaces. For example, a survey by Crosby (2015) finds that the size of an average 3 bedroom new home in densely populated London and the South East shrunk by, respectively, $10m^2$ and $3m^2$ between 2011 and 2015. In contrast, property in the less densely populated East Midlands and Yorkshire and Humber remained unchanged. The sharper decline in more densely populated areas thus results in property sizes that where relatively larger just a few years prior. In other words, we observe larger property sizes in 2011 compared to 2015 in more densely populated areas, while we observe no differences in property sizes in less densely populated areas.

As a last note, this final result also supports our intuition about the dimension of the quality improvement of a monetary policy shock: With quality decreasing more in areas that have less developable land but more amenities (assuming that amenities locate near population centers) the likely quality change takes place along the size dimension, rather than along neighborhood characteristics.

4 Conclusion

The UK housing market features some of the most expensive, yet smallest dwellings in Europe. With interest rates at historic lows, and housing construction experiencing supply shortages, prices have been soaring over the last months. Monetary policy has often been found to contribute to rising prices, as low mortgage rates stimulate housing demand (Taylor, 2007). At the same time, the British Planning System is often blamed for being too rigid, thereby contributing to high housing price growth (e.g. Cheshire and Sheppard (2002)

This paper investigates the relationship between monetary policy and local housing markets, in conjunction with local regulatory and physical constraints. The results can be summarized as follows. First, local housing markets react to an unanticipated change in the policy rate. Specifically, following an unanticipated 25bp cut in the policy rate, transactions increase by 1.5% six quarters after the shock, with prices rising by 1% eight quarters after the shock. In addition to housing demand and prices, monetary policy also affects the size composition of older homes on the market. The property size of re-sales increases following a monetary policy shock relative to 2015 levels.

Second, I find that local differences in the unemployment response to a monetary policy shock play no role in explaining housing market differences across local authorities. This finding is related to Auclert (2019) who suggests that monetary policy affects consumption through 3 channels - income, inflation, and interest rates. In the context of Auclert (2019), my results suggest that monetary policy affects housing primarily through the interest rate, and less through an income effect.

Lastly, I confirm previous findings relating the local regulatory constraints to higher house price growth (e.g. Hilber and Vermeulen (2016)), but also suggest that the relationship between regulatory constraints and housing markets may be more complicated. On one side, tighter regulatory constraints increase the quality adjusted price and make housing less affordable. On the other side, however, local authorities with stricter planning regulations transact relatively larger new builds as a result of a monetary policy shock. These results suggest that planning authorities act as gate-keepers in line with British space standards, limiting the decline in property size.

These findings are important for policy makers as they add to the understanding of distributional effects of monetary policy shocks. Previously, literature has focused on distributional effects by income and other socio-economic characteristics (e.g. Iacoviello (2005), Mian and Sufi (2011), Auclert (2019), Cloyne, Ferreira, and Surico (2020)), but the spatial diffusion of a monetary policy shock are less understood (recent exceptions include Amarasinghe et al. (2018), Furceri, Mazzola, and Pizzuto (2019), or Pizzuto (2020)). Findings imply that monetary policy shocks decrease affordability, especially in more urbanized areas, thereby excluding many first-time buyers from owning property in these areas. Moreover, this paper informs policy by disentangling and identifying the separate impacts of different types of constraints to provide important insights into the current policy debate surrounding Britain's housing affordability and housing standard crisis.

