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Residential construction lags across the US and their implications for housing supply

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Abstract

Housing supply decisions consist of both an extensive margin (new housing starts) and an intensive margin (construction intensity of incomplete houses). While it is well known that housing starts have declined dramatically during the 2006--2009 housing bust, the intensive margin of residential investment has not been studied in the literature. In this paper, we document that construction intensity of incomplete houses has also fallen significantly during the bust. Using the Census micro data for construction lags of single-family houses across the US, we show that average construction lags for completed houses increased during the bust, and that this increase comes from long deferrals of several houses under construction, especially those that were unsold at the early stage of construction. Motivated by these new facts, we study a time-to-build model of residential construction where investment in each stage is irreversible. The model predicts that as the level of uncertainty increases, the ``wait-and-see'' channel becomes relatively more important for the intensive margin than for housing starts. Calibrated to match the house price dynamics during the recent recession, the model accounts for the majority of the observed increase in construction lags, which suggests that the real-options mechanism played an important role in the dynamics of residential investment during the recent bust. Several housing supply implications based on the model follow.

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1 Introduction

Since the Great Recession, understanding housing dynamics has become a main topic of interest for business-cycle studies.[1] While the significant cyclicality and volatility of the housing market were well-known facts even before (Davis and Heathcote, 2005), the recent housing boom-bust cycle has been nevertheless unprecedented in its size. New empirical research finds that the recent housing cycle had a large impact on the macroeconomy and contributed to the severity of the recession.[2]

Our focus of this paper is on understanding how the supply side reacted to the recent housing boom and bust. There are indeed several papers that look into each component of residential investment in the GDP data to study the various investment decisions in the housing market.[3] Like any investment variable, residential investment is also composed of both the extensive margin, new housing starts, and the intensive margins: (i) improvements on existing houses and (ii) construction of incomplete houses.[4] Most papers focus on the supply side determinants of either new housing starts – the extensive margin – or improvements on existing houses – the first intensive margin. Our paper focuses on the *other* intensive margin of residential investment that is often not discussed: the construction intensity of incomplete houses. In detail, we ask how construction intensity responded to the housing boom and bust.

Construction intensity of incomplete houses is an important variable to understand the dynamics of residential investment for the following two reasons.

First, the stock of incomplete houses is large. Building a house takes a significant amount of time. Even after building permits are issued, the average single-family house takes 6 months from start (i.e. excavation) to completion. Multi-family houses take 10 months to build. This implies that for each unit of house started in a given month, 8.3 units of houses are under construction.[5] As a result, even small variations in construction intensity should play a large role for the dynamics of residential investment.

Second, construction intensity affects housing start decisions. When forward-looking homebuilders decide to build a house, they take into account their expected investment intensity during the entire construction process.[6] Therefore, any shift in construction intensity should also have an impact on new housing starts, and hence on residential investment.

In the data, construction intensity is not directly observed. However, construction lags are observed in detail, and they have a sharp inverse relation with construction intensity. In

[1]The second handbook of macroeconomics includes a chapter on housing and macroeconomics, which was not the case in the first version published in 1999.

[2]Recent papers in this literature include Leamer (2007), Mian and Sufi (2011) and Saiz (2010).

[3]Haughwout, Peach, Sporn, and Tracy (2013) give a comprehensive review of this literature and provide some data analysis.

[4]Residential investment also includes brokers' commissions and other ownership transfer costs.

[5]Data from December 1969 to December 2014.

[6]These forward-looking aspects, such as gestation lags or flow adjustment costs, have been widely used in the business-cycle literature to deliver various dynamic responses observed in the data. For example, Christiano et al. (2005) introduce investment adjustment costs to generate hump-shaped investment responses to monetary shocks, and Uribe (1997) introduces gestation lags and convex adjustment costs to capital accumulation to generate the observed slow convergence of inflation between nontradables and tradables in an experiment of an exchange-rate-based stabilization plan. More recently, gestation lags are also used in Arezki et al. (2015) for an application of the effects of news shocks in an open economy.

the data sections, we study the dynamics of construction lags during the recent boom and bust. In section 2, we look into the time series of average construction lags of residential buildings across the US. In section 3, we use the Census micro data to look into the time series of the *distribution* of construction lags for single-family residential buildings across the US. We find that average construction lags increased during both the boom and bust, and that the increase in the bust period is due to long deferrals of several houses rather than an overall shift in the distribution. For "built for sale" houses, we find that long deferrals only occured for houses that were unsold before start.

Existing intuition on the time series behavior of construction lags assume either that construction lags are stable across time (Kydland and Prescott, 1982), or that construction lags would increase if bottlenecks exist for certain type of inputs (Kalouptsidi, 2014). Our finding that construction lags increased in the housing bust era, especially for several unsold houses, is not consistent with either of these assumptions. In section 4, we develop a model of time to build that nests both the standard Kydland and Prescott (1982) and the real options mechanism of Majd and Pindyck (1987), to study the first-order importance of the real options mechanism. In section 5, we apply the model to the recent housing bust. With the high level of uncertainty observed in this period, we find that the real options mechanism significantly accounts for the dynamics of construction lags. Combining with the fall in prices during the bust, we find that our model captures most of the construciton lag dynamics during the recession. Based on the dominant role that house price dynamics and our model mechanisms played in accounting for the observed TTB dynamics, we study several housing supply implications in section 6. In particular, we find that when the intensive margin of investment falls, residential investment does not lag housing supply and its initial movement is dominated by the intensive margin rather than the extensive margin. Section 7 concludes.

Related literature Our paper connects to four broad strands in the literature. First, we connect to the business-cycle literature on time to build and investment dynamics, including Kydland and Prescott (1982), Campbell (1998), Lucca (2007) and Edge (2007). These papers all assume that time-to-build investment is exogenous, and look into the initial investment decisions for time-to-build projects. Our findings suggest that time-to-build investment itself has also been an important margin in the recent recession.

Second, we link to the real options literature of investment, as in Dixit and Pindyck (1994), Leahy and Whited (1996), Bloom et al. (2007), Bloom (2009), Bachmann et al. (2013) and Gilchrist et al. (2014). To the best of our knowledge, we are the first to look into the effects of uncertainty shocks for time-to-build investment decisions. Morever, we contribute to the recent interest on the quantitative importance of uncertainty shocks. We suggest evidence that uncertainty shocks have played a significant role in the intensive margin of residential investment.

Third, we connect to the housing investment literature such as Topel and Rosen (1988), Iacoviello (2005), Green et al. (2005), Glaeser and Gyourko (2005), Glaeser et al. (2005), Glaeser et al. (2008), Saiz (2010), and Kydland et al. (2012). In this literature, we provide new stylized facts on the distribution of construction lags across time.

Lastly, our paper is related to the recent interest in understanding the distinction between the extensive and intensive margin of investment dynamics in Jovanovic and Rousseau (2014).

2 Data and stylized facts: Average construction lags

In this paper we use the "Survey of Construction (SOC)" data available from the Census Bureau, which is a national sample survey (sampling rate: 1/50) on builders and owners of new houses. The dataset contains information on the building and geographic characteristics of new houses across the US in each survey year, including the starting and completed month of houses, sales price and the month in which the house was sold if sold, square footage, number of rooms and so on. Houses authorized by building permits but not started at the end of the year, under construction at the end of the year, or for sale at the end of the year are also included.[7]

Based on this dataset, the Census reports the aggregate series for "average length of time from start to completion," for both single-family and muilt-family units. In each given year, this series reveals information on the average construction lags of completed houses. In this section, we look into this aggregate series. In the next section, we will move on to the underlying micro data to get a detailed understanding of the findings of this section.

2.1 Aggregate facts

Figure 1 depicts the average length of time from start to completion of both single-family and multi-family houses from 1984 to 2013. Notice first that construction lags are relatively constant until 2002. Average construction lags for single-family and multi-family houses during this period were 6 and 9.7 months, respectively.

Second, from 2002 to 2006, construction lags for single-family and multi-family houses increased by 1 and 2 months, respectively. One aspect that may have contributed to this increase is the shortage of construction workers relative to the number of construction projects during this housing boom period.[8] In figure 2, we plot several construction sector time series. We observe that construction activity, such as housing starts and construction employment, surged in this period. We also plot two measures of bottlenecks in the construction sector: (i) construction sector unemployment rate and (ii) construction sector labor market tightness, which is the job openings to unemployed ratio.[9] The low unemployment rate and the high labor market tightness support the view that there was a shortage in available workers in the construction sector during the housing boom period.[10]

Third, from 2006 to 2009, construction lags further increased for both single-family and multi-family houses, each again by 1 and 2 months, respectively.[11] However, measures of bottlenecks in the construction sector no longer support the view that bottlenecks were the main contributor to this further increase in construction lags. In fact, as shown in figure 2, the housing market was entering a bust period with a dramatic fall in both housing starts and construction employment, and bottlenecks were all resolved. This suggests that

[7] Houses for which construction was abandoned after permit issuance or after start are not included.

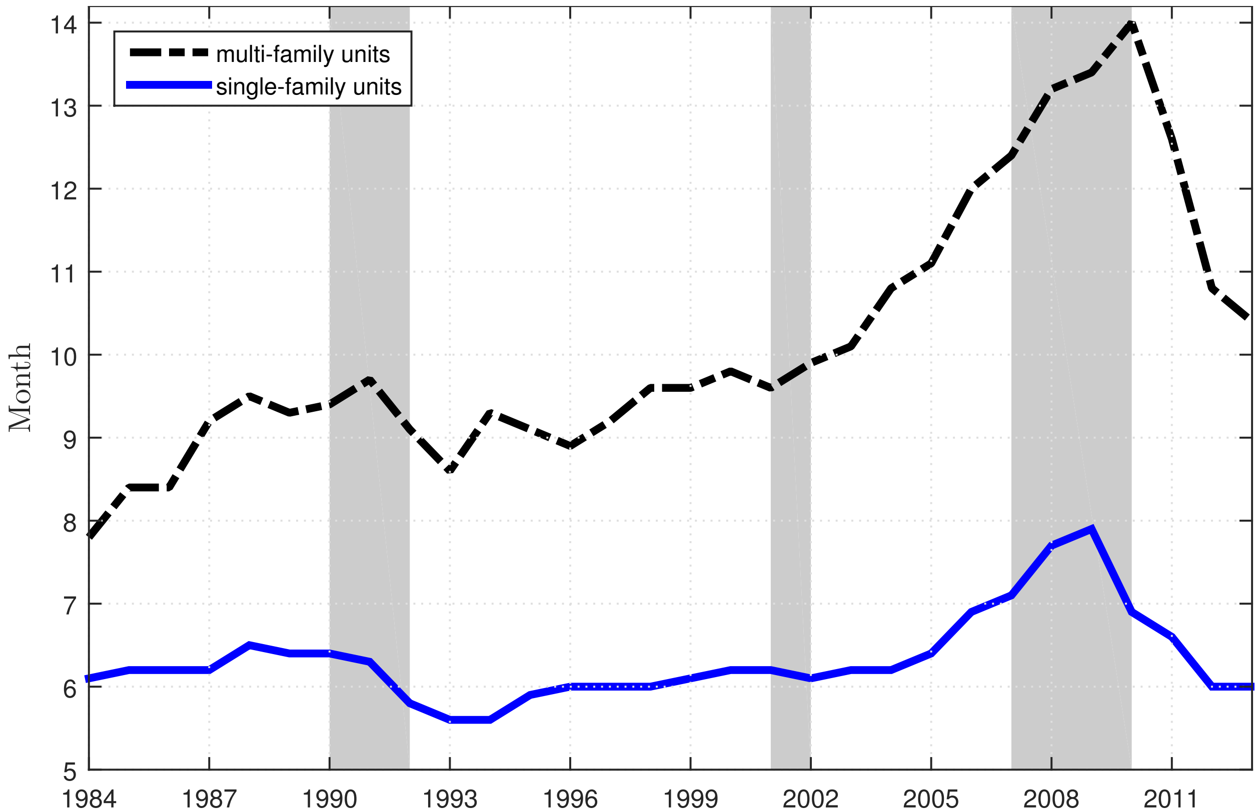
[8] For example, Kalouptsidi (2014) finds that higher investment activity lengthened the production lag of the Greece ship bulking industry, which is capacity constrainted.

