Housing, Stability and the Macroeconomy: International Perspectives

Federal Reserve Bank of Dallas
Journal of Money, Credit and Banking
International Monetary Fund

Supply Restrictions, Subprime Lending and Regional U.S. Housing Prices

Andre Kallålk Anundsen, University of Oslo
Christian Heebøll, University of Copenhagen

This paper was presented at **Housing, Stability and the Macroeconomy: International Perspectives** conference, November 14-15 2013. The conference was sponsored by the Federal Reserve Bank of Dallas, the International Monetary Fund, and the *Journal of Money, Credit and Banking*. The conference was held at Federal Reserve Bank of Dallas (http://dallasfed.org).

Supply restrictions, subprime lending and regional US housing prices*

André Kallåk Anundsen
Department of Economics, University of Oslo

Christian Heebøll
Department of Economics, University of Copenhagen

Abstract

This paper analyzes the recent boom-bust cycle in the US housing market from a regional perspective. Particular attention is paid to supply side restrictions and financial accelerator effects related to subprime lending. Considering 247 Metropolitan Statistical Areas across the entire US, we estimate a simultaneous boom-bust system for housing prices and supply. The model includes non-linear regional specific supply elasticities, determined by geographical and regulatory supply restrictions. In contrast to the predictions of a baseline theory model, our results suggest that tighter supply restrictions lead to both a larger housing price boom and bust following a temporary increase in subprime lending. Extending the model to include a financial accelerator, our results indicate that supply restricted areas are significantly more exposed to this mechanism, which explains the greater housing price volatility in these areas over the course of a boom-bust cycle.

JEL Classification: *E44; E32; G21*

Keywords: *Regional Boom-Bust Cycles; Housing Supply Restrictions; Subprime Lending, Financial Accelerator*

*Contact details: *André Kallåk Anundsen*: Department of Economics, University of Oslo, PO Box 1095 Blindern, N0317 Oslo, Norway. Email: a.k.anundsen@econ.uio.no. *Christian Heebøll:* Department of Economics, University of Copenhagen, Øster Farimagsgade 5, Building 26, DK-1353 Copenhagen K, Denmark. Email: chc@econ.ku.dk.

1 Introduction

The past decades have demonstrated a crucial role of housing markets in transmitting and propagating shocks to the real economy. During the national housing boom of the early 2000s, some regional US markets experienced a dramatic run up in prices, leading to both over-building of new houses and under-savings by home owners (Glaeser et al., 2008). These imbalances contributed to the collapse in property prices in the late 2000s and to the ensuing banking crisis that still impairs the global economy (Ferreira et al., 2010; Levitin and Wachter, 2012). In this paper, we investigate these regional housing market developments over the recent boom-bust cycle. Considering 247 heterogeneous US housing markets, we analyze whether a combination of supply side restrictions, subprime lending and credit acceleration mechanisms can explain the extreme price volatility observed in some areas.

Table 1 reports the percentage change in housing prices and supply for the five areas in our sample experiencing the largest as well as the smallest housing price booms over the 2000–2006 period. As seen, there are huge variations across areas, ranging from around 160 % among the top five to 10-20 % among the bottom five areas. The largest housing price booms were typically observed in coastal areas, such as Florida and California, while the smallest booms were located in the Midwest regions. Further, we do observe some co-movement among all the variables reported in the table; large boom period price increases were associated with large supply increases and followed by large bust period price drops.

Table 1: Cumulative growth in top and bottom five MSAs

MSA	State	Region	Δp_{boom}	Δp_{bust}	Δh_{boom}
Top five MSAs					
Naples-Marco Island	FL	South	163 %	-48 %	29 %
Riverside-San Bernardino-Ontario	CA	West	162 %	-45 %	20 %
Fort Lauderdale-Pompano Beach-Deerfield Beach	FL	South	160 %	-42 %	8 %
Fresno	CA	West	158 %	-41 %	11 %
Bakersfield-Delano	CA	West	158 %	-45 %	16 %
Bottom five MSAs					
Lafayette	IN	Midwest	10 %	1 %	14 %
Kokomo	IN	Midwest	10 %	-11 %	3 %
Fort Wayne	IN	Midwest	16 %	-2 %	8 %
Detroit-Livonia-Dearborn	MI	Midwest	18 %	-33 %	1 %
Dayton	OH	Midwest	18 %	-5 %	4 %
Summary statistics					
Mean			56 %	-7 %	10 %
Standard deviation			38 %	16 %	7 %

Note: The table shows the top and bottom five MSAs ranked according to their housing price increase over the boom period. Δp is the nominal change in housing prices, while Δh labels the percentage change in the housing stock. The regions refer to the definitions applied by the Bureau of Labor Statistics, while the Metropolitan Statistical Area (MSA) definitions are based on the 2004 definitions of the Census Bureau. The boom is here defined as the 2000–2006 period, while the bust runs from 2006 through 2010. *Source:* The Federal Housing Finance Agency (FHFA) housing price index and Moodys data on housing stock.

A branch of the literature explains these variations as caused by heterogeneous supply side restrictions, see e.g. Malpezzi (1996), Green et al. (2005), Gyourko et al. (2008), Saiz (2010) and Glaeser (2009). Some areas are geographically restricted by the coast line or mountains etc. In other areas, local governments try to influence the building activity through their regulatory framework. Against this background, Glaeser et al. (2008) present a theoretical model of boom-bust cycles in heterogeneous housing markets. In the model, more supply restricted areas primarily react to a positive demand shock by increasing housing prices, while less restricted areas mostly absorb the shock in terms of higher construction activity. Thus, during the boom period, their model predicts that some areas build up large *price overhangs*, whereas others build up large *quantity overhangs*. That said, assuming supply is rigid downwards, a corresponding reduction in demand during the bust period should have a negative and equally sized impact on housing prices, independent of the supply elasticity.

When they confront the main predictions of this model empirically, both Glaeser et al. (2008) and Huang and Tang (2012) find that housing price booms are positively affected by supply restrictions. However, the two studies disagree on the importance of these restrictions for the size of the housing price bust. While Glaeser et al. (2008) find that the price and quantity overhang exactly canceled during the bust of the 1990s, Huang and Tang (2012) find that the effect of the price overhang was dominating during the housing bust of the late 2000s. In this paper, we are motivated by this puzzling result, giving a clear indication that other price stimulating mechanisms have gained importance in recent decades.

If a price increase leads to expectations of further price increases, or a relaxation of credit constraints, this can have a strong amplifying effect on demand (Glaeser et al., 2008; Bernanke and Gertler, 1989; Kiyotaki and Moore, 1997; Aoki et al., 2004; Iacoviello, 2005). In this paper, we demonstrate how recent financial innovations (subprime lending) in combination with supply side restrictions have led to regional specific financial accelerator effects, with large consequences for the housing price dynamics in recent, more financially deregulated markets. Theoretically, we show that the inclusion of a financial accelerator effect in a model similar to Glaeser et al. (2008) changes the predictions of the model considerably. More supply restricted areas are predicted to experience an even stronger housing price boom, increasing the price overhang considerably. On the other hand, the difference in the quantity overhang diminishes. This provides a plausible explanation as to why supply restricted areas experienced a greater housing price bust, and – hence – why we have seen these conflicting results in the recent empirical literature.

To analyze these mechanisms empirically, we consider a simultaneous equation system for the boom period, including both a price, supply and credit relationship. The financial accelerator is captured by an endogenous feedback effect between housing prices and credit, while supply restrictions are accounted for by area specific supply elasticities that depend on both geographical and regulatory supply restrictions. Acknowledging that regional subprime exposure might be affected by price developments and the heterogeneous characteristics of the areas, we follow Mian and Sufi (2009) and use the 1996 loan rejection rates to identify the credit relationship. In addition, we consider the loan-to-income ratio as done in Wheaton and Nechayev (2008).

The structural model considered in this paper has the advantage over the reduced form housing price models of Glaeser et al. (2008) and Huang and Tang (2012) in that it allows us to decompose and focus on the price, supply and credit responses through the cycle. Hereby, we can identify the effects resulting from the financial accelerator and, specifically, how these depend on supply restrictions. In that sense, the contribution of our econometric analysis is twofold. First, we study how areas with different supply restrictions react differently in terms of price and supply changes over the course of a boom-bust cycle. Second, we ask whether there is evidence of a financial accelerator and how this depends on the supply restrictions.

Our results suggest that, throughout the recent boom period, financial innovations led to a stronger financial accelerator in more supply restricted areas, with an additional positive effect on both prices and supply. Even though these areas experience a relatively low supply response for a given price increase, the stronger endogenous price acceleration dilutes the relation between the supply restrictions and the total supply increase. This offers a sensible explanation to why more restricted areas are hit harder during the bust period, as found by Huang and Tang (2012). Generally, we also find that regulatory restrictions are more important than geographical restrictions. This implies that political authorities deciding to regulate housing supply should bear in mind how this – in combination with geographical restrictions - affects the dynamics of the housing market through a boom-bust cycle. In fact, such regulations can have a particularly strong effect when imposed in tandem with liberalized credit markets.

The importance of credit markets in explaining regional housing prices has also been addressed in other parts of the literature. One part looks at how imbalances in credit markets may generate imbalances in housing markets. Wheaton and Nechayev (2008) find that the US housing market disequilibria during the early 2000s were driven by regional differences in credit markets – consistent with the results of this paper. That said, the authors are silent about the mechanisms causing these differences, and how it affects the bust period price dynamics.

Pavlov and Wachter (2006) analyze the previous bust in US housing prices in the 1990s. Both theoretically and empirically, they show that regions that were more exposed to aggressive lending instruments during the boom also experienced a larger price drop during the bust. Based on the results of this paper, this can be attributed to a larger financial accelerator effect in more supply restricted areas during the housing price boom. On the contrary, Coleman IV et al. (2008) do not find support for the hypothesis that subprime lending drove housing prices during the 1998–2008 period.

Another related branch of the literature is concerned with the causes of regional credit expansions. Mian and Sufi (2009) analyze regional credit market dynamics through the late 1990s and early 2000s. In contrast to our results, they find that large credit expansions were related to an increased securitization of risky mortgages and not to tighter supply restrictions. This leads them to reject the hypothesis of an expectations driven credit expansion. However, compared to their study, we ask whether the credit expansions were caused by more aggressive housing price increases in supply restricted areas, and not by the restrictions *per se*.

The paper is organized as follows. The next section provides a theoretical motivation to the empirical analysis. In Section 3, we present our econometric models, the empirical hypotheses and describe the data that is utilized in the econometric analysis. Section 4 presents and discusses the empirical results. The final section concludes the paper.

2 Theoretical motivation

2.1 A supply-demand framework for housing boom-bust cycles

Following Glaeser et al. (2008), we consider an economy consisting of several heterogenous housing markets with different supply elasticities. Specifically, some regions are open space areas with no regulations on building permits, while other regions are naturally restricted, e.g. by mountains or water, or by the local regulatory framework. Assuming that all areas initially are hit by a positive and similar sized exogenous demand shock, we analyze how the characteristics of the boom-bust cycle depend on the supply elasticity.

In each period, the law of motion of capital accumulation for area i is given as:[1]

$$H^s_{i,t} = H^s_{i,t-1} + I_{i,t} \tag{1}$$

where $H^s_{i,t}$ is the housing stock at time t, while $I_{i,t}$ represents new investments. We assume that investments are determined according to a Tobin's Q theory (Tobin, 1969), i.e. new construction projects are initiated as long as the market price, $P_{i,t}$, exceeds the marginal cost of construction, $MC_{i,t}$.

When considering heterogenous areas of different sizes, the number of new construction projects initiated in each period will naturally depend of the size of the market in question. To take account of this, we assume that the marginal cost of investments is inversely proportional to the existing housing stock, i.e. there is a larger construction capacity in bigger markets. The marginal cost function for area i takes the following form:

$$MC_{i,t}(I_{i,t}) = C_{0,i}\left(I_{i,t}/H_{i,t-1}+1\right)^{1/\varphi_i} \qquad ,\varphi_i > 0 \;\forall\; i$$

where φ_i is the time-invariant area specific supply elasticity, while $C_{0,i}$ is a positive variable measuring fixed costs of housing construction (we disregard time-varying construction costs for now). Setting the price equal to the marginal cost, we get the following investment function:

$$I_{i,t} = H_{i,t-1}\cdot \max\left\{0,\ \left(\frac{P_{i,t}}{C_{0,i}}\right)^{\varphi_i} - 1\right\} \tag{2}$$

As seen, given a non-zero supply elasticity, there will be positive investments *if and only if* prices are above the fixed costs of construction. The two extreme cases are interesting: In a completely elastic market ($\varphi_i \to \infty$) a positive price-to-cost ratio implies that investments become infinite, while in a completely inelastic market ($\varphi_i \to 0$), investments will be zero and independent of the housing price. From (1) and (2), we find that a log transformation (lower case letters) of the supply equation yields:[2]

$$h^s_{i,t} = h^s_{i,t-1} + \max\left\{0,\ \varphi_i\left(p_{i,t} - c_{0,i}\right)\right\} \tag{3}$$

[1] We abstract from depreciation of the existing stock. Since we restrict our analysis to the short and medium run (the course of a boom-bust cycle), the depreciation will be minor and almost equal across areas.

[2] This is seen by rewriting (1) using (2); $H^s_{i,t} = H^s_{i,t-1}\cdot \max\left\{1,\ \left(\frac{P_{i,t}}{C_{0,i}}\right)^{\varphi_i}\right\}$ and then taking logs.

It follows that the log supply curve will be piecewise linear and kinked; only if the price exceeds the fixed cost of construction, supply increases as a function of the supply elasticity, φ_i, and the price-to-cost ratio (Tobin's Q). Hence, supply is assumed completely downward rigid, motivated by the fact that houses usually are neither destroyed nor dismantled.

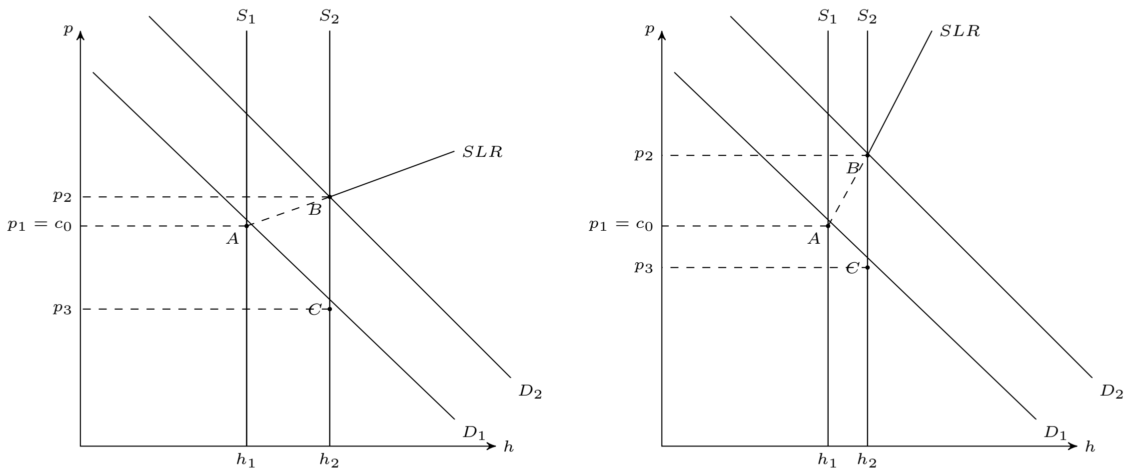
We follow custom when it comes to the modeling of the demand side. For each area, it is assumed that demand is determined in accordance with the commonly used life-cycle model of housing, see e.g. Meen (1990, 2001) and Muellbauer and Murphy (1997), and the references therein. For area i, a logarithmic representation of the inverted demand curve is given as:

$$p_{i,t} = v_{0,i,t} + v_1 h^d_{i,t} \qquad , v_1 < 0 \tag{4}$$

where the term $v_{0,i,t}$ measures exogenous demand shifters, such as income, the user cost of housing as well as – important to the focus of this paper – credit constraints. The parameter v_1 measures the price elasticity of an increase in the number of houses.