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Figures

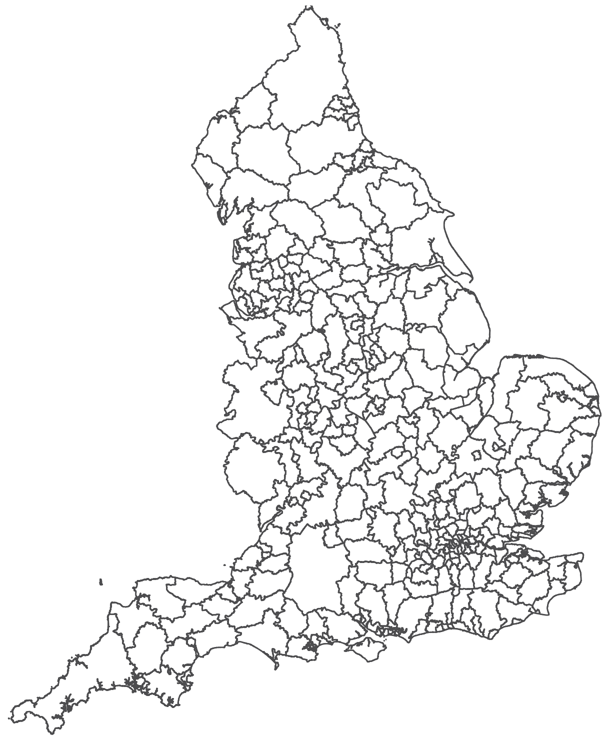


Figure 1: Local Authority Boundaries prior to 2015

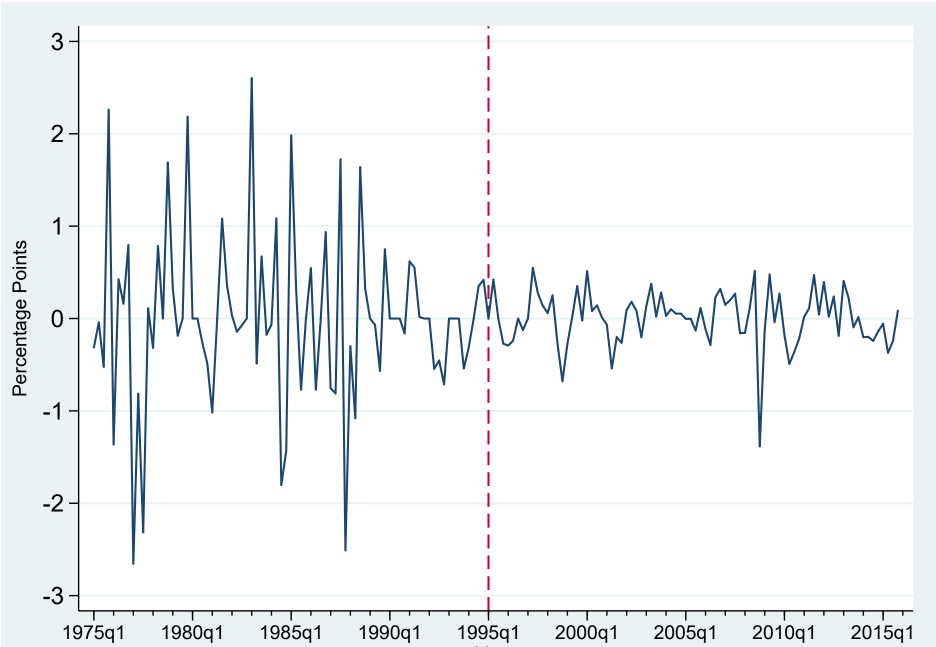
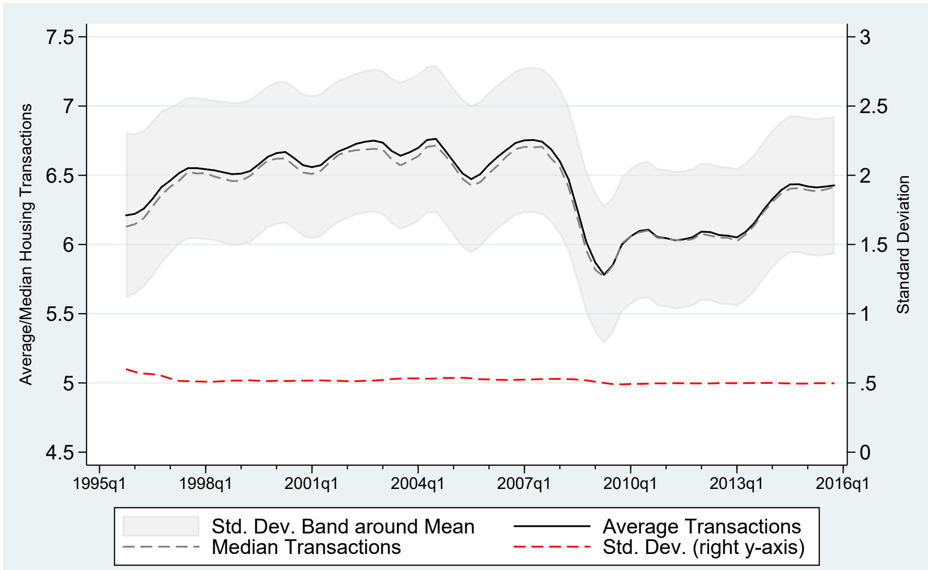
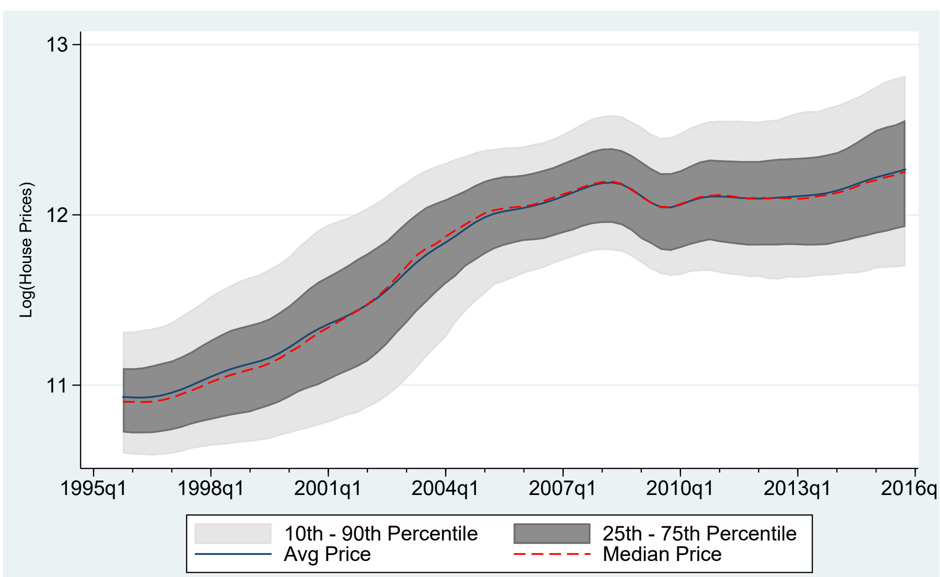


Figure 2: Time Series of Monetary Policy Shock



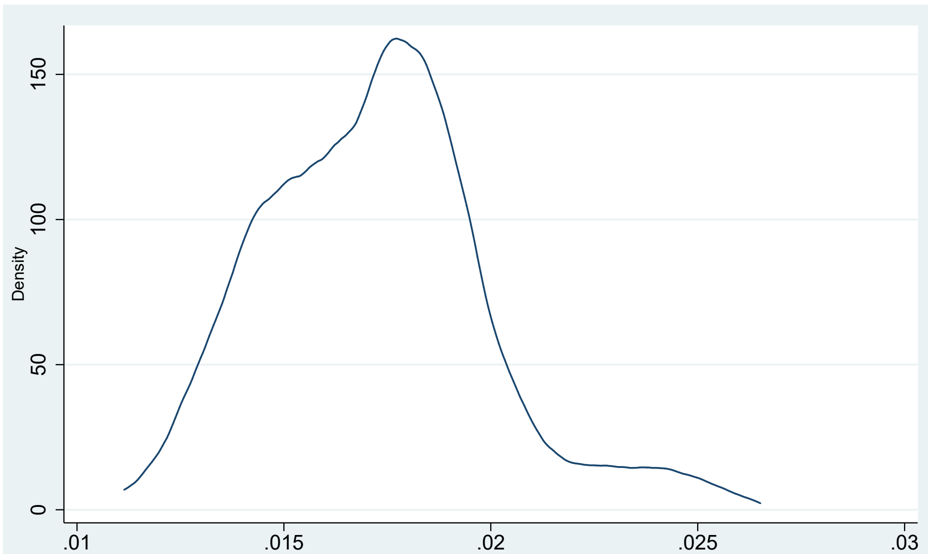
Notes: Backward-looking (current and previous three quarters) moving average of the number of residential housing transactions.

