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Supply Restrictions, Subprime Lending and Regional US Housing Prices

André Kallåk Anundsen
and Christian Heebøll

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Department of Economics
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P. O.Box 1095 Blindern
N-0317 OSLO Norway
Telephone: + 47 22855127
Fax: + 47 22855035
Internet: http://www.sv.uio.no/econ
e-mail: econdep@econ.uio.no

In co-operation with
The Frisch Centre for Economic Research

Gaustadalleén 21
N-0371 OSLO Norway
Telephone: +47 22 95 88 20
Fax: +47 22 95 88 25
Internet: http://www.frisch.uio.no
e-mail: frisch@frisch.uio.no

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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

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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 248 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 supply-demand framework, 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.

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

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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 248 heterogeneous US housing markets, we analyze whether a combination of supply side restrictions, sub-prime 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 %
Miami-Miami Beach-Kendall	FL	South	161 %	-37 %	12 %
Fort Lauderdale-Pompano Beach-Deerfield Beach	FL	South	160 %	-42 %	8 %
Merced	CA	West	159 %	-61 %	19 %
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			57 %	-8 %	10 %
Standard deviation			39 %	16 %	7 %

Note: The table shows the top and bottom five regions 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 period is here defined as 2000–2006, 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 explain 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. We take this as an 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., 2005; Iacoviello, 2005). In this paper, we demonstrate how recent financial innovations (subprime lending) in combination with supply side restrictions have led to a regional specific financial accelerator effect. 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 and in that way increase the price overhang compared to less restricted areas. On the other hand, the difference in the quantity overhang will be diminished. As a consequence, the housing price bust will be unambiguously larger in more restricted areas, which offers a plausible explanation to the conflicting empirical results found in the 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 also consider the loan-to-income ratio as done in Wheaton and Nechayev (2008). Both instruments are found to be valid.

The structural model considered in this paper have 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. As a result, more restricted areas are hit harder during the bust period. 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 what mechanisms caused 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 the 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 the results from our baseline structural boom-bust model, while the results from the extended model that takes the endogenous feedback between housing prices and subprime lending into account are discussed in Section 5. 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 for simplicity 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 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:

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

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]

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

[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 the demand is determined in accordance with a life-cycle utility maximizing framework, 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:

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

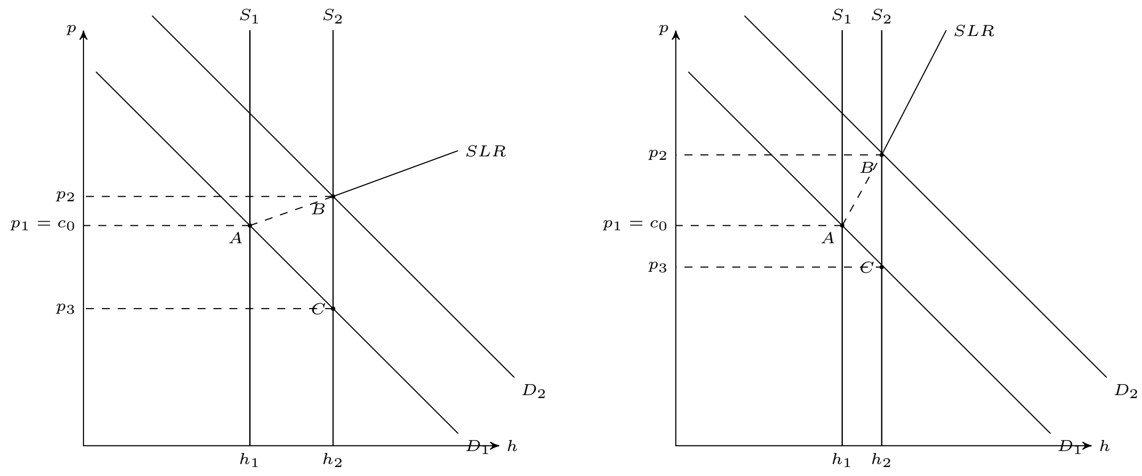
where the term $v_{0,i,t}$ measures exogenous demand shifters, such as income, the user cost of housing as well as – important to the focus of this paper – credit constraints. The parameter v_1 measures the price elasticity of an increase in the number of houses.

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 to 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.

(a) Market 1: Elastic supply

(b) 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 a supply-demand framework, as described 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 and Gertler (1999), Aoki et al. (2005) 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. We follow custom and assume that agents in the economy are faced with a collateral constraint of the following form (see e.g. Kiyotaki and Moore (1997)):

$$b_{i,t} \leq \kappa_0 + \kappa_{1,t} p_{i,t} \qquad , \kappa_1 > 0 \tag{5}$$

where $b_{i,t}$ is the log of the total amount of credit extended in area i, which depends on the housing price through the parameter $\kappa_{1,t}$. With increasing housing prices, agents will experience an increased access to credit. We shall assume that the credit constraint is binding, and that credit is an important 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:

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

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 inverted demand equation can then be expressed as:

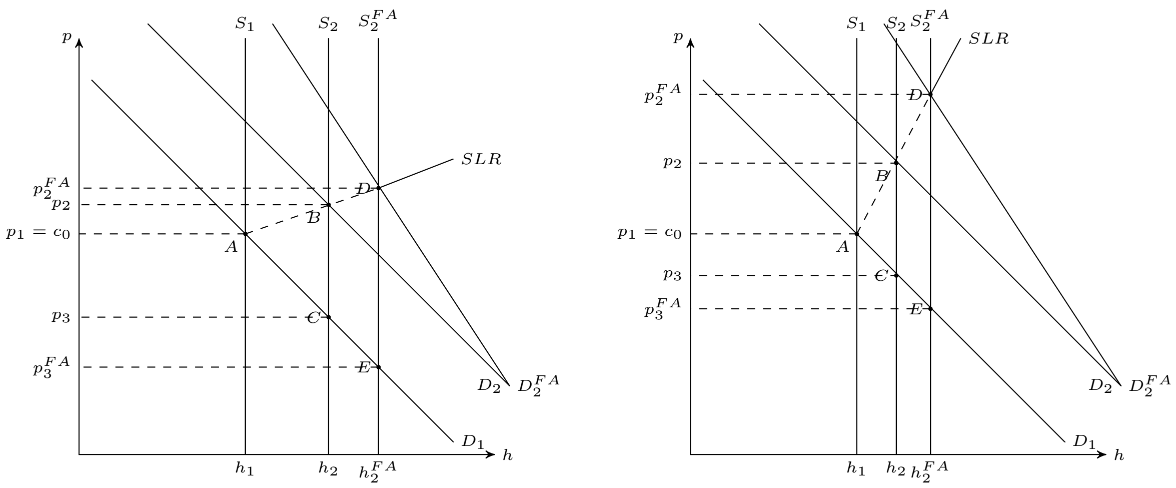
$$p_{i,t} \quad = \quad \frac{1}{1-\eta\kappa_{1,t}}\left[\tilde{v}_{0,i,t}+\eta\kappa_0+v_1 h^d_{i,t}\right] \qquad , v_1<0, \eta, \kappa_0>0 \tag{7}$$

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, the housing boom causes banks to be more liberal on the amount of credit they extend. This is captured by an increase in $\kappa_{1,t}$, which increases the slope of the demand curve (tilting the curve from D_2 to D_2^{FA}). 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. Hence, when taking account of the financial accelerator, the new equilibrium will be at the point D.

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

(a) Market 1: Elastic supply

(b) 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_2^{FA} is the demand curve after the positive shock when we also take account of the financial accelerator . S_1 is the original short run supply curve, S_2 is the short run supply curve after the shock is materialized and S_2^{FA} is the short run supply curve in the financial accelerator model after the shock. The long run supply curve is given by *SLR*.

Compared to the equilibrium B, where we do not account for the financial accelerator (corresponding to the baseline model), Figure 2 and the first derivatives indicate a larger absolute 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 $\eta\kappa_{1,t}$, the additional supply increase caused by the financial accelerator (from h_2 to h_2^{FA}) 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(from h_1 to h_2^{FA}).