Let us assume that market i initially is in equilibrium ($p_{i,t} = c_{0,i}$) and that it is hit by a positive demand shock which triggers a one period boom. After one period, the shock is reversed, which sets off a bust that also lasts for one period. From the reduced form solution of the supply and demand equations, (3) and (4), the housing price and supply responses are given by $\frac{\partial p_{i,t}}{\partial v_{0,i,t}} = \frac{1}{1-v_1\varphi_i}$ and $\frac{\partial h_{i,t}}{\partial v_{0,i,t}} = \frac{\varphi_i}{1-v_1\varphi_i}$. Figure 1 illustrates the housing market dynamics for a supply elastic and a supply inelastic market following a demand shock of a given size (from D_1 to D_2).

Figure 1: Boom-bust cycles of supply elastic vs. inelastic markets.



Market 1: Elastic supply   Market 2: Inelastic supply

Note: D_1 is the original demand curve, while D_2 is the demand curve after the positive demand shock. S_1 is the original short run supply curve and S_2 is the short run supply curve after the shock is materialized. The long run supply curve is given by SLR.

As seen both from Figure 1 and the first derivatives, a positive demand shock primarily leads to supply side adjustments in supply elastic markets, while the shock is mostly absorbed in terms of higher prices in inelastic markets. To ensure market clearing, a larger part of the adjustments have to be done in terms of higher prices the lower is the supply elasticity.

Given our assumption that the model initially starts out in equilibrium ($p_{i,t} = c_{0,i}$), the price will be lower than the fixed cost of construction for any value of φ_i during the bust period. It then follows from (2) that investments drop to zero and, hence, the price drop will be independent of the supply elasticity, only determined from (4); $\frac{\partial p_{i,t}}{\partial v_{0,i,t}} = -1$. At the peak of the boom, the *price overhang* will be greater the *higher* is φ_i, whereas the *quantity overhang* will be greater the *lower* is φ_i. Further, the *price* and the *quantity overhang* are equally important for the size of the bust price drop. This is also seen in Figure 1, where the bust is illustrated by letting the demand curve shift back to its original position (from D_2 to D_1). It is clear that the vertical distance from point B to C is the same in both markets.

In conclusion, a standard supply-demand framework suggests two interesting hypotheses that can be tested against the data. First, the supply elasticity should only determine the relative size of the supply and price reactions during the boom and these should be negatively correlated. Second, the fall in housing prices during the bust should be independent of the supply elasticity (supply restriction irrelevance).

2.2 The financial accelerator

There might be several reasons why the housing price and supply dynamics through a boom-bust cycle do not match the predictions of the simple theory model outlined in Section 2.1. Glaeser et al. (2008) discuss the case when price expectations are formed adaptively and show that this will generate a price-to-price feedback loop resulting in more volatile price dynamics, especially in highly supply restricted areas. In this section, we will argue that similar results apply if housing markets are affected by a financial accelerator (see e.g. Kiyotaki and Moore (1997), Bernanke and Gertler (1989), Bernanke et al. (1999), Aoki et al. (2004) and Iacoviello (2005)).

When housing prices increase, households have more collateral available to pledge and, hence, banks' willingness and/or ability to lend increases. This implies that households are able to bid up prices further, possibly initiating a credit-housing price spiral. In our two-period boom-bust model, we shall distinguish between lending practices in period of increasing and decreasing housing prices. For the boom period, when housing prices are increasing, we follow custom and assume that agents in the economy are faced with a collateral constraint in the spirit of Kiyotaki and Moore (1997). In the bust period, when prices decrease, we assume that the supply of credit is fixed at some level κ_0. We have:

$$b_{i,t} \quad \leq \quad \begin{cases} \kappa_0 + \kappa_1 p_{i,t} & ,\text{for } p_{i,t} > p_{i,t-1} \\ \kappa_0 & ,\text{for } p_{i,t} \leq p_{i,t-1} \end{cases} \tag{5}$$

where $b_{i,t}$ is the log of the total amount of credit extended in area i, which during periods of increasing housing prices depends on the housing price through the parameter κ_1.[3] We shall assume that the credit constraint is binding, and that credit is an important

[3]Note that by also setting $\kappa_1 = 0$, we are back at the baseline model presented in the previous subsection.

demand component, captured by the term $v_{0,i,t}$ in (4). We assume that $v_{0,i,t}$ can be split into two components:

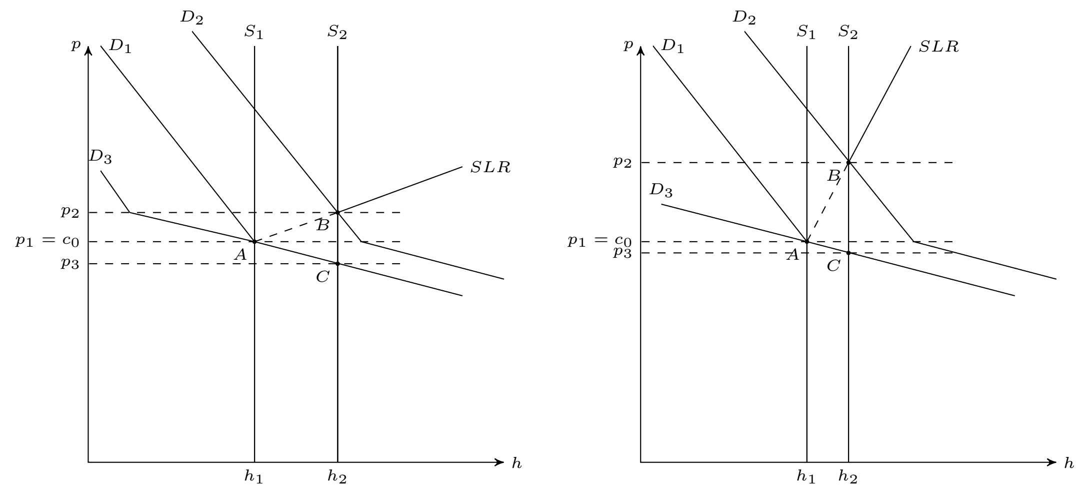
$$v_{0,i,t} \quad = \quad \tilde{v}_{0,i,t} + \eta b_{i,t} \tag{6}$$

where $\eta b_{i,t}$ captures the impact of credit on the demand for housing and $\tilde{v}_{0,i,t}$ measures other demand components. Substituting out for (6) in (4), the "new" inverted demand equation can be expressed as:

$$p_{i,t} \quad \leq \quad \begin{cases} \frac{1}{1-\eta\kappa_{1,t}}\left[\tilde{v}_{0,i,t} + \eta\kappa_0 + v_1 h^d_{i,t}\right] & \text{, for } p_{i,t} > p_{i,t-1} \\ \tilde{v}_{0,i,t} + \eta\kappa_0 + v_1 h^d_{i,t} & \text{, for } p_{i,t} \leq p_{i,t-1} \end{cases} \tag{7}$$

Hereby, the demand curve is kinked at the point where $p_{i,t} = p_{i,t-1}$. Let us consider the same two-period boom-bust cycle scenario as in the baseline model. The boom period housing price, housing supply and credit responses are given as: $\frac{\partial p_{i,t}}{\partial \tilde{v}_{0,i,t}} = \frac{1}{1-v_1\varphi_i-\eta\kappa_1}$, $\frac{\partial h_{i,t}}{\partial \tilde{v}_{0,i,t}} = \frac{\varphi_i}{1-v_1\varphi_i-\eta\kappa_1}$ and $\frac{\partial b_{i,t}}{\partial \tilde{v}_0} = \frac{\kappa_1}{1-v_1\varphi_i-\eta\kappa_1}$. Figure 2 gives a visual depiction of the mechanisms of the model. We maintain the assumption that the boom period is initiated by a positive and similar sized shock, shifting the demand curve outwards (from D_1 to D_2). As in the baseline model, this results in a movement from A to B. In addition to the mechanisms in the baseline model, the housing boom causes banks to be more liberal on the amount of credit they extend. This is captured by the magnitude of $\eta\kappa_1$, which results in the steeper slope of the demand curve during periods of increasing housing prices. Intuitively, housing price changes in the boom period will have a stronger influence on agents' ability to lend, which has an additional stimulating effect on housing demand.

Figure 2: Boom-bust cycles of supply elastic vs. inelastic markets.



Market 1: Elastic supply

Market 2: Inelastic supply

Note: D_1 is the original demand curve, D_2 is the demand curve after the positive demand shock, while D_3 is the demand curve after the shock is reversed. S_1 is the original short run supply curve, S_2 is the short run supply curve after the shock is materialized. The long run supply curve is given by SLR.

Compared to the situation where we do not account for the financial accelerator (corresponding to the baseline model), Figure 2 and the first derivatives indicate a larger price and supply boom in both markets. However, the greater price response in the supply inelastic market feeds into a stronger increase in credit. Hence, comparing the two markets in Figure 2, this increases the difference in the price overhang and diminishes the difference in the quantity overhang, implying an overall stronger boom in the supply inelastic market. Depending on the size of $\eta\kappa_1$, the additional supply increase caused by the financial accelerator effect might be independent of, or even decreasing in the supply elasticity. In the latter case, the effect might be so strong that the supply restriction irrelevance result holds for the total boom period supply response.

Turning to the bust period, we assume that the demand curve returns to its initial position (D_2 to D_1), i.e. the shock is reversed and, giving the decreasing housing prices, the amount of credit is fixed. Given that supply is fixed at the boom period level, the model predicts that prices will drop from B to C when we account for the financial accelerator. As seen, when we do take the financial accelerator into account, the price drop is significantly larger in more inelastic areas (B to C). This results from the fact that, compared to the baseline model, the additional credit driven price and quantity overhangs are relatively larger in inelastic areas.

In summary, taking hold of the financial accelerator, the price volatility is more dependent on the supply elasticity, while the boom period supply increase is less dependent of it. We would also expect there to be some regional variations in demand, leading to variations in housing prices. However, assuming that demand is not directly affected by the supply elasticity, any observed correlation between price dynamics and the supply elasticity is an argument in favor of the financial accelerator effect we describe.

3 Econometric model and data

3.1 The empirical model

Starting by our econometric operationalization of the supply-demand framework, we depart from (3) and (4) in Section 2.1. Consistent with the life-cycle model, $v_{0,i,t}$ in (4) measures typical demand shifters, such as income and credit.[4] For the supply equation (3), we assume that the elasticity of supply, φ_i, is determined by area specific supply restriction indexes, which will be discussed in more detail later. Further, we proxy the cost of construction by construction wages and the supply restriction indexes (non-interacted). In line with the theoretical model, we assume that all areas start in a pre-boom equilibrium, where the price is equal to the fixed cost of construction, $c_{0,i}$.

Considering the model represented by (3) and (4) in first differences, we arrive at the following simultaneous demand-supply system for the boom-period:

$$\Delta p_i^{Boom} = \alpha_1 + \beta_{1,\Delta h}\Delta h_i^{Boom} + \boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i^{Boom} + \varepsilon_{\Delta p,i} \quad (8)$$

$$\Delta h_i^{Boom} = \alpha_2 + \left(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p\times \boldsymbol{Reg}} \times \boldsymbol{Reg}_i\right)\Delta p_i^{Boom} + \boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i^{Boom} + \varepsilon_{\Delta h,i} \quad (9)$$

where Δp_i^{Boom} and Δh_i^{Boom} represent the boom period increase in housing prices and supply for area i, respectively. $\boldsymbol{Reg}_i$ is a vector of supply restriction measures, affecting the area specific supply elasticity. The vector $\boldsymbol{z}_i^{Boom}$ consists of supply shocks, including

[4]Since the interest rate is almost equal across areas, we abstract from the user cost component.

growth in construction wages and income. The term $\boldsymbol{x}_i^{Boom}$ is a vector of demand shocks, including growth in income and the log cumulative increase in subprime originations per capita. Subprime lending will be our main variable capturing exogenous demand shocks to the model. We follow Mian and Sufi (2009) and Huang and Tang (2012) and use the loan denial rates in 1996 as an instrument. Mian and Sufi (2009) argue that the rejection rates in 1996 (before the start of the boom) provide a measure of latent subprime exposure. Areas that had high rejection rates initially are more likely to be exposed to subprime lending at a later stage, since the pool of borrowers falling into this category is larger. As a second instrument, we include the average loan-to-income ratio (LTI) in 1996, which has been considered by Wheaton and Nechayev (2008) as another proxy for looser lending standards. Thus, we take it as a proxy for the exogenous scope for subprime lending during the boom period. We also include various control variables that have been considered in the literature; income level, population, population density and the unemployment rate, all as of 1996. The data sources will be specified in more detail in the next subsection.

Without the interaction terms in (9) – $\boldsymbol{\beta}_{2,\Delta p \times reg} = \mathbf{0}$ – identification of the two equations would be trivial, since it would require that we impose one exclusion restriction in each equation. This would clearly be satisfied, since the subprime measure only enters the price equation, while construction wages only enters the supply equation. Now, following the argument in Wooldridge (2002), we know that identification in the linear model ($\boldsymbol{\beta}_{2,\Delta p \times reg} = \mathbf{0}$) also ensures identification in the non-linear model ($\boldsymbol{\beta}_{2,\Delta p \times reg} \neq \mathbf{0}$). Hence, both equations in our baseline boom system are identified.

While we start by estimating the baseline model represented by (8)–(11), we shall later allow for endogenous price acceleration effects by extending the boom period model, (8)–(9), by an additional equation for subprime lending. With reference to equation (5) in Section 2.2, we assume the following relationship for subprime lending:

$$\Delta sp_i^{Boom} \quad = \quad \alpha_3 + \beta_{3,\Delta p} \Delta p_i^{Boom} + \boldsymbol{\beta}_{\boldsymbol{y}}' \boldsymbol{y}_i^{Boom} + \varepsilon_{\Delta sp,i} \tag{10}$$

where $\boldsymbol{y}_i^{Boom}$ is a vector comprising the growth in income during the boom along with the instruments for subprime lending used in the baseline model. Furthermore, housing prices are allowed to have an effect on subprime lending, which opens for the possibility of a financial accelerator. In particular, this implies that the effect of supply restrictions and subprime lending could be mutually reinforcing, as shown in Section 2.2. Again, following the argument in Wooldridge (2002), identification now requires that two exclusion restrictions are imposed in the price equation, and that one exclusion restriction is imposed in both the supply and the subprime equation. A simple counting exercise demonstrate that this is indeed satisfied, i.e. the three equations in the extended boom system are indeed identified.