Figure 3: Time Series of Housing Sales



Notes: Backward-looking (current and previous three quarters) moving average of the (log of) quality adjusted house prices.

Figure 4: Time Series of Housing Prices

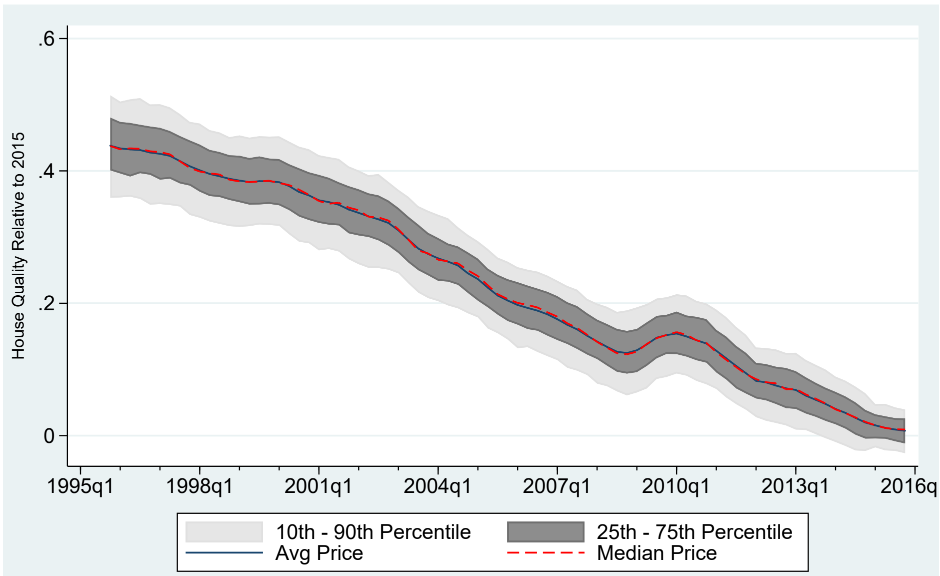


(a) Annual House Price Growth Rate: Avg 1995 - 2015

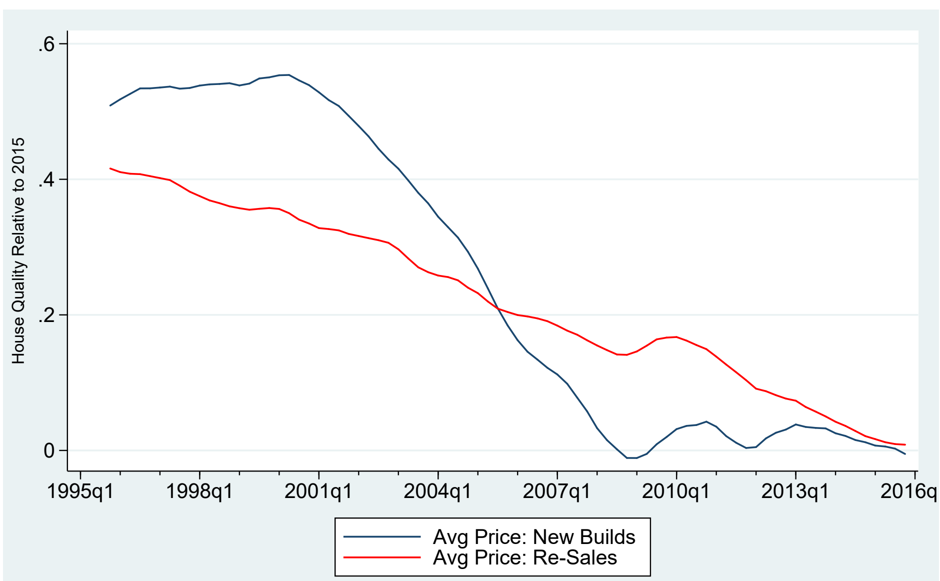
(b) Average House Prices: 1995 and 2015

Notes: Based on quality adjusted house prices of 324 local authorities

Figure 5: Distribution of House Prices and House Price Growth



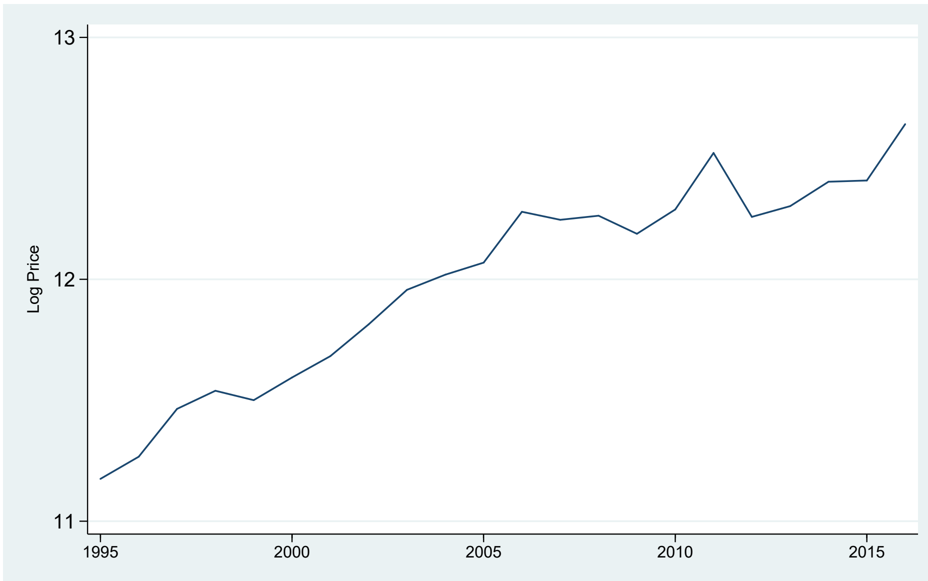
(a) All Dwellings



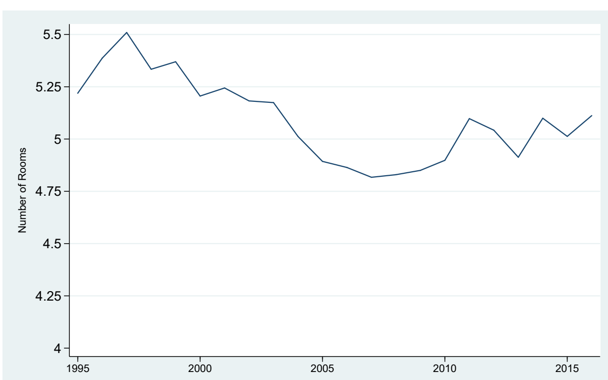
(b) New Builds vs Re-sales

Notes: House Quality is derived from the quality adjusted house price index of first-time sales and re-sales with base year 2015. Please see Section 2.1.3, particularly equation 4 for details.

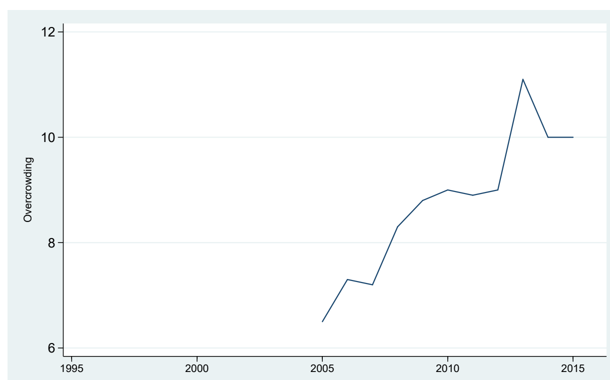
Figure 6: House Quality Relative to 2015



(a) Survey Data - Average Price