Turning to the bust period, we assume that the demand curve returns to its initial position (D_2^{FA} to D_1), i.e. the shock is reversed and the credit markets ($\kappa_{1,t}$) are back at the pre-boom conditions. Given that supply is fixed at the boom period level, the model predicts that prices will drop from D to E when we account for the financial accelerator and from B to C when we do not. As seen, the housing price bust is still independent of the supply elasticity when we abstract from the financial accelerator (B to C). On the other hand, when we do take the financial accelerator into account, the price drop is significantly larger in more inelastic areas (D to E). 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.[3] 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 growth in construction wages and income. The term $\boldsymbol{x}_i^{Boom}$ is a vector of demand shocks,

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

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 a 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 previous literature. More specifically, the controls we include are income, population, population density and the unemployment rate as of 1996. The data sources will be specified in more detail in the next subsection.

To complete our econometric operationalization of the baseline theoretical model, we add an equation for the price development during the bust. 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:

$$\Delta p_i^{Bust} \quad = \quad \mu + \gamma_{\Delta p} \Delta p_i^{Boom} + \gamma_{\Delta h} \Delta h_i^{Boom} + \boldsymbol{\gamma}_{\boldsymbol{w}}' \boldsymbol{w}_i^{Bust} + e_i \tag{10}$$

where $\boldsymbol{w}_i^{Bust}$ comprise demand shocks relevant for the bust period, which contains the growth in disposable income.

While we start by estimating the baseline model represented by (8)–(10), 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:

$$\Delta sp_i^{Boom} \quad = \quad \alpha_3 + \beta_{3,\Delta p} \Delta p_i^{Boom} + \boldsymbol{\beta}_{\boldsymbol{y}}' \boldsymbol{y}_i^{Boom} + \varepsilon_{\Delta sp,i} \tag{11}$$

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.

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).[4] The system is identified by the different exogenous variables entering the individual equations, and is estimated by full information maximum likelihood (FIML) techniques, assuming that the disturbances follow a joint normal distribution.

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

[4] 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.

$\frac{\partial \Delta h^{Boom}}{\partial u_{ij}}$, 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. 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 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 an extreme 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 248 US Metropolitan Statistical Areas (MSA).[5] 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 supply through the hurricane and subsequent floods of Katrina in late August, 2005.[6] We also exclude Barnstable Town (MA), due to extreme degrees of political and geographical supply restrictions. Thus, our effective sample covers a total of 243 MSAs.

Several definitions of boom and bust periods have been considered in the literature (see Cohen et al. (2012) for a discussion). We follow Glaeser et al. (2008) and Huang and Tang (2012) and consider the two alternative boom period definitions 1996–2006 and 2000–2006. This allow us to study how the mechanisms of the model change depending of the stage of the boom considered. Further, it shows the robustness of our results. For the bust period, we follow Huang and Tang (2012) and Cohen et al. (2012) and use the 2006–2010 period.

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

[5] 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.

[6] 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.

(HMDA) loan application registry (LAR) data.[7] 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.[8] We have prepared the data in several steps of calculations, mostly following Avery et al. (2007, 2010) (see Appendix B). 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 rate, 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.[9]

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.[10] 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 water, or where the land has a slope exceeding 15 degrees.[11] 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.[12] 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.[13] 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 by WRLURI(a) and is uncorrelated with UNAVAL.

We should be able to interpret UNAVAL as an exogenous effect of nature given sup-

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

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

[9]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.

[10]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).

[11]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.

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

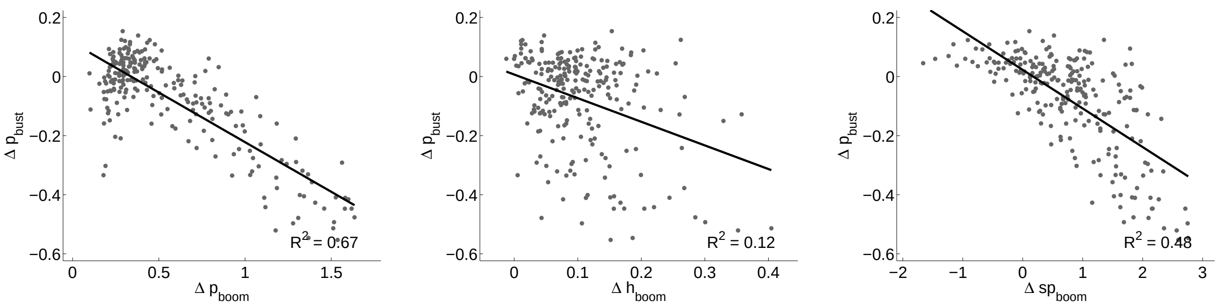
[13]We use the residuals from the following specification to measure the part of WRLRUI that is not explained by UNAVAL: $WRLURI_i = \beta_0 + \beta_1 UNAVAL_i + \varepsilon_i$.

ply 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.[14] 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.[15]

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).[16] 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 -61% in Merced, 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).

Figure 3: Bust price plots



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 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

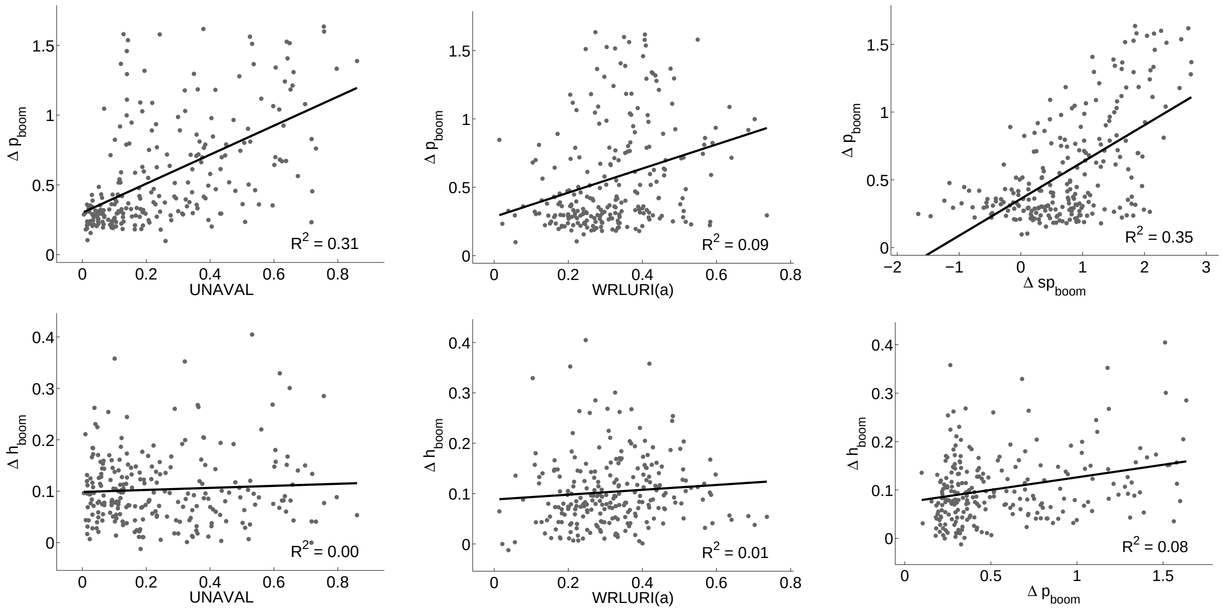
[14] It is not clear in which direction the bias would go: If housing prices increase, the building activity might increase as well. To constrain the high building activity, local governments might respond by enforcing more restrictions. On the other hand, booming housing prices are often accompanied 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.

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

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

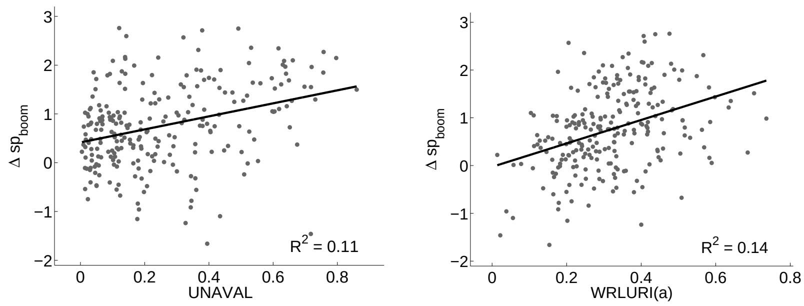
developers and a fast building permit application process (WRLURI(a) = 0.01). On the other extreme, even after controlling for a high degree of geographical supply restrictions, Boulder (CO), has a very high political involvement in the urban development process and a long and complex building application process etc. (WRLURI(a) = 0.74).[17]

Figure 4: Boom price and supply 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 Stockton (CA).