Our econometric models are both simultaneous equation systems. However, they are complicated by the non-linearity of the regression coefficient $\beta_{2,\Delta p} + \boldsymbol{\beta}_{2,\Delta p \times \boldsymbol{Reg}}' \times \boldsymbol{Reg}_i$ in (9).[5] The system is estimated by full information maximum likelihood (FIML) techniques, assuming that the disturbances follow a joint normal distribution.

[5]If we let $\boldsymbol{Y}_i$ denote the vector of endogenous variables and $\boldsymbol{Z}_i$ be a vector of instruments, the matrix representation of (8)–(9) is given by (Hausman, 1983, ch 7.): $\boldsymbol{B}_i \boldsymbol{Y}_i + \boldsymbol{\Gamma} \boldsymbol{Z}_i = \boldsymbol{\varepsilon}_i$. The non-linearity results from the fact that the endogenous effect of the supply elasticity is area specific, i.e. $\boldsymbol{B}_i$ is different for each area.

To explore the relevance of supply side restrictions for the size of the housing price bust, we add an equation for the price development during that period as well. Consistent with the theoretical model, we condition on the price and supply reactions during the boom, i.e. the terms Δp^{Boom} and Δh^{Boom}, measuring the *price* and *quantity* overhang, respectively. This equation takes the following form:

$$\Delta p_i^{Bust} \;=\; \mu + \gamma_{\Delta p}\Delta p_i^{Boom} + \gamma_{\Delta h}\Delta h_i^{Boom} + \boldsymbol{\gamma}_{\boldsymbol{w}}'\boldsymbol{w}_i^{Bust} + e_i \tag{11}$$

where $\boldsymbol{w}_i^{Bust}$ comprise demand shocks relevant for the bust period, which contains the growth in disposable income. Note that introducing this equation does not cause any problems with identification, since it is recursively determined, i.e. there are no feedback from the bust price response to neither the boom price nor supply response.

In parallel to the theoretical discussion, we derive the reduced form expressions for the the boom period price and supply response to a given demand shock: $\frac{\partial \Delta p^{Boom}}{\partial u_{ij}}$ and $\frac{\partial \Delta h^{Boom}}{\partial u_{ij}}$, where $u_{i,j}$ denote the demand shock (confer Appendix C for details). As seen, these responses will depend on the supply restrictions. A central question is whether this dependence is significant, i.e. whether we can reject the hypothesis that supply restrictions are irrelevant for the price and quantity response during the boom. In a similar vein, we derive an expression for the bust period price response:

$$\frac{\partial \Delta p^{Bust}}{\partial u_{i,j}} \;=\; \gamma_{\Delta p}\frac{\partial \Delta p^{Boom}}{\partial u_{i,j}} + \gamma_{\Delta h}\frac{\partial \Delta h^{Boom}}{\partial u_{i,j}} \tag{12}$$

The first term on the left hand side measures the effect resulting through the price overhang, while the second term measures that of the quantity overhang. In the baseline model, the combined effect of the two should be the same in all areas. Hence, the bust price response should be independent of supply side restrictions. This is not the case in the extended model. As we saw in Section 2.2, supply restrictions and subprime lending could have mutually reinforcing effects, meaning that both the boom period price and quantity overhang will be accelerated relatively more in supply restricted areas. Thus, finding evidence of a financial accelerator would suggest that more restricted areas should experience a greater bust period price response. Furthermore, as discussed in Section 2.2, the additional supply response caused by the financial acceleration might be independent of, or even increasing, in the supply restrictions. In the case of a strong financial accelerator effect, this could also be the case for the total supply response. This will be formally tested in the empirical section.

3.2 Data definitions

Our data set originally covers 247 US Metropolitan Statistical Areas (MSA).[6] However, we have excluded some areas from our sample from the outset, as they have experienced extreme exogenous shocks unrelated to the interest of this analysis. In particular, four MSAs situated in Louisiana and Mississippi experienced a large negative shock to housing

[6] We use the 2004 MSA definitions of the Census Bureau. See Table A.2 in Appendix A for an overview of the MSAs included in our data along with the population size and geographical location of each area.

supply through the hurricane and subsequent floods of Katrina in late August, 2005.[7] We also exclude Barnstable Town (MA), due to extreme degrees of political and geographical supply restrictions. Thus, our effective sample covers a total of 242 MSAs.

Several definitions of boom and bust periods have been considered in the literature (see Cohen et al. (2012) for a discussion). We follow Huang and Tang (2012) and consider the 2000–2006 boom period definition. For the bust period, we follow Huang and Tang (2012) and Cohen et al. (2012) and use the 2006–2010 period.[8]

A large number of data sources have been utilized to construct our data set. Data on lending conditions have been constructed based on the Home Mortgage Disclosure Act (HMDA) loan application registry (LAR) data.[9] The HMDA data cover loan applications for about 92 % of the US population and contain information on, among others, the number of applications, the income of the applicant, loan amount, whether the loan was denied or originated, and whether the financial institution extending the loan engages in subprime lending.[10] We have prepared the data in several steps of calculations, mostly following Avery et al. (2007, 2010) (see Appendix B for details). We use the data at the loan applicant level to construct the log cumulative number of subprime originations per capita during each of the boom periods. In addition, the data are used to construct the 1996 denial share and LTI ratio, which we use as instruments for subprime lending.

Data on disposable income, unemployment, population, housing prices and the housing stock have been collected from Moodys Analytics. These data are converted from quarterly to annual basis by taking the four quarter arithmetic mean, with the exception of the housing stock which is aggregated to an annual frequency using the fourth quarter observation. All variables are measured in nominal terms.[11]

Two recent papers are especially important in accounting for regional differences in supply restrictions. Gyourko et al. (2008) construct a local regulatory index – the Wharton Regulatory Land Use Index (WRLURI). This index is originally based on 11 subindexes measuring different types of complications and regulations in the process of getting a building permit.[12] Another dimension of supply restrictions is covered by Saiz (2010), who develops an MSA level measure of geographical land availability constraints; UNAVAL. Specifically, he uses GIS and satellite information to calculate the share of land in a 50 kilometer radius from the MSA main city centers that is covered by wa-

[7]The four areas excluded are New Orleans-Metairie-Kenner (LA), Lake Charles (LA), Alexandria (LA), Monroe (LA). These areas all saw a negative change in housing supply during the 2000–2006 boom period. This is hard to reconcile with any plausible economic interpretation, and must be interpreted as extraordinary circumstances.

[8]In an earlier version of this paper, we also considered the 1996–2006 boom period definition suggested by Glaeser et al. (2008). Similar conclusions are reached when we rely on that alternative boom period definition. The interested reader is referred to Anundsen and Heebøll (2013) for details.

[9]For a summary of the opportunities and limitations of the data, see the discussion in Avery et al. (2007).

[10]To determine this, we had to match the HMDA data with the subprime list provided by the Department of Housing and Urban Development (HUD).

[11]We only have a measure for CPI for 100 of the MSAs in our sample. That said, using the regional CPI to construct real variables, we find results that are similar to those reported below.

[12]The WRLURI index is available at a town (or city) level, which we have aggregated to the MSA level using the sample probability weights of Gyourko et al. (2008).

ter, or where the land has a slope exceeding 15 degrees.[13] An advantage of the index developed by Saiz (2010) is that nature given supply restrictions are truly exogenous to housing market conditions, while this is not necessarily the case for local government enforced regulatory supply restrictions. As noted by Glaeser et al. (2008), the two supply restriction indexes are positively correlated.[14] Instead of leaving out one of the indexes, as done in Glaeser et al. (2008), we assume that UNAVAL is truly exogenous and use this index as is, while the WRLURI index is adjusted for the possible influence of UNAVAL.[15] In order to make the estimated effect of the two indexes comparable, we normalize the index to range between 0 and 1 in the original sample. The adjusted index is labeled WRLURI(a) and is uncorrelated with UNAVAL.

We should be able to interpret UNAVAL as an exogenous effect of nature given supply restrictions. However, some of the observed effect of UNAVAL might be caused by more geographically constrained areas having more regulations on building permits etc., possibly to preserve nature. Regarding WRLURI(a), we may face an endogeneity issue, as it might be affected by the housing market development.[16] While we interpret the estimated coefficient on WRLURI(a) with care, it should be noted that the other coefficients in our model are relatively invariant to leaving out this index, and we think – leaving the possible endogneity issue aside – that it is important to consider both man-made and physical supply restrictions.[17]

3.3 Descriptive statistics

As discussed earlier, there are substantial regional differences across the MSAs covered by our sample. In size, the MSAs vary from a population of 11.6 million in New York-White Plains-Wayne (NY-NJ) to 75 000 in Casper (WY).[18] During the 2000–2006 boom period, the housing price growth ranges from more than 160% in Naples-Marco Island (FL) to a little less than 10 % in Lafayette (IN). In the 2006–2010 bust period, it ranges from -55 % in Modesto, CA to 15.4% in Collage Station-Bryan (TX). Further, despite the typical sluggishness in the construction sector, we can also observe a particular dispersion in the evolution of housing supply over the boom period. The total growth ranges from 40% in Cape Coral-Fort Myers (FL) to -1% in Pine Bluff (AR).

The geographical land restriction measure (UNAVAL) indicates that only 0.05% of the land is rendered undevelopable in Lubbock (TX), while as much as 86% of the land

[13] As pointed our by Saiz (2010), areas with a slope exceeding 15 degrees are typically seen as severely constrained for residential construction. Though Saiz (2010) rely on the 1999 MSA level definitions, the index is calculated for the the biggest city in a given MSA, which we have converted to match the 2004 MSA definitions used in this paper.

[14] In our data and with our MSA definitions this correlation is 0.33.

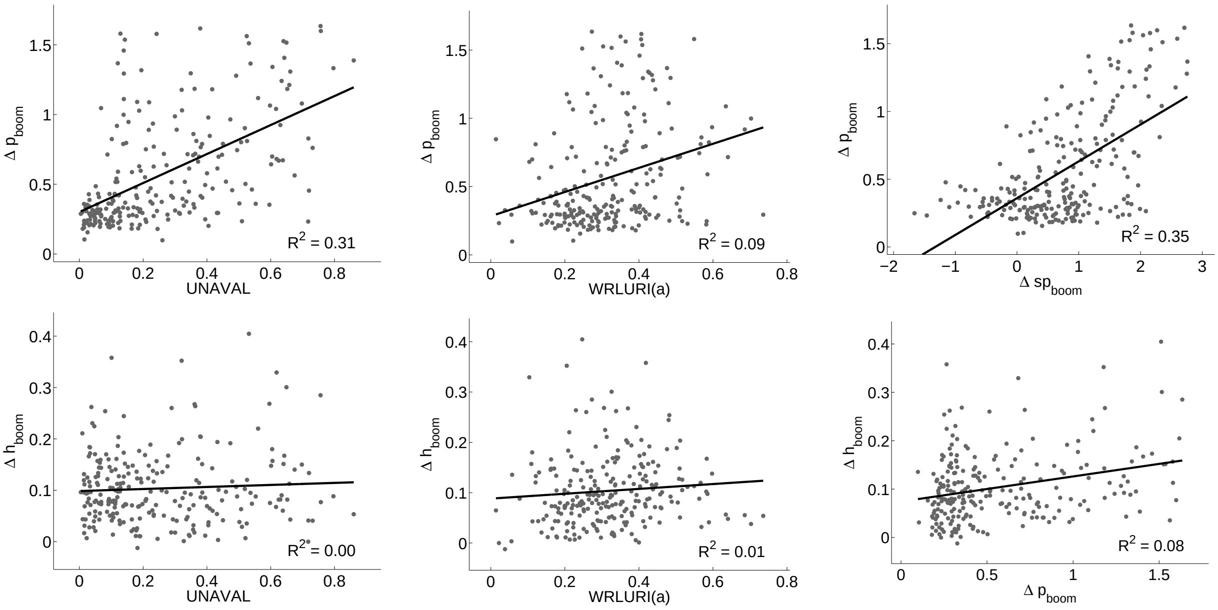
[15] We use the residuals from the following specification to measure the part of WRLRUI that is not explained by UNAVAL: $WRLURI_i = \beta_0 + \beta_1 UNAVAL_i + \varepsilon_i$.

[16] It is not clear in which direction the bias would go: If housing prices increase, the building activity might increase as well. To constrain the high building activity, local governments might respond by enforcing more restrictions. On the other hand, booming housing prices are often accompanied by increasing economic activity, job creation, population growth etc. In order to dampen the pressure on housing prices, or to provide homes for an increasing population, governments might relax regulations on construction activity.

[17] For a discussion on this issue, see Cox (2011) and Huang and Tang (2011).

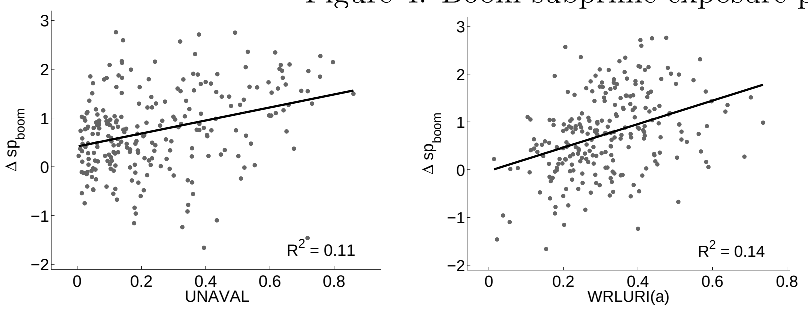
[18] We rely on the population counts as of 2010.

Figure 3: Boom price and supply plots



is considered undevelopable in Santa Barbara-Santa Maria-Goleta (CA). Regarding our measure of regulatory supply side restrictions (WRLURI(a)), Glens Falls (NY) is the least restricted area. Despite the high geographical supply restrictions in the area, it has a low degree of political involvement in the development process, low requirements for developers and a fast building permit application process (WRLURI(a) = 0.01). On the other extreme, even after controlling for a high degree of geographical supply restrictions, Boulder (CO), has a very high political involvement in the urban development process and a long and complex building application process etc. (WRLURI(a) = 0.74).[19]

Figure 4: Boom subprime exposure plots

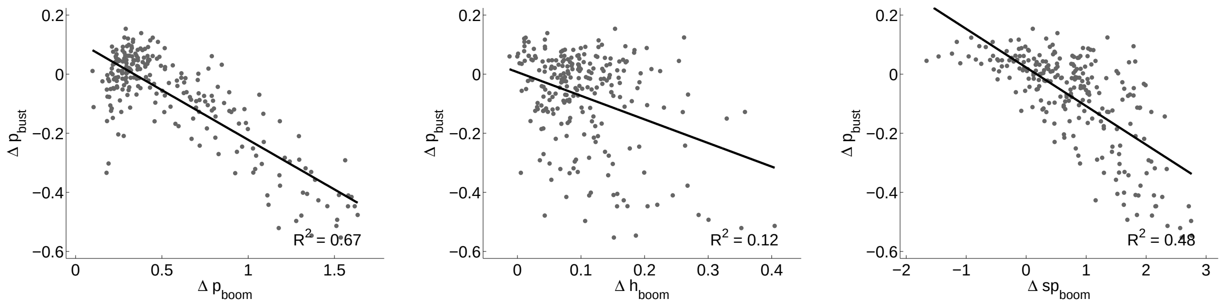


Finally, the number of subprime originations per capita also show huge variations. For the 2000–2006 period, in non-logarithmic terms, this variable ranges from almost zero in Parkersburg-Marietta-Vienna (WV-OH) to 1.5 subprime loans pr. 100 people in

[19] In the original sample Barnstable Town (MA) was the most regulated area (WRLURI(a) = 1), while New Orleans-Metairie-Kenner (LA) was the least regulated area (WRLURI(a) = 0).