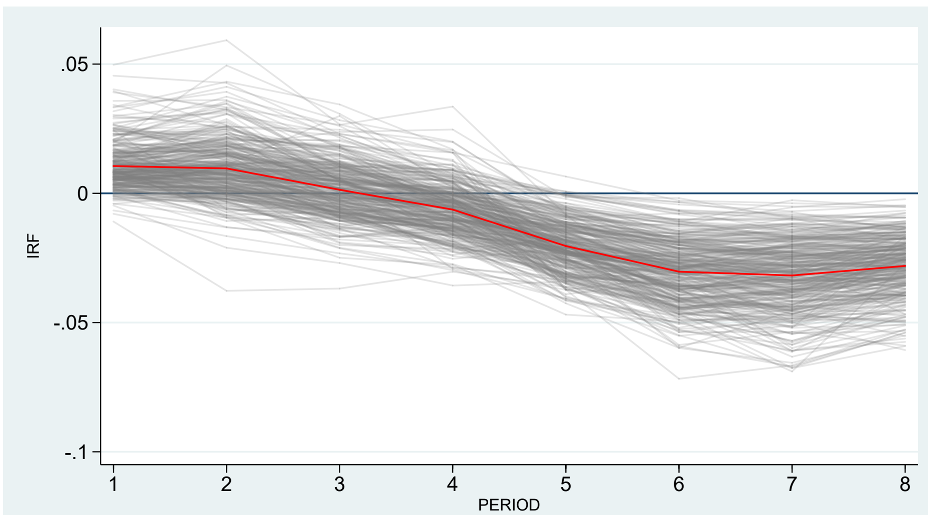
(b) Survey Data - Number of Rooms



(c) EuroStats - % Overcrowded Homes

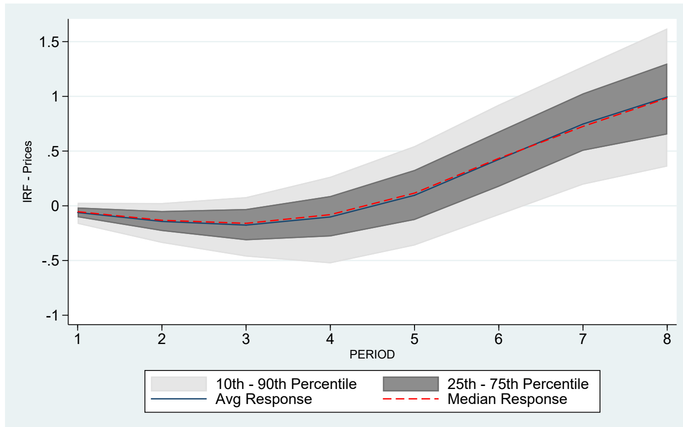
Notes: Survey data on average house prices and number of rooms comes from waves 2009 - 2015 of the UK Household Longitudinal Study (Understanding Society). The sample is restricted to English owner-occupiers that purchased their homes between 1995 and 2015. Data on overcrowded homes comes from EuroStats.

Figure 7: Survey Data - Prices and Size over time

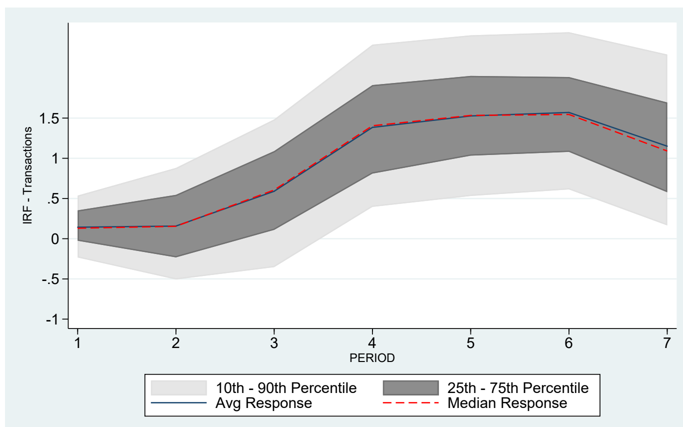


Notes: The figure plots the average impulse responses (β_i^h) from the local projections of equation 5 for each locality $i = 1, ..., 324$ at horizons $h = 1, ..., 8$. The dependent variable is the change in unemployment as measured by the share of claimants in the working age population. The red solid line depicts the average response, while the gray lines represent the 324 individual local responses.

