Federal Reserve Bank of Dallas

Land Price Dynamics and Macroeconomic Fluctuations with Imperfect Substitution in Real Estate Markets

---

J. Scott Davis, Kevin X.D. Huang and Ayse Sapci

Globalization Institute Working Paper 401 September 2020
(Revised June 2021)

Research Department

https://doi.org/10.24149/gwp401r1

Land Price Dynamics and Macroeconomic Fluctuations with Imperfect Substitution in Real Estate Markets*

J. Scott Davis†, Kevin X.D. Huang‡ and Ayse Sapci§

First Draft: September 7, 2020
This Draft: May 18, 2021

Abstract

The collateral channel, whereby an increase in residential house prices leads to an increase in commercial property prices, loosening firm borrowing constraints and leading to higher firm investment, is weaker when residential and commercial real estate are imperfect substitutes. We first show in a reduced form regression with firm level data that the strength of local zoning regulations has a negative effect on the estimated increase in firm investment following an increase in local residential real estate prices. We then modify the DSGE model of the collateral channel in Liu, Wang, and Zha (2013) to allow imperfect substitutability between residential and commercial land. With Bayesian estimation and U.S. data, we estimate that the elasticity of substitution between the two types of land is 0.88. Variance decompositions and impulse responses show that the strength of the collateral channel linking house prices and investment is weaker when the two types of land are imperfect substitutes.

JEL Codes: R10; R30; E30

Keywords: Commercial real estate; residential real estate; housing demand shock; collateral channel

* We would like to thank Zheng Liu and David Thesmar for many helpful comments and suggestions. We would also like to thank Andrew Johnson for excellent research assistance. The views presented here are those of the authors and do not necessarily represent the views of the Federal Reserve Bank of Dallas or the Federal Reserve System.

† Corresponding author: J. Scott Davis, Federal Reserve Bank of Dallas, email: scott.davis@dal.frb.org.

‡ Kevin X.D. Huang, Vanderbilt University, email: kevin.huang@vanderbilt.edu.

§ Ayse Sapci, Utah State University, email: ayse.sapci@usu.edu.

1 Introduction

This paper asks whether increases in residential property prices lead to an increase in business investment through the collateral channel. Liu et al. (2013) (LWZ hereafter) estimate a Bayesian dynamic stochastic general equilibrium (DSGE) model using U.S. aggregate data and argue that a housing demand shock is a major driver of fluctuations in output and investment. Land is used for both housing and an input into production. Land owned by entrepreneurs can serve as collateral, so a positive housing demand shock will push up the price of land, raising the value of collateral for entrepreneurs. Through this collateral channel, a housing demand shock allows entrepreneurs to increase their borrowing and investment.[1]

In this paper, we argue that the strength of this collateral channel depends on the substitutability of residential and commercial real estate. For an increase in local residential real estate prices or a housing demand shock to affect the value of a firm's collateral relies on the fact that residential and commercial real estate are substitutable and thus an increase in residential real estate prices is associated with an increase in commercial real estate prices. LWZ model residential and commercial real estate as perfect substitutes. But as we report in the next section, the correlation between aggregate residential and commercial real estate prices in the U.S. is 0.64, and this masks the fact that this correlation is low or even negative in some states like Connecticut and Ohio with strong zoning or land use restrictions while this correlation is close to one in some states like Texas and Oklahoma with weak zoning or land use restrictions.[2]

Using cross-state heterogeneity in the strength of zoning and land use restrictions as a

[1] Iacoviello and Neri (2010) show that these housing demand shocks explain a large proportion of the fluctuations in residential real estate prices, and Liu et al. (2019) provide a microfoundation for this housing demand shock through a heterogenous agent model with a credit supply shock. Guerrieri and Iacoviello (2017) argue that the effect of housing collateral on the tightness of the borrowing constraint is asymmetric and when the constraint is occasionally binding an increase in collateral values has much less effect than a fall in collateral values.

[2] This ranking of states by the strength of zoning and land-use restrictions is taken from the work of Daniel Shoag and co-authors (see e.g. Shoag and Muehlegger (2015), Ganong and Shoag (2017), and Shoag and Russell (2018)) and will be discussed in the next section.

proxy for cross-state heterogeneity in the substitutability of residential and commercial real estate, we ask how imperfect substitution between residential and commercial real estate affects the strength of the collateral channel.

Chaney et al. (2012) empirically measure the collateral channel using firm level data, and a reduced form estimation approach. They compare the effect of a change in local real estate prices on the investment rates of local property-owning and non-property owning firms, and they argue that an increase in local real estate prices that increases firm collateral by $1 leads to a $0.06 increase in corporate investment for local firms.[3] Other papers find similar evidence in the international data. Using data from Japanese firms, Gan (2007) finds that for every 10 percent drop in collateral value, the investment rate of an average firm is reduced by 0.8 percentage points, while Kleiner (2015) finds evidence of a similar channel in the UK, and Kaas et al. (2016) in France. Adelino et al. (2015) argue that this channel is very important for small business lending, and argue that in the US, local house price fluctuations lead to fluctuations in employment in small businesses that is not seen in large firms in the same area and industry. In a reduced form estimation Catherine et al. (2018) first find that a $1 increase in real estate value leads to a significant $0.04 increase in investment in the US. However, examining data from Chinese firms, Wu et al. (2013) do not find evidence of the same collateral channel from real estate to firm investment in China, and they argue that one reason for this is the fact that state-owned firms do not appear to rely on land collateral values to obtain financing.

First, as motivation, we present a simple extension of the estimation in Chaney et al. (2012). In their original empirical specification the variable of interest is the market value

[3] Note that this is distinct from the residential collateral channel explored by Mian and Sufi (2011) and Mian et al. (2013) and others. In this channel, a rise in residential property prices leads to an increase in household net worth and an increase in consumer spending for credit constrained households. In Chaney et al. the increase in housing demand and house prices leads to an increase in commercial real estate prices, which leads to an increase in investment spending by credit constrained firms. Chaney et al. are able to isolate this channel in the data by examining how investment rates following an increase in local house prices differ between local property owning and non-property owning firms.

of a firm's real estate holdings, and they measure the effect of the value of real estate on the investment rates of land owning firms. The market value of a firm's real estate is proxied by local residential property prices, and thus the empirical strategy is based on measuring the effect of an increase in local residential real estate prices on the investment rates of local land owning firms.

However, this assumes that any change in residential real estate prices is associated with a similar change in commercial real estate prices and thus the value of a firm's collateral. If residential and commercial real estate are close substitutes this should indeed be the case, but if they are not, the channel from a change in residential property prices to a change in the value of a firm's collateral is weaker. To test this, using their same data and specification, we simply interact local residential real estate prices with measures of the strength of zoning or land use restrictions. We take the strength of local zoning or land use restrictions to be a proxy for the ease at which a piece of land can be converted from residential to commercial use, and vice versa, and thus whether a rise in residential property prices will spill over into higher commercial property prices. While Chaney et al. find that on average in the U.S., a \$1 increase firm collateral resulting from an increase in local residential real estate prices leads to a \$0.06 increase in firm investment, with this simple extension we find that this increase is only around \$0.04 in states with the strongest zoning regulations while around \$0.08 in states with the weakest zoning regulations.

With this empirical finding as a motivation, we then consider the model from LWZ, but instead of forcing residential and commercial real estate to be perfect substitutes, we allow the two types of land to be imperfect substitutes. We use the same model and data as LWZ, but with one modification, residential and commercial land are imperfect substitutes with an elasticity of substitution between them. Using Bayesian estimation, we estimate the model, including the elasticity of substitution parameter, and we estimate that this elasticity is around 0.88.

To examine the macroeconomic effects of this imperfect substitution, we then compare the variance decomposition and impulse response results from two versions of the model. One where parameters of the model, including the land elasticity of substitution parameter, are all estimated (the imperfect substitutes model). And one where the parameters of the model are estimated but we impose that the land elasticity of substitution goes to infinity (the perfect substitutes model). Variance decompositions and impulse responses show that allowing for imperfect substitution reduces the effect of an increase in residential land prices on macro variables like investment and output.

Gyourko (2009) compares commercial and residential real estate markets and argues that while there are important differences between the two, the behavior of prices is very similar in the two markets. Bouchouicha and Ftiti (2012) argue that there is a common trend that drives prices in both the residential and commercial real estate markets.

While in many cases residential structures can't be converted to commercial structures and vice versa, the land beneath that structure certainly can be converted from residential to commercial use if the law allows. Davis and Heathcote (2007) decompose the value of the U.S. residential housing stock into the value of structures and the value of underlying land. They show that at the business cycle frequency, the value of the underlying land is 3 times more volatile than the value of the structure, and thus at the business cycle frequency the main driver of the value of real estate is not the non-substitutable structure on top, but the (potentially) substitutable land underneath. Davis et al. (2017) and Davis et al. (2021) use detailed data on either construction costs or appraisals to construct land price indices at the local level and also find that the value of the underlying land is the most volatile component of the price of a piece of real estate Davis (2009) performs a similar exercise looking at the value of underlying land by use, and argues that the price of residential land generally performs very differently than the price of commercial land. Sirmans and Slade (2012) and Nichols et al. (2013) use transactions data to construct residential and commercial land price indices, and they show while the two exhibited many of the same properties during the run up of the housing bubble in the early 2000's, during the peak bubble years the two land prices began to diverge and residential land prices climbed to a higher peak and had a greater fall.

The theoretical model in this paper is an extension of the collateral channel model in LWZ. Other extensions to LWZ include Liu et al. (2016) who incorporate a labor search and matching framework into the same model to explain the observed negative correlation between land prices and unemployment and the fact that housing demand shocks have a large effect on unemployment volatility. Bahaj et al. (2016) allow entrepreneurs to use the residential housing owned by the entrepreneur as collateral or business investment, and Bahaj et al. (2020) show that among UK firms, a £1 increase in the home values of a firm's directors leads to a £0.03 increase in that firm's investment spending, although they find this effect only holds in smaller firms where the value of a director's personal property is sizable compared to the firm's assets.[4] In another extension of the LWZ framework, Gong et al. (2017) alter the household utility function to allow for a substitutability between consumption and leisure. This reduces the labor supply elasticity and the amplification effect of the credit constraint triggered by the housing demand shock on key macroeconomic variables is greatly reduced.

This paper will proceed as follows. Section 2 presents some empirical evidence to motivate our claim that commercial and residential real estate should be treated as imperfect substitutes. We present some data on how the correlation between commercial and residential real estate prices varies across cities in the U.S., and then we present a simple extension of the reduced form empirical model in Chaney et al. to allow for cross-state heterogeneity in zoning and land-use regulations. The theoretical model is presented in Section 3. This is identical to the model in LWZ except the land market clearing condition is modified to allow the two types of land to be imperfect substitutes. The details of the Bayesian estimation of this model are presented in Section 4. The results from this model are presented in Section

[4] Schmalz et al. (2017) compare the effect of local house price differences on entrepreneurial activity between home owners and renters and find additional evidence for this channel where entrepreneurs use their own houses as collateral for business loans.

5. Finally, Section 6 concludes.

2 Evidence of imperfect substitution in the data

In this section we present some empirical evidence of how cross-state heterogeneity in the strength of zoning regulations can affect the strength of the collateral channel that links increases in residential real estate prices to increases in firm investment. We begin by presenting some simple scatter plot regressions that show that cross-state heterogeneity in the strength of zoning regulations has an effect on cross-state heterogeneity in the correlation between residential and commercial real estate prices. We then discuss how the estimation strategy in Chaney et al. can be extended to take account of cross-state heterogeneity in zoning and land-use regulations.

2.1 Zoning Regulations and the Correlation between Commercial and Residential Real Estate Prices

Residential and commercial real estate are not perfect substitutes. When the S&P Case Shiller residential price series and the Federal Reserve Board's commercial real estate price index are both detrended by the core CPE deflator, the correlation between the two series over 1975:Q1 to 2010:Q4 is 0.64.

This imperfect substitutability could be due to any number of factors. One potential candidate is zoning regulations which impose legal barriers to the conversion of a plot of land from residential to commercial use. At the city level, we collect data on commercial (industrial use) real estate prices from CBRE and residential real estate prices from the Federal Housing Administration. With the available data we can construct a balanced panel of these two series for 51 U.S. cities from 1994:Q1 to 2018:Q4.[5] When both are detrended by

[5] The 51 cities are: Albuquerque, Atlanta, Austin, Baltimore, Boston, Charlotte, Chicago, Cincinnati,

the core CPE deflator, the cross-city mean correlation between commercial and residential real estate prices is 0.66. The median is 0.73 and the 25th and 75th percentiles are 0.60 and 0.86.