Stockton (CA).[20]

Figure 5: Bust price plots



To illustrate the variation in the data more clearly, and to get a first hand idea of the correlation among the variables in our data set, Figure 3 plots the boom growth in housing prices and supply against each other, against the two supply restriction indexes, and against the subprime measure. It is clear that more regulated areas – both geographically and regulatory – experienced a greater price boom. In the same way, the subprime exposure is clearly positively correlated with the price growth during the boom. On the other hand – and this is a puzzle to the baseline theory model – there does not seem to be any systematic link between the degree of supply restrictions and the increase in supply over the boom. Likewise, the relation between the supply and price growth during the boom is positive, which is also in contrast to the predictions of the baseline theory model – unless these markets are also systematically hit by more demand shocks. The clear positive correlation between subprime extensions and the supply restrictions, as illustrated in Figure 4, may suggest that the financial accelerator is more important in more restricted areas.

Turning to the correlation between the bust price growth and the boom variables, Figure 5 plots the price growth during the bust against the supply and price growth during the boom, as well as against our measure for subprime lending. It is evident that areas with a high price growth and subprime exposure during the boom also experienced large housing price busts (the correlation between the price growth in the boom and the bust is particularly strong). The quantity overhang does not seem as important, but it is also correlated with the drop in prices.

Although it is the raw correlation between the variables we observe in these plots, it may still be suggestive as a background for the empirical analysis. Hence, these figures give a first indication that the baseline model might not be sufficient in explaining the enormous regional variation.

[20]Note, this definition of subprime loans might deviate from other studies (see Appendix B).

4 Empirical results

4.1 The baseline boom period model

In this section, we start by considering the boom system, as given by (8) and (9). This setup is related to the reduced form specifications considered in earlier work (Glaeser et al., 2008; Huang and Tang, 2012). Even though the reduced form and structural form results are not directly comparable, we will compare the main predictions and the qualitative results of the models. The results obtained when we estimate the boom system, (8) – (9), are displayed in Table 2.

Table 2: The boom period model, 2000–2006

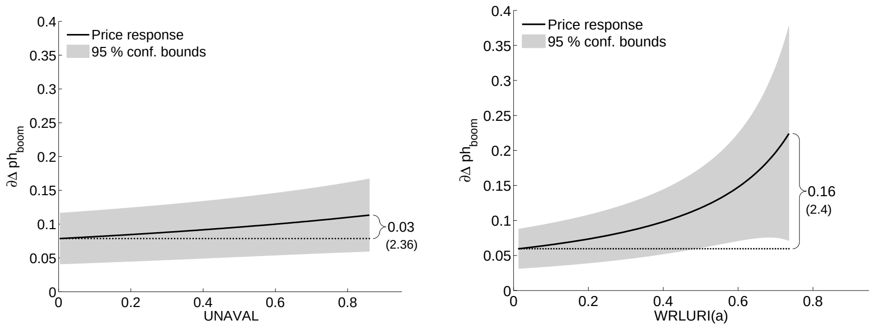
Variables	Δp_{boom}	Δh_{boom}
Δh_{boom}	-13.27 $(-4.94)^{***}$	
Δp_{boom}		0.75 $(3.72)^{***}$
una $\times$ Δp_{boom}		-0.21 $(-2.32)^{***}$
wrl $\times$ Δp_{boom}		-0.77 $(-3.54)^{***}$
Δsp_{boom}	0.60 $(6.20)^{***}$	
ΔHH income$_{boom}$	5.96 $(5.62)^{***}$	0.21 $(1.90)^{*}$
Δc. cost$_{boom}$		-0.23 $(-3.45)^{***}$
Controls		
una		0.12 (1.48)
wrl		-0.17 $(-2.49)^{***}$
HH income$_{1996}$	0.79 $(1.83)^{*}$	-0.17 $(-1.92)^{*}$
log pop$_{1996}$	-0.13 $(-2.41)^{***}$	-0.01 (-1.33)
pop density$_{1996}$	0.02 (0.47)	0.00 (-0.28)
unemp$_{1996}$	-2.22 (-1.23)	-1.81 $(-3.90)^{***}$
Std. error and correlations		
$\varepsilon_{\Delta p,boom}$	0.287	
$\varepsilon_{\Delta h,boom}$	0.230	0.009
Vector normality test	$\chi^2(4) = 22.314[0.0002]^{***}$	
Obs.	242	

Note: The table reports the FIML estimates of the boom system, (8)–(9). The following abbreviations apply: h is the log housing stock, p is log housing prices, *una* is the geographical restriction index of Saiz (2010), *wrl* is the regulatory index of Gyourko et al. (2008) adjusted for *una* and normalized to range between 0 and 1, *sp* is the log cumulative subprime originations per capita, HH income is household disposable income, c.cost is construction wages, pop is population and unemp is the unemployment rate. All variables are nominal, and all variables expect the controls and subprime lending are in percentage changes. Δ is a difference operator. The asterisks denote significance level; * = 10%, ** = 5% and *** = 1%.

The two equations are interpretable as a supply-demand system: With reference to the identifying restrictions, subprime lending is highly significant in the price equation and construction wages are significant in the supply equation. Moreover, as would be expected from theory, changes in supply has a significant negative impact on housing prices, while housing prices enter positively in the supply equation.

Further, we find that an increase in the subprime exposure leads to a positive reaction in housing prices, similar to the results of Huang and Tang (2012).[21] Looking at the supply equation (see Column 3), it is clear that more supply restrictions – both regulatory and geographical – lowers the implied elasticity, which supports the conjectures of the theoretical model.[22] Comparing our implied elasticities to those derived by Saiz (2010), who is using a different approach, we find a correlation of more than 0.7. Further, the model suggests that the more restricted the supply, the more housing prices will increase for a given positive demand shock – a finding that parallels the results of Glaeser et al. (2008) and Huang and Tang (2012).

Figure 6: Boom price response for different degrees of the supply restrictions



Note: This figure shows the boom period price response of a 1 % shock to subprime lending per capita. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

In Figure 6, we analyze the importance of the supply restrictions a little further. Based on the reduced form representation of the price equation, we calculate the response in housing prices following a 1 % exogenous increase in subprime lending per capita. The figure shows the response functions for the full spectra of supply restrictions for each of the two restriction indexes.[23] When varying one index, we keep the other index fixed at its mean.[24] In order to statistically test whether the price increase is greater when we go from the lowest to the highest index value, the figure also shows the numerical size of the difference in the response, along with the t-value (in parenthesis).[25]

First, for both WRLURI(a) and UNAVAL, we clearly see that the response pattern is positive and significant. This suggests that the more restrictive the supply, the more aggressive is the price reaction to a 1 % increase in subprime lending per capita. In fact, the responses are progressively increasing in both indexes. Considering the effects of

[21]Note, this conclusion rests on the exogeneity assumption of our instruments related to the subprime variable being valid.

[22]The implied supply elasticity is given by $\beta_{2,\Delta p} + \beta_{2,wrl\times\Delta p} WRLURI(a) + \beta_{2,una\times\Delta p} UNAVAL$.

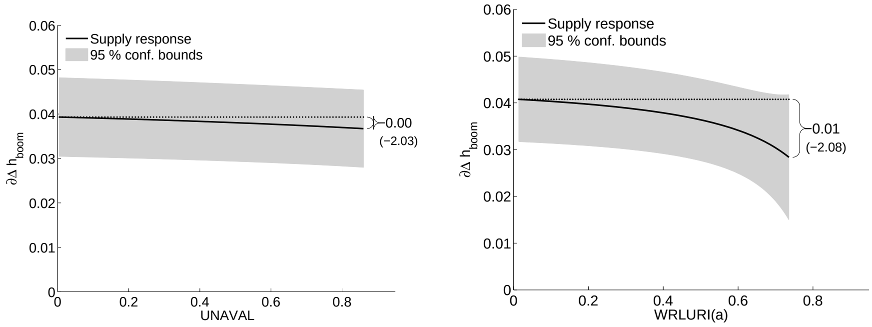
[23]We have generated 10,000 index values that in equal increments goes from the minimum to the maximum. This is done to get the smooth response patterns illustrated in the figures.

[24]The response patterns would of course look different if we fixed the index values at some other level.

[25]To calculate the t-value needed to test the hypothesis of a zero difference between the price response of the two most extreme areas, we have used the delta method.

the individual indexes, we see that politically enforced regulations are more important. The model suggest a difference in the price response of almost 0.16 percentage points when varying the political regulation between the two extremes. For the geographical restrictions, this difference is only 0.03.

Figure 7: Boom supply response for different degrees of the supply restrictions



Note: This figure shows the boom period supply response of a 1 % shock to subprime lending per capita. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

Turning to the supply side of the model, Figure 7 shows the response functions for the housing supply, calculated in a similar way as the price responses in Figure 6. In support of the theoretical model, we find that the supply responses are greater for more restricted areas. For extreme degrees of supply restrictions, the model suggest that the shock is mostly absorbed in terms of price adjustments. As for the price dynamics, the politically enforced supply restrictions are more important than geographical restrictions. We see a difference in the supply response of 0.01 percentage points when varying the political regulation between the two extremes. Still, this difference is much lower when we consider the geographical supply restrictions. Furthermore, not surprisingly, the average supply response is much smaller than it is for prices. From the *t*-values shown in the graphs, we see that the supply response is significantly lower for the highest restriction index value compared to the lowest.

In summary, our results suggest that more supply restrictions lead to larger price adjustments following an exogenous demand shock, whereas areas that are less restricted absorb most of the shock by increasing supply. Furthermore, the non-linearity in the model results in progressive price and supply reaction patterns. These results tell a different story than the reduced form specifications of Glaeser et al. (2008) and Huang and Tang (2012). Given their model structure, the response functions would be linear. Another advantage of a structural model is that it shows the mechanisms clearly; the higher price increase in more restricted areas comes as a result of lower supply side adjustments, implying that housing prices have to increase more to ensure market clearing.

4.2 The extended financial accelerator boom period model

Thus far, our results support the view that supply restricted areas will experience a greater price volatility through the boom period following an increase in subprime lending. The discussion in Section 2 suggested that one possible reason for this is the presence of a financial accelerator mechanism. In this section, we will explore this in more detail by letting the subprime measure be endogenously determined in our system, as given by (10).

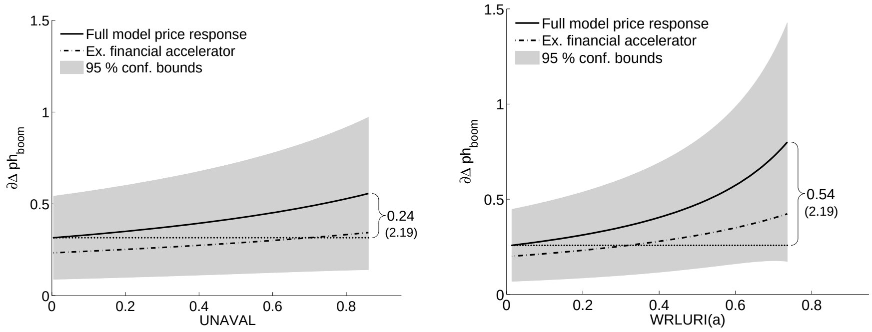
Table 3: The boom period model including a financial accelerator, 2000–2006

Variables	Δp_{boom}	Δh_{boom}	Δsp_{boom}
Δh_{boom}	−7.07 (−3.64)***		
Δp_{boom}		0.33 (3.07)***	1.11 (6.41)***
Δsp_{boom}	0.61 (9.92)***		
una × Δp_{boom}		−0.14 (−2.77)***	
wrl × Δp_{boom}		−0.31 (−2.76)***	
ΔHH income$_{boom}$	3.38 (4.07)***	0.32 (5.37)***	0.35 (1.06)
Δc. cost$_{boom}$		−0.10 (−3.03)***	
Denial rate$_{1996}$			1.00 (3.68)***
LTI$_{1996}$			−0.96 (−1.83)*
Controls			
una		0.06 (1.60)*	
wrl		−0.03 (−0.99)	
HH income$_{1996}$	0.99 (3.48)***	−0.07 (−1.42)	0.26 (5.29)***
log pop$_{1996}$	−0.16 (−4.39)***	0.00 (−0.36)	−0.08 (−1.63)*
pop density$_{1996}$	0.05 (1.55)	−0.01 (−0.91)	−0.89 (−0.53)
unemp$_{1996}$	−0.03 (−0.02)	−0.98 (−3.93)***	0.64 (1.33)
Std. error and correlations			
$\varepsilon_{\Delta p,boom}$	0.348		
$\varepsilon_{\Delta h,boom}$	0.160	0.058	
$\varepsilon_{\Delta sp,boom}$	−2.496	0.511	0.543
Vector normality test	$\chi^2(4) = 26.117[0.0002]^{***}$		
Obs.	242		

Note: The table reports the FIML estimates of the boom system, (8)–(9). The following abbreviations apply: h is the log housing stock, p is log housing prices, *una* is the geographical restriction index of Saiz (2010), *wrl* is the regulatory index of Gyourko et al. (2008) adjusted for *una* and normalized to range between 0 and 1, *sp* is the log cumulative subprime originations per capita, HH income is household disposable income, c.cost is construction wages, denial rate is the share of denied loan application relative to all applications, lti is the loan to income ratio, pop is population and unemp is the unemployment rate. All variables are nominal, and all variables expect the controls and subprime lending are in percentage changes. Δ is a difference operator. The asterisks denote significance level; * = 10%, ** = 5% and *** = 1%.

The boom system is estimated using FIML, and the results are reported in Table 3. As previously, both models seem well identified, and most of the coefficients are close to those reported in Table 2. The coefficients on the supply restrictions are somewhat smaller though. As we saw in Section 2.2, the effects of the supply restrictions and the credit market multiplier are mutually reinforcing, which might explain the smaller coefficient on the supply restrictions in this model. That said, the implied supply elasticities of the model are closely correlated with those of the baseline model (a coefficient of more than 0.9), and they are still close to those of Saiz (2010).