[9] Construction sector unemployment rate is reported in the BLS website. This series is based on the household survey where the number of unemployed people in the construction sector is based on unemployed households that report their previous job in the construction sector.

[10] This view is expressed in, for example, Green et al. (2005).

[11] Average construction lag for multi-family houses peaked in 2010.

Figure 1: Construction lags for completed houses in the US



Note: Shaded areas are NBER recessions.

there must have been a strong mechanism that overturned the negative bottleneck effects for construction lag dynamics during the housing bust.

Finally, after 2010, construction lags recovered back to the pre-2002 level.

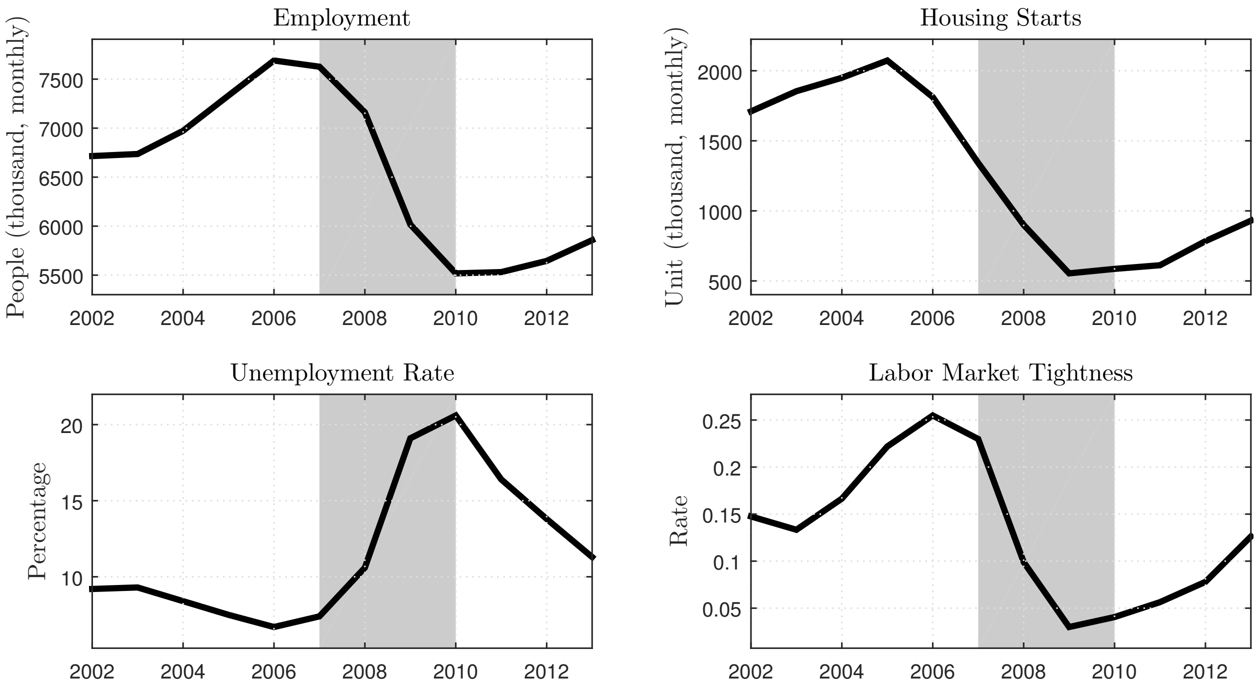
2.2 Implications of aggregate facts

In a standard time-to-build investment model, construction lags are assumed to be constant. This is empirically supported in the period from 1984 to 2002. Although the economy went over two NBER recessions during this period, construction lags showed little variation.

That assumption no longer holds in the recent housing boom-bust cycle, where average construction lags increased by $30\% - 40\%$ relative to their 1984–2002 average. The initial increase in the boom is consistent with bottleneck mechanisms and we find that the labor market of the construction sector was tight during this period.

However, a puzzling feature is the further increase in construction lags during the bust. The data evidence shows that bottlenecks were resolved in the housing bust, and this should imply a fall in the average construction lags. Therefore, the further increase in construction lags during the bust period suggests that bottleneck theories were no longer the main action. Then why did construction lags increase during the housing bust? In the next section, we investigate this using the underlying micro data for construction lags.

Figure 2: Construction sector variables during the housing boom and bust



Note: Labor market tightness is the rate between construction job openings and unemployed with previous jobs from the construction sector. Shaded areas are NBER recessions.

3 Micro data analysis: Distribution of construction lags

Our goal in this section is to understand the dynamics of the *distribution* of construction lags during the boom-bust period. Towards this, we use the underlying micro data for the Census statistics on average construction lags. Our analysis will be based on the distribution of construction lags for *single-family houses*, of which the data is publically available since 2000.[12] We first construct a measure of "economic" construction lag by controlling for geographic and building characteristics of each completed house, and then compare its cross-sectional distribution across time.

3.1 "Economic" construction lags

All buildings are different and construction lags for each house depend on various factors. For example, a larger and more-difficult-to-build house will have lengthy construction lags. Another factor for lengthy construction periods are houses that build on severe weather conditions or stringent regulations.

Our goal in section is to focus on the dynamics of construction lags that are independent from geographic and building characteristics.[13] Since the micro data provides many of

[12]We use our sample for houses that started since January 2000.

[13]We understand that building and geographic characteristics may also be correlated with economic

these features, we construct a measure of "economic" construction lags for each completed single-family building in the US by controlling for them. In particular, for geographical characteristics, we control for the 9 Census divisions, and whether or not the house is built in a Metropolitan area, which is the finest level of geographical information available in the public data. For building characteristics, the list of control variables include building purpose (owner built, contractor built, built for sale, built for rent), building method (site built, panelized, modular), and square footage of the house.

We regress the log of time-to-build on the various control variables listed above. Table 1 reports the result from this regression, using the data from 2000 to 2013. While our main focus is not on understanding the link between the control variables and construction lags, we do find several interesting results that are worth mentioning. The first column summarizes the frequency of the sample. The division with the highest number of completed houses during the sample period is South Atlantic, which consists of 26.9% of the total sample. The least number of houses are built in New England (3.4%). For building purposes, built for sale houses consist the majority of the sample (74%), followed by contractor-built houses (14.2%) and owner-built houses (8.7%). For single-family units, built for rent houses are only a small portion (3.2%).

Looking into regression (a), notice first that New England, Middle Atlantic, and Pacific divisions show lengthy construction lags compared to other divisions. In particular, construction lags are on average 27% higher in Middle Atlantic relative to that of the West South Central division. Second, owner built houses have longer TTB relative to contractor built houses, which may reflect either the efficiency of contractors or the selection into owner built houses for various housing preferences. Built for sale houses on average take the shortest time to build. Third, site built houses have longer TTB than panelized or modular houses, which may reflect the exposure to bad weather conditions for site built houses. Lastly, 2 and more story buildings take longer time than 1 story buildings, and square footage of the building also has a positive relation with construction lags.

In our subsequent analysis, we use the residual of the regression (a) of table 1 as our measure of "economic" construction lags. Regression (b) adds the division-level unemployment rate as an additional variable to control for bottleneck effects. This regression will be discussed later on.

3.2 The distribution of economic construction lags

Using our measure of economic construction lags, we compare their cross-sectional distribution of TTB across three different periods: steady state (2000–03), housing boom (2004–06), and the subsequent bust (2007–09). For a clearer exposition of our argument, we choose 2003 as our steady state, 2005 as the housing boom, and 2009 as the subsequent bust. The annual time series of this distribution is plotted in the appendix.

The left panel of figure 3 compares the kernel density of TTB in 2003 and 2005. We observe that during this period, there was an overall shift to the right of this distribution.

conditions; for example, larger houses may have been built during the boom period. In such case, our estimate should be taken as a conservative measure. However, since our focus of this paper is on the dynamics of construction lags controlling for housing start decisions, we find it best to remain silent on their possible correlations.

Table 1: Regression on construction lags ($\log TTB$)

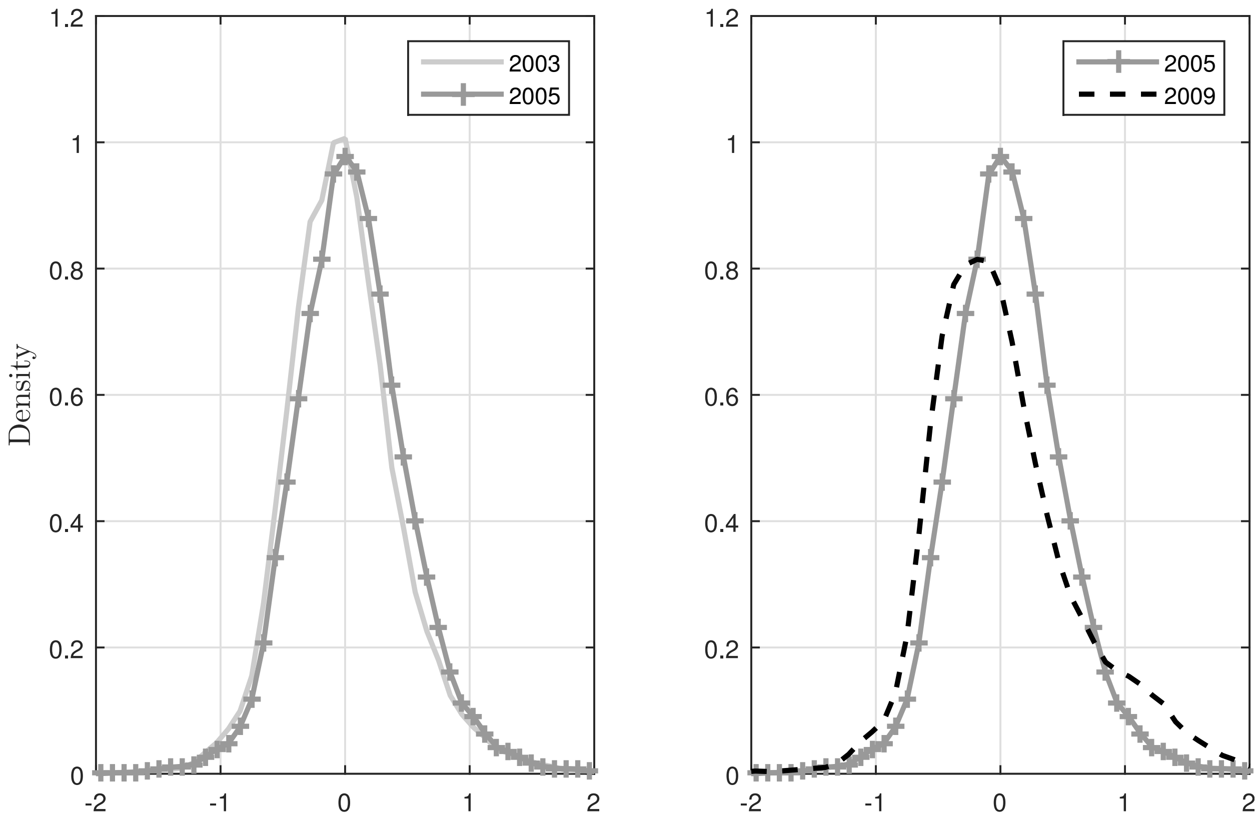
	Frequency	(a)		(b)	
New England	0.034	0.259	(0.00969)	0.242	(0.00966)
Middle Atlantic	0.071	0.270	(0.00736)	0.271	(0.00733)
East North Central	0.124	0.162	(0.00610)	0.183	(0.00609)
West North Central	0.076	0.130	(0.00718)	0.0957	(0.00719)
South Atlantic	0.269	0.0599	(0.00478)	0.0453	(0.00477)
East South Central	0.053	0.0813	(0.00640)	0.0985	(0.00641)
West South Central	0.144	-		-	
Mountain	0.098	0.0388	(0.00625)	0.0223	(0.00621)
Pacific	0.132	0.202	(0.00611)	0.233	(0.00608)
Built for sale	0.740	− 0.210	(0.00828)	− 0.220	(0.00828)
Contractor-built	0.142	− 0.0578	(0.00887)	− 0.0633	(0.00887)
Owner-built	0.087	0.166	(0.00982)	0.159	(0.00983)
Build for rent	0.032	-		-	
Modular	0.028	− 0.532	(0.0106)	− 0.539	(0.0107)
Panelized	0.024	− 0.144	(0.00804)	− 0.143	(0.00802)
Site built	0.948	-		-	
1 Story	0.430	-		-	
2+ Story	0.570	0.00628	(0.00271)	0.00531	(0.00269)
Square foot (×100)		0.00825	(0.000180)	0.00829	(0.000179)
Unemployment rate				− 0.0406	(0.000699)
Constant		2.025	(0.0129)	2.250	(0.0134)
Other controls:					
Metropolitan area		yes		yes	
Number of full bathrooms		yes		yes	
Detached		yes		yes	
Deck		yes		yes	
Parking facility		yes		yes	
Foundation		yes		yes	
Material of wall		yes		yes	
Observations		261,184		261,184	