This considerable heterogeneity in correlation across U.S. cities can be compared to state level heterogeneity in zoning restrictions. U.S. states can be ranked 1 to 50 according to the strength of zoning or land-use regulations. Quantifying zoning regulations across cities is difficult, since many types of zoning or land-use regulations exist. To rank the states we use a data set from the work of Daniel Shoag and co-authors (e.g. Shoag and Muehlegger (2015), Ganong and Shoag (2017), and Shoag and Russell (2018)) which counts the number of state supreme or appellate court decisions that include the words "land use" or "zoning". While of course this measure is imperfect, it does capture the number of times zoning or land use cases appear in a state's courts, and thus is a reasonable proxy for the number and strength of zoning or land use regulations in that state.[6]

In a scatter plot we can plot the city level correlation between residential and commercial real estate against the state level zoning or land use regulations rank. These scatter plots are presented in Figure 1. The coefficient of the trend line in each scatter plot is about 0.008, implying that as the state's zoning rank increases by 1 (meaning zoning or land use regulations become less restrictive) the correlation between residential and commercial real estate increases by about 0.008, which is highly significant in both scatter plots. The intercept is around 0.40, and thus all else equal, a city in a state with the most restrictive zoning or land use regulations (Ohio) should have a correlation of around 0.40 and a city in a state with the least restrictive regulations (Oklahoma) should have a correlation of 0.80. The

Cleveland, Columbus, Dallas, Denver, Detroit, Fort Lauderdale, Fort Worth, Hartford, Houston, Indianapolis, Jacksonville, Kansas City, Las Vegas, Los Angeles, Memphis, Miami, Minneapolis, Nashville, New York, Newark, Oakland, Orange County, Orlando, Philadelphia, Phoenix, Pittsburgh, Portland, Raleigh, Riverside, Sacramento, Salt Lake City, San Diego, San Francisco, San Jose, Seattle, St. Louis, Stamford, Tampa, Tucson, Vallejo, Ventura, West Palm Beach, Wilmington.

[6]As shown by Ganong and Shoag (2017), the ordering of states from least restrictive to most restrictive using this measure based on court decisions is very similar to an ordering based on the land use survey results from Gyourko et al. (2008) and Gyourko et al. (2019).

R^2 from each of these regressions indicates that cross-state heterogeneity in zoning or land use regulations explains about 20% of cross-city heterogeneity in the correlation between commercial and residential real estate.[7]

2.2 Reduced Form Empirical Model

First we briefly describe the estimation strategy in Chaney et al., and our modification to account for cross-state heterogeneity in zoning and land-use restrictions. Here we give a summary of the methodology and data used to produce the main results in Chaney et al., for more details and for robustness checks, we refer the reader to the original paper and their Additional Materials on the AER website.

Chaney et al. collect annual accounting data from U.S. listed firms over the years 1993-2007. They collect data from COMPUSTAT firms active in 1993 with non-missing total assets. They require that a firm in the sample has data for every consecutive year that they appear in the sample, and that the firm's data be available for 3 consecutive years. With this firm-level data they measure how changes in a firm's real state value affects firm investment:

$$INV_{i,t} = \alpha_i + \delta_t + \beta RE\_Val_{i,t} + \gamma P_t^l + controls_{i,t} + \varepsilon_{i,t} \tag{1}$$

where $INV_{i,t}$ is the ratio of investment to lagged PPE by firm i in year t, $RE\_Val_{i,t}$ is the ratio of the value of the firm's real estate holdings in year t to lagged PPE, P_t^l is local residential real estate prices in location l, whether the state or the MSA where firm i is located. Controls include firm specific factors like ROA, total assets, firm age, 2-digit SIC dummies, and the state dummies all interacted with local real estate prices P_t^l. Since they are generally found to be significant predictors of firm level investment in the literature,

[7] The cities with the lowest correlation are Cleveland, OH and Wilmington, DE at -0.16 and -0.18. The city with the highest correlation is Houston, TX at 0.98. Ohio is the most restrictive state for both zoning and land use regulations, and Deleware is the 3rd most restrictive state for land use and the 6th for zoning. Texas is the 49th most restrictive state for both, and Houston is the only major city in the U.S. without city zoning regulations.

Chaney et al. also include a ratio of a firm's cash flow in year t to lagged PPE and the market/book ratio in year t as controls.[8]

The value of a firm's real estate holdings can be estimated using COMPUSTAT data on a firm's property and the accumulated value of depreciation. With this balance sheet data Chaney et al. can calculate the market value of a firm's property in the year it was purchased. Then in all subsequent years the market value at the time of purchase is inflated by the local residential real estate price index to approximate the current market value of a firm's property. In that way $RE\_Val_{i,t}$ is a scalar describing firm i's initial real estate holdings interacted with local real estate prices (and then all normalized by lagged PPE).[9]

Local real estate prices are given by the Home Price Index from the Office of Federal Housing Enterprise Oversight. This enters the regression both as a stand alone variable and as part of $RE\_Val_{i,t}$ and is available at the state and the MSA level. We report the effects of both. In mechanical terms, the estimated coefficient $\hat{\beta}$ measures the effect of an increase in local residential real estate prices on the investment rates of local land holding firms. This coefficient should be a reduced form combination of two factors. First, whether an increase in local residential real estate prices translates into an increase in firm collateral, and second, whether an increase in firm collateral leads to an increase in firm investment. Chaney et al. address the second factor, and show that the link between collateral values and firm investment is stronger among firms that would be classified as credit constrained. Here we address the first of these factors, whether a change in local residential real estate prices translates into a change in the value of a firm's real estate collateral. This will depend

[8] Mian and Sufi (2014) show that the decline in house prices prior to the 2008 crisis had a greater effect on the employment of local non-traded goods firms than traded goods firms. Thus, the Chaney et al. regression specification controls for the industry (designated by 2-digit SIC) interacted with local house prices to make sure that the coefficient of real estate value is not biased if real estate owning firms tend to be more highly concentrated in non-traded sectors.

[9] Specifically, the balance sheet reports the value of a firm's property at cost, not market value. Chaney et al. use balance sheet data on accumulated depreciation to calculate the average age of a firm's real estate (assuming depreciable life of 40 years). The value of the firm's real estate at cost is the approximate market value in the year the property was acquired. This market value in the past is then inflated by the local real estate price index to approximate the current market value of a firm's property.

on the substitutability of residential and commercial real estate, and thus whether a change in residential real estate prices is associated with a similar change in commercial real estate prices.

Thus we modify the original Chaney et al. model to allow for cross-state heterogeneity in zoning or land use regulations. To the regression model in equation (1) we add the term $Rank_l \times RE\_Val_{i,t}$, the interaction between $RE\_Val_{i,t}$ and a state's rank in the strength of zoning or land use regulations, as presented earlier in Figure 1. This new interaction term has a coefficient of λ , and thus the effect of $RE\_Val_{i,t}$ on firm investment in the state with the strongest zoning regulations (Ohio) is $\hat{\beta} + 1 \times \hat{\lambda}$, while the effect of $RE\_Val_{i,t}$ on firm investment in the state with the weakest zoning regulations (Oklahoma) is $\hat{\beta} + 50 \times \hat{\lambda}$, where year to year changes in $RE\_Val_{i,t}$ are proxied by year to year changes in the price of residential real estate.

2.3 Results

The results from this replication and then modification of Chaney et al. are presented in Table 1. The first two columns present the results from the regression specification in columns 3 and 4 of table 5 of Chaney et al. The first column presents the results where the market value of a firm's real estate, RE_Val, is approximated using the residential real estate index at the state level. The second column presents the results where the market value of a firm's real estate is approximated using the residential real estate index at the MSA level. The headline finding of Chaney et al., that a \$1 increase in the value of a firm's collateral leads to a \$0.06 increase in firm investment is shown in the coefficients of RE_Val^{State} or RE_Val^{MSA} in the first two columns. Columns 3 and 4 then modify the regression specification in columns 1 and 2 by adding RE_Val interacted with the state's rank in the strength of zoning regulations, $Rank^{Zone}$. Columns 5 and 6 do the same except the state's rank in zoning regulations is replaced by the state's rank in land use regulations,

$Rank^{Land}$.

The results in columns 3 and 4 show that the estimated coefficient of the interaction term $RE\_Val \times Rank^{Zone}$ is positive and statistically significant. This implies that the same increase in local residential real estate prices has a greater effect on firm investment in a state with weaker zoning regulations. The estimated coefficient of RE_Val falls to about 0.04 when the interaction term is included in the regression and the coefficient of the interaction term $RE\_Val \times Rank^{Zone}$ is .00065. This implies that while a \$1 increase in local residential real estate prices is associated with a \$0.06 increase in firm investment on average in the U.S., this increase is only \$0.04 in the state with the strongest zoning regulations and is as high as \$0.075 in the state with the weakest zoning regulations.

Columns 5 and 6 repeat the same exercise but use state rankings in land use regulation instead of state rankings in zoning regulations. The same results hold.

3 The Model

In this DSGE model the economy consists of three agents: a representative household, a representative entrepreneur and a representative property developer. Households save and entrepreneurs borrow while facing a collateral constraint that binds in equilibrium. Households hold land for residential purposes while entrepreneurs hold land as an input into the production function. Property developers convert land from residential to commercial use or vice versa.

3.1 The Representative Household

The representative household maximizes:

$$E\sum_{t=0}^{\infty}\beta^t A_t \left\{\log(C_{h,t} - \gamma_h C_{h,t-1}) + \varphi_t \log L_{h,t} - \psi_t N_{h,t}\right\} \tag{2}$$

where $C_{h,t}$ is household consumption, $L_{h,t}$ is housing services, $N_{h,t}$ is the household's labor input, β is the subjective discount factor, γ_h is the degree of household habit persistence, A is a shock to the household's patience factor (intertemporal preference shock), φ_t is a shock to household's taste for housing services (housing demand shock), ψ_t is a shock to labor supply.

The three shocks, the preference shock, the housing demand shock, and the labor supply shock follow the processes:

$$\begin{aligned} A_t &= A_{t-1}(1+\lambda_{a,t}) \\ \ln \lambda_{a,t} &= (1-\rho_a)\ln \bar{\lambda}_a + \rho_a \ln \lambda_{a,t-1} + \sigma_a \varepsilon_{a,t} \end{aligned} \tag{3}$$

where $\rho_a \in (-1,1)$ is the persistence parameter, σ_a is the standard deviation of the innovation, $\varepsilon_{a,t}$ is an iid standard normal process.

$$\ln \varphi_t = (1-\rho_\varphi)\ln \bar{\varphi} + \rho_\varphi \ln \varphi_{t-1} + \sigma_\varphi \varepsilon_{\varphi,t} \tag{4}$$

where $\rho_\varphi \in (-1,1)$ is the persistence parameter, $\sigma_\varphi > 0$ is the standard deviation of the innovation, $\varepsilon_{\varphi,t}$ is an iid standard normal process.

$$\ln \psi_t = (1-\rho_\psi)\ln \bar{\psi} + \rho_\psi \ln \psi_{t-1} + \sigma_\psi \varepsilon_{\psi,t} \tag{5}$$

where $\rho_\psi \in (-1,1)$ is the persistence parameter, $\sigma_\psi > 0$ is the standard deviation of the innovation, $\varepsilon_{\psi,t}$ is an iid standard normal process.

The household's budget constraint is given by:

$$C_{h,t} + q_{h,t}\left(L_{h,t} - L_{h,t-1}\right) + \frac{S_t}{R_t} \leq w_t N_{h,t} + S_{t-1} + \Pi_t \tag{6}$$

where $q_{h,t}$ is the relative price of residential land in consumption units, S_t is the household's purchase in period t of the loanable bond that pays off one unit of consumption good in all states of nature in period t+1, R_t is the gross real interest rate, w_t is the real wage and Π_t are the profits from the land developer that are returned lump-sum to the household. The role of the property developer will be discussed more later in this section. The demand side of the market for loanable bonds found through the first order condition of the household's problem with respect to S_t:

$$\frac{1}{R_t} = E_t \left(\beta(1 + \lambda_{a,t+1}) \frac{\mu_{h,t+1}}{\mu_{h,t}} \right) \tag{7}$$

where $\mu_{h,t}$ is the household's marginal utility of consumption.

3.2 The Representative Entrepreneur

The representative entrepreneur maximizes:

$$E \sum_{t=0}^{\infty} \beta^t \left[\log(C_{e,t} - \gamma_e C_{e,t-1}) \right] \tag{8}$$

where $C_{e,t}$ is entrepreneur consumption, and γ_e is the entrepreneur habit persistence parameter.

The entrepreneur owns a firm which produces output Y_t sold in a perfectly competitive market using the following production function:

$$Y_t = Z_t \left[L_{e,t-1}^{\phi} K_{t-1}^{(1-\phi)} \right]^{\alpha} N_{e.t}^{(1-\alpha)} \tag{9}$$

where Z_t is total factor productivity, K_{t-1} is the capital input, $N_{e.t}$ is the labor input, and $L_{e,t-1}$ is the land input.

Total factor productivity, Z_t, is composed of a permanent component Z_t^p and a transitory component ν_t :

$$Z_t = Z_t^p \nu_{z,t} \tag{10}$$

where the permanent component follows:

$$\begin{aligned} Z_t^p &= Z_{t-1}^p \lambda_{z,t} \\ \ln \lambda_{z,t} &= (1-\rho_z)\ln \bar{\lambda}_z + \rho_z \ln \lambda_{z,t-1} + \sigma_z \varepsilon_{z,t} \end{aligned} \tag{11}$$

where $\bar{\lambda}_z$ is the steady state growth rate of Z_t^p, $\rho_z \in (-1,1)$ is the persistence parameter, σ_z is the standard deviation of the innovation, $\varepsilon_{z,t}$ is an iid standard normal process. And the transitory component follows:

$$\ln \nu_{z,t} = \rho_{\nu_z} \ln \nu_{z,t-1} + \sigma_{\nu_z} \varepsilon_{\nu_z,t} \tag{12}$$

where $\rho_{\nu_z} \in (-1,1)$ is the persistence parameter, σ_{ν_z} is the standard deviation of the innovation, $\varepsilon_{\nu_z,t}$ is an iid standard normal process.

Physical capital is accumulated according to:

$$K_t = (1-\delta)K_{t-1} + \left[1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2\right] I_t \tag{13}$$

where I_t is physical capital investment, $\bar{\lambda}_I$ is the steady state growth of investment, δ the capital depreciation parameter, and $\Omega > 0$ is the investment adjustment cost parameter.