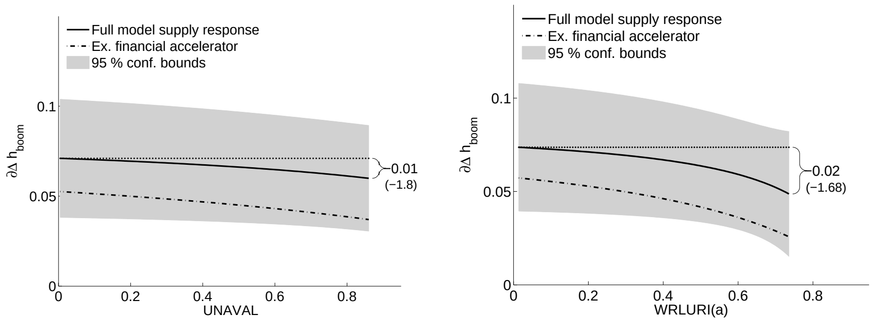
Figure 8: Boom price response for different degrees of the supply restrictions



Note: This figure shows the boom period price response of a 1 % shock to subprime lending per capita both with and without the financial accelerator in the model. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

Housing prices are found to significantly affect regional subprime extensions. Combined with the positive effect of subprime lending on housing price growth, this gives rise to a financial accelerator mechanism where higher housing prices increases subprime lending, and *vice versa*. Moreover, the direct price effect of a given shock is predicted to be greater in more supply restricted areas, suggesting a larger credit multiplier in these areas. This result contradicts the results of Mian and Sufi (2009), who find that credit is not significantly driven by a housing price channel, and that it is not related to supply side restrictions.

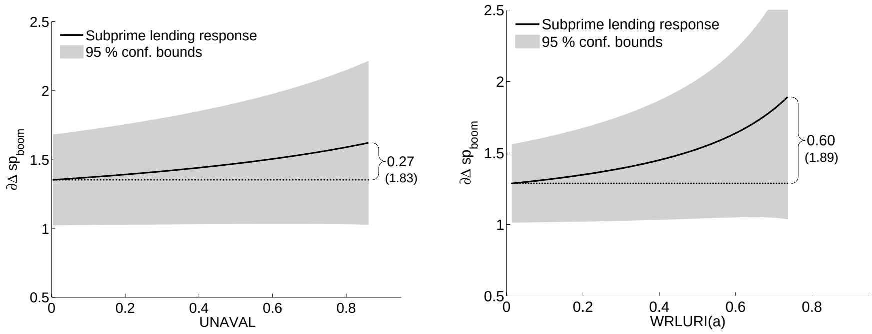
Figure 9: Boom supply response for different degrees of the supply restrictions



Note: This figure shows the boom period supply response of a 1 % shock to subprime lending per capita both with and without the financial accelerator in the model. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

Figure 8–10 show the same response graphs as in the previous section, but to an unexpected increase in subprime lending; $\varepsilon_{\Delta sp,i}$. To analyze the effect of the financial accelerator, we report both the response functions of the extended model and the responses of the model where we “switch off“ the financial accelerator by counterfactually setting $\beta_{3,\Delta p} = 0$. As is evident from inspecting Figure 8, the financial accelerator increases the

Figure 10: Boom subprime lending response for different degrees of the supply restrictions



Note: This figure shows the total boom period subprime response of a 1 % shock to subprime lending per capita both with and without the financial accelerator in the model. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

price reaction in all areas. This results from the fact that this model does not only account for the direct effect of subprime lending on housing prices – as in the baseline model – but also the following endogenous price accelerator. Further, prices are accelerated relatively more in more supply restricted areas. When comparing the responses for the two extreme values of WRLURI(a) there is a difference of 0.54 percentage points when the financial accelerator is accounted for, while this number is less than half that size when it is not. This difference is still somewhat smaller when considering geographical supply restrictions.

Regarding the supply responses, see Figure 9, it is evident that the total supply response is greater when accounting for the financial accelerator. However, in contrast to the price response, the effect of the financial accelerator is more or less the same across all areas. Hence, the financial accelerator is strong enough to eliminate the negative relationship between the supply response and supply restrictions. In fact, we cannot reject the zero differences in the supply reaction across the range of supply restrictions, which is in line with the predictions of the theoretical model outlined in Section 2.2. This suggests that the momentum created by the financial accelerator caused the connection between the total supply response and the elasticity of supply to literally vanish.

The effects of the financial accelerator are partly explained by looking at the response pattern of subprime lending in Figure 10. An increase of 1 % in subprime lending per capita leads to an almost 3 times as large endogenous acceleration when WRLURI(a) is at the maximum relative to the minimum. This pattern is less pronounced when we look at geographical supply restrictions.

In summary, the extended model opens for an interesting interpretation of why more restricted areas witnessed the greatest housing price booms. First, like in the baseline model, these areas see a larger price increase following a positive demand shock, since supply is inelastic. Second, the higher price increase in these areas leads to more subprime lending, which contributes to push prices further. Thus, in contrast to Mian and Sufi (2009), our results suggest that supply restrictions and the implied effects on the recent regional housing price booms contributed significantly to regional credit extensions. Again, due to the simultaneous structure of the model we consider, it is also possible to analyze the implications for both housing supply and subprime lending. Subprime lending is clearly accelerated more in more restricted areas. Through the effect on prices, this accelerates the supply increases almost the same across areas. Specifically, we cannot reject that the total supply response indeed is independent of the supply restrictions.

4.3 The bust period

Turning to the bust period, Table 4 shows the results obtained when we estimate the full system, (8)–(11), using FIML.

Table 4: Bust period model with financial accelerator, 2006–2010

Variables	Δp_{bust}
Δh_{boom}	-0.24 $(-2.01)^{**}$
Δp_{boom}	-0.27 $(-12.67)^{***}$
ΔHH income_{bust}	0.92 $(11.62)^{***}$
Controls	
HH income_{1996}	0.17 $(3.15)^{***}$
log pop_{1996}	0.01 (0.84)
pop density_{1996}	-0.01 (-1.50)
unemp_{1996}	-0.79 $(-3.86)^{***}$
Std. error and correlations	
$\sigma_{\Delta p,bust}$	0.067
$\rho_{\Delta p,boom}$	−0.163
$\rho_{\Delta h,boom}$	−0.320
$\rho_{\Delta sp,boom}$	−0.326
Vector normality test	$\chi^2(6) = 28.604[0.0003]^{***}$
Obs.	242

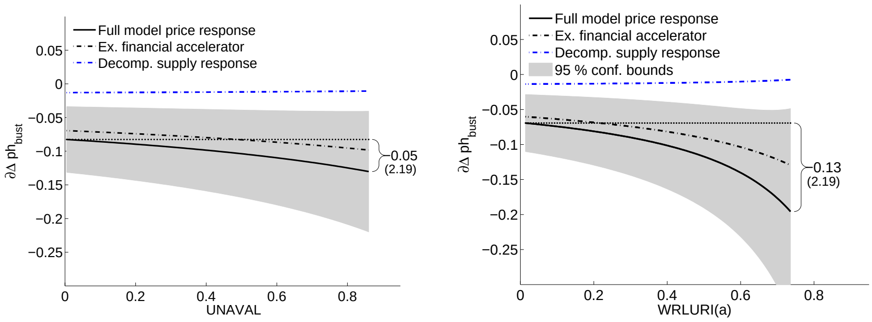
Note: The table reports the bust period FIML estimates of the extended boom-boom system defined by (8)–(10). The following abbreviations apply: h is the log housing stock, p is log housing prices, sp is the log cumulative subprime originations per capita, HH income is households' disposable income, pop is population and unemp is the unemployment rate. All variables are nominal, and all variables expect for the controls and subprime lending are in percentage changes. Δ is a difference operator. The asterisks denote significance level; * = 10%, ** = 5% and *** = 1%.

It is clear that the effect of both prices and quantity overhang is negative and highly significant. Hence, the importance of supply restrictions for the bust price response again boils down to a question of how the boom period price and supply response depend on supply restrictions (confer (12)).

From Figure 8–10, we saw that the boom period price response will be unambiguously higher in *more* regulated areas, while the supply might only be marginally higher in *less* restricted areas. Hence, it should be clear that the bust price response will be significantly larger in more supply restricted areas when we have the financial accelerator in the model.

Figure 11 shows the bust period price response to a 1% increase in subprime lending per capita during the boom. We plot the responses both in the case *with* and *without* the financial accelerator. As seen, the price response is increasing in the supply restrictions, and the financial accelerator has an important impact on the slope of the price response

Figure 11: Bust price response for different degrees of the supply restrictions



Note: This figure shows the bust period price response of a 1 % shock to subprime lending per capita both with and without the financial accelerator in the model. It also shows the contribution coming from the boom period supply overhang. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and E.

function. Generally, when the financial accelerator is accounted for, the price response approximately triples in size when varying each of the indexes from the lowest to the highest value. Not surprisingly, neither in this case can we reject the null of supply restrictions irrelevance. That said, even though the financial accelerator account for the primary part of the price reaction, the model without the financial accelerator still indicates a larger price drop in more supply restricted areas. Comparing the least and most restricted areas in Figure 11, we see a difference of 0.2–0.4 percentage points when we omit the financial accelerator effect.

In conclusion, when introducing the financial accelerator, both the boom period price and the supply response are greater than in the model without such effects. That said, the price acceleration is positively affected by supply restriction, while this is not the case for the supply reactions. Together, this explains the greater price drop in more supply restricted areas during the bust. In contrast to Glaeser et al. (2008) and Huang and Tang (2012), the econometric approach adopted in this paper opens up for an explanation of the economic forces that contributed to make the bust worse in more restricted areas. In particular, we have shown that the main reason is that these areas experienced a particularly large price reaction during the recent boom due to a financial accelerator effect, and that the total supply response following a positive demand shock therefore is unrelated to supply side restrictions.

5 Concluding remarks

In this paper, we have analyzed the importance of supply restrictions and subprime lending for regional US housing market developments through the recent boom-bust cycle. Special emphasis has been given to how housing markets with different supply elasticities respond to an increase in subprime lending. The main goal of the analysis has been to answer the following two questions: How do restrictions on housing supply affect the housing market dynamics over the boom-bust cycle? Secondly, we asked whether there is evidence of a financial accelerator, and in particular how this financial accelerator depends on the supply restrictions.

Theoretically, we show that in a model without a financial accelerator, more restricted areas are predicted to see relatively large adjustments in prices, while areas with few restrictions on the supply side are expected to see large supply adjustments. Both these forces should have a negative impact on housing prices during the bust period. Supply-demand theory even suggest they should cancel, leaving the bust price response independent of the supply elasticity. These theoretical conjectures are changed when we consider a model with a financial accelerator effect. First, restricted areas are expected to see an even larger price adjustment following an increase in subprime lending, since the collateral increases relatively more. Second, the difference in the supply response across areas is expected to narrow, since the larger price acceleration in inelastic markets has an additional stimulating effect on construction activity. Third, it is shown that the bust is no longer independent of the supply elasticity and restricted areas are expected to be hit harder during the bust period.

To study these mechanisms empirically, we have resorted to a structural econometric model. First, disregarding the financial accelerator effect, we confirm the theoretical hypotheses for the boom period. Following an increase in subprime lending, more supply restricted areas primarily react through housing prices, while less restricted areas see larger supply side adjustments. That said, our results contradict the central prediction for the bust period. The effect of the price overhang dominates during the bust, implying that more supply restricted areas experience a greater drop in housing prices.

Extending the model to include an equation for subprime lending, we find that housing prices and credit are mutually reinforcing. Tighter supply restrictions lead to a stronger financial accelerator, with additional positive effects on both the price and quantity overhang. Even though more supply restricted areas experience a relatively low supply response for a given price increase, the stronger endogenous price acceleration in these areas partly dilutes the relation between supply restrictions and the total supply response. In particular, we cannot reject an equal supply response across all areas.

In combination, these results suggest that one reason why more supply restricted areas witnessed a greater price drop during the recent bust period is that they experienced a substantially larger credit boom, as a result of the financial accelerator effect. Hence, these areas had a larger price overhang at the peak of the boom, while the quantity overhang was close to that of the less regulated areas.

We generally find that regulatory supply restrictions are more important than geographical supply restrictions. Hence, from a political perspective, our results suggest that, in order to minimize the amplitude of a housing price cycle and to reduce the risk of over-building and under-savings, political authorities should abstain from aggressive regulation of housing supply. At least, if the the amplitude of boom-bust cycles is a political concern, a tighter regulatory environment for the construction sector should be accompanied by stricter credit market regulations.

In light of our results, a promising avenue for future research is to study these regional specific price acceleration mechanisms, while accounting for possible endogenous political changes in the regulatory framework through the boom-bust cycle. When more data become available, it will be particularly interesting to either consider the effect of changes in regulation in a dynamic panel or by estimating time series models for individual MSAs. Another interesting study is to do a similar analysis on data for several countries.

Acknowledgements

We would like to express our gratitude to Michael Bergman, Douglas Gale, Steinar Holden, Søren Johansen, Andreas Kotsadam, Søren Leth-Petersen, Ragnar Nymoen, Bernt Stigum and Peter Norman Sørensen. Their comments have been very valuable and have contributed to significantly improve this manuscript. The paper has been presented at the 67th European Meeting of the Econometric Society in Gothenburg, August 2013, and at seminars in Norges Bank, the University of Copenhagen and the University of Oslo. We would also like to thank the New York Library staff and Frederic Jean-Baptiste at Moody's analytics for helping us collecting the data.

References

Anundsen, A. K. and C. Heebøll (2013). Supply restrictions, subprime lending and regional US housing prices. Memorandum 4, Department of Economics, University of Oslo.

Aoki, K., J. Proudman, and G. Vlieghe (2004). House prices, consumption, and monetary policy: A financial accelerator approach. *Journal of Financial Intermediation 13*(4), 414–435.

Avery, R. B., N. Bhutta, K. P. Brevoort, and G. B. Canner (2010). The 2009 HMDA data: The mortgage market in a time of low interest rates and economic distress. Bulletin, Federal Reserve.

Avery, R. B., K. P. Brevoort, and G. B. Canner (2007). Opportunities and issues in using HMDA data. *Journal of Real Estate Research 29*(4), 351 – 379.

Bernanke, B. and M. Gertler (1989). Agency costs, net worth, and business fluctuations. *American Economic Review 79*(1), 14–31.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999). *The financial accelerator in a quantitative busniess cycle framework*, Volume 1. North-Holland, Amsterdam.

Calhoun, C. A. (2006). Using 2004 HMDA data to analyze piggyback lending. Working paper.

Cohen, J. P., C. C. Coughlin, and D. A. Lopez (2012). The boom and bust of US housing prices from various geographic perspectives. *Federal Reserve Bank of St. Louis Review 94*(5), 341–67.

Coleman IV, M., M. LaCour-Little, and K. D. Vandell (2008). Subprime lending and the housing bubble: Tail wags dog? *Journal of Housing Economics 17*(4), 272 – 290.

Cox, W. (2011). Constraints on housing supply: Natural and regulatory. *Econ Joural Watch 8*(1), 13 – 27.

Ferreira, F., J. Gyourko, and J. Tracy (2010). Housing burst and household mobility. *Journal of Urban Economics 68*, 34–45.

Glaeser, E. (2009). Housing supply. *Annual Review of Economics 1*, 295–318.

Glaeser, E., J. Gyourko, and A. Saiz (2008). Housing supply and housing bubbles. *Journal of Urban Economics 64*(2), 198–217.

Green, R. K., S. Malpezzi, and S. K. Mayo (2005). Metropolitan-specific estimates of the price elasticity of supply of housing, and their sources. *American Economic Review 95*(2), 334–339.