Note: Robust standard errors are in parentheses. Regression (b) also with the unemployment rate.

Economic TTB increased for all types of houses, and bottleneck theories are consistent with this distributional shift.

On the other hand, the right panel of figure 3 compares the kernel density of TTB in 2005 and 2009. We observe two facts. First, the mass of the distribution including the mode has shifted back to the left. Second, a fat tail to the right has appeared. The left shift in the mass of the distribution is consistent with bottlenecks being resolved. During the housing bust, the supply side may have had less issues with finding available construction workers to build

Figure 3: Distribution of economic construction lags (Total sample)



Note: Kernel density of economic TTB for total single-family houses in logs. Left compares 2003 and 2005, and right compares 2005 and 2009.

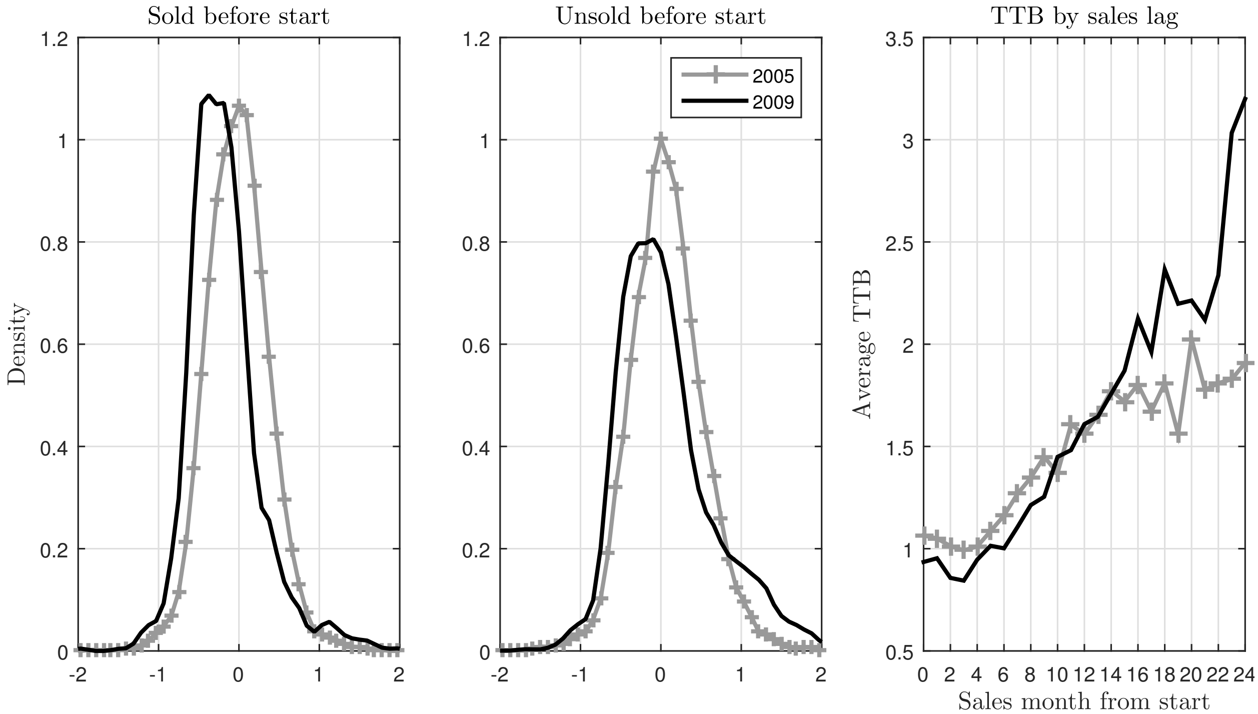
a house. Nevertheless, the fat tail to the right indicates that several incomplete houses during the housing bust remained underconstructed for a long period. Linking this observation to the aggregate fact, the increase in TTB coming from this fat tail to the right dominated the negative bottleneck effect, and hence average construction lags increased further in 2009 compared to 2005.

3.3 Subsample evidence: Built for sale

From the overall distribution, we observe that there were long deferrals of construction into several incomplete houses during the bust period. In this section, we narrow our focus into a subsample of the distribution, "built for sale" houses, to better understand where these long deferrals are disproportionately coming from. We look into the "built for sale" subsample for two reasons: (i) "built for sale" houses contain information on the sales month and price that we can use to better infer the economic channels; (ii) "built for sale" houses comprise the majority of single-family houses in the sample (74%) as shown in table 1, at the same time a significant fat tail to the right is observed for this category during the recent bust.

Based on the sales month information for these houses, we split this sample into two

Figure 4: Distribution of economic construction lags (Built for sale)



Note: Left two figures are kernel density of economic TTB for built-for-sale houses in logs, for 2005 and 2009. The right figure plots the average economic construction lags by sales month from start, for 2005 and 2009. Houses that were sold before start are lumped into 0, and 24 includes all houses that were sold after 24 months or not sold.

categories: houses sold before start, and unsold before start. In figure 4, we observe that for houses that were sold before start, we only observe one pattern: the distribution shifting back to the left. For this category of houses, bottleneck effects must have been the main force in the dynamics of construction lags. On the other hand, for houses that were unsold before start, the fat tail to the right is pronounced for the 2009 distribution. Therefore, almost all of the increase in the fat tail to the right in this subsample comes from houses that were unsold before start.

Within houses that were unsold before start, we break this down further and compute the average economic TTB based on the time lag between starting date of construction and the sales occuring date. We plot this for years 2005 and 2009 in the right panel of figure 4. In this figure, houses that were sold before start are all lumped into 0, and houses that were sold after 24 months or never sold are lumped into 24. Sales month lag and average TTB are positively correlated. That is, houses that are unsold for a long time tend to have lengthy construction lags. In 2009, this pattern has become more apparent. Comparing 2005 and 2009, houses that were sold at the early stage of construction were actually built faster in 2009. However, houses in the bust period that faced difficulty in selling early took a much longer time to complete. From this figure, we find that long deferrals in 2009 were especially concentrated on houses that took a long period to sell, even compared to those in 2005.

3.4 Economic construction lags not explained by bottlenecks

To get a quantitative sense of the increase in economic construction lags for "built for sale" houses, we compare the average TTB in the Census data, our measure of "economic" TTB, and our measure of "ex-bottleneck" TTB that we explain below. The results are plotted in figure 5.

First, looking into the Census raw data, we find that average TTB increased by 29% between 2003 and 2009. In particular, average TTB increased 12% by 2006 and the remaining 17% increased from 2006 to 2009. Therefore, for "built for sale" houses, the increase in average TTB were concentrated in the housing bust rather than in the boom.

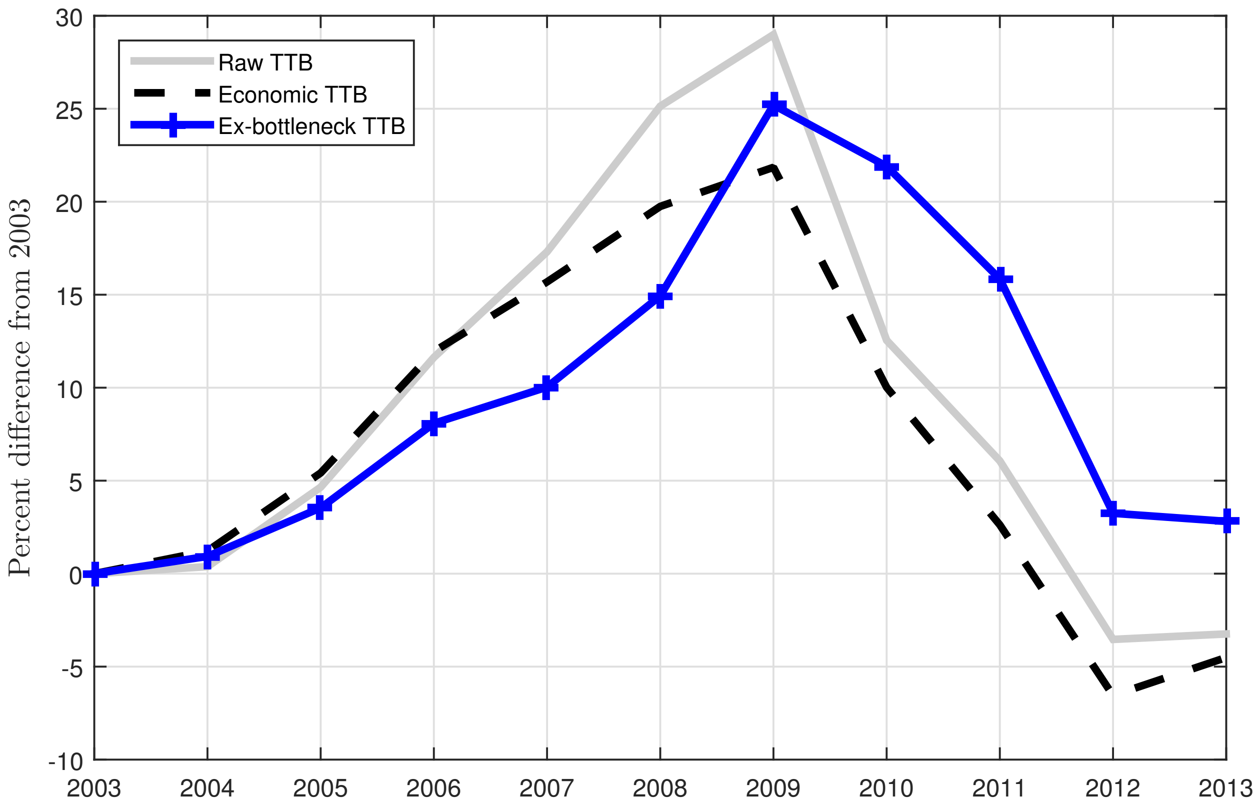
Second, looking into the average of our "economic" TTB, we find that TTB increased by 22% between 2003 and 2009, which is smaller than the increase observed in the raw data. Since we control for geographic and building characteristics in our constructed measure, this implies that some of the increase in TTB in the raw data originates from these characteristics. That is, houses that were built during the recent boom-bust era might be larger and higher quality, or built in regions where houses take a longer time to build. From 2003 to 2006, the increase is 12%, and the remaining 10% increased from 2006 to 2009.