The entrepreneur's budget constraint is given by:

$$C_{e,t} + q_{e,t}\left(L_{e,t} - L_{e,t-1}\right) + B_{t-1} = Z_t \left[L_{e,t-1}^{\phi} K_{t-1}^{(1-\phi)}\right]^{\alpha} N_{e.t}^{(1-\alpha)} - \frac{I_t}{Q_t} - w_t N_{e,t} + \frac{B_t}{R_t} \tag{14}$$

where $q_{e,t}$ is the relative price of residential land in consumption units, and B_t is the representative entrepreneur's debt, and Q_t is an investment-specific technology shock.

The investment-specific technology shock Q_t is composed of a permanent component Q_t^p and a transitory component $\nu_{q,t}$:

$$Q_t = Q_t^p \nu_{Q,t} \tag{15}$$

where the permanent component follows:

$$\begin{aligned} Q_t^p &= Q_{t-1}^p \lambda_{Q,t} \\ \ln \lambda_{Q,t} &= (1-\rho_Q)\ln \bar{\lambda}_Q + \rho_Q \ln \lambda_{Q,t-1} + \sigma_Q \varepsilon_{Q,t} \end{aligned} \tag{16}$$

where $\bar{\lambda}_Q$ is the steady state growth rate of Q_t^p, $\rho_Q \in (-1,1)$ is the persistence parameter, σ_Q is the standard deviation of the innovation, $\varepsilon_{Q,t}$ is an iid standard normal process. And the transitory component follows:

$$\ln \nu_{Q,t} = \rho_{\nu_Q} \ln \nu_{Q,t-1} + \varepsilon_{\nu_Q,t} \tag{17}$$

where $\rho_{\nu_Q} \in (-1,1)$ is the persistence parameter, σ_{ν_Q} is the standard deviation of the innovation, $\varepsilon_{\nu_Q,t}$ is an iid standard normal process. Given the growth rate of the permanent component of the investment-specific technology shock, $\bar{\lambda}_Q$, and the growth rate of the permanent component of total factor productivity, $\bar{\lambda}_Z$, the growth rate of per capita output g_γ can be derived from the stationary distribution of the model where $g_\gamma = \bar{\lambda}_Z^{\frac{1}{1-(1-\phi)\alpha}} \bar{\lambda}_Q^{\frac{(1-\phi)\alpha}{1-(1-\phi)\alpha}}$.

The entrepreneur is subject to a collateral constraint that the total values of their debt cannot be larger than a fraction of the expected value of their land and physical capital assets:

$$B_t \leq \theta_t E_t \left[q_{e,t+1} L_{e,t} + q_{k,t+1} K_t \right] \tag{18}$$

where $q_{k,t+1}$ is the shadow price of capital in consumption units. Since the price of new capital is $\frac{1}{Q_t}$, Tobin's q in the model is given by $q_{k,t} Q_t$ which is the ratio of the value of installed capital to the price of new capital.

If the entrepreneur fails to pay the debt, the creditor can seize the land and the accumulated capital. Since it is costly to liquidate the seized land and capital stock, the creditor can recoup up to a fraction θ_t of the total value of collateral assets, where:

$$\ln \theta_t = (1 - \rho_\theta) \ln \bar{\theta} + \rho_\theta \ln \theta_{t-1} + \sigma_\theta \varepsilon_{\theta,t} \tag{19}$$

where $\bar{\theta}$ is the steady state value of θ_t, $\rho_\theta \in (0, 1)$ is the persistence parameter, σ_θ is the standard deviation, and $\varepsilon_{\theta,t}$ is an iid standard normal process.

The supply side of the market for loanable bonds is given by:

$$\frac{1}{R_t} = \beta E_t \frac{\mu_{e,t+1}}{\mu_{e,t}} + \frac{\mu_{b,t}}{\mu_{e,t}} \tag{20}$$

where $\mu_{e,t}$ is the entrepreneur's marginal utility of consumption and $\mu_{b,t}$ is the multiplier on the entrepreneur's collateral constraint.

3.3 The Representative Property Developer

Households hold residential land and entrepreneurs hold commercial land, and the representative property developer converts the land from one use to another, and thus sets the relative prices of the two types of land. Assume that the property developer's firm is owned by the household, and as we see from the household's budget constraint in (6), any profit from the property developer is simply returned lump-sum to the household, where:

$$\Pi_t = q_{h,t}\left(L_{h,t} - L_{h,t-1}\right) + q_{e,t}\left(L_{e,t} - L_{e,t-1}\right) \tag{21}$$

The property developer's production function, which determines the rate which they can convert land from one use to another, is given by the following:

$$\left[\left(\frac{\bar{L}_e}{\bar{L}}\right)^{-\frac{1}{\lambda}}\left(L_{e,t}\right)^{\frac{1+\lambda}{\lambda}} + \left(\frac{\bar{L}_h}{\bar{L}}\right)^{-\frac{1}{\lambda}}\left(L_{h,t}\right)^{\frac{1+\lambda}{\lambda}}\right]^{\frac{\lambda}{1+\lambda}} = \bar{L} \tag{22}$$

where the constant $\bar{L}$ is total supply of land, $\bar{L}_h$ and $\bar{L}_e$ are the steady state levels of household and entrepreneur land, and $\lambda > 0$ is the elasticity of substitution between the two. The property developer chooses $L_{h,t}$ and $L_{e,t}$ to maximize the discounted sum of future profits:

$$\sum_{t=0}^{\infty} \beta^t A_t \mu_{h,t} \Pi_t \tag{23}$$

Since the representative property developer's firm is owned by the household, future profits are discounted using the household's stochastic discount factor. The first order condition of the property developer's problem is:

$$\left(q_{h,t} - \frac{1}{R_t} q_{h,t+1}\right)\left(\frac{L_{h,t}}{\bar{L}_h}\right)^{-\frac{1}{\lambda}} = \left(q_{e,t} - \frac{1}{R_t} q_{e,t+1}\right)\left(\frac{L_{e,t}}{\bar{L}_e}\right)^{-\frac{1}{\lambda}} \tag{24}$$

After linearizing this first order condition:

$$\hat{q}_{h,t} - \hat{q}_{e,t} - \beta\left(1 + \bar{\lambda}_a\right)\left(\hat{q}_{h,t+1} - \hat{q}_{e,t+1}\right) = \left(1 - \beta\left(1 + \bar{\lambda}_a\right)\right)\frac{1}{\lambda}\left(\hat{L}_{h,t} - \hat{L}_{e,t}\right) \tag{25}$$

where $\beta\left(1 + \bar{\lambda}_a\right)$ is the inverse of the steady state value of the gross interest rate. Solving this forward:

$$\hat{q}_{h,t} - \hat{q}_{e,t} = \sum_{\tau=0}^{\infty} \left(\beta\left(1+\bar{\lambda}_a\right)\right)^{\tau} \left(1-\beta\left(1+\bar{\lambda}_a\right)\right) \frac{1}{\lambda} \left(\hat{L}_{h,t+\tau} - \hat{L}_{e,t+\tau}\right) \tag{26}$$

Thus the difference between the residential and commercial land price, $\hat{q}_{h,t} - \hat{q}_{e,t}$, is the discounted future value of the deviations of $\hat{L}_{h,t} - \hat{L}_{e,t}$ from its steady state value, multiplied by the inverse of the elasticity of substitution between the two types of land $\frac{1}{\lambda}$. If the two types of land are perfect substitutes and $\lambda \to \infty$ then the property development sector becomes trivial and the land market clearing condition in (22) becomes $L_{e,t} + L_{h,t} = \bar{L}$ and the property developer's first order condition in (24) becomes $q_{h,t} = q_{e,t}$.

Note that $\lambda < \infty$ slows down reallocation in the land market. In the linearized equilibrium condition in equation (24),when λ is finite, then if the discounted future sum of $\hat{L}_{h,t} - \hat{L}_{e,t} > 0$ and the allocation of land to households is higher than its steady state level, then $\hat{q}_{h,t} > \hat{q}_{e,t}$ and land for households is relatively more expensive. Following a shock like a housing demand shock this will slow the reallocation of land from entrepreneurs to households. At the same time, by limiting the increase in commercial property prices, it will dampen the collateral channel where a housing demand shock leads to an increase in commercial property prices, loosening the entrepreneur's collateral constraints and spurring investment spending.

3.4 Market Clearing Conditions

Output Y_t can be used for household consumption, entrepreneur consumption, or physical capital investment:

$$C_{h,t} + C_{e,t} + \frac{I_t}{Q_t} = Y_t \tag{27}$$

The total labor supplied by households is equal to the total labor employed by firms:

$$N_{e,t} = N_{h,t} \tag{28}$$

The total savings of households is equal to the total debt of entrepreneurs;

$$S_t = B_t \tag{29}$$

A competitive equilibrium consists of sequence prices $\{w_t, q_{h,t}, q_{e,t}, R_t\}_{t=0}^{\infty}$ and allocations $\{C_{h,t}, C_{e,t}, I_t, N_{h,t}, N_{e,t}, L_{h,t}, L_{e,t}, S_t, B_t, K_t, Y_t\}_{t=0}^{\infty}$ such that taking prices as given, the allocations solve the optimizing problems for the households and entrepreneurs and all the markets clear.

4 Estimation

Following LWZ, we estimate this model using Bayesian techniques. We first log-linearize the model around the steady state while assuming that the collateral constraint always binds. The only difference between this model and that in LWZ is the imperfect substitutability of land. This model simply adds one new equation to the original model, the first order condition for the property developer's problem in (24) which links the prices of the two types of land. All other equations in the model are identical to those in LWZ, except in LWZ there is only one price of land $q_{l,t}$, but in this model the price of residential land is $q_{h,t}$ and the price of commercial land is $q_{e,t}$.[10]

We use the same six U.S. time series for the period of 1975Q1-2010Q4 from LWZ in our estimation: the real price of land, the inverse of the quality-adjusted relative price of investment, real per capita consumption, real per capita investment (in consumption units), real per capita non-farm non-financial business debt, and the log of per capita hours worked (as a fraction of total time endowment). To match these 6 observable series we consider the following series from the model: the growth rate in the price of residential land, $q_{h,t}$, the

[10]Note that this model does include the profits of the property developer, Π_t, that are returned lump-sum to the household and thus appear in the household budget constraint. But this is equal to zero in the linearization. Similarly, the CES land market clearing contion in this model is a general case of the perfect substitutes land market clearing condition in LWZ, but these are identical in the linearization.

growth in the relative price of investment, Q_t, the growth in household and entrepreneur consumption, $C_{h,t} + C_{e,t}$, the growth in investment spending, I_t, the growth in entrepreneur loanable bonds, B_t, and the log of the labor input, $N_{h,t}$.[11]

We estimate the model using Bayesian methods with the Metropolis-Hastings algorithm which is run for 150,000 draws. The Markov Chain Monte Carlo (MCMC) converges to its ergodic distribution. The optimization is efficient and can find the posterior modes. The full list of model parameter values is presented in Table 2. We follow LWZ in splitting these parameters into three groups. The first are the parameters γ_h, γ_e, Ω, g_γ, and $\bar{\lambda}_Q$. These are the two habit persistence parameters, the investment adjustment cost parameter, the growth rate of per capita output, and the growth rate of per capita investment. As shown in the table, we estimate these parameters using Bayesian techniques and using the same priors as LWZ. The second set of parameters is the AR(1) shock process parameters ρ_i and σ_i for $i = \{a, z, \nu_z, Q, \nu_Q, \varphi, \psi, \theta\}$. These shocks are from LWZ and we reestimate using their same priors.

Finally the last set of parameters β, $\bar{\lambda}_a$, $\bar{\varphi}$, ϕ, δ, α, $\bar{\theta}$, and $\bar{\psi}$ are simply set to match certain steady state values. We fix the values of the last 3 of these: $\alpha = 0.3$ to match a labor share of 70%, $\bar{\theta} = 0.75$ to match the average non-farm and non-financial business loan-asset ratio, and the steady state value of the disutility of labor $\bar{\psi}$ is set so that steady state market hours are 25% of the time endowment. The values of the five parameters, β, $\bar{\lambda}_a$, $\bar{\varphi}$, ϕ, and δ, are set such that as the values of the earlier estimated parameters change, five steady state ratios and levels will hold: the steady state level of average real prime loan rate (4% annually), the capital-output ratio (1.15 annually), investment-capital ratio (0.209 annually), the average ratio of commercial land to private output (0.65 annually), and the

[11] In LWZ, there is just one price of land, so the model variable to match the observed land price series is simply the growth in that land price. In the model with imperfect subtitution there are two land prices, but the land price series in LWZ is the land price backed out of the residential house price series using the method in Davis and Heathcote (2007), so we use the residential land price series as the model observable variable.

average ratio of residential land to private output (1.45 annually).

To these 21 parameters we then add λ, the elasticity of substitution between the two types of land. Of course λ can take any positive value as the two types of land vary from being perfect complements to perfect substitutes. To facilitate the estimation of λ we instead estimate $\chi = \frac{\lambda}{1+\lambda}$ where our prior is that χ is distributed uniform between 0 and 1.

The estimation results for the imperfect land substitutes model (where χ is estimated) and the perfect land substitutes model (where $\chi = 1$) are presented in the first two columns of Table 2. The priors for each parameter are the same under each estimation (except of course in the perfect substitutes model, χ is not estimated). When the value of χ is estimated, the model estimates a mode of 0.47, implying that $\lambda \approx 0.88$. Table 2 presents the posterior modes of the parameters in the two models, the posterior means and 90% confidence intervals for each parameter estimation in each model is presented in the appendix. As reported in the appendix, the 90% confidence interval for χ is between 0.38 and 0.54, implying that the 90% confidence interval for the elasticity of substitution λ is between 0.61 and 1.17.