Gyourko, J., A. Saiz, and A. Summers (2008). A new measure of the local regulatory environment for housing markets. *Urban Studies 45*(3), 693–729.

Hausman, J. A. (1983). *Handbook of Econometrics*, Volume 1. North-Holland Publishing Company.

Huang, H. and Y. Tang (2011). Dropping the geographic-constraints variable makes only a minor difference: Reply to cox. *Econ Journal Watch 8*(1), 28–32.

Huang, H. and Y. Tang (2012). Residential land use regulation and the us housing price cycle between 2000 and 2009. *Journal of Urban Economics 71*(1), 93–99.

Iacoviello, M. (2005). House prices, borrowing constraints, and monetary policy in the business cycle. *American Economic Review 95*(3), pp. 739–764.

Kiyotaki, N. and J. Moore (1997). Credit cycles. *Journal of Political Economy 105*(2), 211–48.

LaCour-Little, M., C. A. Calhoun, and W. Yu (2011). What role did piggyback lending play in the housing bubble and mortgage collapse? *Journal of Housing Economics 20*(2), 81–100.

Levitin, A. J. and S. M. Wachter (2012). Why housing? Research paper, University of Pennsylvania.

Malpezzi, S. (1996). Housing prices, externalities, and regulation in U.S. metropolitan areas. *Journal of Housing Research 7*(2), 209–241.

Meen, G. (1990). The removal of mortgage market constraints and the implications for econometric modelling of UK house prices. *Oxford Bulletin of Economics and Statistics 52*(1), 1–23.

Meen, G. (2001). *Modelling Spatial Housing Markets: Theory, Analysis and Policy.* Kluwer Academic Publishers, Boston.

Mian, A. and A. Sufi (2009). The consequences of mortgage credit expansion: Evidence from the u.s. mortgage default crisis. *Quarterly Journal of Economics 124*(4), 1449–1496.

Muellbauer, J. and A. Murphy (1997). Booms and busts in the UK housing market. *Economic Journal 107*(445), 1701–1727.

Pavlov, A. and S. Wachter (2006). Agressive lending and real estate markets. Technical Report 566, Wharton School WP.

Saiz, A. (2010). The geographic determinants of housing supply. *Quarterly Journal of Economics 125*(3), 1253–1296.

Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of Money, Credit and Banking 1*(1), pp. 15–29.

Wheaton, W. C. and G. Nechayev (2008). The 1998–2005 housing "bubble"and the current correction: What's different this time? *Journal of Real Estate Research 30*(1), pp. 1–26.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data* (2 ed.). MIT Press.

Appendix A: Data definitions

Table A.1: Variable definitions and data sources

Name	Description	Source
unemp	Unemployment rate	Moody's
HH income	Personal Income, (mill. $)	Moody's
Pop	Total Population (thou.)	Moody's
Pop density	Population Density (Pop. pr. sq. mile)	
WRLURI	The Wharton residential land use regulation index	Gyourko et al. (2008)
UNAVAL	The index on physical land use restrictions	Saiz (2010)
c.cost	Construction wages	FRED
P	Housing price index	FHFA
H	Housing Stock (thou.)	Moody's
sp	Cumulative increase in subprime per capita	HMDA
Denial share	Share of loans denied to applied	HMDA
LTI	Avg. loan-to-income ratio for originated loans	HMDA

Table A.2: General information on the MSA covered by our sample

Nr.	MSA name and state	Code	Pop. (th.)	WRLURI(a)	UNAVAL
1	Abilene, TX	10180	156.35	0.41	0.02
2	Akron, OH	10420	687.26	0.38	0.06
3	Albany, GA	10500	155.58	0.28	0.13
4	Albany-Schenectady-Troy, NY	10580	828.01	0.33	0.23
5	Albuquerque, NM	10740	700.16	0.44	0.12
6	Allentown-Bethlehem-Easton, PA-NJ	10900	722.06	0.35	0.21
7	Altoona, PA	11020	131.08	0.38	0.36
8	Amarillo, TX	11100	217.58	0.32	0.04
9	Ann Arbor, MI	11460	303.13	0.52	0.10
10	Appleton, WI	11540	191.59	0.31	0.18
11	Asheville, NC	11700	347.92	0.13	0.67
12	Atlanta-Sandy Springs-Marietta, GA	12060	3751.73	0.39	0.04
13	Atlantic City-Hammonton, NJ	12100	242.15	0.36	0.65
14	Auburn-Opelika, AL	12220	102.19	0.16	0.09
15	Augusta-Richmond County, GA-SC	12260	482.75	0.18	0.10
16	Austin-Round Rock-San Marcos, TX	12420	1073.04	0.34	0.04
17	Bakersfield-Delano, CA	12540	626.72	0.41	0.24
18	Baltimore-Towson, MD	12580	2501.45	0.63	0.22
19	Bangor, ME	12620	145.36	0.46	0.19
20	Baton Rouge, LA	12940	678.50	0.17	0.34
21	Beaumont-Port Arthur, TX	13140	380.42	0.24	0.19
22	Billings, MT	13740	135.81	0.34	0.11
23	Binghamton, NY	13780	256.70	0.18	0.34
24	Birmingham-Hoover, AL	13820	1022.43	0.31	0.14
25	Bismarck, ND	13900	91.60	0.33	0.06
26	Bloomington-Normal, IL	14060	142.36	0.36	0.01
27	Boise City-Nampa, ID	14260	409.47	0.23	0.36
28	Boston-Quincy, MA	14484	1766.87	0.64	0.34
29	Boulder, CO	14500	264.63	0.74	0.43
30	Bremerton-Silverdale, WA	14740	226.58	0.38	0.52
31	Brownsville-Harlingen, TX	15180	312.09	0.16	0.28
32	Buffalo-Niagara Falls, NY	15380	1194.17	0.30	0.19
33	Burlington-South Burlington, VT	15540	191.04	0.51	0.45
34	Canton-Massillon, OH	15940	405.92	0.21	0.13
35	Cape Coral-Fort Myers, FL	15980	400.72	0.25	0.53
36	Casper, WY	16220	65.86	0.22	0.14
37	Cedar Rapids, IA	16300	227.94	0.27	0.04
38	Champaign-Urbana, IL	16580	205.40	0.32	0.01
39	Charleston, WV	16620	313.16	0.02	0.72
40	Charleston-North Charleston-Summerville, SC	16700	517.97	0.11	0.60
41	Charlotte-Gastonia-Rock Hill, NC-SC	16740	1194.84	0.31	0.05
42	Charlottesville, VA	16820	161.58	0.17	0.22
43	Chattanooga, TN-GA	16860	462.09	0.21	0.26
44	Chicago-Joliet-Naperville, IL	16974	7374.60	0.30	0.40
45	Chico, CA	17020	196.33	0.49	0.35

Continued on next page

Table A.2 – General information on the MSA covered by our sample (*Continued from previous page*)

Nr.	MSA name and state	Code	Pop. (th.)	WRLURI(a)	UNAVAL
46	Cincinnati-Middletown, OH-KY-IN	17140	1953.61	0.29	0.10
47	Cleveland-Elyria-Mentor, OH	17460	2153.60	0.28	0.40
48	College Station-Bryan, TX	17780	172.34	0.45	0.06
49	Colorado Springs, CO	17820	496.54	0.50	0.22
50	Columbia, MO	17860	138.47	0.11	0.06
51	Columbia, SC	17900	608.95	0.23	0.15
52	Columbus, GA-AL	17980	279.73	0.33	0.06
53	Columbus, OH	18140	1531.61	0.24	0.02
54	Corpus Christi, TX	18580	398.53	0.26	0.38
55	Corvallis, OR	18700	77.78	0.30	0.46
56	Dallas-Plano-Irving, TX	19124	3076.61	0.34	0.09
57	Davenport-Moline-Rock Island, IA-IL	19340	374.71	0.22	0.05
58	Dayton, OH	19380	856.09	0.29	0.01
59	Decatur, AL	19460	141.59	0.18	0.16
60	Decatur, IL	19500	116.57	0.21	0.02
61	Deltona-Daytona Beach-Ormond Beach, FL	19660	418.49	0.43	0.61
62	Denver-Aurora-Broomfield, CO	19740	1959.55	0.51	0.17
63	Des Moines-West Des Moines, IA	19780	457.29	0.23	0.06
64	Detroit-Livonia-Dearborn, MI	19804	2113.48	0.39	0.25
65	Dothan, AL	20020	127.06	0.21	0.09
66	Dover, DE	20100	121.45	0.37	0.38
67	Dubuque, IA	20220	89.10	0.20	0.11
68	Duluth, MN-WI	20260	272.43	0.25	0.34
69	EL PASO, TX	21340	656.48	0.52	0.05
70	Elkhart-Goshen, IN	21140	172.58	0.23	0.07
71	Elmira, NY	21300	92.97	0.18	0.35
72	Erie, PA	21500	282.58	0.17	0.51
73	Eugene-Springfield, OR	21660	311.00	0.31	0.63
74	Evansville, IN-KY	21780	338.08	0.19	0.09
75	Fargo, ND-MN	22020	166.69	0.16	0.03
76	Fayetteville, NC	22180	324.87	0.27	0.16
77	Fayetteville-Springdale-Rogers, AR-MO	22220	312.02	0.26	0.29
78	Flagstaff, AZ	22380	112.69	0.28	0.18
79	Flint, MI	22420	433.30	0.32	0.10
80	Fort Collins-Loveland, CO	22660	228.35	0.43	0.31
81	Fort Lauderdale-Pompano Beach-Deerfield Beach, FL	22744	1481.33	0.35	0.76
82	Fort Smith, AR-OK	22900	260.60	0.16	0.20
83	Fort Wayne, IN	23060	374.84	0.24	0.03
84	Fort Worth-Arlington, TX	23104	1551.04	0.34	0.05
85	Fresno, CA	23420	761.41	0.55	0.13
86	Gadsden, AL	23460	103.06	0.29	0.17
87	Gainesville, FL	23540	219.65	0.37	0.15
88	Gary, IN	23844	668.51	0.20	0.32
89	Glens Falls, NY	24020	123.62	0.01	0.41
90	Goldsboro, NC	24140	112.90	0.27	0.21
91	Grand Junction, CO	24300	108.13	0.38	0.43
92	Grand Rapids-Wyoming, MI	24340	709.75	0.40	0.09
93	Great Falls, MT	24500	82.43	0.35	0.18
94	Greeley, CO	24540	156.14	0.42	0.10
95	Green Bay, WI	24580	270.88	0.45	0.23
96	Greensboro-High Point, NC	24660	605.18	0.34	0.03
97	Greenville, NC	24780	142.60	0.58	0.28
98	Greenville-Mauldin-Easley, SC	24860	524.03	0.20	0.13
99	Gulfport-Biloxi, MS	25060	233.48	0.23	0.52
100	Hagerstown-Martinsburg, MD-WV	25180	211.92	0.41	0.19
101	Harrisburg-Carlisle, PA	25420	501.99	0.44	0.24
102	Hartford-West Hartford-East Hartford, CT	25540	1126.40	0.43	0.23
103	Hickory-Lenoir-Morganton, NC	25860	321.91	0.25	0.21
104	Houston-Sugar Land-Baytown, TX	26420	4334.02	0.34	0.08
105	Huntsville, AL	26620	327.53	0.12	0.24
106	Indianapolis-Carmel, IN	26900	1439.68	0.27	0.01
107	Jackson, MS	27140	479.44	0.24	0.11
108	Jackson, TN	27180	101.36	0.17	0.09
109	Jacksonville, FL	27260	1052.36	0.28	0.47
110	Janesville, WI	27500	149.94	0.34	0.05
111	Johnson City, TN	27740	174.30	0.08	0.55

Continued on next page

Table A.2 – General information on the MSA covered by our sample (*Continued from previous page*)

Nr.	MSA name and state	Code	Pop. (th.)	WRLURI(a)	UNAVAL
112	Johnstown, PA	27780	158.59	0.40	0.33
113	Joplin, MO	27900	149.46	0.15	0.05
114	Kalamazoo-Portage, MI	28020	309.06	0.25	0.10
115	Kankakee-Bradley, IL	28100	102.30	0.39	0.03
116	Kansas City, MO-KS	28140	1757.33	0.25	0.06
117	Kennewick-Pasco-Richland, WA	28420	181.61	0.51	0.12
118	Killeen-Temple-Fort Hood, TX	28660	318.61	0.21	0.03
119	Knoxville, TN	28940	597.92	0.27	0.39
120	Kokomo, IN	29020	101.04	0.22	0.02
121	La Crosse, WI-MN	29100	123.92	0.39	0.36
122	Lafayette, IN	29140	173.34	0.06	0.26
123	Lake County-Kenosha County, IL-WI	29404	739.15	0.39	0.48
124	Lakeland-Winter Haven, FL	29460	454.51	0.37	0.32
125	Lancaster, PA	29540	455.78	0.42	0.12
126	Lansing-East Lansing, MI	29620	447.04	0.42	0.07
127	Las Vegas-Paradise, NV	29820	1099.89	0.21	0.32
128	Lawrence, KS	29940	93.38	0.28	0.06
129	Lewiston-Auburn, ME	30340	102.97	0.51	0.26
130	Lexington-Fayette, KY	30460	386.12	0.42	0.06
131	Lima, OH	30620	109.57	0.23	0.02
132	Lincoln, NE	30700	253.90	0.53	0.02
133	Little Rock-North Little Rock-Conway, AR	30780	584.86	0.21	0.14
134	Longview, TX	30980	190.56	0.14	0.11
135	Los Angeles-Long Beach-Glendale, CA	31084	9127.04	0.36	0.52
136	Louisville-Jefferson County, KY-IN	31140	1122.59	0.28	0.13
137	Lubbock, TX	31180	247.10	0.26	0.00
138	Lynchburg, VA	31340	221.87	0.20	0.22
139	Madison, WI	31540	483.76	0.44	0.11
140	Mansfield, OH	31900	128.89	0.25	0.04
141	McAllen-Edinburg-Mission, TX	32580	503.41	0.31	0.01
142	Medford, OR	32780	170.72	0.39	0.70
143	Memphis, TN-MS-AR	32820	1153.56	0.58	0.12
144	Milwaukee-Waukesha-West Allis, WI	33340	1486.05	0.38	0.42
145	Minneapolis-St. Paul-Bloomington, MN-WI	33460	2801.33	0.42	0.19
146	Mobile, AL	33660	396.16	0.13	0.29
147	Modesto, CA	33700	415.16	0.41	0.14
148	Montgomery, AL	33860	335.01	0.19	0.11
149	Myrtle Beach-North Myrtle Beach-Conway, SC	34820	171.86	0.10	0.62
150	Naples-Marco Island, FL	34940	209.21	0.27	0.76
151	New Haven-Milford, CT	35300	811.00	0.31	0.45
152	New York-White Plains-Wayne, NY-NJ	35644	10900.00	0.42	0.40
153	Newark-Union, NJ-PA	35084	2040.28	0.46	0.31
154	Niles-Benton Harbor, MI	35660	162.87	0.20	0.50
155	Norwich-New London, CT	35980	258.74	0.36	0.51
156	Oakland-Fremont-Hayward, CA	36084	2243.33	0.37	0.62
157	Oklahoma City, OK	36420	1051.89	0.33	0.02
158	Olympia, WA	36500	196.25	0.41	0.38
159	Omaha-Council Bluffs, NE-IA	36540	736.94	0.29	0.03
160	Orlando-Kissimmee-Sanford, FL	36740	1469.62	0.37	0.36
161	Oxnard-Thousand Oaks-Ventura, CA	37100	710.22	0.43	0.80
162	Palm Bay-Melbourne-Titusville, FL	37340	455.89	0.34	0.64
163	Parkersburg-Marietta-Vienna, WV-OH	37620	166.03	0.15	0.39
164	Pensacola-Ferry Pass-Brent, FL	37860	388.48	0.12	0.53
165	Peoria, IL	37900	366.52	0.33	0.05
166	Philadelphia, PA	37964	3807.74	0.59	0.10
167	Phoenix-Mesa-Glendale, AZ	38060	2855.71	0.48	0.14
168	Pine Bluff, AR	38220	107.71	0.04	0.18
169	Pittsburgh, PA	38300	2471.21	0.33	0.30
170	Pittsfield, MA	38340	136.66	0.21	0.36
171	Pocatello, ID	38540	81.72	0.22	0.32
172	Port St. Lucie, FL	38940	297.95	0.33	0.65
173	Portland-South Portland-Biddeford, ME	38860	463.88	0.56	0.49
174	Portland-Vancouver-Hillsboro, OR-WA	38900	1797.07	0.34	0.38
175	Poughkeepsie-Newburgh-Middletown, NY	39100	594.99	0.30	0.30
176	Providence-New Bedford-Fall River, RI-MA	39300	1541.70	0.70	0.14
177	Provo-Orem, UT	39340	337.67	0.31	0.60