Figure 5: Boom subprime exposure 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 shows scatter plots between the bust price growth and the supply and price growth during the boom, as well as

[17]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).

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.

Turning to the correlation between the boom period variables and the supply restriction indexes, Figure 4 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 supply-demand framework – 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 standard demand-supply theory – unless these markets are also systematically hit by more demand shocks.

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. The clear positive correlation between subprime extensions and the supply restrictions, as illustrated in Figure 5, may suggest that the financial accelerator is more important in more restricted areas.

4 Econometric results for the baseline model

4.1 The boom period

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), for both of the boom period definitions are displayed in Table 2.[18]

The results are indeed robust to the alternative boom definitions, and 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

[18]As seen, normality is rejected. However, this should not be crucial for the results of the models. As a robustness check, we have also estimated the models leaving out extreme observations, in which case the normality assumptions are satisfied and the models give approximately the same results. These results are available upon request from the authors.

Table 2: The boom period model

Variables	1996–2006 Δp_{boom}	1996–2006 Δh_{boom}	2000–2006 Δp_{boom}	2000–2006 Δh_{boom}
Δh_{boom}	−9.31 (−7.96)***		−13.27 (−4.94)***	
Δp_{boom}		0.52 (3.31)***		0.75 (3.72)***
una × Δp_{boom}		−0.25 (−3.18)***		−0.21 (−2.32)***
wrl × Δp_{boom}		−0.52 (−3.26)***		−0.77 (−3.54)***
Δsp_{boom}	0.46 (7.26)***		0.60 (6.20)***	
ΔHH income$_{boom}$	4.51 (8.22)***	0.46 (9.96)***	5.96 (5.62)***	0.21 (1.90)*
Δc. cost$_{boom}$		−0.19 (−3.57)***		−0.23 (−3.45)***
Controls				
una		0.22 (2.17)***		0.12 (1.48)
wrl		−0.08 (−1.31)		−0.17 (−2.49)***
HH income$_{1996}$	4.51 (8.22)***	−0.09 (−1.11)	5.96 (5.62)***	−0.17 (−1.92)*
log pop$_{1996}$	0.84 (1.95)*	−0.03 (−2.84)***	0.79 (1.83)*	−0.01 (−1.33)
pop density$_{1996}$	−0.20 (−3.56)***	0.00 (0.30)	−0.13 (−2.41)***	0.00 (−0.28)
unemp$_{1996}$	0.09 (1.66)*	−0.84 (−2.45)***	0.02 (0.47)	−1.81 (−3.90)***
Diagnostics				
$\varepsilon_{\Delta p,boom}$	0.541		0.287	
$\varepsilon_{\Delta h,boom}$	0.464	0.097	0.230	0.009
Vector normality test	$\chi^2(4) = 49.185[0.0000]$***		$\chi^2(4) = 22.314[0.0002]$***	
Obs.	243		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%.

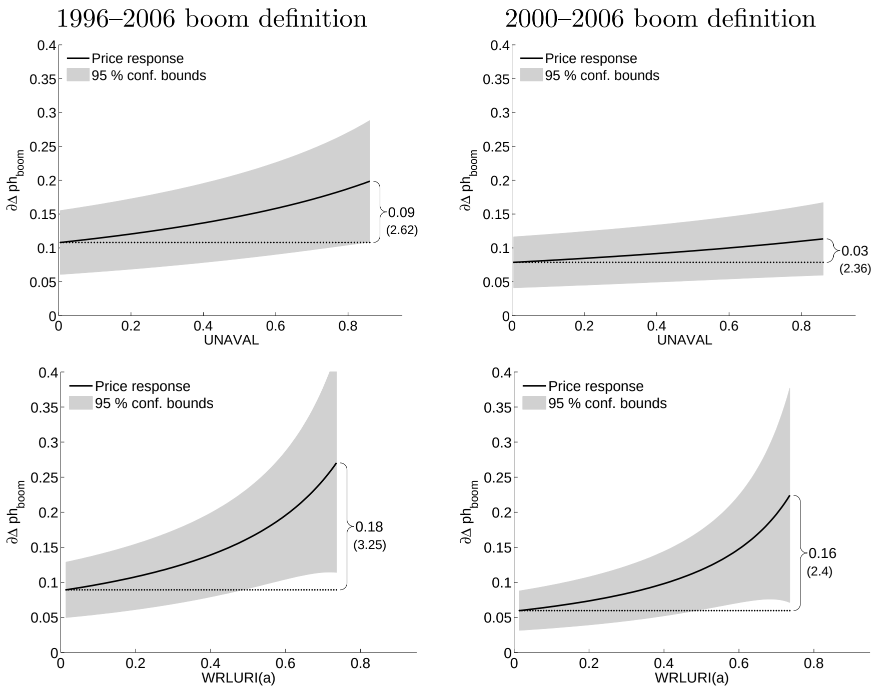
in housing prices, similar to the results of Huang and Tang (2012).[19] Looking at the supply equation (see Column 2 and 4), it is clear that more supply restrictions – both regulatory and geographical – lowers the implied elasticity, which supports the conjectures of the theoretical model.[20] Comparing 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). The effect of subprime lending, as well as the price and supply elasticities are more pronounced when we consider the 2000–2006 boom

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

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

period definition. This is possibly because this is the period with the most extreme price dynamics. Only the effect of geographical supply restrictions is less important in this period.

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.[21] When varying one index, we keep the other index fixed at its mean.[22] 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).[23]

First, for both WRLURI(a) and UNAVAL, we clearly see that the response pattern is positive and significant. This holds regardless of which boom definition we consider, and it 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 the individual indexes, we see that

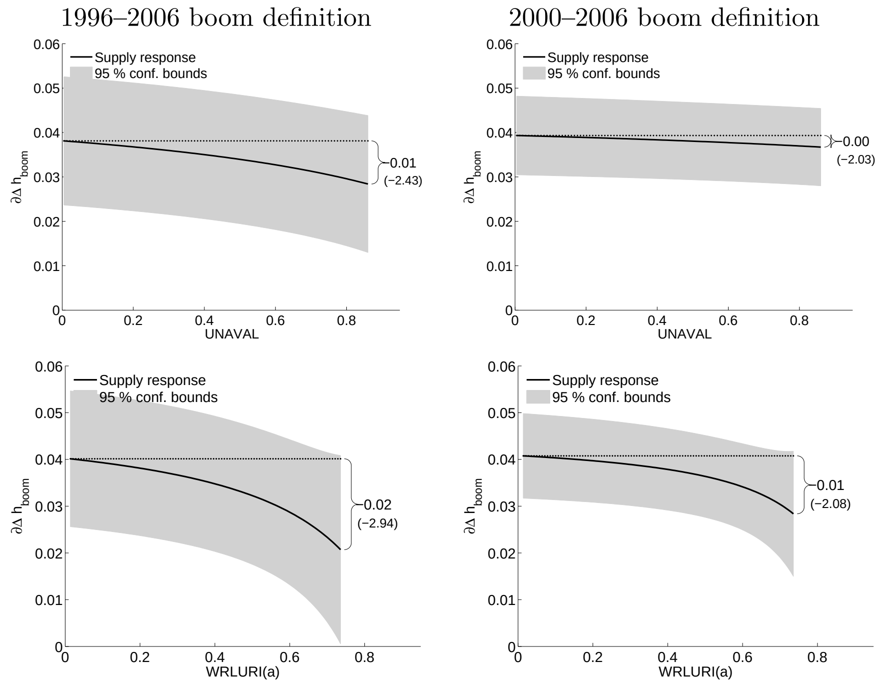
[21] We have generated 10 000 index values that in equal increments goes from the minimum to the maximum. This is done to get the smooth response patterns illustrated in the figures.

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

[23] 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.

politically enforced regulations are more important. Relying on the 1996–2006 boom period definition, the model suggest a difference in the price response of almost 0.18 percentage points when varying the political regulation between the two extremes. For the geographical restrictions, this difference is only about half the size. Somewhat the same picture is seen when we consider the 2000–2006 boom period definition.

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. Again, considering the 1996–2006 boom period definition, we see a difference in the supply response of 0.02 percentage points when varying the political regulation between the two extremes. This difference is again only half the size 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 bust period

We now turn to the price dynamics of the bust period. The results for the bust equation (10), when estimating the full baseline system (8)–(10) are reported in Table 3.