To show how imperfect land substitution affects the estimates of the other parameters in the model, we present the results from these estimations under different values of χ in Figures 2, 3, and 4. We reestimate the model across a range of given values of χ as χ goes from 1 to 0.1 In these figures, the posterior mode of each parameter as a function of the elasticity parameter χ is plotted with the blue line. The figures also plot the 90% confidence intervals of these parameters in the perfect substitutes model.

First, Figure 2 shows that the posterior modes of most of the model parameters change very little as the model is reestimated using different values of χ, and most modes stay within the 90% confidence bounds from the perfect substitutes model. The exceptions are the entrepreneur habit persistence parameter, γ_e, which gets larger for small values of χ. Similarly the investment adjustment cost parameter Ω falls monotonically as χ falls. In the perfect substitutes case when $\chi = 1$ the strength of the collateral channel means the investment adjustment cost parameter needs to be higher to match the observed investment series. As χ and the two types of land become poorer substitutes, the collateral channel is weakened and the necessary investment adjustment cost if smaller.

Figures 3, and 4 show that with a few notable exceptions, the posterior modes of the shock process parameters change very little as the model is reestimated using different values of χ, and most modes stay within the 90% confidence bounds from the perfect substitutes model. For the AR(1) shock persistence parameters in Figure 3, only the labor supply shock persistence parameter ρ_ψ and the collateral shock persistence parameter ρ_θ drift outside of the confidence bounds, and then only at very low values of χ. The estimated labor supply persistence gets larger as χ falls and the estimate collateral shock persistence gets smaller. The estimated standard deviations of the shocks are presented in Figure 4. Again we can see that the posterior modes for most of the estimates remain within the confidence bounds as χ falls. One notable exception is the standard deviation of the household's housing demand shock, φ_t. The estimated standard deviation of this shock falls monotonically as χ falls. When the two types of land are perfect substitutes, following a housing demand shock, the elasticity of land supply is relatively high, since commercial land can be easily converted into residential land, keeping the supply curve relatively flat. Due to this high elasticity it takes a relatively large housing demand shock for the model to match observed fluctuations in the price of residential land. But when χ falls and the substitution between the two types of land falls, this elasticity of residential land supply falls and the residential land supply curve gets steeper. With a lower elasticity, the model can match observed fluctuations in the price of residential land with a smaller housing demand shock.

Finally, in Figure 5 we consider how the log data density changes as the model is reestimated using different values of χ. Not surprisingly given the results from the estimation of χ, the point with the highest log data density is around the point where $\chi \approx 0.5$.

5 Results

To present the results from this estimated model and discuss how imperfect substitution between the two types of land affects the strength of the collateral channel, we first present variance decomposition results and show how imperfect substitution affects the share of the variance of the macroeconomic variables like investment, labor, and output, that is due to the housing demand shock. We then compare impulse responses from the perfect substitutes model with impulse responses from the model where the two types of land are imperfect substitutes.

5.1 Variance Decompositions

Variance decompositions of the two land prices, investment, and output under the two models is presented in Tables 3 and 4. Table 3 reports the share of the variance of the residential or commercial land price that can be explained by each of the eight structural shocks at the 1, 4, 8, 16, and 24 quarter horizons. Recall that in the perfect substitutes model the elasticity of substitution between the two types of land $\lambda \to \infty$, but in the imperfect substitutes model the elasticity is estimated as $\lambda = 0.88$.

For each variable, the top panel presents the results from the imperfect substitutes model, and the bottom panel presents the results from the perfect substitutes model. In the perfect substitutes model, around 90% of the variance of both land prices is due to the housing demand shock, the other 10% is explained by the permanent TFP shock, the labor supply shock, and to a lesser extent, the patience shock. For the residential land prices, this is true in the imperfect substitutes model as well. However, in the imperfect substitutes model, the share of the variance of the commercial land price that is due to the housing demand shock falls to just over 50%. The other 50% is explained by the permanent TFP, labor supply, and patience shocks.

Table 4 reports the share of the variance of investment and output that can be explained by each of the eight structural shocks at the same horizons. In the perfect substitutes model, 30-40% of the variance of investment and 17-30% of the variance of output is due to the housing demand shock. In the imperfect substitutes model these shares fall considerably. In the imperfect substitutes model, around 12-15% of the variance of investment and 4-12% of the variance of output is due to the housing demand shock.

Tables 3 and 4 present the variance decomposition results for two estimated models. The same variance decomposition results are instead presented for a range of estimated models, where χ is taken as given in each estimation and χ varies from 0.1 to 1 are presented in Figures 6 and 7. Figure 6 presents the 24 quarter ahead variance decomposition of the commercial real estate price, and Figure 7 presents the 24 quarter ahead variance decomposition of investment.

Figure 6 shows that when the two types of land are perfect substitutes, the housing demand shock explains 90% of the variance of the commercial land price. But this share falls monotonically as χ falls and the two types of land become less substitutable. When $\chi = 0.1$ and the two types of land are nearly perfect complements, the housing demand shock explains less than 5% of the variance. As χ falls there is a monotonic increase in the share due to the permanent productivity, labor supply, and patience shocks. When $\chi = 0.1$, 50% of the variance of the commercial land price is due to the permanent productivity shock, another 25% is due to the labor supply shock, and another 12% is due to the patience shock.

Similarly, Figure 7 shows that when the two types of land are perfect substitutes, the housing demand shock explains nearly 40% of the variance of investment. But this share falls monotonically as χ falls and the two types of land become less substitutable. When $\chi = 0.1$ and the two types of land are nearly perfect complements, the housing demand shock explains close to 0% of the variance of investment. As χ falls the share of the variance due to the other shocks, especially the permanent productivity, permanent investment, and collateral shocks increases.

5.2 Impulse Responses

The response of the residential land price q_t^h, the commercial land price q_t^e, investment, I_t, and output Y_t to a one percent shock to housing demand, φ_t, is presented in Figure 8.[12]

We plot the responses of the variables from the imperfect substitutes model, using the estimated posterior modes in the first column of Table 2, with the blue solid line. And we plot the responses from the perfect substitutes model, using the estimated posterior modes in the second column of Table 2, with the green dashed line. The dotted lines plot the upper and lower bounds of the 68% confidence interval. To highlight the model's propagation mechanism we plot both the impulse response from imperfect and perfect substitutes models, next to the impulse responses from the two models under the counterfactual that the value of the entrepreneur's collateral in the collateral constraint in (18) is held constant at its steady state value. The responses from the actual model are plotted in the left-hand column of the figure and the responses from the counterfactual are plotted in the right-hand column.

First consider the impulse responses of the two land prices. When the two types of land are perfect substitutes the responses for the two land prices are of course identical. In the imperfect substitutes model the response of the commercial real estate price to the same housing demand shock is much smaller and the response of the residential real estate price is greater. Imperfect substitution between the two types of land means that less commercial land can be transformed into residential land after the shock, and this should reduce the elasticity of the commercial land price to a housing demand shock and increase the elasticity of the residential land price to the housing demand shock. The responses of the two real estate prices barely change between the actual model and the counterfactual model where the value of collateral is held constant.

Next consider investment and output. We will start with the actual model in the left-

[12] Note that the shock is a 1% shock and not a one standard deviation shock. Since the standard deviation of the shocks differ between the two models, to make a direct comparison in the responses between the two models, we normalize the impulse size. To put these impulse responses on the same scale as the impulse responses in LWZ, multiply these responses by the shock standard deviations in Table 2.

hand column. There is much greater amplification and propagation of the housing demand shock in the perfect substitutes model than in the imperfect substitutes model where there is much less response in the commercial real estate price. While the responses on impact are about the same in the two models, there is a much larger hump-shape in both investment and output in the perfect substitutes model, and the duration of the response is much longer in the perfect substitutes model.

Turning now to the counterfactual in the right hand column where the value of the entrepreneur's collateral is held constant. In this counterfactual the impact of the housing demand shock on investment and output is lower in both models. But what is interesting is that the difference in the responses between the two models is much smaller and in the counterfactual the two models are similar in both propagation and amplification of the shock.

The responses of the residential land price q_t^h, the commercial land price q_t^e, investment, I_t, and output Y_t to a one percent shock to permanent TFP, z_t, is presented in Figure 9. It's interesting to note that there is little difference in the responses between the perfect substitutes and imperfect substitutes models. In the imperfect substitutes model, there is very little difference between the two land prices. The response of the commercial land price is greater on impact, but that difference quickly dissipates and within a few quarters of the shock, the two land prices are nearly equal. With a small difference in the land price between the two models, there is very little difference between the two models in the responses of either investment or output.

6 Conclusion

This paper sets out to model how changes in the substitutability of residential and commercial real estate affects the transmission of a housing shock to the broader macroeconomy. We find that an increase in residential real estate prices is associated with an increase in commercial real estate prices which should then lead to an increase in the value of collateral, borrowing, and investment spending for credit constrained firms. But we conjecture that the strength of this collateral channel linking housing demand and residential real estate prices to firm investment depends on the substitutability of the two types of land.

As an empirical motivation we show that this conjecture is confirmed with a reduced form empirical model using firm level data. We use state level heterogeneity in the strength of zoning restrictions as a proxy for heterogeneity in the substitutability of the two types of real estate; we find that the estimated effect of an increase in local residential real estate prices on local firm investment spending is nearly twice as high in states with weak zoning regulations, where residential and commercial real estate are close substitutes. We then modify the model of the collateral channel in Liu, Wang, and Zha (2013) by adding the potential imperfect substitutability of the two types of real estate. Through Bayesian estimation using U.S. data we find that the elasticity of substitution between residential and commercial land is around 0.88. With impulse responses and variance decompositions we then show that the strength of the collateral channel, measured by the effect of a residential housing demand shock on macroeconomic variables like firm investment and output, is significantly weaker when the two types of land are imperfect substitutes.

References

Adelino, M., Schoar, A., Severino, F., 2015. House prices, collateral, and self-employment. Journal of Financial Economics 117 (2), 288–306.
https://doi.org/10.1016/j.jfineco.2015.03.005

Bahaj, S., Foulis, A., Pinter, G., 2020. Home values and firm behavior. American Economic Review 110 (7), 2225–70.
https://www.aeaweb.org/articles?id=10.1257/aer.20180649

Bahaj, S. A., Foulis, A., Pinter, G., 2016. The residential collateral channel. Working Paper.

Bouchouicha, R., Ftiti, Z., 2012. Real estate markets and the macroeconomy: A dynamic coherence framework. Economic Modelling 29 (5), 1820–1829.
https://doi.org/10.1016/j.econmod.2012.05.034

Catherine, S., Chaney, T., Huang, Z., Sraer, D. A., Thesmar, D., 2018. Quantifying reduced-form evidence on collateral constraints. working paper.
http://dx.doi.org/10.2139/ssrn.2631055

Chaney, T., Sraer, D., Thesmar, D., 2012. The collateral channel: How real estate shocks affect corporate investment. American Economic Review 102 (6), 2381–2409.
http://doi.org/10.1257/aer.102.6.2381

Davis, M. A., 2009. The price and quantity of land by legal form of organization in the united states. Regional Science and Urban Economics 39 (3), 350–359.
https://doi.org/10.1016/j.regsciurbeco.2009.01.002

Davis, M. A., Heathcote, J., 2007. The price and quantity of residential land in the united states. Journal of Monetary Economics 54 (8), 2595–2620.
https://doi.org/10.1016/j.jmoneco.2007.06.023

Davis, M. A., Larson, W. D., Oliner, S. D., Shui, J., 2021. The price of residential land for counties, zip codes, and census tracts in the united states. Journal of Monetary Economics 118, 413–431.
https://doi.org/10.1016/j.jmoneco.2020.12.005

Davis, M. A., Oliner, S. D., Pinto, E. J., Bokka, S., 2017. Residential land values in the washington, dc metro area: New insights from big data. Regional Science and Urban Economics 66, 224–246.
https://doi.org/10.1016/j.regsciurbeco.2017.06.006

Gan, J., 2007. Collateral, debt capacity, and corporate investment: Evidence from a natural experiment. Journal of Financial Economics 85 (3), 709–734.
https://doi.org/10.1016/j.jfineco.2006.06.007

Ganong, P., Shoag, D., 2017. Why has regional income convergence in the us declined? Journal of Urban Economics 102, 76–90.
https://doi.org/10.1016/j.jue.2017.07.002

Gong, L., Wang, C., Zhao, F., Zou, H.-f., 2017. Land-price dynamics and macroeconomic fluctuations with nonseparable preferences. Journal of Economic Dynamics and Control 83, 149–161.
https://doi.org/10.1016/j.jedc.2017.07.008

Guerrieri, L., Iacoviello, M., 2017. Collateral constraints and macroeconomic asymmetries. Journal of Monetary Economics 90, 28–49.
https://doi.org/10.1016/j.jmoneco.2017.06.004

Gyourko, J., 2009. Understanding commercial real estate: How different from housing is it? The Journal of Portfolio Management 35 (5), 23–37.
https://doi.org/10.3905/JPM.2009.35.5.023

Gyourko, J., Hartley, J., Krimmel, J., 2019. The local residential land use regulatory environment across us housing markets: Evidence from a new wharton index. NBER Working Paper No. 26573.
https://doi.org/10.3386/w26573

Gyourko, J., Saiz, A., Summers, A., 2008. A new measure of the local regulatory environment for housing markets: The wharton residential land use regulatory index. Urban Studies 45 (3), 693–729.
https://doi.org/10.1177/0042098007087341