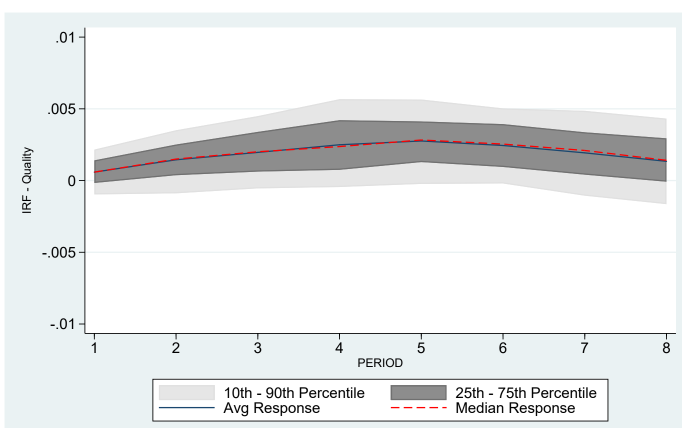
Figure 8: Local and Average Response of Unemployment to MPS



(a) Impulse Response - Prices



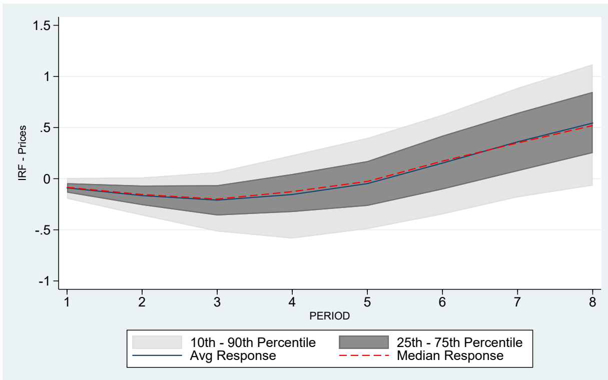
(b) Impulse Response - Transactions



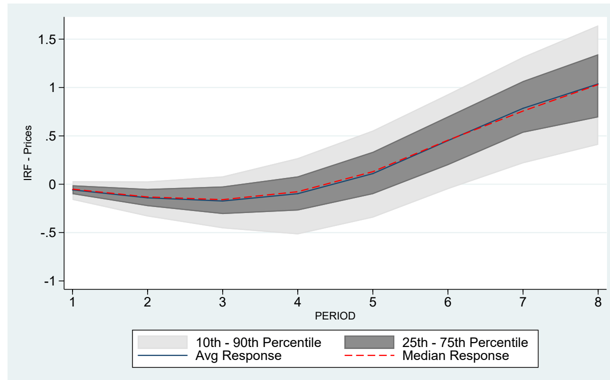
(c) Impulse Response - Quality

Notes: The figure plots the average (median) impulse responses (β_i^h) from the local projections of equation 5 for each locality $i = 1, ..., 324$ at horizons $h = 1, ..., 8$. The dependent variable is (a) the average quality adjusted house price of all dwellings sold, (b) the number of transactions of all dwellings sold, and (c) the average house size all dwellings sold.

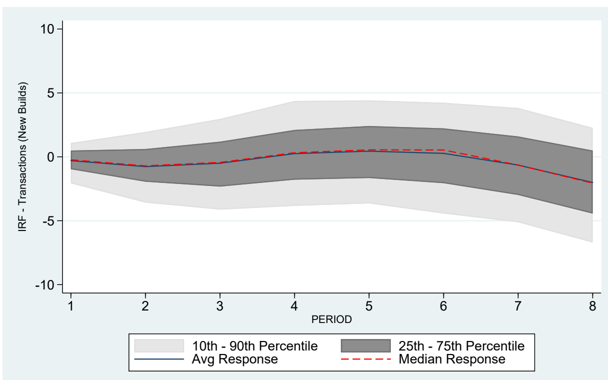
Figure 9: Impulse Response to a 25bp cut in Policy Rate: All Dwellings



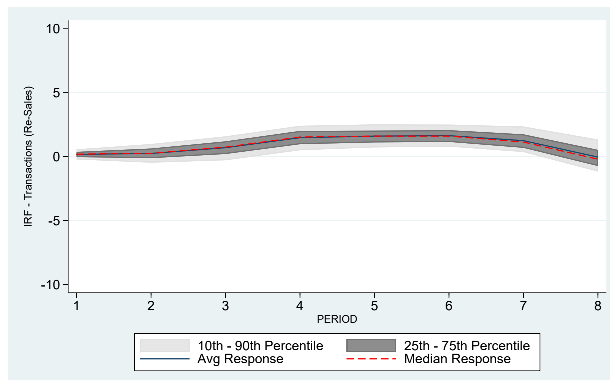
(a) Prices (New Builds)



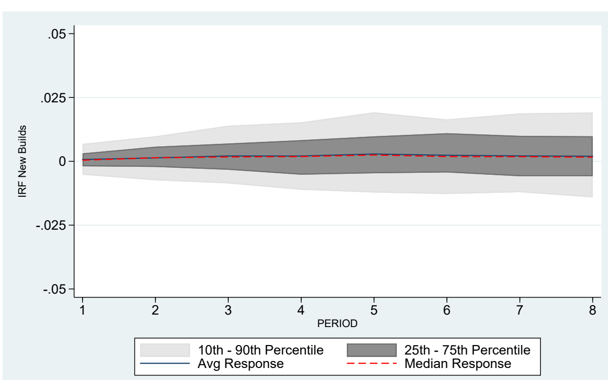
(b) Prices (Re-sales)