Third, since our subsequent analysis aims at understanding the increase in TTB during the bust, we also control for bottleneck effects in our "economic" TTB by regressing our series with bottleneck measures. Unfortunately, it is difficult to find direct measures of bottlenecks in the construction sector at the regional level. Our approach is to take the unemployment rate as a proxy for regional bottlenecks. Specifically, compared to our measure of "economic" TTB, we also control for the average division-level unemployment rate for the first three months from the starting month of construction and compute its residual, as shown in regression (b) of table 1. Based on this "ex-bottleneck" measure of TTB, we find that total TTB increased by 25% from 2003 to 2009, and that during the boom, the increase was only 8%, whereas during the bust, the increase was 17%. That is, controlling for the lax bottlenecks during the bust period, the increase in TTB not related to bottlenecks were large and quantitatively comparable to the overall increase in TTB from 2003 to 2009. We conclude that even quantitatively, there is a sizable variation in TTB in the recent bust period that cannot be explained by geographic and building characteristics, as well as the bottleneck effects.

3.5 Summary

We summarize our findings in this section as follows. First, the increase in TTB during the boom was from a shift to the right of the overall distribution. Second, the further increase in TTB during the bust was a combination of two counteracting forces: a shift to the left of the mass of the distribution, and a fat tail to the right. The fat tail to the right was the dominating force and average TTB increased. To study the potential channels of this increase in TTB, we focus on houses that are "built for sale" where we find the same pattern. Within this sample, we compare houses that were sold and unsold before start. We find that the fat tail to the right only appears for houses that were unsold before start. In fact, during the housing bust, average TTB decreased for houses that were sold before start. We quantify the effects and find that controlling for geographic and building characteristics,

Figure 5: Three measures of average construction lags for single-family houses



as well as for bottleneck effects, average TTB increased by 17% from 2003 to 2009.

4 Model of construction lags

Based on the empirical facts, our next task is to understand the economic forces that deliver the observed increase in TTB during the recent bust. In this section, we ask whether the "wait-and-see" channel is of first-order importance to account for the observed TTB dynamics. Towards this, we illustrate a TTB model of residential investment that incorporates the real options mechanism and quantify the fall in construction intensity during the recent housing bust. We start with a discussion of the real options mechanism in our data and then illustrate our model.

4.1 Why the real options mechanism?

In a classical investment model, the decision to invest in a project depends on the the net present value of expected cash flows.[14] However, for projects with large sunk costs, investment also entails a significant opportunity cost by making a commitment and giving up the option of waiting. The real options model of investment extensively explored in Dixit

[14]Hall and Jorgenson (1967)

Table 2: Single-Family House Construction Cost Breakdown (2013)

Stage of Construction	Cumulative
1. Site Work (Permit, Inspections, Architecture)	6.8%
2. Foundations (Excavation, Concrete)	16.3%
3. Framing (Roof, Metal, Steel)	35.4%
4. Exterior Finishes (Wall, Windows, Doors)	49.8%
5. Major Systems Rough-ins (Plumbing, Electrical, HVAC)	63.2%
6. Interior Finishes (Insulation, Painting, Lighting, Flooring)	92.5%
7. Final Steps (Landscaping, Outdoor Structures, Clean Up)	99.1%
8. Other	100.0%

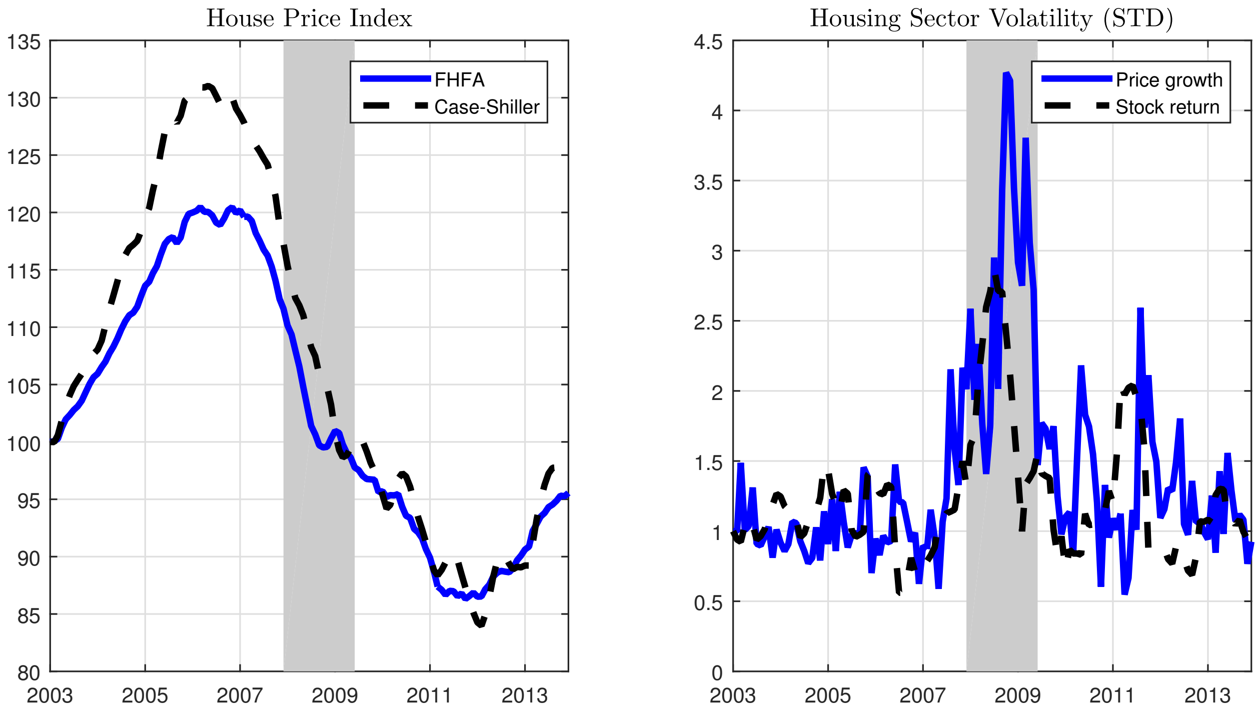
Note: Survey data available from National Association of Home Builders

and Pindyck (1994) demonstrates that this opportunity cost could be a major factor for investment decisions under plausible parameter values.

We argue that the real options model is a natural fit for our residential construction data for two broad reasons. First, housing supply decisions involve significant costs that are irreversible, such as resources spent on both acquiring permits and building foundations, and the time spent on construction. The irreversible resources and time required on these investments introduce a significant option value not only at the beginning of construction but also at the continuation stage. As shown in table 2, homebuilders report a large amount of spending occurring at the later stage of construction. In fact, only 16.3% of the total construction cost is spent when foundations are completed, hence continuing the project from that stage still requires a significant amount of resources and time.

Second, the dynamics of the housing market in the recent bust period also share many features that are consistent with the real options mechanism. Our finding that investment deferrals were especially concentrated on unsold houses during the recent housing bust is consistent with the "wait-and-see" behavior implied by real options models. Moreover, house prices fell a lot (first moment), and volatility (or uncertainty) surrounding the housing market increasing signficantly (second moment). We use three datasets to confirm this statement: (i) the monthly purchase-only house price index published by the Federal Housing Finance Agency, (ii) the monthly S&P/Case-Shiller national home price index, and (iii) the daily Philadelphia Stock Exchange housing sector index. On the left panel of figure 6, we plot the two home price indices, divided by the monthly consumer price index. We find that the fall in both house price indices is steep and large during the recent bust. On the right panel, we plot both the previous 6 month moving average standard deviation of the monthly growth rate of house prices (the blue solid line), and the standard deviation of daily stock returns for each month (the black dashed line). During the recession period, both the house price growth rate volatility and the stock return volatility have increased significantly. The standard deviation for both measures have increased by more than twice the pre-recession average. These large movements in house prices and housing market uncertainty motivate us to study the first-order importance of the real options mechanism in the housing supply decisions.

Figure 6: Price and uncertainty measures of the housing market



Note: For the house price index, we use both the monthly Federal Housing Finance Agency (FHFA) purchase-only index and the monthly S&P/Case-Shiller national home price index. We also compute two volatility measures. First, using the FHFA index to compute the monthly home price growth rate, we plot the standard deviation for the previous 6 months. For the stock price index, we use the daily Philadelphia Stock Exchange housing sector index, and take the standard deviation of daily stock returns for each month. All measures are normalized at its January 2003 value and divided by the monthly consumer price index. Shaded areas are NBER recessions.

4.2 Model details

The model we lay out incorporates both the standard fixed TTB assumption as in the business-cycle literature and the real options channel for TTB investment. Through this model, our goal is to investigate the first-order importance of the real-options view of TTB investment. The model considers the case where a project takes time to complete with multiple irreversible stages each requiring a certain cost. Payoff occurs only after the project is completed and hence irreversible investment decisions are made sequentially at each stage under uncertainty about its future payoff.

The model blends three key elements widely discussed in the investment literature. First, we introduce a real options channel by illustrating a discrete-time version of sequential irreversible investment literature of Majd and Pindyck (1987) and Dixit and Pindyck (1994). Second, we introduce investment adjustment cost parameters to be consistent with the fixed TTB assumption of Kydland and Prescott (1982). Third, we study the effect of uncertainty on TTB investment following the work of Bloom (2009).

Getting into the details, a house takes a total real investment of $\bar{K}$. In each period, a project can take up to κ investment. If $\kappa \geq \bar{K}$, then it is possible to complete the project in one period. However, if $\kappa < \bar{K}$, then investment takes time to build, with the minimum TTB being $\bar{K}/\kappa$.

For house i, the total remaining capital for completion in period t is denoted as K_{it}. When $K_{it} = \bar{K}$, the house is yet to be started and the investment decision is on the extensive margin. On the other hand, when $K_{it} < \bar{K}$, then the homebuilder decides on the construction intensity of an existing project. The flow cost of investment in period t is denoted as I_{it}.