Table 3: Bust period model

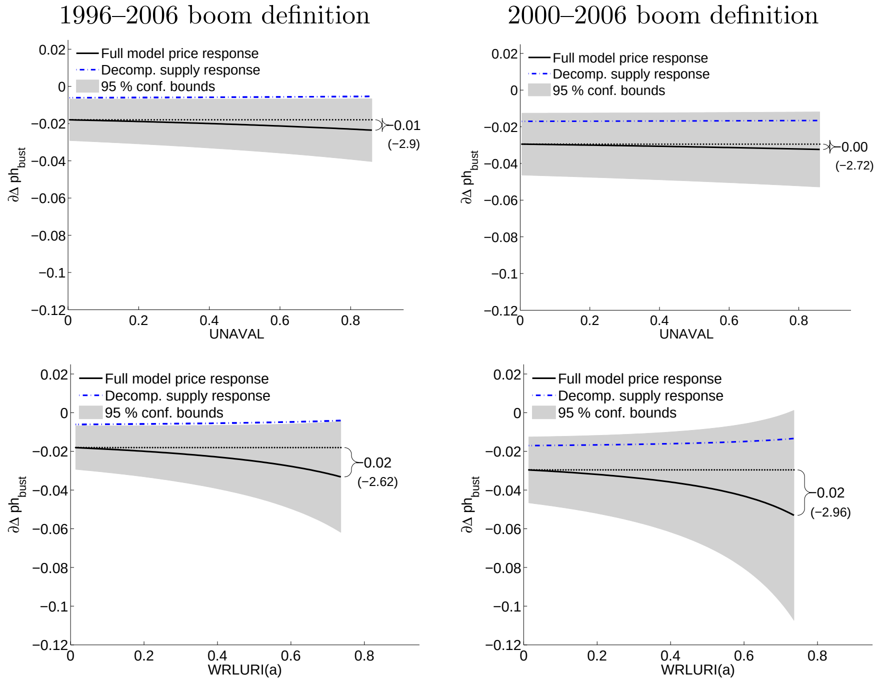
Variables	Boom 1996 – 2006 Δp_{bust}	Boom 2000 – 2006 Δp_{bust}
Δh_{boom}	-0.23 $(-4.08)^{***}$	-0.46 $(-4.33)^{***}$
Δp_{boom}	-0.18 $(-13.90)^{***}$	-0.24 $(-11.86)^{***}$
ΔHH income$_{bust}$	0.82 $(10.12)^{***}$	1.05 $(13.75)^{***}$
Controls		
log pop$_{1996}$	0.11 $(2.08)^{**}$	0.19 $(3.56)^{***}$
pop density$_{1996}$	0.01 (1.29)	0.01 (1.59)
HH income$_{1996}$	-0.01 (-1.41)	-0.01 $(-2.27)^{***}$
unemp$_{1996}$	-1.27 $(-6.99)^{***}$	-0.99 $(-5.03)^{***}$
Diagnostics		
$\sigma_{\Delta p,bust}$	0.069	0.064
$\rho_{\Delta p,boom}$	-0.377	-0.214
$\rho_{\Delta h,boom}$	-0.130	-0.027
Vector normality test	$\chi^2(6) = 51.628[0.0000]^{***}$	$\chi^2(6) = 33.313[0.0000]^{***}$
Obs.	243	242

Note: The table reports the bust period FIML estimates of the boom-boom system defined by (8)–(10). The following abbreviations apply: h is the log housing stock, p is log housing prices, 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 are in percentage changes. Δ is a difference operator. The asterisks denote significance level; * = 10%, ** = 5% and *** = 1%.

It is evident that both the price and quantity overhang are important in explaining the size of the bust. The estimated coefficient on the quantity overhang is about twice the size of the price overhang when we rely on the 2000–2006 boom period definition. Using the 1996–2006 definition, the difference is much lower. However, remembering the huge differences in the boom period price and supply response, it seems unlikely that this is enough to ensure the theoretically expected supply restriction irrelevance for the bust period price response.

This is confirmed by inspecting Figure 8, which shows the bust price response plotted against the two regulation indexes. In addition to the total price effect, we use (12) to concentrate on the effect resulting through the boom period quantity overhang. In general, the price response is greater the more restricted the supply. Again this is most

Figure 8: 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.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.

pronounced for the politically enforced restrictions. In that case, the price drop is about twice as large when comparing the price response for the highest and the lowest index value. Finally, for the total bust price response to be constant across all areas, we would expect the effect resulting through the boom period quantity overhang to have a clear positive slope. This is obviously not the case. Formally, we test this by exploring the hypothesis of a zero difference between the price response of the two most extreme areas (see the t-values in the graphs). This hypothesis is rejected, and we find that the most restricted area is significantly worse hit during the bust.

We conclude that the bust price response is generally greater in more restricted areas, and that the baseline model is not sufficient to account for the regional differences in housing price dynamics during the recent boom-bust cycle. Compared to the results of Glaeser et al. (2008) and Huang and Tang (2012), our model allows a decomposition of the effect through the price and quantity overhang. This clearly demonstrates that the reason that the supply restriction irrelevance result is rejected for the recent boom-bust cycle is that the price response has been too dependent on the supply restrictions.

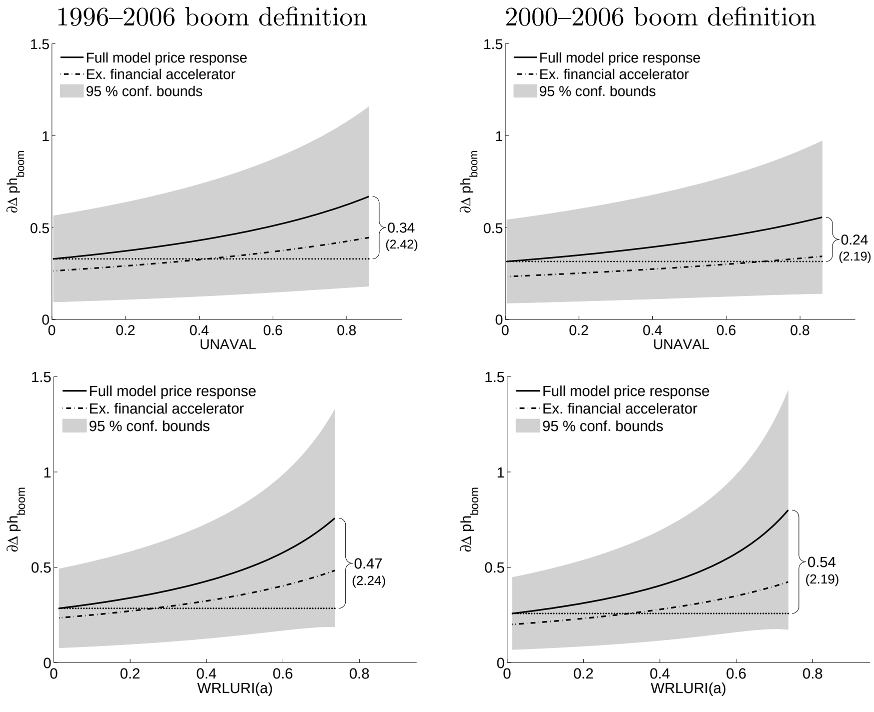
5 The financial accelerator

5.1 The boom period

Thus far, our results support the view that supply restricted areas will experience a greater price volatility through the housing cycle 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 (11).

The boom system is estimated using FIML, and the results are reported in Table 4. 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 9: 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.