Iacoviello, M., Neri, S., 2010. Housing market spillovers: evidence from an estimated dsge model. American Economic Journal: Macroeconomics 2 (2), 125–64.
https://doi.org/10.1257/mac.2.2.125

Kaas, L., Pintus, P. A., Ray, S., 2016. Land collateral and labor market dynamics in france. European Economic Review 84, 202–218.
https://doi.org/10.1016/j.euroecorev.2014.11.002

Kleiner, K., 2015. Collateral and small firm labor. Kelley School of Business Research Paper (16-49).
http://dx.doi.org/10.2139/ssrn.2704069

Liu, Z., Miao, J., Zha, T., 2016. Land prices and unemployment. Journal of Monetary Economics 80, 86–105.
https://doi.org/10.1016/j.jmoneco.2016.05.001

Liu, Z., Wang, P., Zha, T., 2013. Land price dynamics and macroeconomic fluctuations. Econometrica 81 (3), 1147–1184.
https://doi.org/10.3982/ECTA8994

Liu, Z., Wang, P., Zha, T., 2019. A theory of housing demand shocks. NBER Working Paper No. 25667.
https://doi.org/10.3386/w25667

Mian, A., Rao, K., Sufi, A., 2013. Household balance sheets, consumption, and the economic slump. Quarterly Journal of Economics 128 (4), 1687–1726.
https://doi.org/10.1093/qje/qjt020

Mian, A., Sufi, A., 2011. House prices, home equity-based borrowing, and the us household leverage crisis. American Economic Review 101 (5), 2132–56.
https://doi.org/10.1257/aer.101.5.2132

Mian, A., Sufi, A., 2014. What explains the 2007–2009 drop in employment? Econometrica 82 (6), 2197–2223.
https://doi.org/10.3982/ECTA10451

Nichols, J. B., Oliner, S. D., Mulhall, M. R., 2013. Swings in commercial and residential land prices in the united states. Journal of Urban Economics 73 (1), 57–76.
https://doi.org/10.1016/j.jue.2012.06.004

Schmalz, M. C., Sraer, D. A., Thesmar, D., 2017. Housing collateral and entrepreneurship. The Journal of Finance 72 (1), 99–132.
https://doi.org/10.1111/jofi.12468

Shoag, D., Muehlegger, E., 2015. Commuting times and land use regulations. Procedia Engineering 107, 488–493.
https://doi.org/10.1016/j.proeng.2015.06.108

Shoag, D., Russell, L., 2018. Land use regulations and fertility rates. In: One Hundred Years of Zoning and the Future of Cities. pp. 139–149.
https://doi.org/10.1007/978-3-319-66869-7-7

Sirmans, C., Slade, B. A., 2012. National transaction-based land price indices. The Journal of Real Estate Finance and Economics 45 (4), 829–845.
https://doi.org/10.1007/s11146-011-9306-3

Wu, J., Gyourko, J., Deng, Y., 2013. Is there evidence of a real estate collateral channel effect on listed firm investment in china? NBER Working Paper No. 18762. https://doi.org/10.3386/w18762

A Appendix - For online publication

In this appendix we first present the details of the solution to the model, and present the constrained maximization problems and first order conditions for the three agents in the model, the household, the entrepreneur, and the property developer. Then in Table 5 we present the posterior mean and the lower and upper bounds of the 90% confidence intervals for the estimated parameters in the model.

A.1 Model Solution

A.1.1 Representative household

The maximization problem for the representative household is:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t A_t \left[\begin{array}{c} \log(C_{h,t} - \gamma_h C_{h,t-1}) + \varphi_t \log L_{h,t} - \psi_t N_{h,t} \\ +\mu_{h,t}(w_t N_{h,t} + S_{t-1} - C_{h,t} - q_{h,t}\left(L_{h,t} - L_{h,t-1}\right) - \frac{S_t}{R_t}) \end{array} \right]$$

The first order conditions with respect to $C_{h,t}$, $L_{h,t}$, $N_{h,t}$, and S_t are:

wrt $C_{h,t}$:

$$A_t \left(\frac{1}{C_{h,t} - \gamma_h C_{h,t-1}} - E_t(1 + \lambda_{a,t+1}) \frac{\beta\gamma_h}{C_{h,t+1} - \gamma_h C_{h,t}} \right) = \mu_{h,t}$$

This FOC equates marginal utility of income and consumption.

wrt $L_{h,t}$:

$$\beta E_t \frac{\mu_{h,t+1}}{\mu_{h,t}} q_{h,t+1} + \frac{A_t \varphi_t}{\mu_{h,t} L_{h,t}} = q_{h,t}$$

This FOC equates the current relative price of land to the marginal benefit of purchasing an extra unit of land, which consists of the current utility benefits (MRS between housing and consumption) and the land's discounted future resale value.

wrt $N_{h,t}$:

$$w_t = \frac{A_t \psi_t}{\mu_{h,t}}$$

This FOC equates the real wage and the marginal rate of substitution between leisure and income.

wrt S_t :

$$\frac{1}{R_t} = \beta E_t \left(1 + \lambda_{a,t+1}\right) \frac{\mu_{h,t+1}}{\mu_{h,t}}$$

A.1.2 Representative entrepreneur

The maximization problem for the representative entrepreneur is:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \log(C_{e,t} - \gamma_e C_{e,t-1}) \\ +\mu_{e,t} \left(Z_t \left[L_{e,t-1}^{\phi} K_{t-1}^{(1-\phi)} \right]^{\alpha} N_{e.t}^{(1-\alpha)} + \frac{B_t}{R_t} - \frac{I_t}{Q_t} - w_t N_{e,t} - C_{e,t} - q_{e,t} \left(L_{e,t} - L_{e,t-1} \right) - B_{t-1} \right) \\ +\mu_{k,t} \left((1-\delta) K_{t-1} + \left[1 - \frac{\Omega}{2} \left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I \right)^2 \right] I_t - K_t \right) \\ +\mu_{b,t} \left(\theta_t E_t \left[q_{e,t+1} L_{e,t} + q_{k,t+1} K_t \right] - B_t \right) \end{array} \right]$$

The first order conditions with respect to $C_{e,t}$, $N_{e,t}$, I_t, $L_{e,t}$, K_t, B_t, are:

wrt $C_{e,t}$:

$$\mu_{e,t} = \frac{1}{C_{e,t} - \gamma_e C_{e,t-1}} - E_t \frac{\beta \gamma_e}{C_{e,t+1} - \gamma_e C_{e,t}}$$

wrt $N_{e,t}$:

$$w_t = \frac{(1-\alpha)\, Y_t}{N_{e,t}}$$

wrt I_t :

Define shadow price of capital in consumption units:

$$q_{k,t} = \frac{\mu_{k,t}}{\mu_{e,t}}$$

$$\frac{1}{Q_t} = q_{k,t}\left[1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2 - \Omega\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)\left(\frac{I_t}{I_{t-1}}\right)\right]$$
$$+ E_t q_{k,t+1}\frac{\mu_{e,t+1}}{\mu_{e,t}}\beta\Omega\left(\frac{I_{t+1}}{I_t} - \bar{\lambda}_I\right)\left(\frac{I_{t+1}}{I_t}\right)^2$$

wrt $L_{e,t}$:

$$\frac{\mu_{e,t+1}}{\mu_{e,t}}\beta\alpha\phi\frac{Y_{t+1}}{L_{e,t}} + \frac{\mu_{b,t}}{\mu_{e,t}}\theta_t q_{e,t+1} + \frac{\mu_{e,t+1}}{\mu_{e,t}}\beta q_{e,t+1} = q_{e,t}$$

wrt K_t :

$$\beta E_t\frac{\mu_{e,t+1}}{\mu_{e,t}}\left(\frac{\alpha(1-\phi)Y_{t+1}}{K_t} + q_{k,t+1}(1-\delta)\right) + \frac{\mu_{b,t}}{\mu_{e,t}}\theta_t E_t q_{k,t+1} = q_{k,t}$$

wrt B_t :

$$\frac{1}{R_t} = \beta E_t\frac{\mu_{e,t+1}}{\mu_{e,t}} + \frac{\mu_{b,t}}{\mu_{e,t}}$$

A.1.3 Representative Property Developer

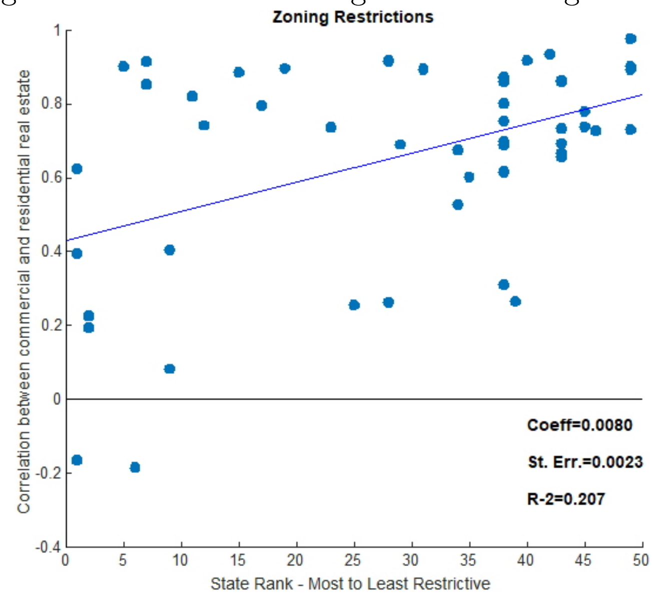
The maximization problem for the representative property developer is:

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t A_t \mu_{h,t} \left[\begin{array}{c} q_{h,t} \left(L_{h,t} - L_{h,t-1} \right) + q_{e,t} \left(L_{e,t} - L_{e,t-1} \right) \\ -q_{l,t} \left(\left[\left(\frac{\bar{L}_e}{\bar{L}} \right)^{-\frac{1}{\lambda}} \left(L_{e,t} \right)^{\frac{1+\lambda}{\lambda}} + \left(\frac{\bar{L}_h}{\bar{L}} \right)^{-\frac{1}{\lambda}} \left(L_{h,t} \right)^{\frac{1+\lambda}{\lambda}} \right]^{\frac{\lambda}{1+\lambda}} - \bar{L} \right) \end{array} \right]$$

The first order conditions with respect to $L_{h,t}$ and $L_{e,t}$ after rearranging become:

$$\left(q_{h,t} - \frac{1}{R_t} q_{h,t+1} \right) \left(\frac{L_{h,t}}{\bar{L}_h} \right)^{-\frac{1}{\lambda}} = \left(q_{e,t} - \frac{1}{R_t} q_{e,t+1} \right) \left(\frac{L_{e,t}}{\bar{L}_e} \right)^{-\frac{1}{\lambda}}$$

Figure 1: Scatter plots of the city-level correlation between residential and commercial (industrial) real estate against state rank in zoning or land use regulations.