Continued on next page

Table A.2 – General information on the MSA covered by our sample (*Continued from previous page*)

Nr.	MSA name and state	Code	Pop. (th.)	WRLURI(a)	UNAVAL
178	Racine, WI	39540	185.66	0.23	0.54
179	Raleigh-Cary, NC	39580	694.50	0.48	0.08
180	Rapid City, SD	39660	110.99	0.22	0.22
181	Reading, PA	39740	360.38	0.46	0.16
182	Redding, CA	39820	159.74	0.28	0.54
183	Reno-Sparks, NV	39900	310.17	0.21	0.56
184	Richmond, VA	40060	1042.56	0.32	0.09
185	Riverside-San Bernardino-Ontario, CA	40140	2990.32	0.41	0.38
186	Roanoke, VA	40220	282.92	0.29	0.39
187	Rockford, IL	40420	309.64	0.29	0.02
188	Rocky Mount, NC	40580	141.57	0.26	0.18
189	Saginaw-Saginaw Township North, MI	40980	211.93	0.33	0.16
190	Salem, OR	41420	324.46	0.39	0.33
191	Salinas, CA	41500	362.22	0.30	0.66
192	Salt Lake City, UT	41620	909.74	0.18	0.72
193	San Antonio-New Braunfels, TX	41700	1599.43	0.34	0.03
194	San Diego-Carlsbad-San Marcos, CA	41740	2651.55	0.32	0.63
195	San Francisco-San Mateo-Redwood City, CA	41884	1679.88	0.36	0.73
196	San Jose-Sunnyvale-Santa Clara, CA	41940	1652.86	0.29	0.64
197	San Luis Obispo-Paso Robles, CA	42020	232.98	0.44	0.66
198	Santa Barbara-Santa Maria-Goleta, CA	42060	386.11	0.35	0.86
199	Santa Cruz-Watsonville, CA	42100	241.17	0.37	0.72
200	Santa Fe, NM	42140	121.03	0.31	0.37
201	Santa Rosa-Petaluma, CA	42220	428.40	0.49	0.63
202	Savannah, GA	42340	283.48	0.16	0.60
203	Scranton-Wilkes-Barre, PA	42540	573.89	0.33	0.29
204	Seattle-Bellevue-Everett, WA	42644	2200.55	0.46	0.44
205	Sherman-Denison, TX	43300	102.99	0.20	0.07
206	Sioux Falls, SD	43620	173.96	0.22	0.03
207	South Bend-Mishawaka, IN-MI	43780	312.12	0.15	0.11
208	Spokane, WA	44060	408.20	0.46	0.27
209	Springfield, MO	44180	346.32	0.25	0.07
210	St. Cloud, MN	41060	160.56	0.33	0.21
211	St. Joseph, MO-KS	41140	119.19	0.11	0.06
212	St. Louis, MO-IL	41180	2684.10	0.25	0.11
213	State College, PA	44300	134.10	0.51	0.12
214	Stockton, CA	44700	524.66	0.48	0.12
215	Sumter, SC	44940	105.94	0.18	0.23
216	Syracuse, NY	45060	660.38	0.26	0.18
217	Tacoma, WA	45104	656.25	0.57	0.37
218	Tampa-St. Petersburg-Clearwater, FL	45300	2256.46	0.26	0.42
219	Terre Haute, IN	45460	171.68	0.14	0.05
220	Toledo, OH	45780	656.92	0.29	0.19
221	Topeka, KS	45820	221.25	0.22	0.05
222	Trenton-Ewing, NJ	45940	339.15	0.69	0.12
223	Tucson, AZ	46060	783.69	0.60	0.23
224	Tulsa, OK	46140	816.28	0.24	0.06
225	Tyler, TX	46340	166.09	0.40	0.10
226	Utica-Rome, NY	46540	305.70	0.20	0.18
227	Vallejo-Fairfield, CA	46700	367.61	0.44	0.49
228	Vineland-Millville-Bridgeton, NJ	47220	145.43	0.57	0.36
229	Virginia Beach-Norfolk-Newport News, VA-NC	47260	1547.92	0.22	0.60
230	Visalia-Porterville, CA	47300	350.73	0.43	0.19
231	Washington-Arlington-Alexandria, DC-VA-MD-WV	47894	3494.17	0.41	0.14
232	Waterloo-Cedar Falls, IA	47940	163.01	0.24	0.03
233	Wausau, WI	48140	122.56	0.40	0.12
234	West Palm Beach-Boca Raton-Boynton Beach, FL	48424	1040.14	0.30	0.64
235	Wheeling, WV-OH	48540	157.35	0.06	0.43
236	Wichita Falls, TX	48660	151.17	0.29	0.03
237	Wichita, KS	48620	548.98	0.18	0.02
238	Wilmington, DE-MD-NJ	48864	624.83	0.42	0.15
239	York-Hanover, PA	49620	369.78	0.59	0.12
240	Youngstown-Warren-Boardman, OH-PA	49660	614.37	0.33	0.11
241	Yuba City, CA	49700	136.16	0.40	0.14
242	Yuma, AZ	49740	137.25	0.27	0.07

Note: This table reports general information on the MSAs included in our data set. The MSA code is the 2004 FIPS code of the US Census Bureau. The classification of regions is based on the definitions of the Bureau of Labor Statistics.

Appendix B: HMDA data calculations

As a part of the supervisory system, the US congress mandated in 1975, through the Home Mortgage Disclosure Act (HMDA), that most banks in metropolitan areas disclose information on certain characteristics of the loan applications they have received during a calendar year. In 1989, the coverage was extended to also include information on race, ethnicity, loan decisions, etcetera, at the applicant level. These data are available from 1990-2010, and we were able to collect data at the loan applicant level from 1996-2010, covering the recent US housing boom-bust cycle. The HMDA data has a wide coverage and is likely to be representative of lending in the United States. For a great summary of the opportunities and limitations of the data, see the discussion in Avery et al. (2007). As of 2010, the LAR covered 7923 home lending institutions and 12.95 million applications (see Avery et al. (2010)). In contrast, in the years prior to the housing collapse (the 2000-2006 period), the average number of applications reported in the registry was nearly 32 million.

While the data is available at the applicant level, the focus of our study is regional differences in US housing price dynamics, and in particular the role of credit conditions in the recent boom-bust cycle. The individual data do have regional identifiers, which we have utilized to construct our data set. That said, due to definitional changes by Census in the geographical composition of the different MSAs in 1993, 1999 and 2004, the data construction process was considerably complicated. To keep the geographical area spanned by the different MSAs constant and to remain consistent with the MSA definitions used in the Moodys data, we have relied on the 2004 definitions.

We limit ourselves to one-to-four family housing units, and follow the suggestion of Avery et al. (2007) and leave out small business loans from the calculations. That is, we drop all loans where information on sex and race of both the applicant and the co-applicant is missing. We also noted some extremely large loan and income observations in the data, that lead to insensible average income amounts as well as loan amounts. We suspect this is caused by reporting errors, and use the error list sent by HMDA to the reporting institutions to eliminate these from our sample. Information on the list for validity and syntactical edits is provided here: http://www.ffiec.gov/hmda/edits.htm. Detailed information on the error check list and how we implemented this is available upon request. Very few loans are in fact deleted from the data, but the average loan size as well as income figures are much more reasonable after this has been done.

Before to 2004, the HMDA data contained no information on the lien status of the loan, which is important to avoid "double counting". To take hold of this, we have followed an approach similar to Calhoun (2006). The approach may be described in two steps. First, at step one, we do as Avery et al. (2007) and sort all observation in a given MSA and within a given year by certain person identifiers and a bank identifer (the respondent ID). The person identifiers include income of applicant, tract code, race of applicant, race of co-applicant, sex of applicant, sex of co-applicant and information on whether the property that the loan is secured against is an owner-occupied unit or not. If we get a match, we identify this as the same borrower and the smaller of the two loans is classified as the second lien (the "Piggyback") and the larger is the first lien loan. We then exclude these observations from our selection sample. Next, at step two, we follow Calhoun (2006) and LaCour-Little et al. (2011) and do a similar sorting and matching procedure, only now we leave out the bank identifer. These observations are then removed from the sample, and we have three data sets: One with multi-loans as identified at step one, one with multi-loans as identified at step two and one containing only single loans. Finally, we match all these data sets and perform our calculations to generate variables at an MSA level. We deviate from previous papers in that we do not allow loans without income information to be included in a loan portfolio. The argument is that missing income information does not allow us to uniquely (to the extent it is possible without a social security number) identify the borrower. For the years 2004-2010, where we also have information on the lien status of the loan, we have performed a robustness check of the second liens as classified by our procedure, and we find a very high match. This is important to get a more precise measure of average LTI ratios and the number of loans originated in general. In the end, after correcting the data, we identify a loan as being a subprime loan if the bank extending the loan appears on the HUD Subprime and Manufactured Home Lender List: http://www.huduser.org/portal/datasets/manu.html.

Appendix D: Reduced form representations

The baseline model

The reduced form representation of the boom system with the subprime measure treated as endogenous (equation (8), (9) and (10)) is given by:

$$\Delta p_i^{Boom} = \frac{1}{A^B}\left[(\alpha_1 + \beta_{1,\Delta h}\alpha_2) + \boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \beta_{1,\Delta h}\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i +\right] + u^B_{1,i} \tag{D.1}$$

$$\begin{aligned}\Delta h_i^{Boom} &= \frac{1}{A^B}\left[(\alpha_1(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) + \alpha_2)\right.\\ &\left.+ (\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i\right] + u^B_{2,i}\end{aligned} \tag{D.2}$$

where the reduced form disturbances also are functions of the structural parameters, and A^B is defined as $A^B = 1 - \beta_{1,\Delta h}\left(\beta_{2,\Delta p} + \beta_{2,\Delta h\times \boldsymbol{Reg}}\boldsymbol{Reg_i}\right)$. The bust equation may therefore be expressed in terms of the structural parameters in the boom system in the following way:

$$\begin{aligned}\Delta p_i^{Bust} &= \mu + \gamma_{\Delta p}\left[\frac{1}{A^B}\left[(\alpha_1 + \beta_{1,\Delta h}\alpha_2) + \boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \beta_{1,\Delta h}\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i\right] + u_{1,i}\right]\\ &+ \gamma_{\Delta h}\left[\frac{1}{A^B}\left[(\alpha_1(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) + \alpha_2)\right.\right.\\ &+ (\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i\\ &+ \left.\left.\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i\right] + u_{2,i}\right] + e_i\end{aligned} \tag{D.3}$$

The extended model

The reduced form representation of the boom system with the subprime measure treated as endogenous (equation (8), (9), (10) and (11)) is given by:

$$\Delta p_i^{Boom} = \frac{1}{A^E}\left[(\alpha_1 + \beta_{1,\Delta h}\alpha_2 + \beta_{1,\Delta sp}\alpha_3) + \boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \beta_{1,\Delta h}\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i + \beta_{1,\Delta sp}\boldsymbol{\beta}'_{3,\boldsymbol{w}}\boldsymbol{w}_i\right] + u_{1,i} \tag{D.4}$$

$$\begin{aligned}\Delta h_i^{Boom} &= \frac{1}{A^E}\left[(\alpha_1(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) + \alpha_2(1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})\right.\\ &+ \alpha_3\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i))\\ &+ (\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + (1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i\\ &+ \left.\beta_{1,sp}(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{3,\boldsymbol{w}}\boldsymbol{w}_i\right] + u_{2,i}\end{aligned} \tag{D.5}$$

$$\begin{aligned}\Delta sp_i^{Boom} &= \frac{1}{A^E}\left[\beta_{3,\Delta p}\alpha_1 + \beta_{1,\Delta h}\beta_{3,\Delta p}\alpha_2 + (1 - \beta_{1,\Delta h}(\beta_{2,\Delta h} + \beta_{2,\Delta h\times \boldsymbol{Reg}}\boldsymbol{Reg}_i))\alpha_3\right.\\ &+ \left.\beta_{3,\Delta p}\boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \beta_{1,\Delta h}\beta_{3,\Delta p}\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i + (1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \beta_{2,\Delta h\times \boldsymbol{Reg}}\boldsymbol{Reg}_i))\boldsymbol{\beta}'_{3,\boldsymbol{w}}\boldsymbol{w}_i\right] + u_{3,i}\end{aligned} \tag{D.6}$$

where the reduced form disturbances, $u_{j,i}$, also are functions of the structural parameters, and A^E is defined as $A^E = 1 - \beta_{1,\Delta h}\left(\beta_{2,\Delta p} + \beta_{2,\Delta h\times \boldsymbol{Reg}}\boldsymbol{Reg_i}\right) - \beta_{3,\Delta p}\beta_{1,\Delta sp}$. The bust equation may therefore be expressed in terms of the structural parameters in the boom system in the following way:

$$\begin{aligned}\Delta p_i^{Bust} &= \mu + \gamma_{\Delta p}\left[\frac{1}{A^E}\left[(\alpha_1 + \beta_{1,\Delta h}\alpha_2 + \beta_{1,\Delta sp}\alpha_3) + \boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i + \beta_{1,\Delta h}\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i + \beta_{1,\Delta sp}\boldsymbol{\beta}'_{3,\boldsymbol{w}}\boldsymbol{w}_i\right] + u_{1,i}\right] \\ &+ \gamma_{\Delta h}\left[\frac{1}{A^E}\left[(\alpha_1(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) + \alpha_2(1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})\right.\right. \\ &+ \alpha_3\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)) + (\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{1,\boldsymbol{x}}\boldsymbol{x}_i \\ &+ \left.\left.(1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})\boldsymbol{\beta}'_{2,\boldsymbol{z}}\boldsymbol{z}_i + \beta_{1,sp}(\beta_{2,\Delta p} + \beta_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\boldsymbol{\beta}'_{3,\boldsymbol{w}}\boldsymbol{w}_i\right] + u_{2,i}\right] + e_i\end{aligned} \tag{D.7}$$

Appendix E: The analytical expressions for the response functions

The baseline model

In the baseline model (confer (D.1) – (D.3)), the subprime measure is part of the vector $\boldsymbol{x}_i$. If we let the subprime measure be denoted Δsp_i, and also let $\beta_{1,\Delta sp}$ be the coefficients on the subprime measure in the housing price equation (just as in the extended model), while remembering that $A^B = 1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)$, it is straight forward to show that the effect on housing prices and supply during the boom, as well as prices during the bust, of an increase in subprime lending is given as:

$$\frac{\partial \Delta p^{Boom}}{\partial \Delta sp_i} = \frac{1}{A^B}\beta_{1,\Delta sp} \tag{E.1}$$

$$\frac{\partial \Delta h^{Boom}}{\partial \Delta sp_i} = \frac{1}{A^B}\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) \tag{E.2}$$

$$\begin{aligned}\frac{\partial \Delta p^{Bust}}{\partial \Delta sp_i} &= \gamma_{\Delta p}\frac{\partial \Delta p^{Boom}}{\partial \Delta sp_i} + \gamma_{\Delta h}\frac{\partial \Delta h^{Boom}}{\partial \Delta sp_i} \\ &= \frac{1}{A^B}\beta_{1,\Delta sp}\left(\gamma_{\Delta p} + \gamma_{\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\right)\end{aligned} \tag{E.3}$$

As long as $A^B > 0$ and $|\beta_{2,\Delta p}| > |\boldsymbol{\beta}'_{2\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i|$ for all values of the regulation indexes, then both housing prices and supply will increase following a shock to subprime lending, and prices will fall during the bust.