Another retained result is that most coefficients are larger when we consider the 2000–2006 boom period definition, although the difference is not as pronounced as in the baseline model. This is possibly because the more extreme price dynamics in the 2000-

Table 4: The boom period model including a financial accelerator

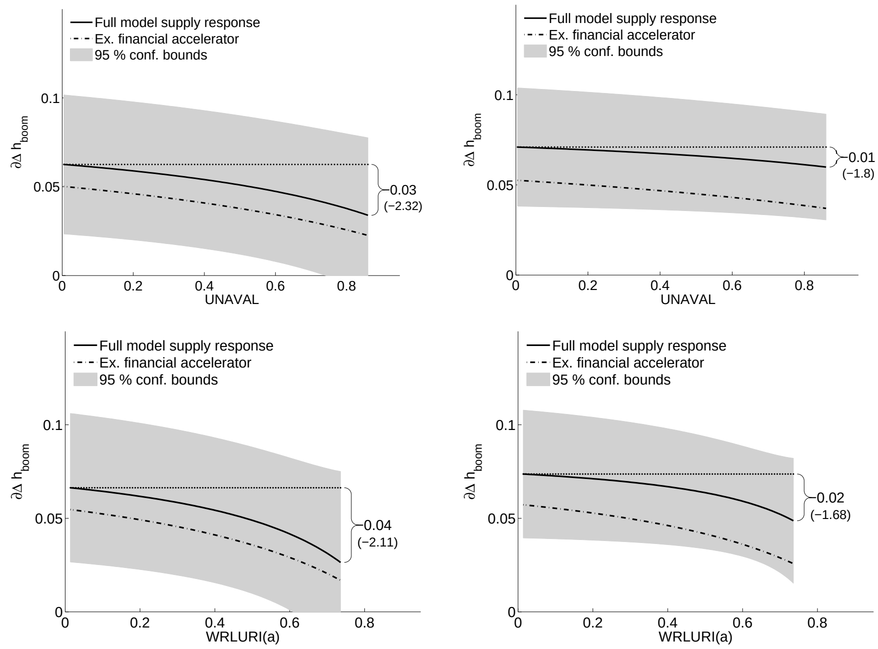
Variables	1996–2006			2000–2006		
	Δp_{boom}	Δh_{boom}	Δsp_{boom}	Δp_{boom}	Δh_{boom}	Δsp_{boom}
Δh_{boom}	−6.57			−7.07		
	(−5.26)***			(−3.64)***		
Δp_{boom}		0.28	0.75		0.33	1.11
		(2.25)***	(6.58)***		(3.07)***	(6.41)***
Δsp_{boom}	0.59			0.61		
	(8.28)***			(9.92)***		
una × Δp_{boom}		−0.16			−0.14	
		(−2.64)***			(−2.77)***	
wrl × Δp_{boom}		−0.27			−0.31	
		(−2.40)***			(−2.76)***	
ΔHH income$_{boom}$	3.25	0.44	0.66	3.38	0.32	0.35
	(5.49)***	(11.84)***	(1.64)*	(4.07)***	(5.37)***	(1.06)
Δc. cost$_{boom}$		−0.12			−0.10	
		(−2.79)***			(−3.03)***	
Denial rate$_{1996}$			1.13			1.00
			(4.21)***			(3.68)***
LTI$_{1996}$			−0.64			−0.96
			(−1.34)			(−1.83)*
Controls						
una		0.14			0.06	
		(2.13)***			(1.60)*	
wrl		0.01			−0.03	
		(0.19)			(−0.99)	
HH income$_{1996}$	1.05	−0.04	0.24	0.99	−0.07	0.26
	(3.05)***	(−0.58)	(5.22)***	(3.48)***	(−1.42)	(5.29)***
log pop$_{1996}$	−0.22	−0.02	−0.09	−0.16	0.00	−0.08
	(−5.02)***	(−2.05)**	(−1.97)**	(−4.39)***	(−0.36)	(−1.63)*
pop density$_{1996}$	0.10	0.00	0.97	0.05	−0.01	−0.89
	(2.53)***	(−0.39)	(0.69)	(1.55)	(−0.91)	(−0.53)
unemp$_{1996}$	0.91	−0.49	0.00	−0.03	−0.98	0.00
	(0.87)	(−1.85)*	(0.00)	(−0.02)	(−3.93)***	(0.00)
Diagnostics						
$\varepsilon_{\Delta p,boom}$	0.421			0.348		
$\varepsilon_{\Delta h,boom}$	0.432	0.076		0.160	0.058	
$\varepsilon_{\Delta sp,boom}$	−1.844	0.243	0.515	−2.496	0.511	0.543
Vector normality test	$\chi^2(4) = 33.341[0.0000]$***			$\chi^2(4) = 26.117[0.0002]$***		
Obs.	243			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%.

2006 period are now captured by the financial accelerator effect. This interpretation is backed by our results, which show that housing prices are significantly affecting 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 10: Boom supply response for different degrees of the supply restrictions

1996–2006 boom definition 2000–2006 boom definition

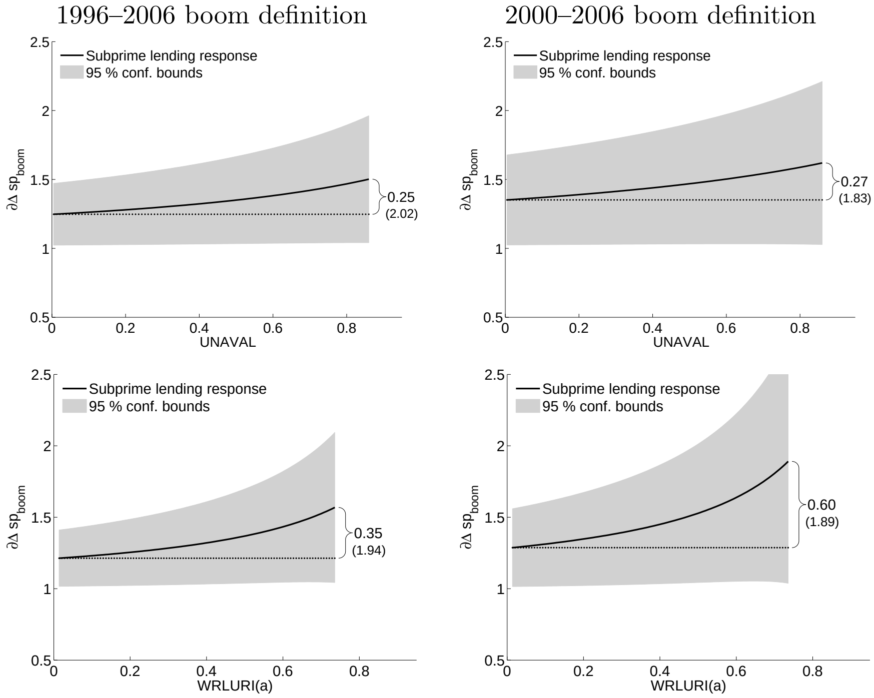


Note: This figure shows the boom period supply response of a 1 % shock to subprime lending per capita both with and without the financial accelerator in the model. The calculations are based on the first derivatives, and the confidence bounds are calculated using the delta method, see Appendix D and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

Figure 9–11 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 9, the financial accelerator increases the 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), relying on the 1996–2006 boom definition, there is a difference of 0.47 percentage points when the financial accelerator is accounted for, while this number is only about half that size when it is not. More or less the same effect is seen when we use the 2000–2006 boom definition, but it is still somewhat smaller when considering geographical supply restrictions.

Regarding the supply responses, see Figure 10, 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, considering the 2000–2006 boom period definition, we cannot reject the zero differences in the supply

Figure 11: 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.

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, as the boom reached its height, 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 11. For the 1996–2006 boom definition, an increase of 1 % in subprime lending per capita is endogenously accelerated by 20 % when WRLURI(a) is at the minimum, while it is accelerated with 55 % when it is at the maximum. This pattern is even more pronounced when we consider the 2000–2006 boom period definition, but smaller 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, by the structural 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 by more the less the same across areas. Specifically, in the 2000–2006 period, we cannot reject that the total supply response indeed is independent of the supply restrictions.

5.2 The bust period

Turning to the bust period, Table 5 shows the results obtained when we estimate the full system, (8)–(10), using FIML.