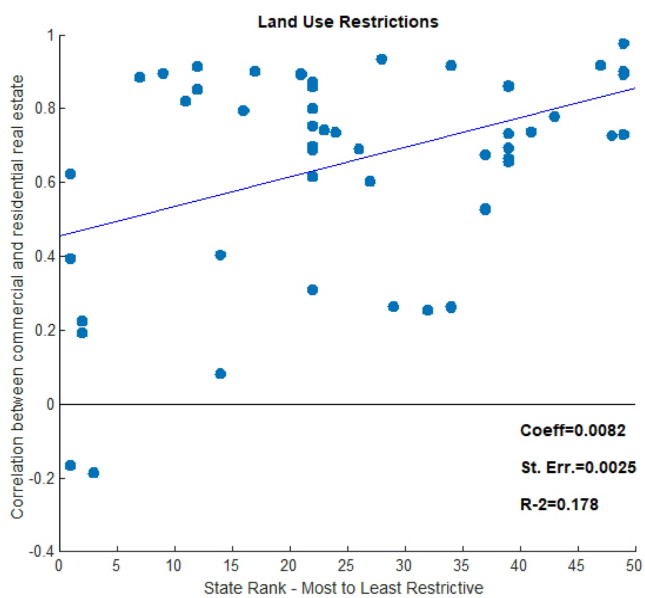
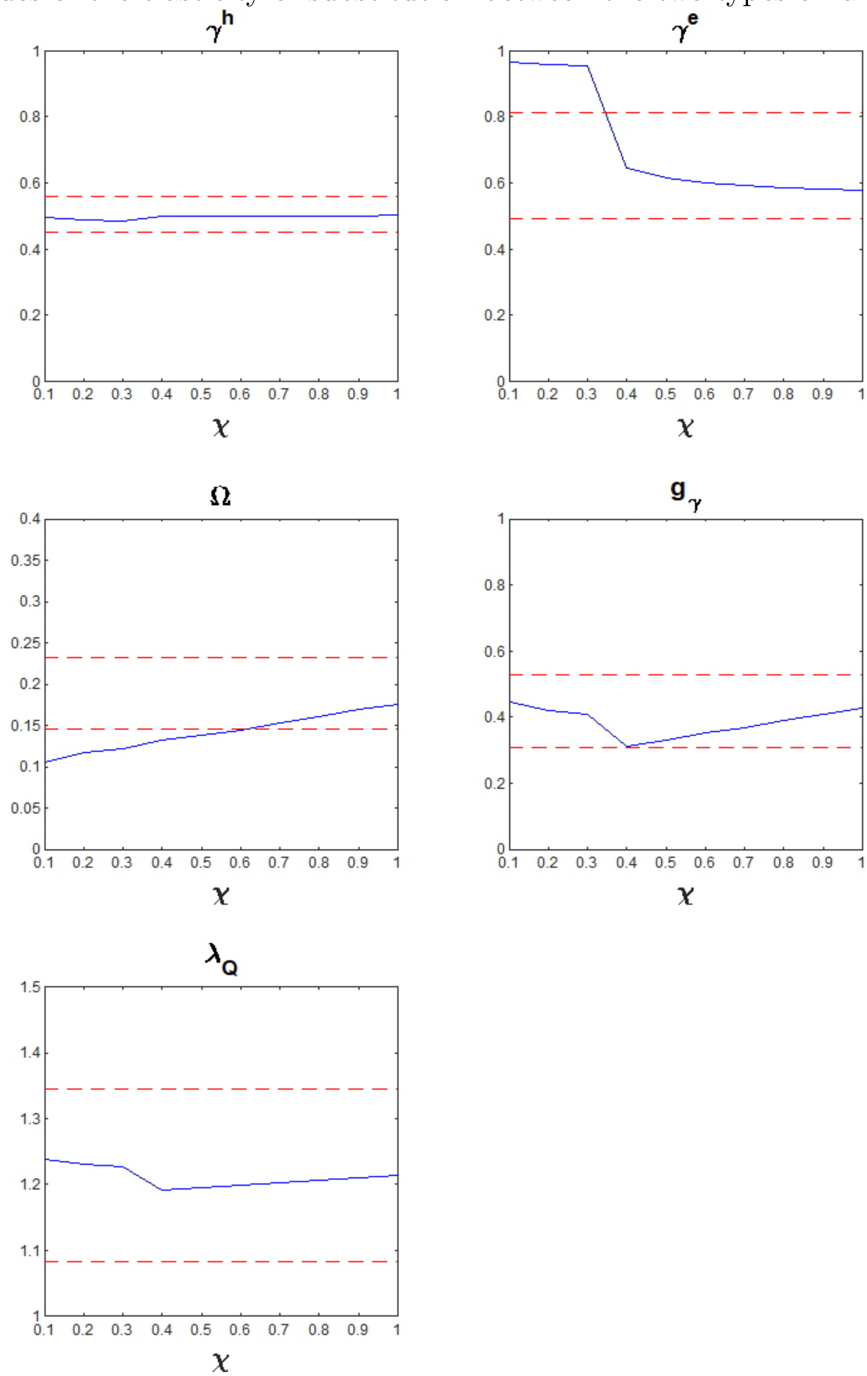
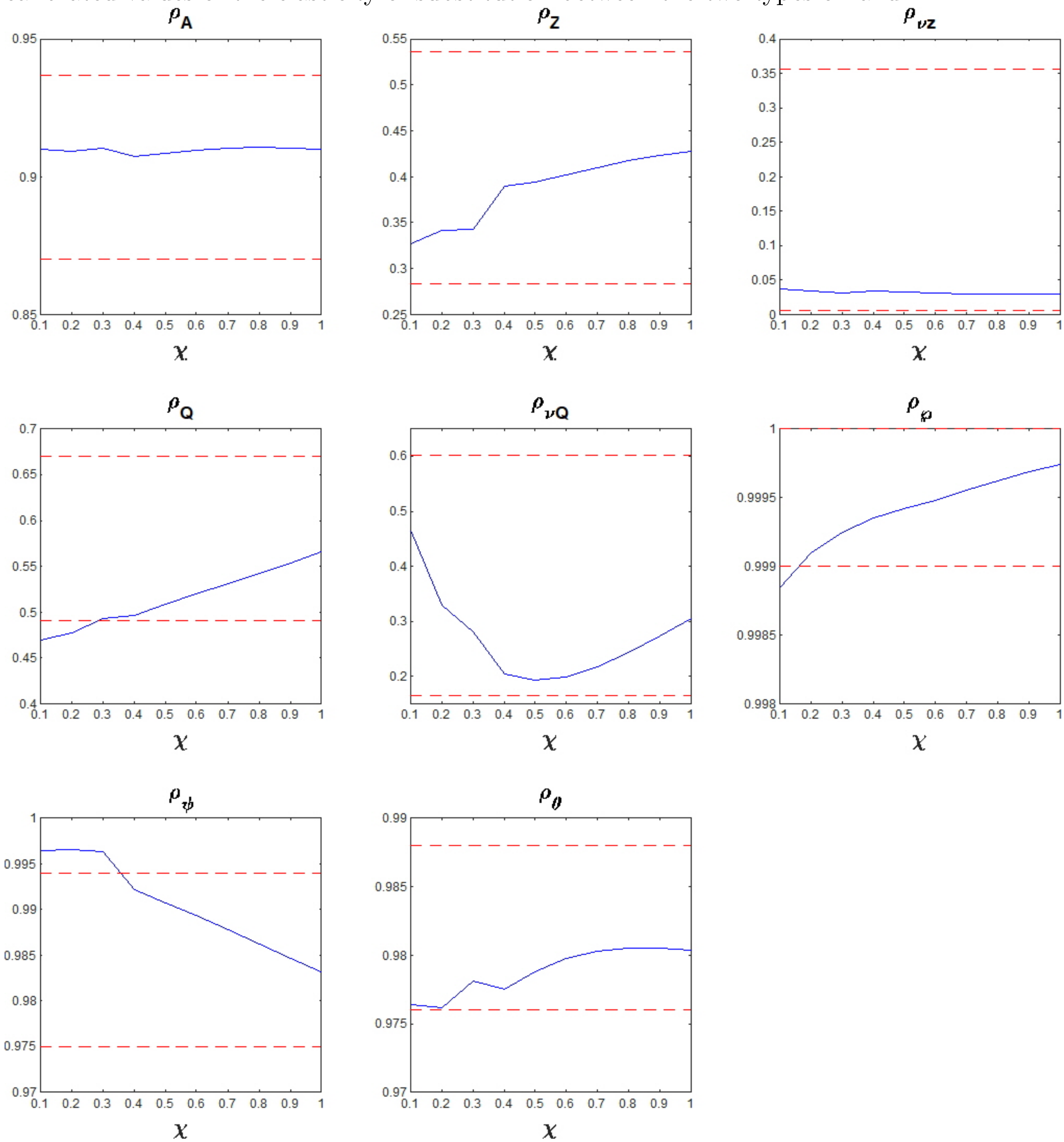


Figure 2: The estimated mode of the parameters in the model when estimated under different calibrated values of the elasticity of substitution between the two types of land.



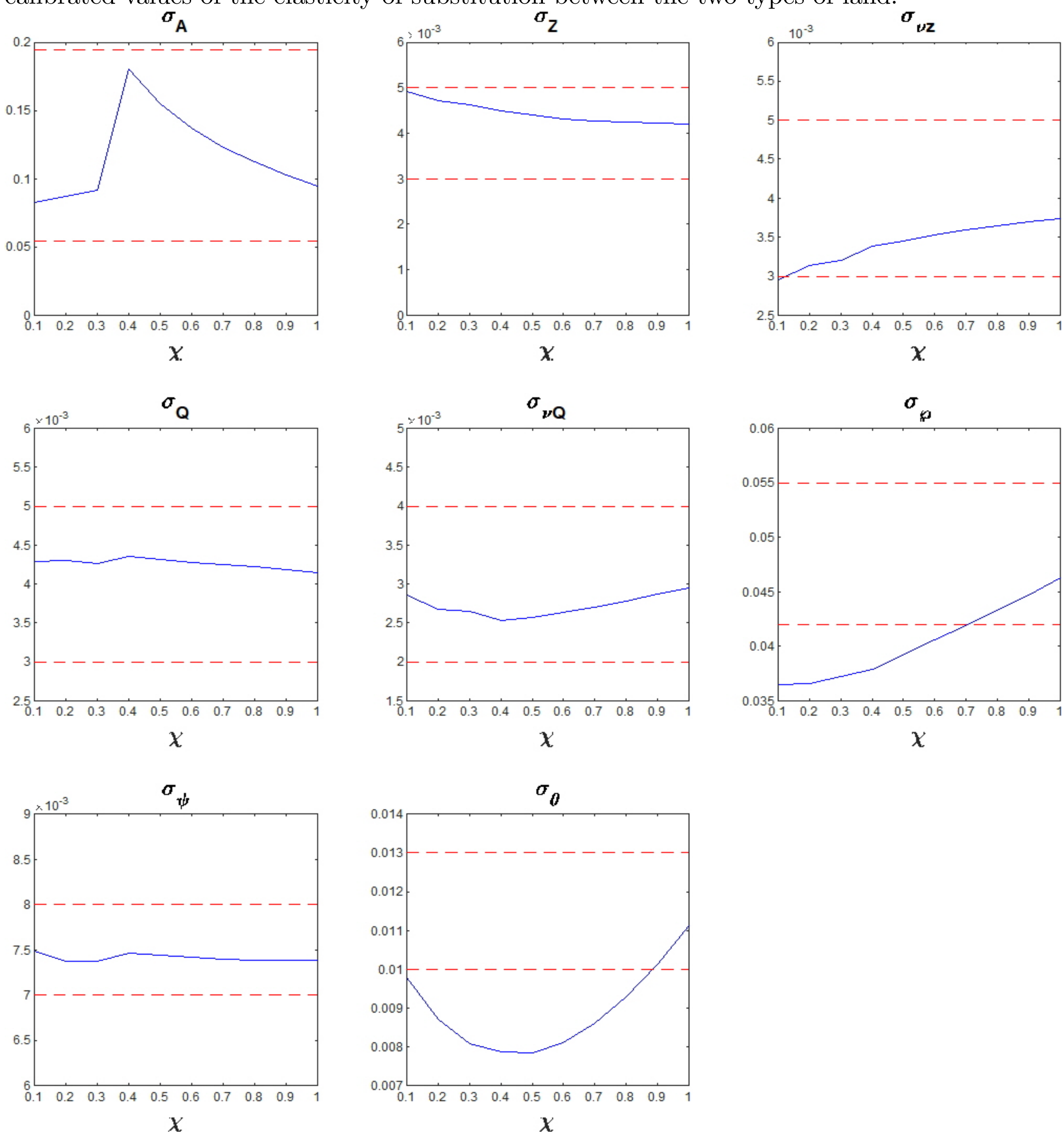
Notes: The blue solid lines are the estimates of the posterior mode of the parameter in different estimations of the model when changing the χ parameter. The red dashed lines are the 90% confidence bands for the parameter from the estimation where $\chi = 1$.

Figure 3: The estimated mode of the parameters in the model when estimated under different calibrated values of the elasticity of substitution between the two types of land.



Notes: The blue solid lines are the estimates of the posterior mode of the parameter in different estimations of the model when changing the χ parameter. The red dashed lines are the 90% confidence bands for the parameter from the estimation where $\chi = 1$.

Figure 4: The estimated mode of the parameters in the model when estimated under different calibrated values of the elasticity of substitution between the two types of land.



Notes: The blue solid lines are the estimates of the posterior mode of the parameter in different estimations of the model when changing the χ parameter. The dashed lines are the 90% confidence bands for the estimation where $\chi = 1$.

Figure 5: The log data density from the estimated model under different calibrated values of the elasticity of substitution between the two types of land.

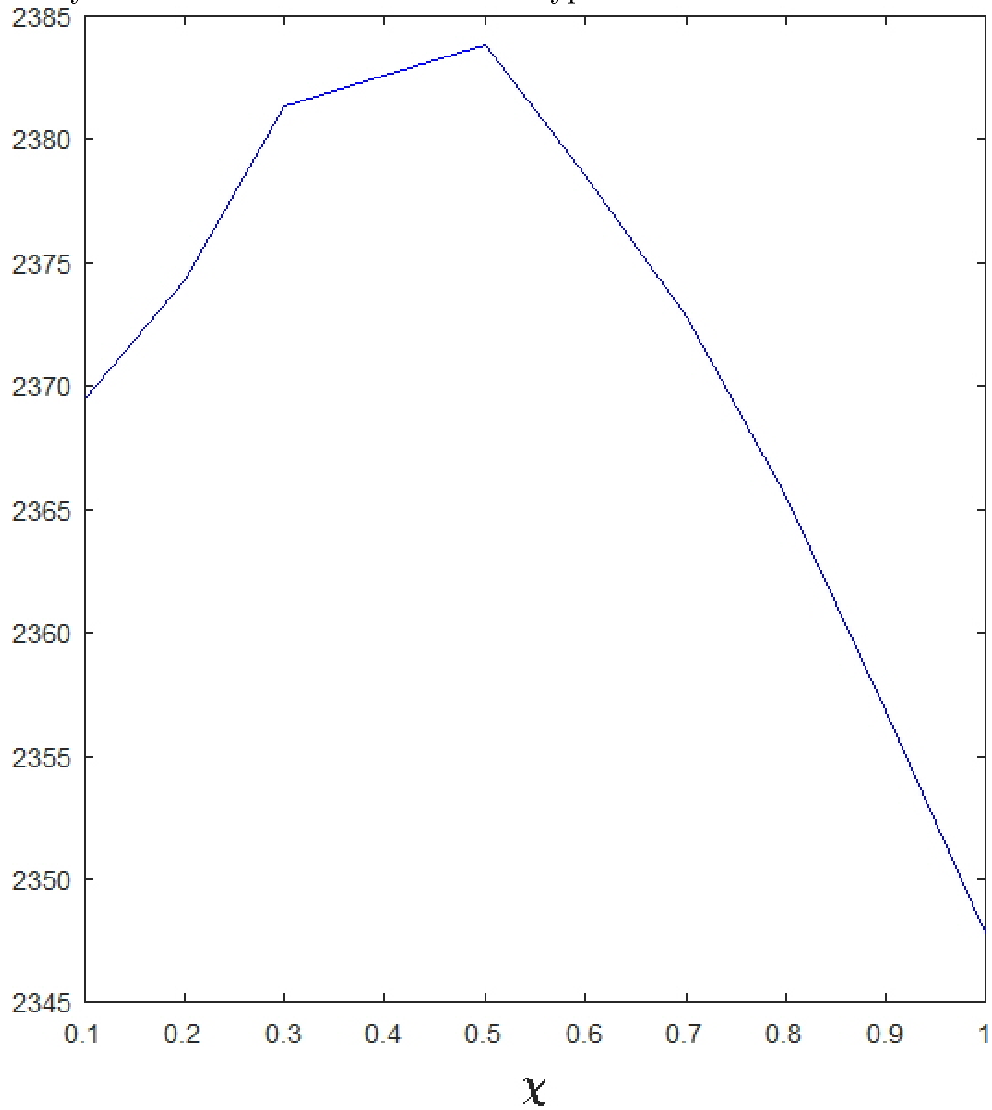


Figure 6: The share of the forecast error variance of the commercial real estate price at the 24 quarter horizon that is explained by each shock.