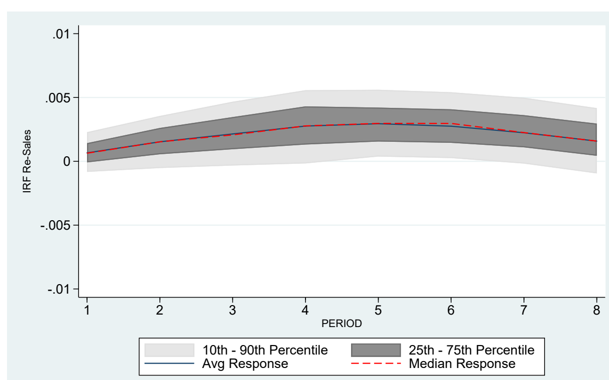
(c) Transactions (New Builds)



(d) Transactions (Re-Sales)



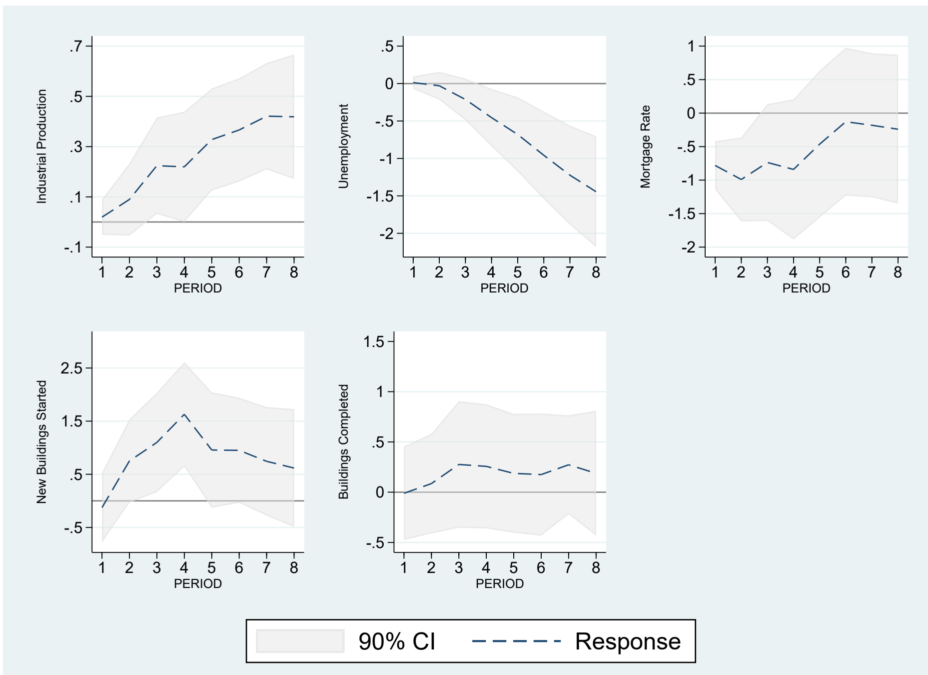
(e) Quality (New Builds)



(f) Quality (Re-Sales)

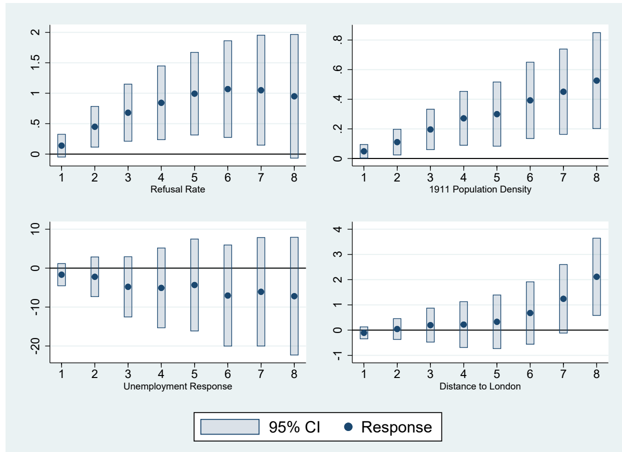
Notes: The figure plots the average (median) impulse responses (β_i^h) from the local projections of equation 5 for each locality $i = 1, ..., 324$ at horizons $h = 1, ..., 8$. The dependent variable is i) the average quality adjusted house price of new builds (a) and resales (b), ii) the number of transactions of all first-time sales (c) and re-sales (d), and iii) the average house size of all first-time sales (e) and re-sales (f).

Figure 10: Impulse Response to a 25bp cut in Policy Rate: New Build vs Re-sales

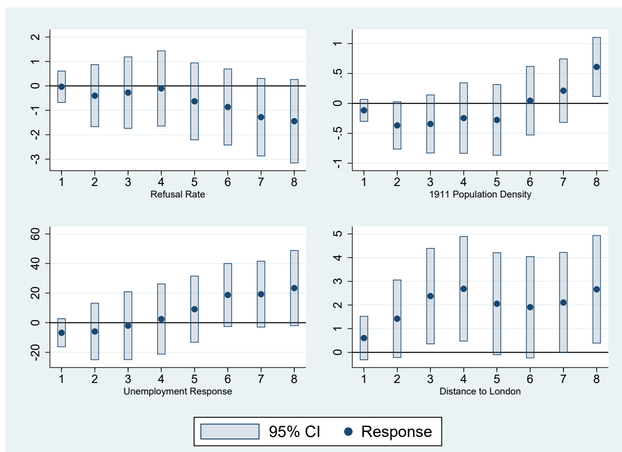


Notes: The figure plots the impulse responses from a local projection of England-wide macroeconomic variables to a monetary policy shock. Lags and co-variates are as in equation 5.