Table 5: Bust period model

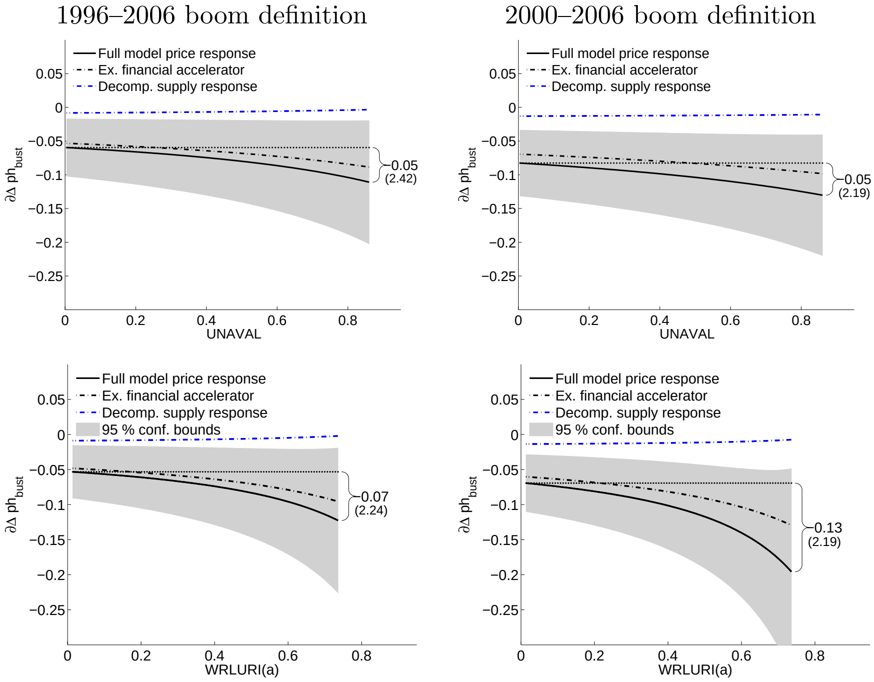
Variables	Boom 1996 – 2006 Δp_{bust}	Boom 2000 – 2006 Δp_{bust}
Δh_{boom}	-0.19 $(-3.55)^{***}$	-0.24 $(-2.01)^{**}$
Δp_{boom}	-0.19 $(-14.54)^{***}$	-0.27 $(-12.67)^{***}$
ΔHH income$_{bust}$	0.69 $(8.68)^{***}$	0.92 $(11.62)^{***}$
Controls		
log pop$_{1996}$	0.10 $(1.73)^{*}$	0.17 $(3.15)^{***}$
pop density$_{1996}$	0.01 (1.01)	0.01 (0.84)
HH income$_{1996}$	-0.01 (-1.43)	-0.01 (-1.50)
unemp$_{1996}$	-1.19 $(-6.53)^{***}$	-0.79 $(-3.86)^{***}$
Diagnostics		
$\sigma_{\Delta p,bust}$	0.070	0.067
$\rho_{\Delta p,boom}$	-0.294	-0.163
$\rho_{\Delta h,boom}$	-0.282	-0.320
$\rho_{\Delta sp,boom}$	-0.328	-0.326
Vector normality test	$\chi^2(6) = 40.160[0.0000]^{***}$	$\chi^2(6) = 28.604[0.0003]^{***}$
Obs.	243	242

Note: The table reports the bust period FIML estimates of the extended boom-boom system defined by (8)–(11). 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 both $\gamma_{\Delta p}$ and $\gamma_{\Delta h}$ are 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 9–11, 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 12 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 12: 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. Again, the financial accelerator effect is most pronounced as the boom reached its height, i.e. when considering the 2000–2006 boom period definition. Generally, when the financial accelerator is accounted for, the difference 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 12, 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. 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.

6 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 of 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 of 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, for the 2000–2006 period, 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 results 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 would do a similar analysis on data for several countries.

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Appendix A: Data

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

MSA name	MSA code	Region	Pop.	WRLURI	UNAVAL
Abilene, TX	10180	South	161.01	0.1	0.02
Akron, OH	10420	Midwest	699.67	-0.01	0.06
Albany, GA	10500	South	166.43	-0.5	0.13
Albany-Schenectady-Troy, NY	10580	Northeast	860.78	-0.09	0.23
Albuquerque, NM	10740	West	869.08	0.37	0.12
Alexandria, LA	10780	South	154.71	-1.68	0.19
Allentown-Bethlehem-Easton, PA-NJ	10900	Northeast	820.37	0.02	0.21
Altoona, PA	11020	Northeast	126.4	0.37	0.36
Amarillo, TX	11100	South	249.26	-0.4	0.04
Ann Arbor, MI	11460	Midwest	350.26	0.79	0.1
Appleton, WI	11540	Midwest	224.07	-0.24	0.18
Asheville, NC	11700	South	416.36	-0.61	0.67
Atlanta-Sandy Springs-Marietta, GA	12060	South	5564.5	0.03	0.04
Atlantic City-Hammonton, NJ	12100	Northeast	272.64	0.61	0.65
Auburn-Opelika, AL	12220	South	138.64	-1.19	0.09
Augusta-Richmond County, GA-SC	12260	South	543.58	-1.09	0.1
Austin-Round Rock-San Marcos, TX	12420	South	1756.54	-0.28	0.04
Bakersfield-Delano, CA	12540	West	817.44	0.36	0.24
Baltimore-Towson, MD	12580	South	2703.67	1.6	0.22
Bangor, ME	12620	Northeast	149.59	0.59	0.19
Barnstable Town, MA	12700	Northeast	220.8	4.31	0.74
Baton Rouge, LA	12940	South	794.41	-0.81	0.34
Beaumont-Port Arthur, TX	13140	South	379.56	-0.64	0.19
Billings, MT	13740	West	156.78	-0.19	0.11
Binghamton, NY	13780	Northeast	244.54	-0.78	0.34
Birmingham-Hoover, AL	13820	South	1138.92	-0.3	0.14
Bismarck, ND	13900	Midwest	107.99	-0.3	0.06
Bloomington-Normal, IL	14060	Midwest	169.8	-0.2	0.01
Boise City-Nampa, ID	14260	West	613.88	-0.46	0.36
Boston-Quincy, MA	14484	Northeast	1937.23	1.79	0.34
Boulder, CO	14500	West	306.47	2.44	0.43
Bremerton-Silverdale, WA	14740	West	242.06	0.57	0.52
Brownsville-Harlingen, TX	15180	South	403.67	-0.96	0.28
Buffalo-Niagara Falls, NY	15380	Northeast	1123.41	-0.31	0.19
Burlington-South Burlington, VT	15540	Northeast	209.03	1.18	0.45
Canton-Massillon, OH	15940	Midwest	407.07	-0.89	0.13
Cape Coral-Fort Myers, FL	15980	South	585.16	-0.15	0.53
Casper, WY	16220	West	75.92	-0.82	0.14
Cedar Rapids, IA	16300	Midwest	257.76	-0.69	0.04
Champaign-Urbana, IL	16580	Midwest	228.3	-0.39	0.01
Charleston, WV	16620	South	305.04	-1.16	0.72
Charleston-North Charleston-Summerville, SC	16700	South	670.98	-0.81	0.6
Charlotte-Gastonia-Rock Hill, NC-SC	16740	South	1784.51	-0.44	0.05
Charlottesville, VA	16820	South	198.34	-0.98	0.22