The extended model

In the extended model, we showed in Appendix C that:

$$A^E = 1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) - \beta_{3,\Delta p}\beta_{1,\Delta sp}$$

i.e. if – hypothetically – all coefficient estimates are equal in the baseline and the extended model, then $A^E < A^B$ as long as prices affect subprime lending ($\beta_{3,\Delta p} > 0$). This is due to the financial accelerator effect (as captured by $\beta_{3,\Delta p}\beta_{1,\Delta sp}$). Again, it is straight forward to show that the effect on housing prices, supply and subprime lending during the boom, as well as prices during the bust, of an increase in subprime lending (now interpreted as a shock to $\varepsilon_{3,i}$ in equation (10)) are given as:

$$\frac{\partial \Delta p^{Boom}}{\partial \varepsilon_{3,i}} = \frac{1}{A^E}\beta_{1,\Delta sp} \tag{E.4}$$

$$\frac{\partial \Delta h^{Boom}}{\partial \varepsilon_{3,i}} = \frac{1}{A^E}\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i) \tag{E.5}$$

$$\frac{\partial \Delta sp^{Boom}}{\partial \varepsilon_{3,i}} = \frac{1}{A^E}(1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)) \tag{E.6}$$

$$\begin{aligned}\frac{\partial \Delta p^{Bust}}{\partial \varepsilon_{3,i}} &= \gamma_{\Delta p}\frac{\partial \Delta p^{Boom}}{\partial \varepsilon_{3,i}} + \gamma_{\Delta h}\frac{\partial \Delta h^{Boom}}{\partial \varepsilon_{3,i}} \\ &= \frac{1}{A^E}\beta_{1,\Delta sp}\left(\gamma_{\Delta p} + \gamma_{\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p\times \boldsymbol{Reg}}\boldsymbol{Reg}_i)\right)\end{aligned} \tag{E.7}$$

If $\beta_{3,\Delta p} = 0$ (no effect on subprime lending of higher housing prices), then $A^E = A^B$ and we are back at the baseline model.

Appendix F: Calculation of standard errors using the delta method

In general, if $G(\theta)$ is a function of coefficients, then we know from the delta method that the variance of $G(\theta)$ is:

$$Var(G(\theta)) = G'(\theta)\Sigma_\theta(G'(\theta))^T \tag{F.1}$$

This expression will be used throughout this appendix to derive the analytical expressions for all the variances we are interested in.

The baseline model

The calculations here are based on the expressions for the first derivatives derived in Appendix D. The calculations are done to construct the confidence intervals used in the figures for the response functions in Section **??**, and to test the supply restriction irrelevance hypothesis.

Standard error for boom price response

From (E.1), we have that:

$$G(\theta^{\Delta p^{Boom}}) = \frac{\partial \Delta p^{Boom}}{\partial \Delta sp_i} = \frac{\beta_{1,\Delta sp}}{A^B}$$

with $A^B = 1 - \beta_{1,\Delta h}\left(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2\right)$.
Let $\theta^{\Delta p^{Boom}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2)$. The vector of derivatives for $G(\theta^{\Delta p^{Boom}})$ is given as:

$$G'(\theta^{\Delta p^{Boom}}) = \left(\tfrac{1}{A}, \tfrac{\beta_{1,\Delta sp}\left(\beta_{2,\Delta p}+\beta_{2,Reg_1}Reg_1+\beta_{2,Reg_2}Reg_2\right)}{A^2}, \tfrac{\beta_{1,\Delta sp}\beta_{1,\Delta h}}{A^2}, \tfrac{\beta_{1,\Delta sp}\beta_{1,\Delta h}Reg_1}{A^2}, \tfrac{\beta_{1,\Delta sp}\beta_{1,\Delta h}Reg_2}{A^2}\right) \quad (F.2)$$

Using (F.1), we can then calculate the variance of $G(\theta^{\Delta p^{Boom}})$.

Standard errors for boom supply response

From (E.2), we have that:

$$G(\theta^{\Delta h^{Boom}}) = \frac{\partial \Delta h^{Boom}}{\partial \Delta sp_i} = \frac{\beta_{1,\Delta sp}\left(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2\right)}{A^B}$$

Let $\theta^{\Delta h^{Boom}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2)$. We then find that the vector of derivatives for $G(\theta^{\Delta h^{Boom}})$ is given as:

$$G'(\theta^{\Delta h^{Boom}}) = \left(\tfrac{\beta_{2,\Delta p}+\beta_{2,Reg_1}Reg_1+\beta_{2,Reg_2}Reg_2}{A}, \tfrac{\beta_{1,\Delta sp}\left(\beta_{2,\Delta p}+\beta_{2,Reg_1}Reg_1+\beta_{2,Reg_2}Reg_2\right)^2}{A^2}, \tfrac{\beta_{1,\Delta sp}}{A^2}, \tfrac{\beta_{1,\Delta sp}Reg_1}{A^2}, \tfrac{\beta_{1,\Delta sp}Reg_2}{A^2}\right) \quad (F.3)$$

We can again use the expression in (F.1) to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.

Standard errors for bust price response

From (E.3), we have that:

$$G(\theta^{\Delta p^{Bust}}) = \frac{\partial \Delta p^{Bust}}{\partial \Delta sp_i} = \gamma_{\Delta p} G(\theta^{\Delta p^{Boom}}) + \gamma_{\Delta h} G(\theta^{\Delta h^{Boom}})$$

Let $\theta^{\Delta p^{Bust}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2, \gamma_{\Delta p}, \gamma_{\Delta h})$. We then find that the vector of derivatives for the $G(\theta^{\Delta h^{Bust}})$ function is given as:

$$\begin{aligned}
G'(\theta^{\Delta p^{Bust}}) = \Big[& \left(\gamma_{\Delta p} G'(\theta_1^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_1^{\Delta h^{Boom}})\right) \\
& , \left(\gamma_{\Delta p} G'(\theta_2^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_2^{\Delta h^{Boom}})\right) \\
& , \left(\gamma_{\Delta p} G'(\theta_3^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_3^{\Delta h^{Boom}})\right) \\
& , \left(\gamma_{\Delta p} G'(\theta_4^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_4^{\Delta h^{Boom}})\right) \\
& , \left(\gamma_{\Delta p} G'(\theta_5^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_5^{\Delta h^{Boom}})\right) \\
& , G'(\theta_1^{\Delta p^{Boom}}) \\
& , G'(\theta_1^{\Delta h^{Boom}}) \Big]
\end{aligned} \quad (F.4)$$

Where $G'(\theta_j^k),\ k = \Delta p^{Boom}, \Delta h^{Boom}, j = 1, ..., 5$ is element j in the vector of derivatives of the function under consideration.
And expression (F.1) is used to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.

The extended model

The calculations below are based on expression (E.4)–(E.7). The analytical expressions derived here are used to construct the confidence intervals used in the figures for the response patterns in the extended model, see Section **??**.

Standard error for boom price response

From (E.4), we have that:

$$G(\theta^{\Delta p^{Boom}}) = \frac{\partial \Delta p^{Boom}}{\partial \varepsilon_{3,i}} = \frac{\beta_{1,\Delta sp}}{A^E}$$

with $A^E = 1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i) - \beta_{3,\Delta p}\beta_{1,\Delta sp}$.
Let $\theta^{\Delta p^{Boom}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2, \beta_{3,\Delta p})$.
The vector of derivatives for $G(\theta^{\Delta p^{Boom}})$ is given as:

$$G'(\theta^{\Delta p^{Boom}}) = \Bigg(\frac{1 - \beta_{1,\Delta h}\left(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i\right)}{A^2}, \frac{\beta_{1,\Delta sp}\left(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2\right)}{A^2} \\ , \frac{\beta_{1,\Delta sp}\beta_{1,\Delta h}}{A^2}, \frac{\beta_{1,\Delta sp}\beta_{1,\Delta h} Reg_1}{A^2}, \frac{\beta_{1,\Delta sp}\beta_{1,\Delta h} Reg_2}{A^2}, \frac{\beta_{1,\Delta sp}^2}{A^2} \Bigg) \tag{F.5}$$

Using the expression in (F.1), we then derive the variance of the function $G(\theta)$.

Standard errors for boom supply response

From (E.5), we have that:

$$G(\theta^{\Delta h^{Boom}}) = \frac{\partial \Delta h^{Boom}}{\partial \varepsilon_{3,i}} = \frac{\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i)}{A^E}$$

Let $\theta^{\Delta h^{Boom}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2, \beta_{3,\Delta p})$. We then find that the vector of derivatives for $G(\theta^{\Delta h^{Boom}})$ is given as:

$$G'(\theta^{\Delta h^{Boom}}) = \Bigg(\frac{(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2)(1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2))}{A^2}, \frac{\beta_{1,\Delta sp}\left(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2\right)^2}{A^2} \\ , \frac{\beta_{1,\Delta sp}(1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})}{A^2}, \frac{\beta_{1,\Delta sp} Reg_1 (1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})}{A^2}, \frac{\beta_{1,\Delta sp} Reg_2 (1 - \beta_{1,\Delta sp}\beta_{3,\Delta p})}{A^2} \\ , \frac{\beta_{1,\Delta sp}^2(\beta_{2,\Delta p} + \beta_{2,Reg_1} Reg_1 + \beta_{2,Reg_2} Reg_2)}{A^2} \Bigg)$$

We can again use expression in (F.1) to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.

Standard errors for boom subprime response

From (E.6), we have that:

$$G(\theta^{\Delta sp^{Boom}}) = \frac{\partial \Delta sp^{Boom}}{\partial \varepsilon_{3,i}} = \frac{(1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i))}{A^E}$$

Let $\theta^{\Delta sp^{Boom}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2, \beta_{3,\Delta p})$. We then find that the vector of derivatives for $G(\theta^{\Delta sp^{Boom}})$ is given as:

$$G'(\theta^{\Delta sp^{Boom}}) = \Bigg(\frac{\beta_{3,\Delta p}(1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i))}{A^2}, \frac{\beta_{3,\Delta p}\beta_{1,\Delta sp}(\beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i)}{A^2}, \frac{\beta_{3,\Delta p}\beta_{1,\Delta sp}\beta_{1,\Delta h}}{A^2}$$
$$, \frac{\beta_{3,\Delta p}\beta_{1,\Delta sp}\beta_{1,\Delta h} Reg_1}{A^2}, \frac{\beta_{3,\Delta p}\beta_{1,\Delta sp}\beta_{1,\Delta h} Reg_2}{A^2}, \frac{(1 - \beta_{1,\Delta h}(\beta_{2,\Delta p} + \beta_{2,\Delta p} + \boldsymbol{\beta}'_{2,\Delta p \times \boldsymbol{Reg}} \boldsymbol{Reg}_i))\beta_{1,\Delta sp}}{A^2} \Bigg)$$

We can again use expression in (F.1) to calculate the variance of the function $G(\theta^{\Delta sp^{Boom}})$.

Standard errors for bust price response

The derivative of the bust price with respect to one of the boom demand shifters is given as:

$$G(\theta^{\Delta p^{Bust}}) = \frac{\partial \Delta p^{Bust}}{\partial \varepsilon_{3,i}} = \gamma_{\Delta p} \frac{\partial \Delta p^{Boom}}{\partial \varepsilon_{3,i}} + \gamma_{\Delta h} \frac{\partial \Delta h^{Boom}}{\partial \varepsilon_{3,i}} = \gamma_{\Delta p} G(\theta^{\Delta p^{Boom}}) + \gamma_{\Delta h} G(\theta^{\Delta h^{Boom}}))$$

Let $\theta^{\Delta p^{Bust}} = (\beta_{1,\Delta sp}, \beta_{1,\Delta h}, \beta_{2,\Delta p}, \beta_{2,Reg_1} Reg_1, \beta_{2,Reg_2} Reg_2, \gamma_{\Delta p}, \gamma_{\Delta h}, \beta_{3,\Delta p})$. We then find that the vector of derivatives for $G(\theta^{\Delta p^{Bust}})$ is given as:

$$\begin{aligned} G'(\theta^{\Delta p^{Bust}}) = \Big[& \Big(\gamma_{\Delta p} G'(\theta_1^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_1^{\Delta h^{Boom}}) \Big) \\ & , \Big(\gamma_{\Delta p} G'(\theta_2^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_2^{\Delta h^{Boom}}) \Big) \\ & , \Big(\gamma_{\Delta p} G'(\theta_3^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_3^{\Delta h^{Boom}}) \Big) \\ & , \Big(\gamma_{\Delta p} G'(\theta_4^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_4^{\Delta h^{Boom}}) \Big) \\ & , \Big(\gamma_{\Delta p} G'(\theta_5^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_5^{\Delta h^{Boom}}) \Big) \\ & , G'(\theta_1^{\Delta p^{Boom}}) \\ & , G'(\theta_1^{\Delta h^{Boom}}) \\ & , \Big(\gamma_{\Delta p} G'(\theta_6^{\Delta p^{Boom}}) + \gamma_{\Delta h} G'(\theta_6^{\Delta h^{Boom}}) \Big) \Big] \end{aligned} \tag{F.6}$$

Where $G'(\theta_j^k),\ k = \Delta p^{Boom}, \Delta h^{Boom}, j = 1, ..., 5$ is element j in the vector of derivatives of the function under consideration.
And expression (F.1) is used to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.