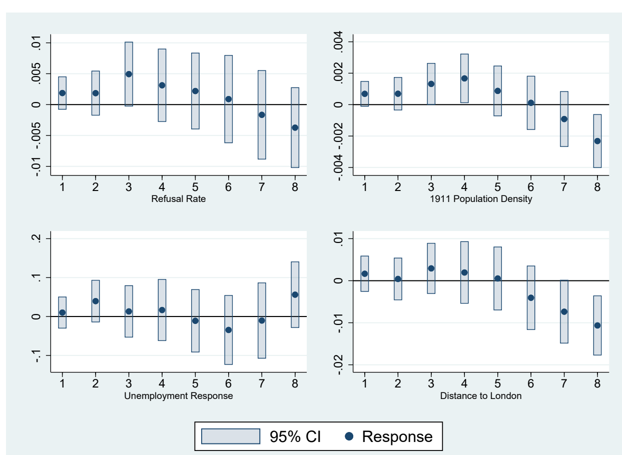
Figure 11: Response of UK Macroeconomic Variables to MPS



(a) Effect of Local Factors - Prices



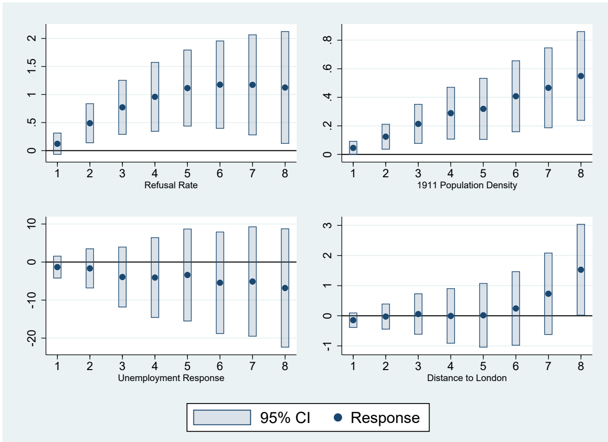
(b) Effect of Local Factors - Transactions



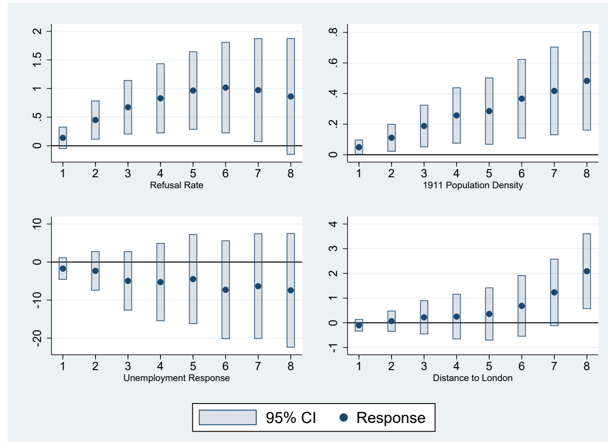
(c) Effect of Local Factors - Quality

Notes: The figure plots the coefficients $(\alpha_1, \alpha_2, \alpha_3, and \alpha_4)$ from the cross sectional regression of equation 6 for each horizon $h = 1, ..., 8$. The dependent variable is the impulse response β_i^h of the a) quality adjusted house prices to a monetary policy shock, b) number of housing transactions to a monetary policy shock, and c) home sizes to a monetary policy shock.

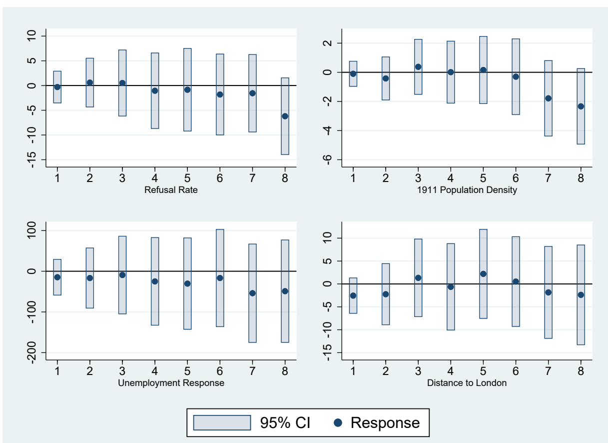
Figure 12: Effect of Local Factors: All Dwellings



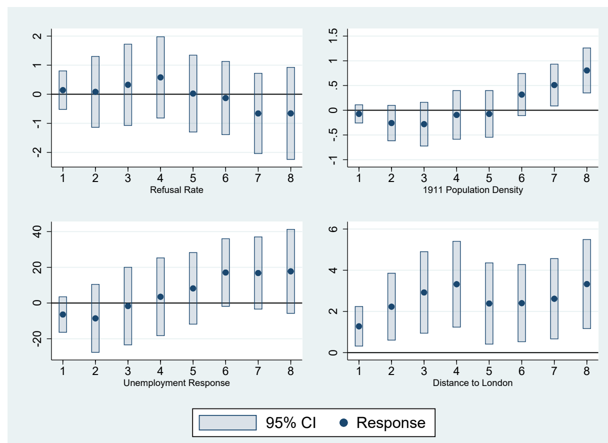
(a) Prices (New Builds)



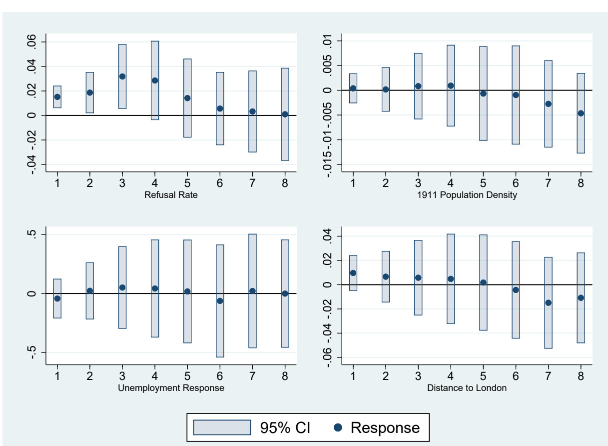
(b) Prices (Re-sales)