Continued on next page

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

MSA name	MSA code	Region	Pop.	WRLURI	UNAVAL
Chattanooga, TN-GA	16860	South	528.41	-0.72	0.26
Chicago-Joliet-Naperville, IL	16974	Midwest	8053.67	-0.04	0.4
Chico, CA	17020	West	221.6	0.94	0.35
Cincinnati-Middletown, OH-KY-IN	17140	South	2185.04	-0.46	0.1
Cleveland-Elyria-Mentor, OH	17460	Midwest	2087.47	-0.15	0.4
College Station-Bryan, TX	17780	South	217.44	0.38	0.06
Colorado Springs, CO	17820	West	635.11	0.87	0.22
Columbia, MO	17860	Midwest	168.29	-1.53	0.06
Columbia, SC	17900	South	756.69	-0.76	0.15
Columbus, GA-AL	17980	South	298.39	-0.31	0.06
Columbus, OH	18140	Midwest	1822.86	-0.83	0.02
Corpus Christi, TX	18580	South	418.86	-0.25	0.38
Corvallis, OR	18700	West	83.42	0.07	0.46
Dallas-Plano-Irving, TX	19124	South	4426.54	-0.23	0.09
Davenport-Moline-Rock Island, IA-IL	19340	Midwest	381.09	-0.91	0.05
Dayton, OH	19380	Midwest	832.38	-0.58	0.01
Decatur, AL	19460	South	152.39	-0.99	0.16
Decatur, IL	19500	Midwest	108.03	-1	0.02
Deltona-Daytona Beach-Ormond Beach, FL	19660	South	494.32	0.94	0.61
Denver-Aurora-Broomfield, CO	19740	West	2604.09	0.84	0.17
Des Moines-West Des Moines, IA	19780	Midwest	571.72	-0.84	0.06
Detroit-Livonia-Dearborn, MI	19804	Midwest	1901.88	0.28	0.25
Dothan, AL	20020	South	143.9	-0.94	0.09
Dover, DE	20100	South	159.94	0.32	0.38
Dubuque, IA	20220	Midwest	93.51	-0.96	0.11
Duluth, MN-WI	20260	Midwest	277.57	-0.37	0.34
Elkhart-Goshen, IN	21140	Midwest	200.9	-0.83	0.07
Elmira, NY	21300	Northeast	88.76	-0.77	0.35
EL PASO, TX	21340	South	764.35	0.73	0.05
Erie, PA	21500	Northeast	280.98	-0.63	0.51
Eugene-Springfield, OR	21660	West	353.37	0.34	0.63
Evansville, IN-KY	21780	Midwest	353.23	-1.05	0.09
Fargo, ND-MN	22020	Midwest	204.28	-1.27	0.03
Fayetteville, NC	22180	South	366.11	-0.51	0.16
Fayetteville-Springdale-Rogers, AR-MO	22220	South	473.78	-0.4	0.29
Flagstaff, AZ	22380	West	131.28	-0.42	0.18
Flint, MI	22420	Midwest	419.05	-0.32	0.1
Fort Collins-Loveland, CO	22660	West	303.93	0.57	0.31
Fort Lauderdale-Pompano Beach-Deerfield Beach, FL	22744	South	1779.48	0.72	0.76
Fort Smith, AR-OK	22900	South	294.93	-1.04	0.2
Fort Wayne, IN	23060	Midwest	416.81	-0.84	0.03
Fort Worth-Arlington, TX	23104	South	2168.25	-0.27	0.05
Fresno, CA	23420	West	927.05	1.01	0.13
Gadsden, AL	23460	South	103.84	-0.39	0.17
Gainesville, FL	23540	South	262.28	0.07	0.15
Gary, IN	23844	Midwest	706.18	-0.69	0.32
Glens Falls, NY	24020	Northeast	128.9	-1.6	0.41
Goldsboro, NC	24140	South	114.22	-0.42	0.21
Grand Junction, CO	24300	West	150.31	0.46	0.43
Grand Rapids-Wyoming, MI	24340	Midwest	779.23	0.13	0.09
Great Falls, MT	24500	West	82.31	-0.01	0.18
Greeley, CO	24540	West	260.71	0.25	0.1
Green Bay, WI	24580	Midwest	307.2	0.57	0.23
Greensboro-High Point, NC	24660	South	722.12	-0.3	0.03
Greenville, NC	24780	South	182.85	1.39	0.28
Greenville-Mauldin-Easley, SC	24860	South	649.04	-0.94	0.13
Gulfport-Biloxi, MS	25060	South	241.49	-0.27	0.52
Hagerstown-Martinsburg, MD-WV	25180	South	267.99	0.33	0.19
Harrisburg-Carlisle, PA	25420	Northeast	539.96	0.56	0.24
Hartford-West Hartford-East Hartford, CT	25540	Northeast	1200.69	0.49	0.23
Hickory-Lenoir-Morganton, NC	25860	South	367.44	-0.58	0.21
Houston-Sugar Land-Baytown, TX	26420	South	6010.38	-0.19	0.08
Huntsville, AL	26620	South	415.38	-1.22	0.24
Indianapolis-Carmel, IN	26900	Midwest	1766.2	-0.7	0.01
Jackson, MS	27140	South	544.44	-0.73	0.11
Jackson, TN	27180	South	114.27	-1.13	0.09

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

MSA name	MSA code	Region	Pop.	WRLURI	UNAVAL
Jacksonville, FL	27260	South	1339.45	-0.02	0.47
Janesville, WI	27500	Midwest	160.09	-0.28	0.05
Johnson City, TN	27740	South	198.95	-1.06	0.55
Johnstown, PA	27780	Northeast	143.49	0.44	0.33
Joplin, MO	27900	Midwest	175.99	-1.34	0.05
Kalamazoo-Portage, MI	28020	Midwest	329.18	-0.7	0.1
Kankakee-Bradley, IL	28100	Midwest	113.74	0	0.03
Kansas City, MO-KS	28140	Midwest	2088.56	-0.75	0.06
Kennewick-Pasco-Richland, WA	28420	West	254.38	0.79	0.12
Killeen-Temple-Fort Hood, TX	28660	South	378.63	-1.01	0.03
Knoxville, TN	28940	South	706.13	-0.23	0.39
Kokomo, IN	29020	Midwest	98.08	-0.96	0.02
La Crosse, WI-MN	29100	Midwest	134.17	0.41	0.36
Lafayette, IN	29140	Midwest	199.07	-1.56	0.26
Lake Charles, LA	29340	South	195.33	-1.05	0.49
Lake County-Kenosha County, IL-WI	29404	Midwest	884.05	0.56	0.48
Lakeland-Winter Haven, FL	29460	South	586.51	0.26	0.32
Lancaster, PA	29540	Northeast	511.67	0.29	0.12
Lansing-East Lansing, MI	29620	Midwest	452.36	0.19	0.07
Las Vegas-Paradise, NV	29820	West	1926.17	-0.66	0.32
Lawrence, KS	29940	Midwest	118.1	-0.58	0.06
Lewiston-Auburn, ME	30340	Northeast	106	0.97	0.26
Lexington-Fayette, KY	30460	South	477.77	0.19	0.06
Lima, OH	30620	Midwest	103.8	-0.94	0.02
Lincoln, NE	30700	Midwest	301.3	0.76	0.02
Little Rock-North Little Rock-Conway, AR	30780	South	694.76	-0.85	0.14
Longview, TX	30980	South	209.25	-1.28	0.11
Los Angeles-Long Beach-Glendale, CA	31084	West	9913.37	0.49	0.52
Louisville-Jefferson County, KY-IN	31140	South	1267.65	-0.47	0.13
Lubbock, TX	31180	South	281.9	-0.75	0
Lynchburg, VA	31340	South	249.27	-0.83	0.22
Madison, WI	31540	Midwest	577.9	0.4	0.11
Mansfield, OH	31900	Midwest	123.89	-0.76	0.04
McAllen-Edinburg-Mission, TX	32580	South	761.32	-0.46	0.01
Medford, OR	32780	West	202.06	0.85	0.7
Memphis, TN-MS-AR	32820	South	1310.77	1.18	0.12
Merced, CA	32900	West	246.17	0.64	0.1
Miami-Miami Beach-Kendall, FL	33124	South	2522.21	0.94	0.77
Milwaukee-Waukesha-West Allis, WI	33340	Midwest	1568.53	0.45	0.42
Minneapolis-St. Paul-Bloomington, MN-WI	33460	Midwest	3301.56	0.37	0.19
Mobile, AL	33660	South	414.1	-1.12	0.29
Modesto, CA	33700	West	513.05	0.25	0.14
Monroe, LA	33740	South	175.16	-0.86	0.17
Montgomery, AL	33860	South	367.19	-1.04	0.11
Myrtle Beach-North Myrtle Beach-Conway, SC	34820	South	268.85	-0.83	0.62
Naples-Marco Island, FL	34940	South	321.47	0.29	0.76
Newark-Union, NJ-PA	35084	Northeast	2135.63	0.72	0.31
New Haven-Milford, CT	35300	Northeast	850.12	0.1	0.45
New Orleans-Metairie-Kenner, LA	35380	South	1211.98	-1.24	0.75
New York-White Plains-Wayne, NY-NJ	35644	Northeast	11800	0.63	0.4
Niles-Benton Harbor, MI	35660	Midwest	160.59	-0.42	0.5
Norwich-New London, CT	35980	Northeast	267.84	0.46	0.51
Oakland-Fremont-Hayward, CA	36084	West	2568.38	0.63	0.62
Oklahoma City, OK	36420	South	1246.1	-0.36	0.02
Olympia, WA	36500	West	256.37	0.57	0.38
Omaha-Council Bluffs, NE-IA	36540	Midwest	859.73	-0.56	0.03
Orlando-Kissimmee-Sanford, FL	36740	South	2103.6	0.32	0.36
Oxnard-Thousand Oaks-Ventura, CA	37100	West	811	1.21	0.8
Palm Bay-Melbourne-Titusville, FL	37340	South	536.27	0.52	0.64
Parkersburg-Marietta-Vienna, WV-OH	37620	South	160.83	-0.85	0.39
Pensacola-Ferry Pass-Brent, FL	37860	South	457.06	-0.86	0.53
Peoria, IL	37900	Midwest	379.09	-0.29	0.05
Philadelphia, PA	37964	Northeast	4031.74	1.19	0.1
Phoenix-Mesa-Glendale, AZ	38060	West	4441.09	0.64	0.14
Pine Bluff, AR	38220	South	100.1	-1.76	0.18
Pittsburgh, PA	38300	Northeast	2354.01	-0.01	0.3