The homebuilder observes the price of the house P_{it}, as well as the aggregate house-price index, P_t^M. The standard deviation of a house, σ_{it}, is also observed. As is apparent from the time-subscript, the standard deviation of the house price is allowed to be time varying.

The value of the construction project, $V(\cdot)$, is written as:

$$\begin{aligned} V(P_{it}, K_{it}, I_{i,t-1}, \sigma_{it}, P_t^M) = \max_{I_{it} \in [0,\kappa]} \Big\{ &- I_{it} - \phi(I_{i,t-1}, I_{it}, K_{it}) \\ &+ \left(\frac{1}{1+r}\right) \mathbb{E}_t V(P_{i,t+1}, K_{i,t+1}, I_{it}, \sigma_{i,t+1}, P_{t+1}^M) \Big\}. \end{aligned} \tag{1}$$

Investment $I_{it} \in [0, \kappa]$ is the decision variable, and the value function carries five state variables: total remaining capital for completion $K_{i,t}$, and the previous level of investment $I_{i,t-1}$, the current price of its house P_{it}, its uncertainty σ_{it}, and the aggregate house-price index P_t^M. We discuss each of these state variables.

First, the evolution function for the state variable K_{it} is

$$K_{i,t+1} = K_{it} - I_{it}, \tag{2}$$

since given the current remaining capital K_{it}, investment into the project I_{it} reduces the future remaining capital to completion.

Second, the previous level of investment is also carried as a state variable due to the existence of investment adjustment costs, $\phi(\cdot)$. Specifically, we assume that a construction project faces the following adjustment cost function:

$$\phi(I_{i,t-1}, I_{it}, K_{it}) = \gamma_0 1_{\{K_{it}=\bar{K} \ \& \ I_{it}>0\}} + \gamma_1 1_{\{I_{i,t-1}=0 \ \& \ I_{it}>0\}} + \gamma_2 1_{\{I_{i,t-1}>0 \ \& \ I_{it}=0\}}, \tag{3}$$

where $1_{\{\cdot\}}$ is an indicator function for the arguments within the parenthesis and $\{\gamma_0, \gamma_1, \gamma_2\}$ are nonnegative values. Three different types of adjustment costs are assumed by this functional form. First, the parameter γ_0 denotes the fixed cost to the extensive margin of construction. This cost parameter incorporates the various suck costs in the decision to start a house. Second, the parameter γ_1 denotes the fixed cost to an upward adjustment of investment for an existing construction project. That is, if previous investment is zero and current investment is positive, then reinitiating the project bears an adjustment cost of γ_1. Third, the parameter γ_2 denotes the fixed cost to a downward adjustment of investment for an existing project, which is exactly the opposite logic of the parameter γ_1.

Lastly, the three state variables P_{it}, σ_{it}, and P_t^M are taken as given by the following processes:

$$\begin{aligned}
P_{it} &= P_{it}^{U} P_{t}^{M}, && (4)\\
\log P_{it}^{U} &= \log P_{i,t-1}^{U} + \mu + \sigma_{it} W_{it}, \qquad W_{it} \sim N(0,1), && (5)\\
\log P_{t}^{M} &= \log P_{t-1}^{M} + \epsilon_{t}, && (6)\\
\sigma_{it} :& \quad \text{First-order Markov Chain.}
\end{aligned}$$

In words, house price depends on its idiosyncratic component which follows a log-normal distribution, and an aggregate factor. This price process has been used extensively in the investment literature and we follow Bloom (2009) in introducing a time-varying uncertainty component.

When the project is completed ($K_{it} = 0$), the value of the house is its own price:

$$V(P_{it}, 0, I_{i,t-1}, \sigma_{it}, P_{t}^{M}) = P_{it}. \tag{7}$$

By setting different values for γ_1 and γ_2, our model incorporates two views on TTB investment. On the one hand, when γ_1 and γ_2 are large, the builder of an existing project always continues to invest until completion as in Kydland and Prescott (1982). On the other hand, when $\gamma_1 = \gamma_2 = 0$, then the model is a discrete-time version of a pure real options model of TTB investment as in Majd and Pindyck (1987).

5 Model solution and simulation

We assume a monthly frequency when solving the model. We restrict TTB investment to take on two discrete values: 0 or κ. In our model without the intensive margin adjustment costs ($\gamma_1 = \gamma_2 = 0$), the value function is linear in I_{it} and hence equilibrium TTB investment is indeed a bang-bang type, which is the case in the continuous-time version of the model (Majd and Pindyck, 1987). In general, this discrete investment decision assumption could be relaxed by solving the model with a higher frequency and aggregating across time. We start by calibrating the parameters of the model and then move on to a discussion of the optimal investment decision under constant uncertainty. Afterwards, we simulate the model with time-varying uncertainty through the housing bust period to gauge the quantitative importance of the real-options mechanism.

5.1 Calibration

The parameters to calibrate in the structure of the model are the net monthly interest rate r, the physical TTB $\bar{K}/\kappa$, and the overall construction cost $\bar{K}$. As in Bloom (2009), we set r such that the annual interest rate is 10 percent. We also set the physical TTB as 5 months, which is the median value for single-family houses in the steady-state period (2000–2003). Net of adjustment costs, the model is scale-invariant so we normalize by setting $\bar{K} = 1$.

For the adjustment cost parameters, we set $\gamma_0 = 0.073\bar{K}$, which implies that the initial sunk cost is 6.8 percent of total construction spending (table 2). For the intensive margin adjustment cost parameters of γ_1 and γ_2, we set them both to be zero to study the pure real-options mechanism. We will later set different values for these parameters to study their counterfactual implications.

For the price process, we assume that there is no drift in prices ($\mu = 0$), since we keep the total construction cost $\bar{K}$ as constant in our model. If prices drift upwards, then construction cost will become relatively smaller as time goes such that after a certain period, investment will always occur which makes the problem less interesting to study.

We start the next section by assuming a constant price uncertainty $\sigma_t = \bar{\sigma}$. There has not been a consensus on the values of $\bar{\sigma}$ in the literature. However, most papers use values within 0.1 to 0.4 at the steady state. In the simulation section with time-varying uncertainty, we assume that uncertainty follows a first-order two-state Markov Chain. We set the two transition probabilities (low to high uncertainty, high to low uncertainty) such that the half-life of the uncertainty shock is 1 year. We set the low uncertainty value as $\sigma_L = 0.2$ and set σ_H consistent with our simulation target as we address below.

Lastly, in equation (6), we hold fixed the aggregate house-price factor (i.e. $\epsilon_t = 0$), and experiment with a one-off shock to the house-price index, which delivers the perfect foresight transition dynamics that we report. The value of the initial house-price factor is matched to the gross revenue to construction cost ratio for single-family homebuilders in the data. In particular, single-family home builders in 2002 spent 52.9% of the sales price on both construction cost (labor, materials, and sub contractors) and financing cost.[15] We set the initial macro house price factor as twice the total construction cost which is consistent with this evidence.

5.2 Solution of the model with constant uncertainty

The solution of the model is characterized by a cutoff price for each stage of construction, $P^*(K;\bar{\sigma})$, such that

$$I_{it} = \begin{cases} \kappa & \text{if } P_{it} \geq P^*(K;\bar{\sigma}); \\ 0 & \text{if } P_{it} < P^*(K;\bar{\sigma}). \end{cases} \tag{8}$$

Notice that $P^*(1;\bar{\sigma})$ indicates the housing start cutoff price, and $P^*(K;\bar{\sigma})$ for $K < 1$ refers to the TTB investment cutoff price with remaining construction level K. We assume that the idiosyncratic price factor gets locked in when the house starts construction. For the extensive margin decision, we assume that the initial price is drawn from a log-normal distribution with its mean at the house price index. With these two assumptions, the builder is not forced to start construction at an area with a bad history of prices, but once she starts, she is locked in to the local shocks in that area. We numerically solve the model with constant uncertainty by assuming the following 3 values: 0.2, 0.4, 0.6.

The first observation is that when uncertainty is higher, both housing starts (for $K = 1$)

[15] This number is based on National Association of Home Builders Business Management & Information Technology (2014). Profit margin for homebuilders in the data is lower because of lot cost, overhead cost, and general expenses.

and TTB investment (for $K < 1$) require a higher cutoff price:

$$P^*(K; 0.6) > P^*(K; 0.4) > P^*(K; 0.2), \qquad \forall K \in \left\{1, \frac{4}{5}, \frac{3}{5}, \frac{2}{5}, \frac{1}{5}\right\}.$$

Consistent with the literature on irreversible investment and uncertainty, the option value increases with the level of uncertainty and housing start decisions require a higher price.

Second, conditional on starting a house, the TTB investment cutoff price falls as the construction process nears completion:

$$P^*(4/5; \bar{\sigma}) > P^*(3/5; \bar{\sigma}) > P^*(2/5; \bar{\sigma}) > P^*(1/5; \bar{\sigma}), \qquad \forall \bar{\sigma} \in \{0.2, 0.4, 0.6\}.$$

Intuitively, as TTB investment occurs, the future payoff period becomes closer to realization, which lowers the option value.

These two results delivered by our calibrated model are also consistent with the findings of sequential irreversible investment models outlined in Dixit and Pindyck (1994). Using our model, we now ask whether periods of high uncertainty are also when TTB investment decisions become even more cautious than housing start decisions.

In figure 7, we plot the log cutoff price of each stage relative to its initial cutoff price when the project started, scaled by the level of uncertainty:

$$W_K^* - W_1^* = \frac{1}{\bar{\sigma}}\left[\log P^*(K; \bar{\sigma}) - \log P^*(1; \bar{\sigma})\right]. \tag{9}$$

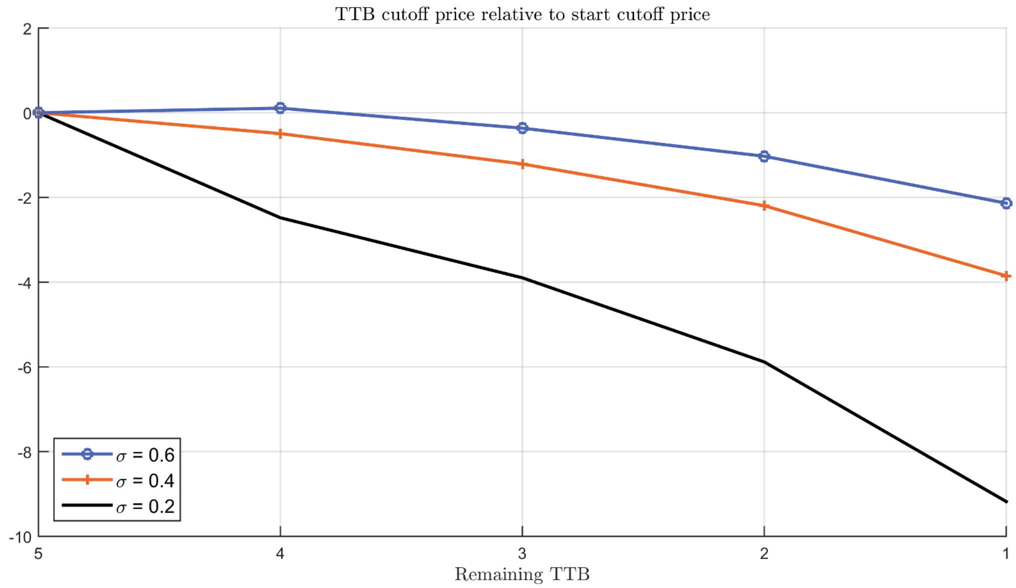
The left-hand side variables W_K^* and W_1^* are cutoff innovation values for TTB investment at stage K and housing starts, respectively, in terms of the standard normal distribution as assumed in (5). Since the scale of these cutoff innovation values are uncertainty-invariant, the above measure allows us to compare the cutoff price of each stage relative to the start cutoff price across different levels of uncertainty.