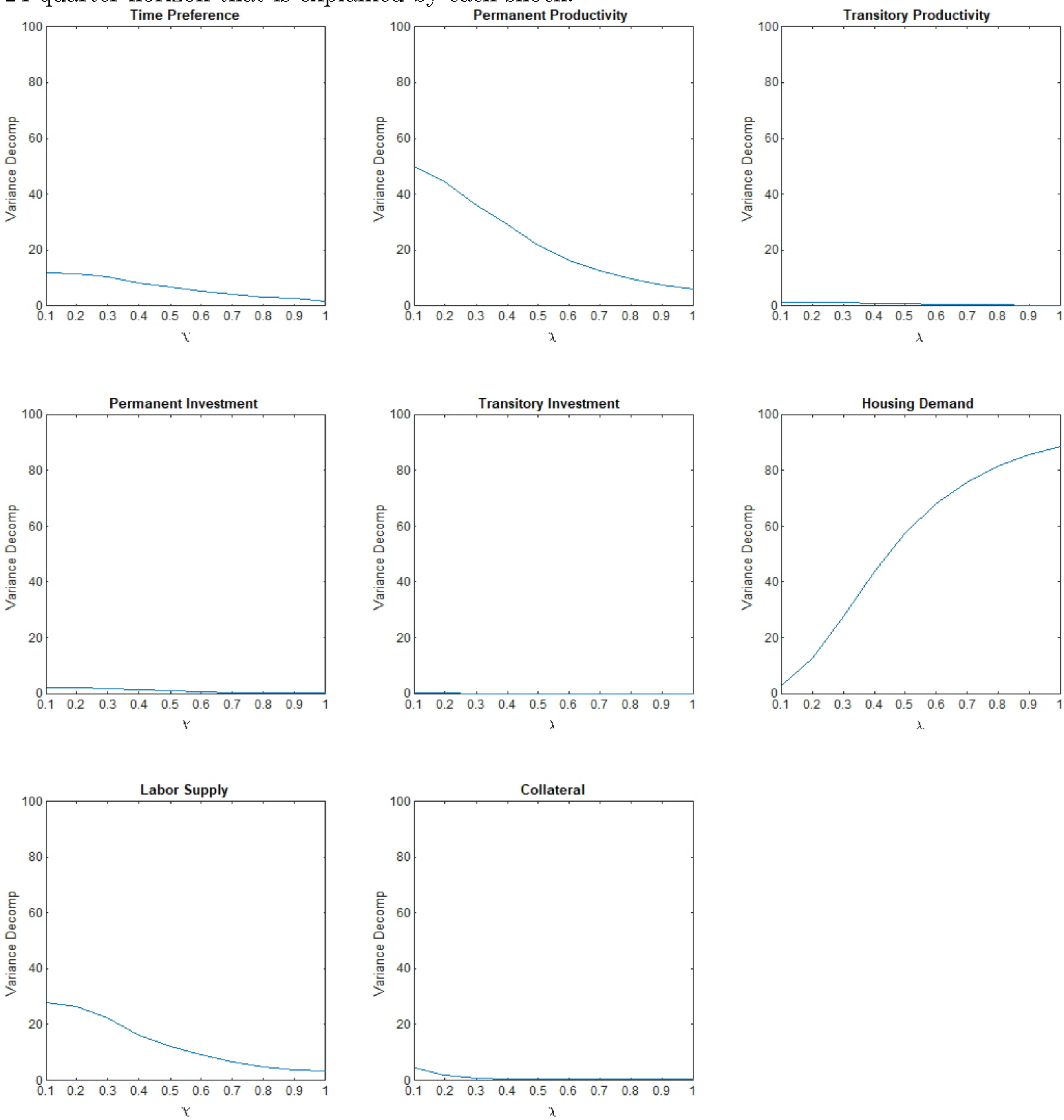


Figure 7: The share of the forecast error variance of investment at the 24 quarter horizon that is explained by each shock.

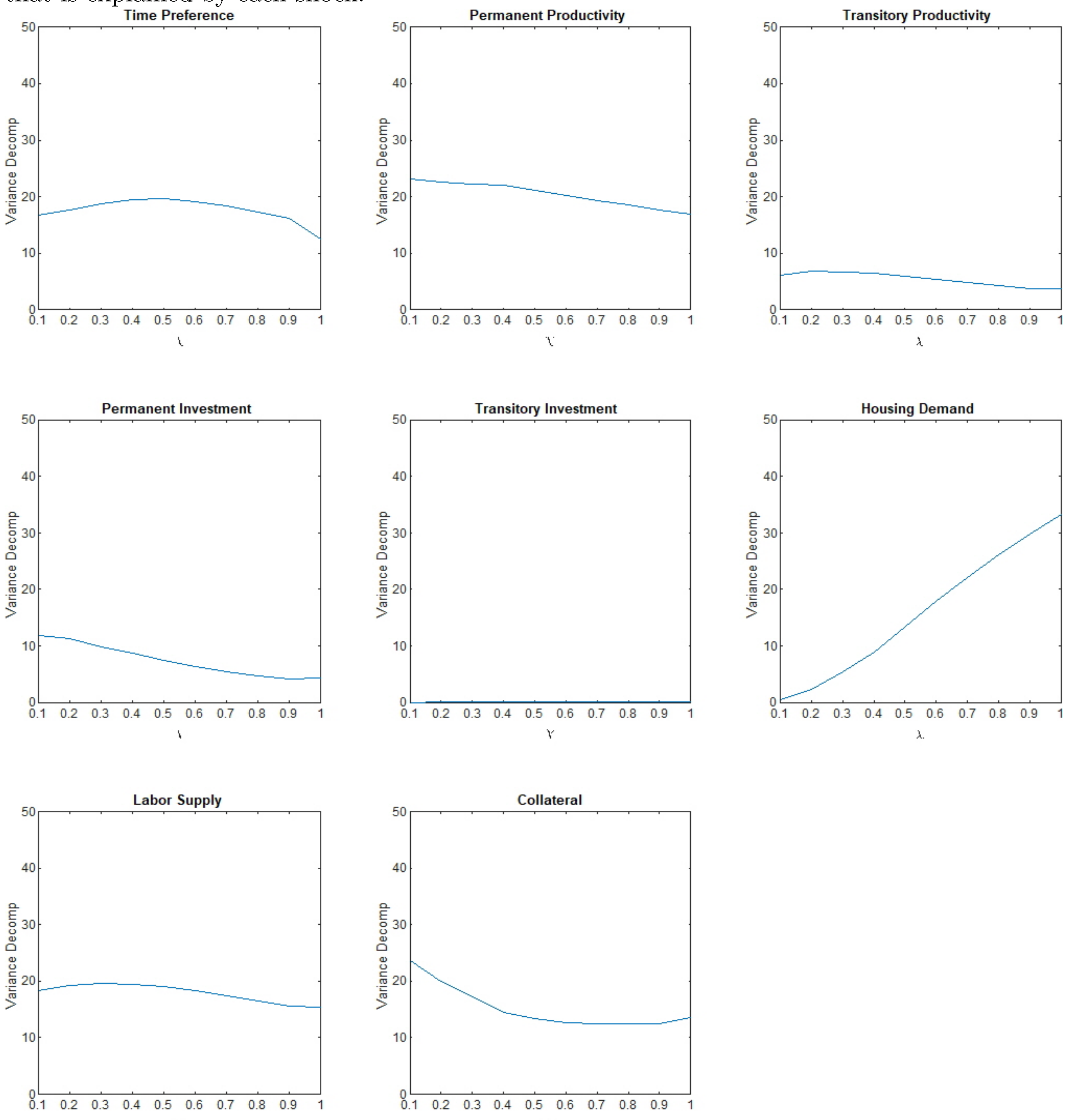
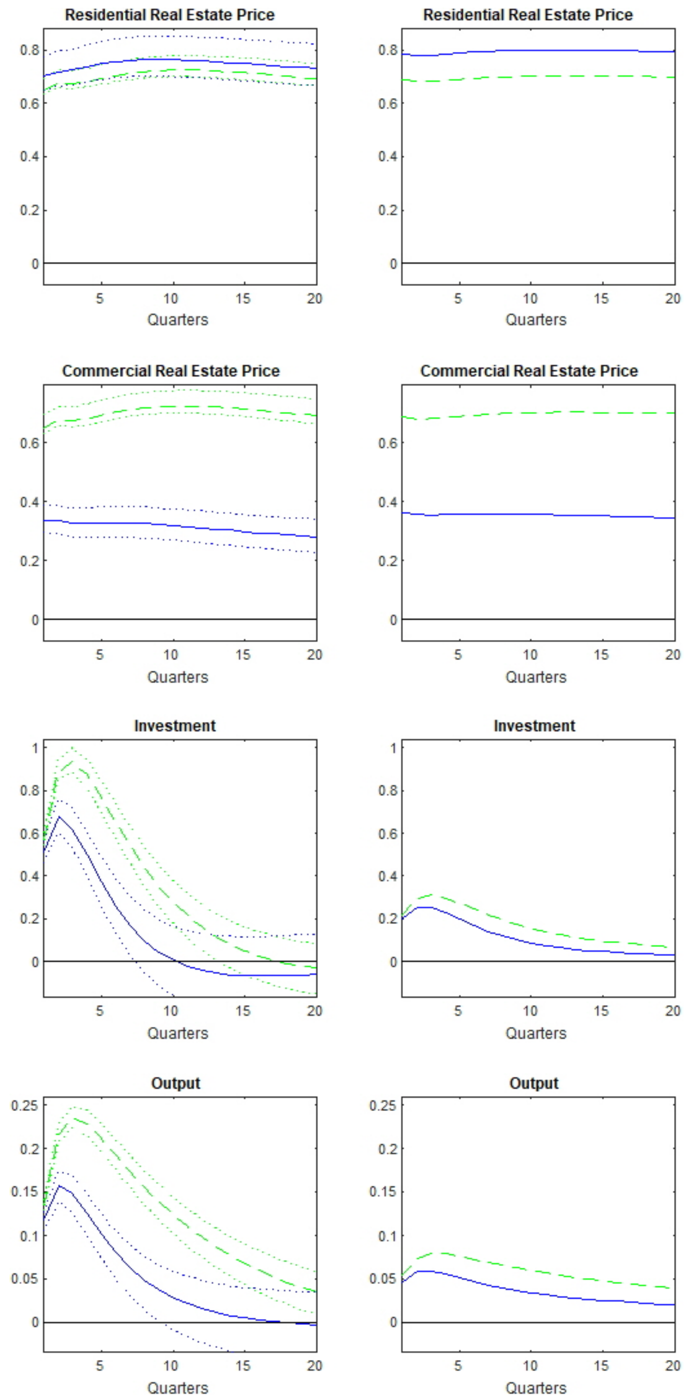
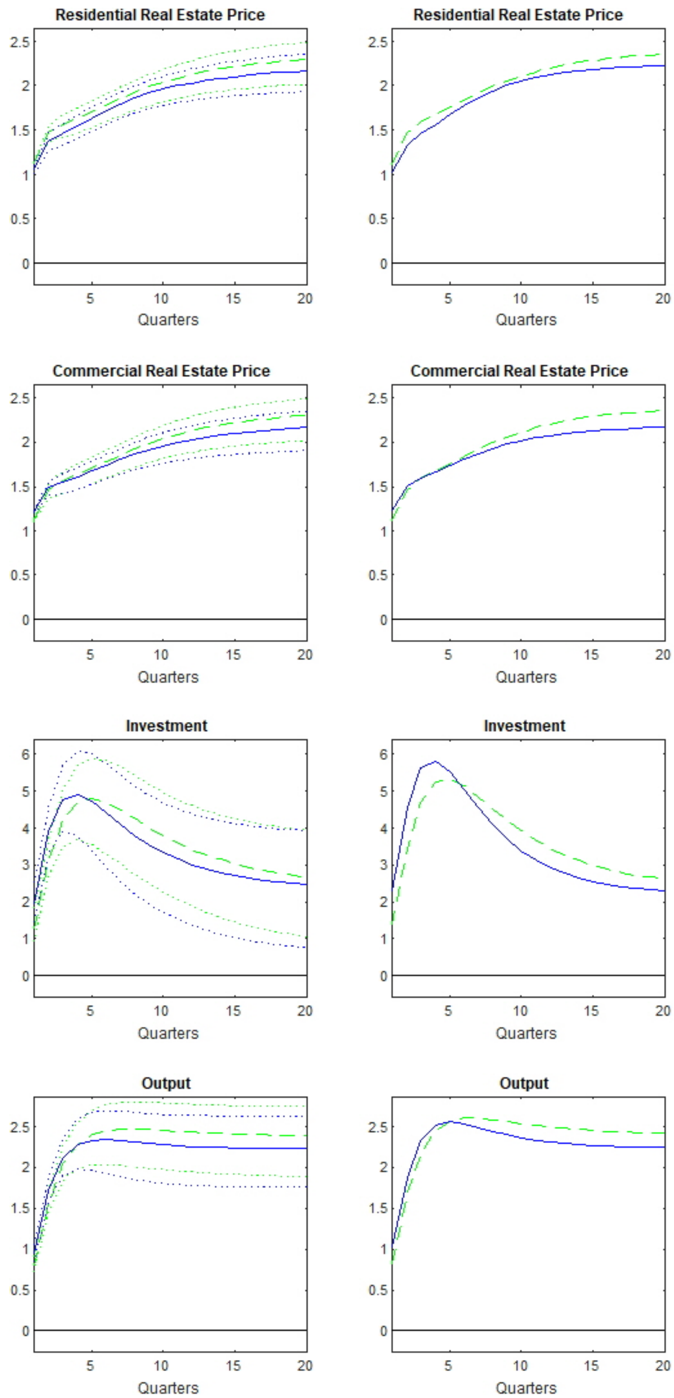


Figure 8: Impulse responses following a housing demand shock of the residential land price, the commercial land price, investment, and output in the imperfect substitutes model and the perfect substitutes model.