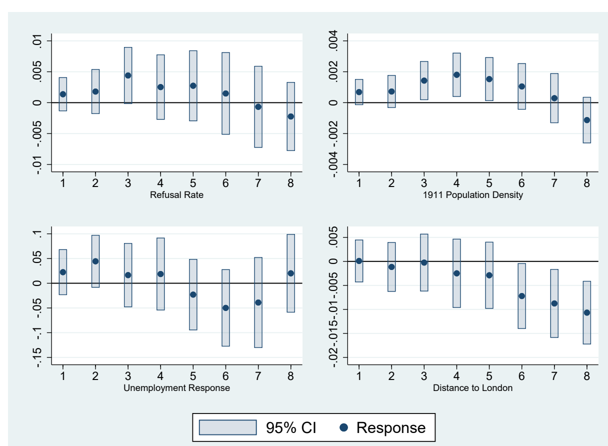
(c) Transactions (New Builds)



(d) Transactions (Re-Sales)



(e) Quality (New Builds)



(f) Quality (Re-Sales)

Notes: The figure plots the coefficients ($\alpha_1, \alpha_2, \alpha_3$, and α_4) from the cross sectional regression of equation 6 for each horizon $h = 1, ..., 8$. The dependent variable is the impulse response β_i^h of i) the average quality adjusted house price of new builds (a) and resales (b), ii) the number of transactions of all first-time sales (c) and re-sales (d), and iii) the average house size of all first-time sales (e) and re-sales (f).

Figure 13: Effect of Local Factors: New Build vs Re-sales

Tables

Table 1: Descriptive Statistics

	Mean	S.D.	Min	Max	N
Quality Adjusted Price - All Dwellings	149,599	90,925	26,514	1,345703	27,216
Quality Adjusted Price - Old Dwellings	147,778	90,915	26,483	1,363775	27,216
Quality Adjusted Price - New Dwellings	170,984	92,391	27,772	1,115755	27,216
Sales - All Dwellings	732	513	4	6,052	27,216
Sales- Old Dwellings	658	465	4	5,479	27,216
Sales- New Dwellings	75	72	1	1,300	27,216
Distance to London (km)	153	107	2.6	429	324
Refusal Rate	0.30	0.08	0.14	0.47	324
1911 Population Density	755	2,598	3.25	22,029	324
Unemployment	7.78	0.89	5.58	10.73	324

Appendix

Appendix A: Variable Definitions and Sources

Name	Definition	Source
Quality Adjusted House Prices	Quality Adjusted House Price Index (Base Year = 2015)	UK Land Registry
Raw House Prices	Price Paid data in British Pounds, converted to real values (CPI 2015=100)	UK Land Registry
House Transactions	Number of residential property transactions at full market value	UK Land Registry
Monetary Policy Shock	Meeting-by-meeting measure of unanticipated official bank rate change	Champagne and Sekkel (2018)
Refusal Rate	District Planning Application Statistics - Average decision granted relative to average decisions made (1975 - 2015)	GOV.UK
Population Density	Population density in 1911 (persons per square km)	Hilber and Vermeulen (2014)
Distance	Distance from Traffalgar Square in km	Hilber and Vermeulen (2014)
Unemployment	Claimants as a proportion of residents aged 16-64	NOMIS
Share of Overcrowded Homes	Percentage of the population living in an overcrowded household	Eurostat
Number of Rooms	Number of Rooms in accommodation (variable code hsbeds + hsrooms) from Understanding Society – The UK Household Longitudinal Study	Survey Data
Industrial Production - UK	Industrial Production (ONS Data Code: CVMSA)	ONS
Unemployment - UK	Unemployment rate (aged 16 and over, seasonally adjusted) (ONS Data Code: MGSX)	ONS
Mortgage Rate - UK	Household Variable Mortgage Rate in the United Kingdom (FRED Data Code: HVMRUKQ)	FRED
New Buildings Started and Completed - UK	House building, UK: permanent dwellings started and completed	ONS

Appendix B: Derivation of the UK House Price Index and Quality Measure

The estimation of the UK House Price Index (HPI) is based on the following hedonic model:

$$y_{jt} = \alpha_t + \beta x_{jt} + \epsilon_{it} \tag{7}$$

where $y_{jt} = ln(p_{jt})$ is the log of the transaction price of a house j at time t, and x_{jt} are features or characteristics of that house. The model includes the following features: location (local authority), type of neighborhood (ACRON Classification), dwelling type, number of habitable rooms, old/new, first-time buyer (FTB). In addition, the hedonic model includes the following interactions: $ACORN \times dwelling\_type$, $ACORN \times FTB$, and $dwelling\_type \times old/new$.

Since I use the natural log of house prices, the natural log of the price index at time t relative to base year period 0 is defined to be the difference between the constant term estimates:

$$ln(PI_t) = \hat{\alpha}_t - \hat{\alpha}_0 \tag{8}$$

For intuition, think of estimation by OLS, which we know implies

$$\begin{aligned} \hat{\alpha}_t &= \frac{1}{n}\sum_{j=1}^{n} y_{jt} - \hat{\beta}\frac{1}{n}\sum_{j=1}^{n} x_{jt} \\ \hat{\alpha}_t &= \bar{y}_t - \hat{\beta}\bar{x}_t \end{aligned} \tag{9}$$

Then we have

$$\begin{aligned} ln(PI_t) &= (\bar{y}_t - \bar{y}_0) + \hat{\beta}(\bar{x}_0 - \bar{x}_t) \\ PI_t &= \left(\frac{\Pi_{j=1}^{n} p_{jt}^{1/n}}{\Pi_{j=1}^{n} p_{j0}^{1/n}}\right) exp[\hat{\beta}(\bar{x_0} - \bar{x_t})] \end{aligned} \tag{10}$$