In the figure with low uncertainty ($\bar{\sigma} = 0.2$), the scaled relative cutoff price steeply falls as construction approaches completion. At the last stage of construction, the builder needs to observe a 9 standard deviation fall in the price innovation relative to the initial price innovation to defer the project. Therefore, once a project starts, unless the price innovation falls by a significant amount, the builder continues investment into the project until completion.

On the other hand, with medium uncertainty ($\bar{\sigma} = 0.4$), the fall in the scaled relative cutoff price is only gradual. Even at the last stage of construction, the builder defers the project when observing a 3 standard deviation fall in the price innovation relative to the initial price innovation. In fact, with high uncertainty ($\bar{\sigma} = 0.6$), the first-stage TTB investment cutoff price becomes even higher than the start cutoff price. Therefore, when uncertainty is high, the same change in the uncertainty-invariant price innovation would lead to deferrals of TTB investment which is not the case under low uncertainty.

To summarize our point, we stress two results from our model solution: with higher uncertainty, (i) both housing start and TTB investment cutoff prices increase, and (ii) TTB investment cutoff prices increase more than the housing start cutoff price. That is, even controlling for housing start decisions, TTB investment decisions are disproportionately af-

Figure 7: Uncertainty-invariant cutoff price relative to start cutoff price



Note: The plotted measure is $(1/\bar{\sigma})[\log P^*(K;\bar{\sigma}) - \log P^*(1;\bar{\sigma})]$, and the x-axis is $5 \times K$.

fected as the level of uncertainty grows. Intuitively, the option value becomes relatively more sensitive to the degree of uncertainty as the project nears completion. At the last stage of construction ($K = 1/5$), our model becomes a standard 1-stage irreversible investment model which is extensively studied in Bloom (2009). In our sequential irreversible investment model, deferral of TTB investment (or construction intensity of incomplete houses) occurs when there is either a steep fall in the house price (first moment) or a rise in uncertainty (second moment). We will now move on to the simulation to quantify each of these effects.

5.3 Model simulation

In this section, we simulate the model to study the dynamics of construction intensity with regards to shifts in house price dynamics.

5.3.1 Simulation details

We simulate an economy with 20,000 builders. In each period, a builder might have an incomplete building under construction or not. Builders without an ongoing project decide whether to start a new building. Builders who have an incomplete project, on the other hand, make TTB decisions. After a project is completed, the builder gets a fresh price draw based on the aggregate house-price index, until they start constructing a new building. Their idiosyncratic house price process is locked in after they start construction.

The simulation is repeated 100 times for 30 years, with a burn-in period of 20 years. In every period, each builder is randomly assigned a level of uncertainty σ_L or σ_H based on the assumed Markov Chain process.

Our simulated TTB time series is the average duration of completed projects in each period, consistent with the reported Census data statistic. One point to make is that if the duration distribution is extremely skewed to the right, then the mean is potentially driven by a few outliers. In the simulation, some building projects have very low price realizations for a long time. When these projects eventually complete their construction, they significantly drive up the average, and may potentially overestimate the dynamics of TTB after an uncertainty shock. In the data, we compute extreme values for the raw TTB of completed projects between 2000 and 2013. The maximum observed TTB is 89 months, the 99.9 quantile is 46 months, and the 99.0 quantile is 27 months. We discipline our simulation using data information on extreme values for TTB. That is, our baseline simulation allows the maximum duration of a project to be 46 months by imposing the builder to drop the project if it is incomplete by then.

We experiment with two aggregate shocks. To shift the first moment of prices, we set ϵ_0 in equation (6) different from zero and look into the perfect foresight dynamics. Given the random walk structure, this shock has a permanent effect. To shift the second moment of prices, we shock the economy in period 0 by setting a high level of uncertainty for all builders, which is the same experiment as in Bloom (2009). This implies that for builders already at a high level of uncertainty, nothing changes. Therefore, the rate of increase in aggregate uncertainty is below σ_H/σ_L. After period 0, the model approaches back the steady state following the transition matrix for uncertainty.

5.3.2 Simulation results

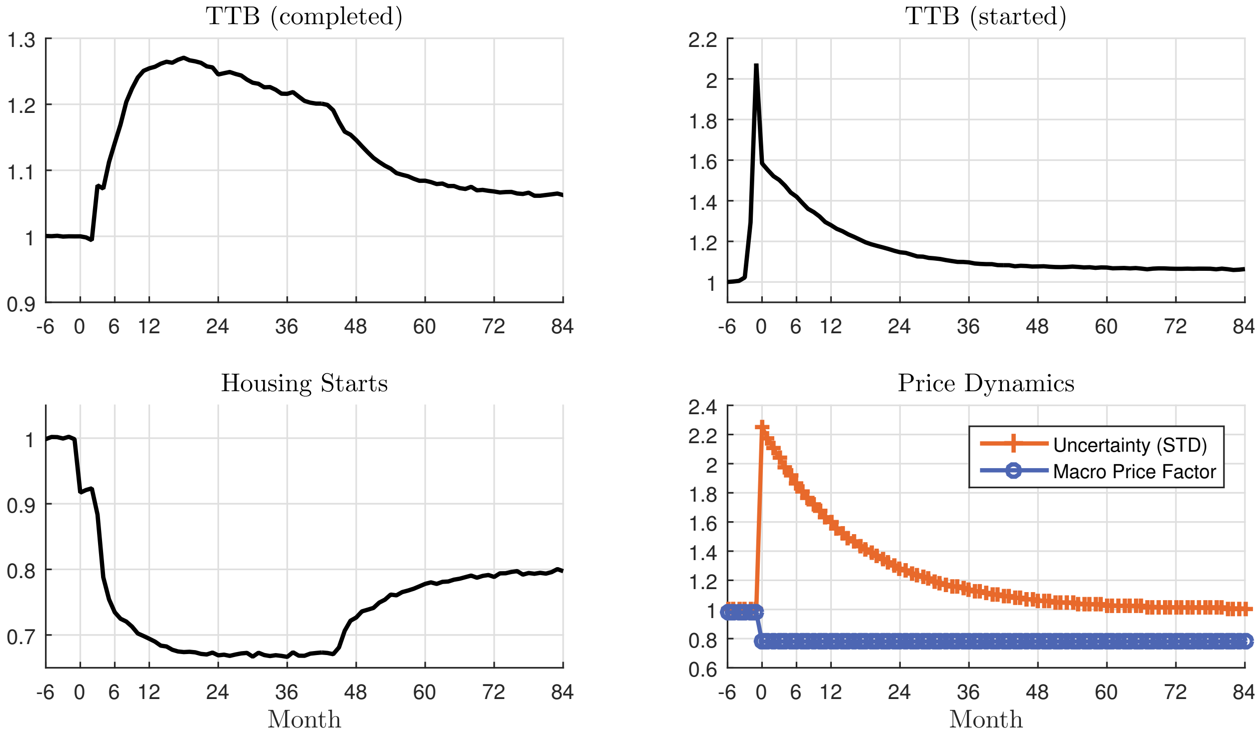
To gauge the first-order importance of our model mechanisms during the housing bust, we start by a stylized experiment of both a permanent 20 percent fall in the macro house-price factor, and an initial quarterly doubling in uncertainty. These first- and second-moment shocks are consistent with the observed size of price dynamics between 2006 and 2009 as in figure 6.[16]

In figure 8, we find that with regards to our housing bust, the monthly average TTB for completed houses increases by 26% and the peak occurs at 18 months. Recall that in section 3.4, our measure of annual economic TTB (ex-bottleneck TTB) increased by 22% (25%) between 2003 and 2009, or by 10% (17%) between 2006 and 2009. Given the persistent increase in our simulated monthly TTB, even annual TTB would increase by at least 20%. Therefore, our model mechanisms feeded in by the observed exogenous price dynamics more than accounts for the increase of TTB in the data.

To break down the channels of the model, we also look into average TTB based on start months (first panel, second column of figure 8). As expected, the peak TTB occurs for houses that started before the shock, since prices and uncertainty suddenly changed for these incomplete houses where builders have already entered. However, the average TTB by start months is also high after the realization of shocks. Even 12 months afterwards, TTB (started) is 30 percent above its pre steady-state value. Therefore, the persistent increase in TTB based on completed months also comes from the fact that even after the

[16]We emphasize that the structure of the two exogenous processes are stylized and follow standard assumptions in the investment and uncertainty literature. The exact structure of the price processes is beyond the focus of this paper and we rather stick to the standard assumptions.

Figure 8: Housing bust and TTB dynamics

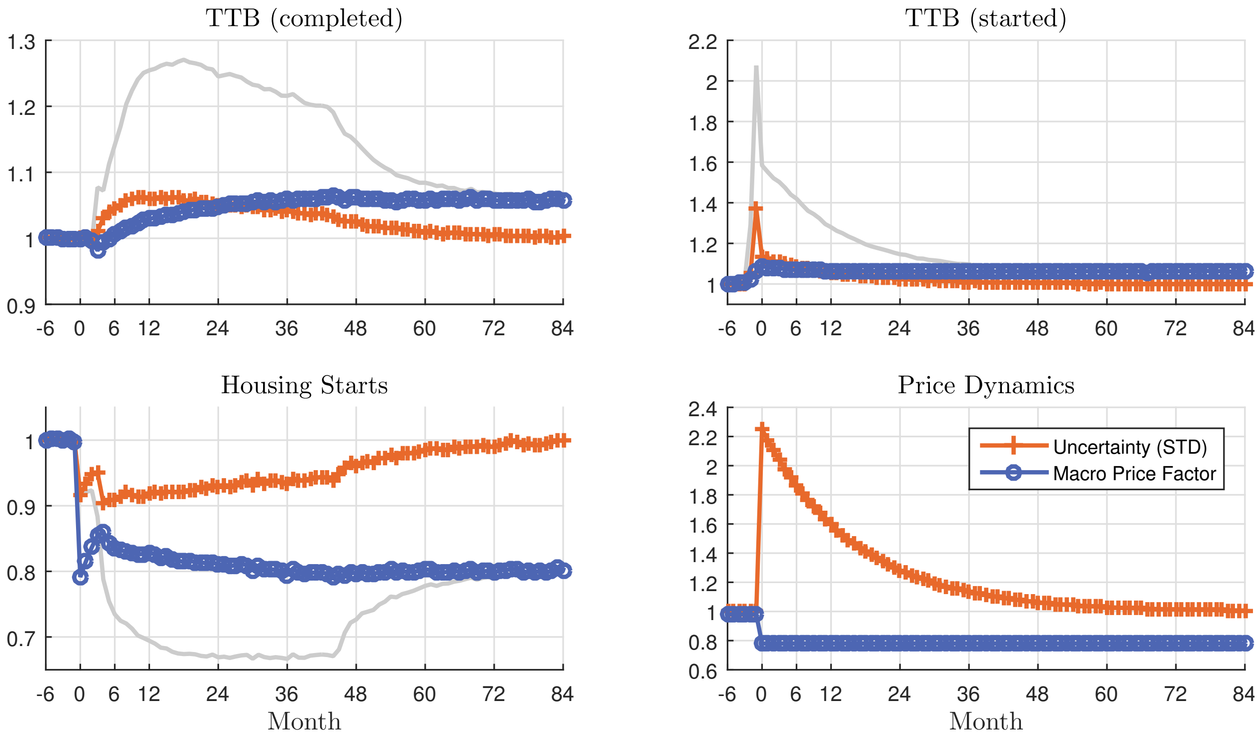


realization of both shocks, newly entering builders tend to optimally defer investment during their construction process. Both pre-existing builders and newly entering builders optimally delay investment, and therefore wait-and-see behavior is not limited to a set of unfortunate builders.