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

MSA name	MSA code	Region	Pop.	WRLURI	UNAVAL
Pittsfield, MA	38340	Northeast	128.98	-0.6	0.36
Pocatello, ID	38540	West	91.54	-0.56	0.32
Portland-South Portland-Biddeford, ME	38860	Northeast	517.52	1.56	0.49
Portland-Vancouver-Hillsboro, OR-WA	38900	West	2279.14	0.14	0.38
Port St. Lucie, FL	38940	South	407.92	0.45	0.65
Poughkeepsie-Newburgh-Middletown, NY	39100	Northeast	682.08	-0.14	0.3
Providence-New Bedford-Fall River, RI-MA	39300	Northeast	1601.53	1.88	0.14
Provo-Orem, UT	39340	West	571.47	0.26	0.6
Racine, WI	39540	Midwest	201.05	-0.21	0.54
Raleigh-Cary, NC	39580	South	1161.53	0.57	0.08
Rapid City, SD	39660	Midwest	126.8	-0.74	0.22
Reading, PA	39740	Northeast	409.36	0.55	0.16
Redding, CA	39820	West	181.59	0.03	0.54
Reno-Sparks, NV	39900	West	421.79	-0.31	0.56
Richmond, VA	40060	South	1249.12	-0.3	0.09
Riverside-San Bernardino-Ontario, CA	40140	West	4192.88	0.54	0.38
Roanoke, VA	40220	South	301.83	-0.11	0.39
Rockford, IL	40420	Midwest	354.05	-0.57	0.02
Rocky Mount, NC	40580	South	146.63	-0.52	0.18
Saginaw-Saginaw Township North, MI	40980	Midwest	199.2	-0.17	0.16
St. Cloud, MN	41060	Midwest	190.72	-0.11	0.21
St. Joseph, MO-KS	41140	Midwest	127.32	-1.51	0.06
St. Louis, MO-IL	41180	Midwest	2862.59	-0.68	0.11
Salem, OR	41420	West	401.77	0.41	0.33
Salinas, CA	41500	West	415.06	0.3	0.66
Salt Lake City, UT	41620	West	1149.27	-0.29	0.72
San Antonio-New Braunfels, TX	41700	South	2113.67	-0.26	0.03
San Diego-Carlsbad-San Marcos, CA	41740	West	3088.35	0.4	0.63
San Francisco-San Mateo-Redwood City, CA	41884	West	1805.32	0.74	0.73
San Jose-Sunnyvale-Santa Clara, CA	41940	West	1869.56	0.21	0.64
San Luis Obispo-Paso Robles, CA	42020	West	268.81	1.12	0.66
Santa Barbara-Santa Maria-Goleta, CA	42060	West	410.32	0.87	0.86
Santa Cruz-Watsonville, CA	42100	West	259.49	0.76	0.72
Santa Fe, NM	42140	West	149.66	0.02	0.37
Santa Rosa-Petaluma, CA	42220	West	477.48	1.32	0.63
Savannah, GA	42340	South	351.62	-0.52	0.6
Scranton-Wilkes-Barre, PA	42540	Northeast	549.61	0.01	0.29
Seattle-Bellevue-Everett, WA	42644	West	2652.24	0.93	0.44
Sherman-Denison, TX	43300	South	121.26	-1.01	0.07
Sioux Falls, SD	43620	Midwest	242.79	-0.96	0.03
South Bend-Mishawaka, IN-MI	43780	Midwest	316.72	-1.24	0.11
Spokane, WA	44060	West	475	0.69	0.27
Springfield, MO	44180	Midwest	435.61	-0.75	0.07
State College, PA	44300	Northeast	146.8	0.77	0.12
Stockton, CA	44700	West	680.72	0.59	0.12
Sumter, SC	44940	South	104.62	-0.9	0.23
Syracuse, NY	45060	Northeast	647.12	-0.54	0.18
Tacoma, WA	45104	West	806.2	1.42	0.37
Tampa-St. Petersburg-Clearwater, FL	45300	South	2764.21	-0.22	0.42
Terre Haute, IN	45460	Midwest	169.88	-1.39	0.05
Toledo, OH	45780	Midwest	670.98	-0.36	0.19
Topeka, KS	45820	Midwest	231.79	-0.94	0.05
Trenton-Ewing, NJ	45940	Northeast	367.76	1.75	0.12
Tucson, AZ	46060	West	1030.15	1.41	0.23
Tulsa, OK	46140	South	941.14	-0.78	0.06
Tyler, TX	46340	South	208.13	0.16	0.1
Utica-Rome, NY	46540	Northeast	293.74	-0.86	0.18
Vallejo-Fairfield, CA	46700	West	407.9	0.86	0.49
Vineland-Millville-Bridgeton, NJ	47220	Northeast	158.71	1.42	0.36
Virginia Beach-Norfolk-Newport News, VA-NC	47260	South	1678.21	-0.2	0.6
Visalia-Porterville, CA	47300	West	436.96	0.46	0.19
Washington-Arlington-Alexandria, DC-VA-MD-WV	47894	South	4354.77	0.25	0.14
Waterloo-Cedar Falls, IA	47940	Midwest	166.19	-0.84	0.03
Wausau, WI	48140	Midwest	132.22	0.18	0.12
West Palm Beach-Boca Raton-Boynton Beach, FL	48424	South	1289.89	0.31	0.64
Wheeling, WV-OH	48540	South	144.3	-1.34	0.43

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

MSA name	MSA code	Region	Pop.	WRLURI	UNAVAL
Wichita, KS	48620	Midwest	621.82	-1.18	0.02
Wichita Falls, TX	48660	South	147.29	-0.59	0.03
Wilmington, DE-MD-NJ	48864	South	706.15	0.3	0.15
York-Hanover, PA	49620	Northeast	432.05	1.2	0.12
Youngstown-Warren-Boardman, OH-PA	49660	Midwest	559.39	-0.22	0.11
Yuba City, CA	49700	West	166.06	0.2	0.14
Yuma, AZ	49740	West	200.64	-0.61	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. We have therefore used the individual level data to construct several measures for lending practices at an MSA level. 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.[24] 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.[25] We allow some extreme observations, but set a cut-off at 1% of the loans.[26] 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

[24]The procedure we follow to leave out the small business loans, is to drop all loans where information on sex and race of both the applicant and the co-applicant is missing, which is required by the reporting institution if the borrower is not a human being.

[25]Information on the list for validity and syntactical edits is provided here http://www.ffiec.gov/hmda/edits.htm.

[26]Detailed information on the error check list and how we implemented this is available upon request.

(the respondent ID).[27] 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 multiple 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 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 addition, these data have an intrinsic value. The Piggybacks are usually used to circumvent private mortgage insurance (PMI) where more than 80% of the housing purchase is financed by borrowing, and could be used in future research.

[27]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.

Appendix C: 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 (11)) is given by:

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

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

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:

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

The extended model

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

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

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

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

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:

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

Appendix D: The analytical expressions for the response functions

The baseline model

In the baseline model (confer (C.1) – (C.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:

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

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

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

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 (11)) are given as:

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

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

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

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

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 E: 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:

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

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 4, and to test the supply restriction irrelevance hypothesis.

Standard error for boom price response

From (D.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:

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

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

Standard errors for boom supply response

From (D.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:

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

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

Standard errors for bust price response

From (D.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:

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

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 (E.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 (D.4)–(D.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 5.

Standard error for boom price response

From (D.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:

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

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

Standard errors for boom supply response

From (D.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 (E.1) to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.

Standard errors for boom subprime response

From (D.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 (E.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:

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

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 (E.1) is used to calculate the variance of the function $G(\theta^{\Delta h^{Boom}})$.