Notes: The blue solid line is from the imperfect substitutes model, the green dashed line is from the perfect substitutes model,and the dotted lines are he upper and lower bounds of the 68% confidence interval. The responses in the left-hand column are from the actual estimated model, the responses in the right-hand column are from the counterfactual where the value of the entrepreneur's collateral in the collateral constraint is held fixed at its steady state value.

Figure 9: Impulse responses following a permanent TFP shock of the residential land price, the commercial land price, investment, and output in the imperfect substitutes model and the perfect substitutes model.



Notes: The blue solid line is from the imperfect substitutes model, the green dashed line is from the perfect substitutes model,and the dotted lines are he upper and lower bounds of the 68% confidence interval. The responses in the left-hand column are from the actual estimated model, the responses in the right-hand column are from the counterfactual where the value of the entrepreneur's collateral in the collateral constraint is held fixed at its steady state value.

Table 1: The effect of firm real estate value on firm investment

	Dependent Variable: INV					
	(1)	(2)	(3)	(4)	(5)	(6)
RE_Val^{State}	0.0584***		0.0406***		0.0379***	
	(11.56)		(4.07)		(4.00)	
P^{State}	-0.218		-0.257		-0.225	
	(-1.04)		(-1.22)		(-1.07)	
RE_Val^{MSA}		0.0581***		0.0396***		0.0358***
		(11.56)		(4.02)		(3.90)
P^{MSA}		-0.00226**		-0.00239***		-0.00223**
		(-2.51)		(-2.64)		(-2.47)
$RE\_Val \times Rank^{Zone}$			0.000649**	0.000675**		
			(2.07)	(2.16)		
$RE\_Val \times Rank^{Land}$					0.000729**	0.000795***
					(2.49)	(2.72)
$Cash$	0.0230***	0.0230***	0.0230***	0.0229***	0.0230***	0.0230***
	(8.26)	(8.34)	(8.25)	(8.33)	(8.27)	(8.34)
$Market/book$	0.0637***	0.0638***	0.0636***	0.0638***	0.0637***	0.0638***
	(19.66)	(20.95)	(19.64)	(20.93)	(19.63)	(20.94)
$Controls \times P^{State}$	Yes	No	Yes	No	Yes	No
$Controls \times P^{MSA}$	No	Yes	No	Yes	No	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
$Obs.$	25902	25726	25902	25726	25902	25726
$\bar{R}^2$	0.309	0.309	0.309	0.309	0.309	0.309

Notes: ***/**/* denote 1/5/10% significance levels. This table reports the empirical link between the value of a firm's real estate assets and firm investment. The dependent variable is firm investment normalized by lagged PPE. Columns 1, 3, and 5 use state level residential real estate prices as a proxy for the market value of a firm's real estate assets, Columns 2,4, and 6 proxy instead by MSA level residential real estate prices. All regressions control for firm-level initial characteristics (five quintiles of age, asset, and ROA, as well as two-digit industry and state of location) interacted with Real Estate Prices. All regressions, control for Cash and previous year Market/Book. All specifications use year and firm fixed effects and cluster observations at the state-year or MSA-year level. T-stats are in parentheses.

Table 2: Prior and Posterior Distribution of Parameters.

	Posterior Modes		Prior Distributions				
	ImperfectSub.	PerfectSub.	PriorDist.	a	b	Low	High
Estimated Parameters:							
χ	0.470	1.000	Uniform(a,b)	0	1	0.050	0.950
γ_h	0.500	0.503	Beta(a,b)	1.000	2.000	0.025	0.776
γ_e	0.623	0.580	Beta(a,b)	1.000	2.000	0.025	0.776
Ω	0.136	0.176	Gamma(a,b)	1.000	0.500	0.103	5.991
$100(g_\gamma - 1)$	0.326	0.429	Gamma(a,b)	1.861	3.012	0.100	1.500
$100(\bar{\lambda}_q - 1)$	1.194	1.214	Gamma(a,b)	1.861	3.012	0.100	1.500
ρ_a	0.908	0.910	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_z	0.393	0.427	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_{ν_z}	0.033	0.029	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_Q	0.506	0.566	Beta(a,b)	1.000	2.000	0.025	0.776
$\rho_{\nu Q}$	0.195	0.305	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_φ	0.999	1.000	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_ψ	0.991	0.983	Beta(a,b)	1.000	2.000	0.025	0.776
ρ_θ	0.978	0.980	Beta(a,b)	1.000	2.000	0.025	0.776
σ_a	0.162	0.095	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_z	0.004	0.004	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_{ν_z}	0.003	0.004	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_q	0.004	0.004	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_{ν_q}	0.003	0.003	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_φ	0.039	0.046	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_ψ	0.007	0.007	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
σ_θ	0.008	0.011	InvGamma(a,b)	0.326	1.45E-04	0.0001	2.000
Simulated Parameters:							
β	0.988	0.985					
$\bar{\lambda}_a$	0.005	.009					
$\bar{\varphi}$	0.052	.045					
ϕ	0.069	.069					
δ	0.038	.038					

Notes: Low and High denote the bounds of the 90% confidence interval for the prior distribution

Table 3: Variance decompositions of the two land price variables.

Horizon	Patience	Perm. TFP	Trans. TFP	Perm. Inv	Trans Inv.	Housing	Labor	Collateral
	Residential Land Price, $q_{h,t}$							
	Imperfect Substitutes							
1Q	3.36	2.33	0.72	0.17	0.02	90.70	2.41	0.29
4Q	2.97	3.77	0.18	0.06	0.01	90.55	2.38	0.08
8Q	2.87	4.64	0.14	0.07	0.00	89.27	2.86	0.15
16Q	2.34	5.96	0.12	0.06	0.00	87.95	3.40	0.17
24Q	1.79	6.85	0.09	0.17	0.00	87.43	3.55	0.12
	Perfect Substitutes							
1Q	4.29	2.07	1.41	0.02	0.03	89.52	2.66	0.01
4Q	3.50	3.36	0.36	0.06	0.01	90.27	2.34	0.10
8Q	3.11	4.05	0.23	0.08	0.01	89.78	2.50	0.24
16Q	2.46	5.14	0.17	0.06	0.00	89.04	2.78	0.34
24Q	1.92	5.98	0.14	0.14	0.00	88.72	2.81	0.28
	Commercial Land Price, $q_{e,t}$							
	Imperfect Substitutes							
1Q	15.16	7.96	6.52	0.67	0.22	57.53	11.51	0.43
4Q	13.12	12.64	2.28	1.38	0.09	59.15	10.89	0.44
8Q	11.72	15.39	1.60	1.28	0.05	57.97	11.63	0.37
16Q	9.25	20.10	1.08	0.73	0.02	55.70	12.89	0.22
24Q	7.21	23.69	0.79	0.89	0.02	53.78	13.34	0.28
	Perfect Substitutes							
1Q	4.29	2.07	1.41	0.02	0.03	89.52	2.66	0.01
4Q	3.50	3.36	0.36	0.06	0.01	90.27	2.34	0.10
8Q	3.11	4.05	0.23	0.08	0.01	89.78	2.50	0.24
16Q	2.46	5.14	0.17	0.06	0.00	89.04	2.78	0.34
24Q	1.92	5.98	0.14	0.14	0.00	88.72	2.81	0.28

Notes: Columns 2 to 9 report the contributions of the patience shock (Patience), the housing demand shock (Housing), the labor supply shock (Labor), the permanent component of the TFP shock (Perm. TFP), the transitory component of the TFP shock (Trans TFP), the permanent component of the investment-specific technology shock (Perm. Inv.) the transitory component of the investment-specific technology shock (Trans. Inv.), and the collateral shock (Collateral)

Table 4: Variance decompositions of investment and total output.

Horizon	Patience	Perm. TFP	Trans. TFP	Perm. Inv	Trans Inv.	Housing	Labor	Collateral
				Investment, I_t				
				Imperfect Substitutes				
1Q	21.04	2.16	18.94	10.96	0.36	15.20	14.89	16.44
4Q	24.36	8.76	9.30	5.43	0.13	16.51	17.55	17.96
8Q	24.08	14.25	7.58	4.84	0.16	14.68	19.26	15.17
16Q	21.23	18.85	6.58	7.02	0.14	12.81	19.43	13.95
24Q	19.62	21.41	6.12	7.88	0.13	12.00	19.21	13.64
				Perfect Substitutes				
1Q	18.50	1.10	14.68	7.06	0.91	33.54	12.33	11.89
4Q	18.48	5.79	5.17	2.32	0.21	39.69	12.48	15.85
8Q	17.58	9.77	3.94	1.95	0.19	38.38	13.39	14.81
16Q	16.07	14.25	3.48	3.19	0.19	35.12	14.52	13.17
24Q	15.19	16.84	3.29	3.90	0.18	33.24	14.66	12.71
				Total Output, Y_t				
				Imperfect Substitutes				
1Q	14.42	8.21	19.75	8.82	0.26	11.84	24.18	12.51
4Q	14.26	22.57	7.76	3.93	0.08	11.38	27.73	12.30
8Q	11.91	33.67	5.13	2.42	0.07	8.46	29.85	8.49
16Q	8.27	44.54	3.23	2.97	0.05	5.33	30.35	5.27
24Q	6.20	50.11	2.38	3.85	0.03	3.93	29.44	4.06
				Perfect Substitutes				
1Q	11.92	6.89	16.58	5.67	0.60	27.20	22.24	8.90
4Q	11.04	17.50	4.95	1.88	0.12	30.99	21.67	11.85
8Q	9.57	25.80	3.31	1.06	0.08	27.46	22.70	10.04
16Q	7.37	36.43	2.36	1.55	0.06	21.02	24.12	7.10
24Q	5.91	43.58	1.88	2.44	0.05	16.68	23.96	5.50

Notes: Columns 2 to 9 report the contributions of the patience shock (Patience), the housing demand shock (Housing), the labor supply shock (Labor), the permanent component of the TFP shock (Perm. TFP), the transitory component of the TFP shock (Trans TFP), the permanent component of the investment-specific technology shock (Perm. Inv.) the transitory component of the investment-specific technology shock (Trans. Inv.), and the collateral shock (Collateral)

Table 5: Posterior distribution of the model parameters in the imperfect and perfect substitution models.

	Imperfect Substitution			Perfect Substitution		
	Mean	5%	95%	Mean	5%	95%
Model Parameters:						
χ	0.462	0.381	0.539	1.000	na	na
γ_h	0.509	0.457	0.565	0.507	0.452	0.559
γ_e	0.537	0.144	0.958	0.647	0.494	0.815
Ω	0.141	0.106	0.174	0.190	0.146	0.233
$100(g_\gamma - 1)$	0.322	0.237	0.391	0.417	0.310	0.529
$100(\bar{\lambda}_q - 1)$	1.199	1.083	1.314	1.215	1.082	1.345
Shock Process:						
ρ_a	0.903	0.875	0.931	0.902	0.870	0.937
ρ_z	0.378	0.269	0.495	0.406	0.283	0.536
ρ_{ν_z}	0.092	0.002	0.205	0.178	0.005	0.357
ρ_Q	0.513	0.421	0.617	0.577	0.491	0.670
$\rho_{\nu Q}$	0.312	0.087	0.540	0.354	0.165	0.602
ρ_φ	0.999	0.998	1.000	0.999	0.999	1.000
ρ_ψ	0.991	0.983	0.999	0.984	0.975	0.994
ρ_θ	0.979	0.973	0.985	0.982	0.976	0.988
σ_a	0.210	0.082	0.356	0.125	0.054	0.195
σ_z	0.005	0.004	0.005	0.004	0.003	0.005
σ_{ν_z}	0.004	0.003	0.004	0.004	0.003	0.005
σ_q	0.004	0.004	0.005	0.004	0.003	0.005
σ_{ν_q}	0.003	0.002	0.003	0.003	0.002	0.004
σ_φ	0.043	0.034	0.051	0.049	0.042	0.055
σ_ψ	0.008	0.007	0.009	0.008	0.007	0.008
σ_θ	0.008	0.007	0.009	0.011	0.010	0.013

Notes: 5% and 95% refer to the lower and upper bound of the 90% confidence intervals.