We can also compare the increase in TTB (completed) with housing starts. A 26% increase in TTB for completed houses implies that construction intensity for incomplete houses fell by 20%. For housing starts (second panel, first column of figure 8), the fall is 33%. Therefore, our model implies that while the fall in the intensive margin is less than the extensive margin, the magnitudes of both margins are comparable.

In figure 9, we experiment with each shock separately imposed. We find that the fall in the first moment of price itself (blue circle line) accounts for the long-run movements of house price, given its nonstationarity. However, its initial impact is limited. On the other hand, the increase in uncertainty has a stronger effect on the short-run dynamics of average TTB, based on either completed months or started months. Comparing with its respective housing starts, price dynamics have a strong effect on housing starts, while uncertainty has a strong effect on TTB dynamics. It is also interesting to find that the combination of both shocks lead to nonlinear effects, and all statistics are amplified with both shocks. In particular, housing starts stay low for a very long period with a combination of shocks. This comes partly from the long construction lags of existing projects. With builders stuck with old projects, there are not enough available lots to immediately pick up new housing starts. With project delays, the incomplete house inventory overhang generates a slow recovery of new housing starts.

Figure 9: Separate first- and second-moment shocks



5.3.3 Discussion: Financial frictions and the extensive margin

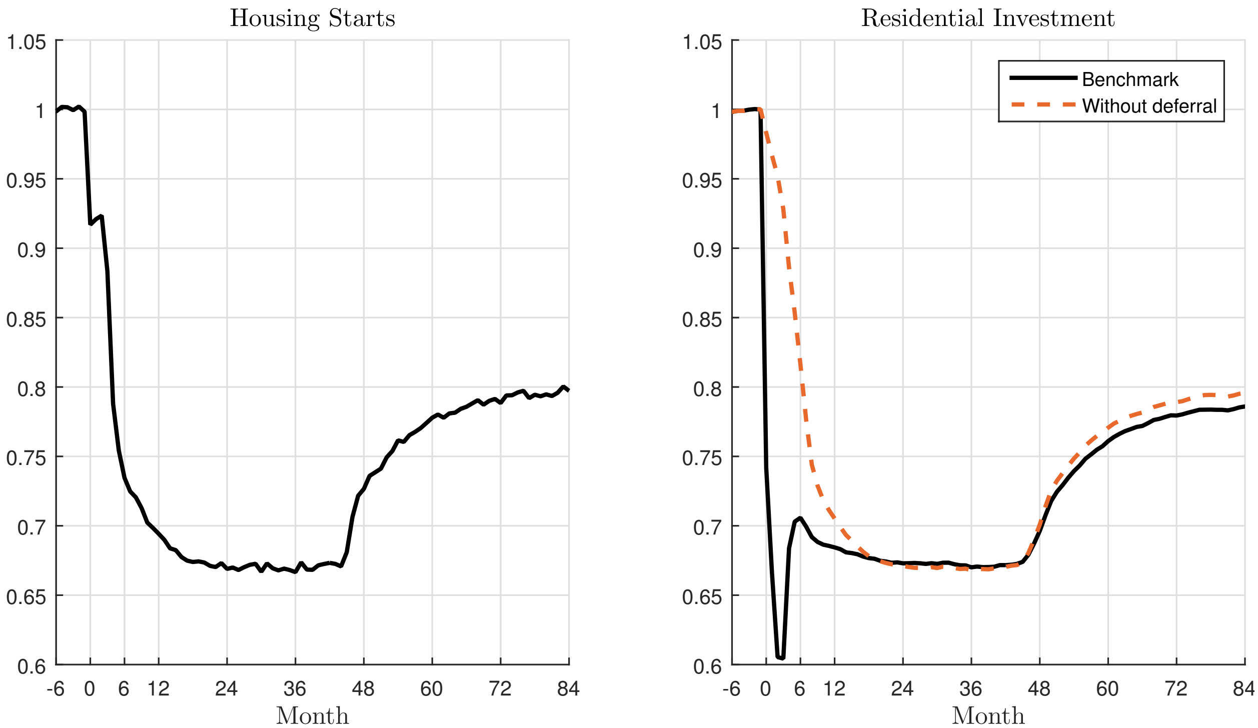
In the model simulations, we find that the observed house price dynamics generate our TTB dynamics both qualitatively and quantitatively. In particular, while both shocks are necessary, uncertainty shocks have a stronger effect on TTB dynamics relative to first-moment shocks. On the other hand, first-moment shocks have a stronger effect on housing start dynamics.

Before moving on to the next section, we note that our model does not fully account for the observed fall in housing starts. In figure 2, we find that housing starts have fallen by more than 70% from peak. Even from 2003, the fall in housing starts have been more than 60%. In our simulation, housing starts fall by 33%, which is relatively mild. Therefore, we suspect that for the extensive margin decisions, the observed price dynamics itself does not fully justify its massive fall and other channels may be more important, such as financial frictions in acquiring construction loans. However, for the intensive margin of construction, the observed price dynamics is enough to account for the data moments. Intuitively, this reflects the fact that once an extensive margin decision is made, construction loan contracts are signed and there must have been a less role for financial frictions to affect this margin.

6 Housing supply implications

Our results imply that the real options mechanism is of first-order importance in accounting for TTB dynamics. In this section, we use our simulation to look into several housing supply implications that follow from the channel we have studied so far. While understand-

Figure 10: Housing starts and residential investment



ing the dynamics of construction lags are interesting in itself, it is even more important by their implications on housing supply dynamics. We deliver three insights through our model. First, we look into its implications on residential investment under our baseline simulation. Second, we study how variable construction intensity driven by the observed house price dynamics affect housing start dynamics, by comparing the results with a simulation under fixed construction intensity. Third, we also simulate the model with lengthy physical TTB, to study the model implications for multi-family houses or longer commercial construction projects under the same set of shocks.

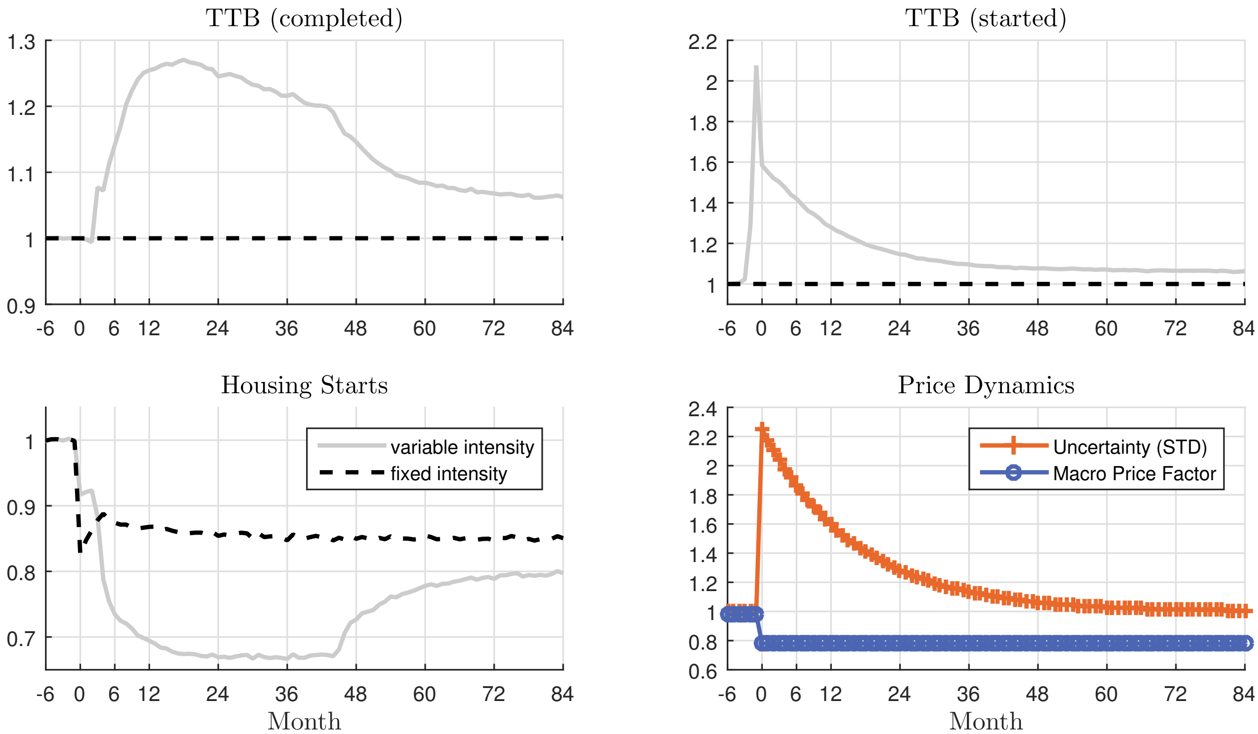
6.1 Residential investment with variable construction intensity

Housing starts and residential investment are key data of interest to macroeconomists and policymakers, both because of their high volatility and their stable lead-lag structure with GDP (Davis and Heathcote, 2005). In this part, we ask how our intensive margin affects the dynamics and lead-lag structure of residential investment.

In figure 10, we plot total housing starts and residential investment based on our simulated data and the shocks studied in the previous section. We find that both housing starts and residential investment also fell during this period. To gauge the importance of TTB dynamics in affecting residential investment, we also plot a counterfactual time series for residential investment, where we shut down the TTB channel, by assuming that there are no deferrals and hence economic TTB and physical TTB are the same.

We make two points from this figure. First, for the initial periods after our experiment, construction intensity of incomplete houses drives the dynamics of residential investment

Figure 11: Housing dynamics with variable and fixed construction intensity



rather than housing starts. For the first 6 months, the counterfactual residential investment, which only contains information on housing starts, falls by only a half of the actual simulated residential investment. The initial movements in residential investment are dominated by the intensive margin rather than the extensive margin. Second, while the counterfactual residential investment series lags housing starts, the actual residential investment responds immediately to the shock and hence does not lag housing starts.

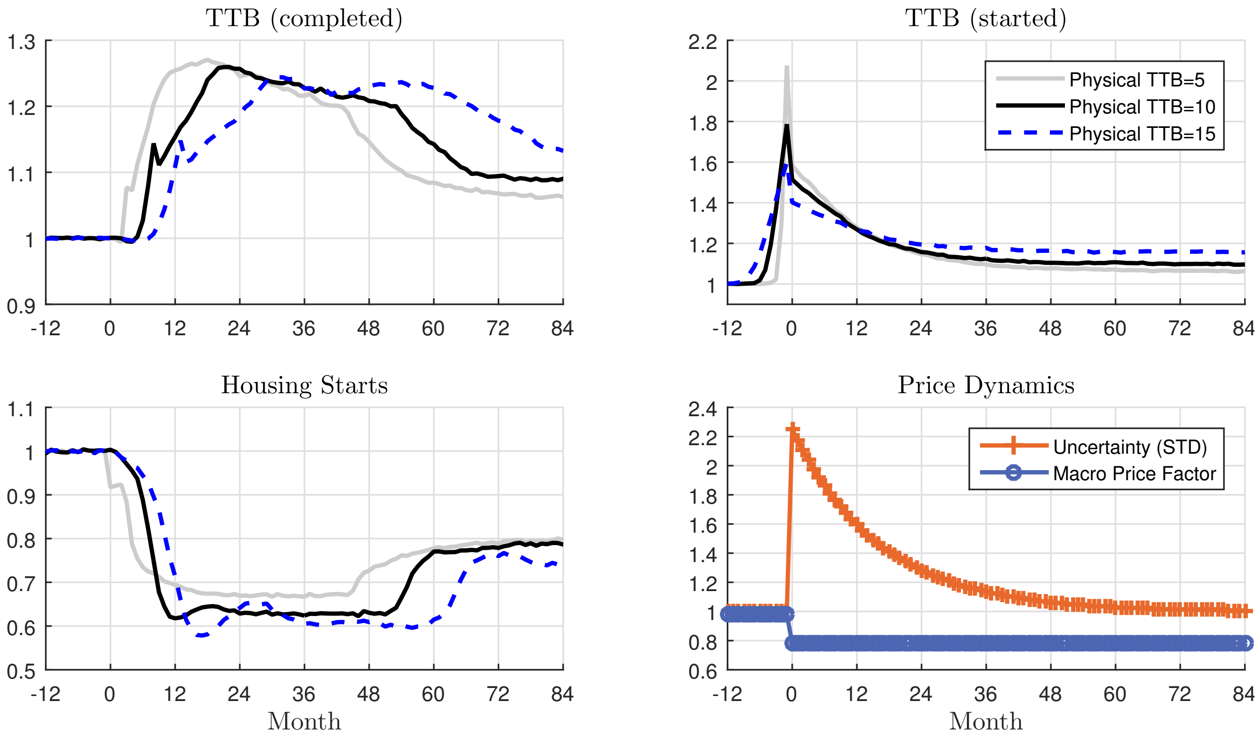
Therefore, neglecting the intensive margin of residential investment and forecasting residential investment based only on housing starts data would potentially lead to incorrect short-term estimates, especially when the movement of house price dynamics are large such as the recent recession. In particular, both the volatility and the lead-lag structure of residential investment are substantially different from their correct measures.

6.2 Housing starts with variable construction intensity

In this part, we ask through our model how variable construction intensity affects housing starts. In particular, we compare our result with that under the commonly used fixed TTB assumption. Figure 11 compares the dynamics of housing starts for variable and fixed construction intensity. Under fixed construction intensity, the initial fall in housing starts is large and immediate, quickly approaching the new steady state. On the other hand, under variable construction intensity, the initial fall in housing starts is muted, but the fall is persistent and large, only slowly converging back to a lower steady state.[17]

[17] In our model, the average starting price of houses under fixed intensity is higher than that under variable intensity. Since existing projects are relatively "unhealthy" under variable intensity, with a lower

Figure 12: Longer physical TTB



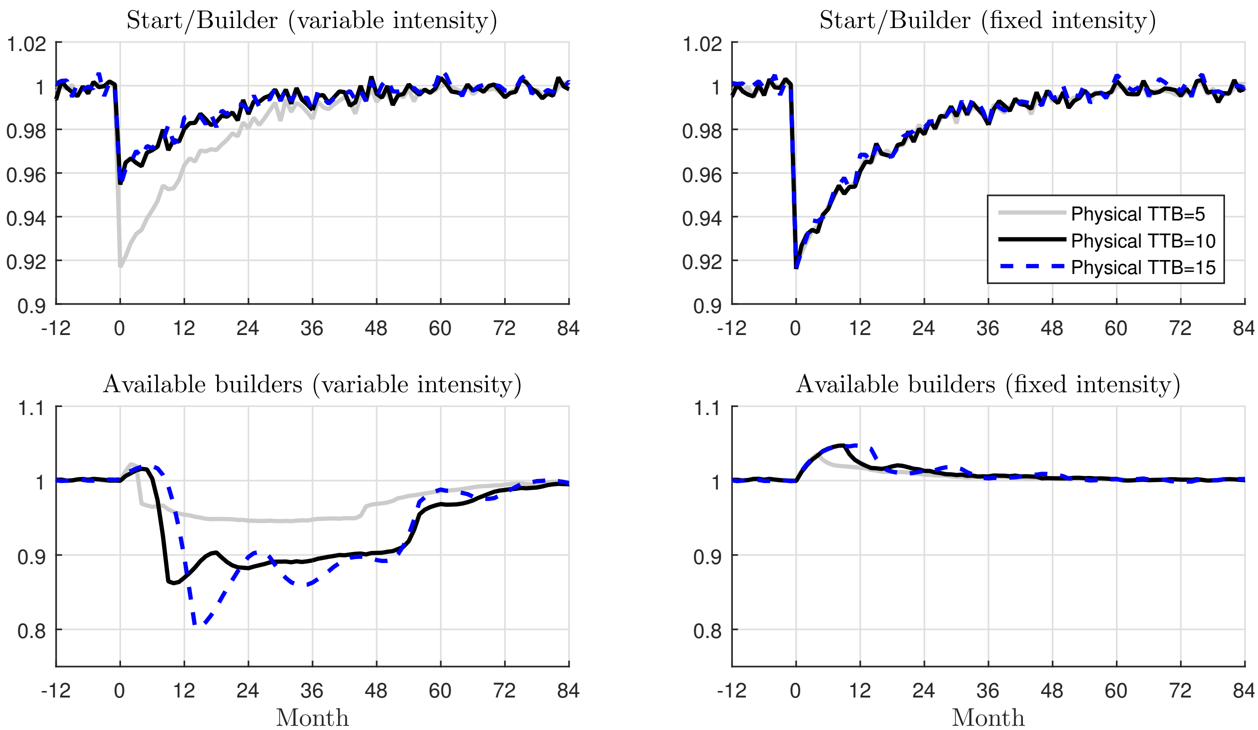
For the economic interpretation, we find that with fixed intensity, investment decisions are all loaded onto housing starts. Therefore, with the new information on price dynamics, housing starts take a big fall on impact. However, since pre-existing projects are committed to complete on schedule, there is a relatively stable flow of builders completing a project and recovering their option to start a new house by drawing a new price. On the other hand, with variable intensity, investment decisions are spread out at each stage of construction. Therefore builders do not sensitively respond. However, since pre-existing projects are now deferred with the new pricing information, completion rate falls and hence available builders for new projects remain lower for the long time. As the overhang of incomplete houses gradually resolves, housing starts recover as available builders steadily flow in.

6.3 Longer physical TTB

In the data, the average multi-family house is constructed in 10 months, and some large-scale commercial building projects can even take several years to complete. While our main focus of this paper is on single-family houses, in this part, we also conduct a counterfactual exercise to study projects with longer physical construction lags. Through this exercise, our goal is to gain some insights that our model delivers to these types of projects as well. In figure 12, we plot housing dynamics under the same set of shocks, varying only the physical

price, these houses now more frequently defer during construction, which leads to a higher average economic TTB. Therefore, there is a lower flow of available builders in the new price regime, which leads to the lower level of starts. We do not emphasize this result since it might be sensitive to the long-run adjustment of construction cost with regards to house price movements that we abstract from in this paper.

Figure 13: Uncertainty shock and housing starts



TTB.[18] We stress two results.

First, for longer projects, the average TTB for completed houses increases more gradually. For example, while average TTB of 5-month projects peaks in 17 months, that of 10- and 15-month projects peak in 22 and 30 months, respectively. This result is consistent with figure 1, where average TTB for multi-family houses lags that of single-family houses.

Second, the impact and short run movements of housing starts are smaller, but they eventually fall more in the later periods. This could be better understood by shutting down the price shock and only looking into uncertainty shocks. In figure 13, we plot the transition dynamics of housing starts under uncertainty shocks, where housing starts are decomposed into the start rate per builder and the number of available builders. Looking into the first panel of the first column, we find that under an uncertainty shock, the impact effect on the start rate is smoother with long projects. The impact fall of 10 or 15 month projects are half that of 5 month projects. This may be due to either the transitory nature of uncertainty shocks for longer projects or the lower information loading on housing starts for longer projects. To control for the transitory nature, we look into the first panel of the second column, where construction intensity is fixed by setting a large intensive margin adjustment cost. Surprisingly, the transitory nature of uncertainty shocks plays a minor role, if any, in start rate dynamics. With an uncertainty shock, even though longer projects face lower average uncertainty during the total construction process, the fall in the start rate is the

[18] In the simulation, we also impose a different abandon criterion since 46 months may be relatively small for projects that take a minimum of 15 months. In particular, we set the abandon period for 10 month projects as 56 months, and 15 month projects as 66 months. Our main point is not affected by this calibration.

same. Therefore, most of the effect comes from allowing for variable construction intensity. For longer projects, many TTB decisions follow, and hence start decisions are less sensitive to the initial uncertainty shock.

In the lower panel, we also plot the number of available builders under two scenarios. In the first column, we find that for longer projects, available builders increase initially for a longer period. This mostly comes from more builders deciding not to start a new project, which is also the case in the second column under fixed intensity. However, the two figures depart in the later period since with variable construction intensity, pre-existing projects are all delayed and hence inventory overhang leads to less new projects available. On the other hand, available builders do not fall below the steady state in the second column, since no delays occur with fixed construction intensity.

To sum up, our model delivers the following result: for long term projects under the same set of shocks, the short-run housing start response is muted but the later response is larger with a slower recovery. Variable construction intensity plays a signficant role in generating this pattern. In fact, comparing housing starts for single- and multi-family houses in the data, the fall in multi-family housing starts lagged the fall in single-family housing starts, but the fall was eventually larger. Although there are many explanations for this observation, our simulation also generates a pattern that is consistent.

7 Conclusion

In this paper, we document some new facts on the distribution of residential construction lags across the US. Importantly, we emphasize that the fall in economic activity is not limited to extensive investment, but also expands to intensive investment. Contrary to the notion that time-to-build projects that have already started are costly to stop, we find that a significant portion of it has been deferred during the recent housing bust. Given the large movements in house prices during the era, we study a model where time-to-build investment responds solely to prices and uncertainty and simulate the model with the level of price and uncertainty movements observed in the recent recession. We find that our real-options mechanism is capable to account for all the drop in intensive investment during the housing bust. We argue that the real-options mechanism is of first-order importance for construction lags during the recent recession.

Before concluding, it is important to note that in this paper, we left aside the financial frictions channel in time-to-build investment projects. We are indeed aware that the construction sector is a levered industry, and that the recent housing boom-bust cycle is closely related to the availability of credit. Builders and lenders with different financing conditions and contracts would have behaved differently to the housing bust, and the overall financial constraints may have exacerbated the aggregate housing market collapse. Our aim is rather on addressing the first-order importance of the real options mechanism in the recent housing cycle given the unprecedented magnitude of house price dynamics, than on providing a complete picture of the housing supply side behavior. While we find that the real-options mechanism is capable of accounting for most of the investment activity for projects under construction, its potential endogeneity with financial frictions is a topic of interest. We leave this out as a future research project.

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