Time-Varying Role of Macroeconomic Shocks on House Prices in the US and UK: Evidence from Over 150 Years of Data

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Abstract

In this paper, we study the effect of macroeconomic shocks in the determination of house prices. Focusing on the U.S. and the U.K. housing market, we employ time-varying Vector Autoregression models using Bayesian methods covering the periods of 1830-2016 and 1845-2016 respectively. We consider real house prices, output growth, short-term interest rates and inflation as input variables in order to unveil the effect of macroeconomic shocks on house prices. From the examination of the impulse responses of house prices on macroeconomic shocks, we find that technology shocks dominate in the U.S. real estate market, while their effect is unimportant in the U.K. In contrast, monetary policy drives most of the evolution of the U.K. house prices, while transitory house supply shocks are unimportant in either country. These findings are further corroborated with the analysis of conditional volatilities and correlations to macroeconomic shocks. Overall, we are able to better understand the dynamic linkages in the relationship of the macro economy and house prices. Over time, we analyze the variations in economic events happening at the imposition of the shock and uncover characteristics missed in the time-invariant approaches of previous studies.

Keywords: time-varying VAR, house prices, macroeconomic shocks

JEL Codes: C32, R30

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1. Introduction

In the aftermath of the Great Recession (2008-2010), considered by the International Monetary Fund as the worst global recession since World War II (International Monetary Fund, 2009), a growing literature attempts to uncover the underlying mechanism that led to this recession (Stock and Watson, 2012; Snowden, 2015). Although the latest 2008 financial crisis has similar characteristics to previous ones (Reinhart and Rogoff, 2009), the usefulness of economic models in forecasting recessions is questioned (Gadea and Perez-Quiros, 2015).

A number of studies emphasize the role of asset price fluctuations, especially house prices, in driving financial and business cycle dynamics (Leamer, 2007; Miller et al., 2011; Balcilar et al., 2014; Nyakabawo et al., 2015; Emirmahmutoglu et al., 2016). Asset price variations affect the real economy as a consequence of the direct effect of households' wealth on consumption (e.g., Iacoviello and Neri, 2010; André et al., 2012; Iacoviello, 2012; Zhou and Carroll, 2012; Case et al. 2013; Liu et al., 2013; Guerrieri and Iacoviello, 2013; Mian et al., 2013; Simo-Kengne et al., 2015). The housing construction sector represents a large part of the total economic activity and consequently reflects a large portion of the total wealth of the economy (Case and Schiller, 2003). Furthermore, forward-looking, rational economic agents incorporate the fluctuations in asset prices in their expectations (Gelain and Lansing, 2014), which, in turn, affects the propagation mechanism of shocks.

While the effect of housing market spillovers onto the real economy, and even onto inflation (Stock and Watson, 2003) has been extensively studied, the link from the real economy to the housing market has attracted less attention. This is true even though the literature on forecasting housing prices have regularly considered the role of many macroeconomic variables (see for example, Gupta et al. (2011) and Plakandaras et al. (2015) for detailed reviews in this regard). What seems to dominate the structural analysis of the housing market is the role of monetary policy (Iacoviello and Minetti, 2003, 2008; Del Negro and Otrok, 2007; Bjørnland and Jacobsen, 2010, 2013; Gupta et al. 2012a, b; Rahal, 2016). The evidence in terms of the importance of monetary policy is mixed. However, this cannot be gauged completely, as other macro shocks affecting the housing market are not explicitly identified. Demary (2010) is an exception to this line of research since the study goes beyond monetary

policy and identifies three transmission channels between macroeconomic variables and real estate prices based on economic intuition. These channels are i) a contractionary monetary policy leads to an increase in mortgage rates, higher housing costs and lower demand for houses that ultimately lowers house prices; ii) the inflation channel states that an increase in inflation may cause heterogeneous impacts on houses prices. Given that real estate investments can be used to hedge inflation, an increase in inflation encourages residential investment that, in turn, leads to an increase in real estate prices (Demary, 2010). In contrast, the monetary authority is likely to respond to rising inflation by increasing interest rates. This may lead to an increase in housing finance which may lower the demand for real estate and house prices and, iii) a positive shock to output increases the disposable income that can be used to enhance consumption or as investment in real estate. As the economy thrives, the demand for private and professional housing space increases, thus, triggering an increase in construction activities and house prices.

Empirically, Beltratti and Morana (2010) examine the links between macroeconomic variables and the housing market for G-7 countries using a Factor Vector Autoregressive (FVAR) model. The response of the housing industry to macroeconomic shocks indicates that only global-supply side shocks are important determinants of house price fluctuations. Under a similar framework, Del Negro and Otrok (2007) consider a structural VAR model and identify monetary policy shocks by imposing sign restrictions on responses. They find that the impact of policy shocks on the U.S. house prices is rather small in comparison to the response on idiosyncratic shocks. Gattini and Hiebert (2010) examine the long-run relationship between real house prices and real housing investment, real per capita income and real interest rates in the euro area, using a vector error-correction model (VECM). Their empirical findings suggest that real disposable per capita income is important in explaining house price fluctuations in the long run. However, in the short run, it is only housing preferences and specific endogenous factors in the housing market that affect prices.

Assenmacher-Wesche and Gerlach (2008) study a panel dataset comprised of 18 OECD countries and conclude that the impact of monetary policy on house prices is modest. Carstensen et al. (2009) perform a VAR panel regression on the same dataset but use different methods to identify structural shocks. In contrast to Assenmacher-Wesche and Gerlach (2008), they suggest that monetary policy shocks

have a large impact on house prices. Nevertheless, as it is explicitly stressed in both studies, there is large uncertainty and cross-country variation in their estimates. Jarocinski and Smets (2008) and Musso et al. (2011) examine country-specific factors for the U.S. and the euro area such as housing construction flexibility, transaction costs, taxes, mortgage market regulation and the proportion of fixed to variable rate mortgages. Their results suggest a modest response of house prices to the aforementioned factors that varies between countries.

Terrones and Otrok (2004) study the dynamics of house prices for 13 industrial countries over the period 1980-2004 using factor models with time-varying construction of the factors based on growth rate, stock prices, per capita output per capita consumption, residential investment and long and short-term interest rate. Their results indicate the significant role of real income growth, interest rates and an autoregressive component in the determination of house prices. Tsatsaronis and Zhu (2004) argue that house prices depend on inflation, the yield curve and bank credit and are more sensitive to short-term rates, since in short-term financing floating mortgage rates and aggressive lending practices are widely used.

Kahn (2008) develops a stochastic Markov-Switching model where the trend of productivity growth explains medium to long-run fluctuations of house prices. Under the specific growth model, short-run price fluctuations are assumed to be the result of a faster growth of housing wealth to private income; thus, this rise inflates and collapses exhibiting a "bubbly" behavior. Focusing on the U.K. housing market, Brooks and Tsolacos (1999) uncover a strong causal relationship between unexpected inflation interest rate term spread and property market. However, the most significant influence on real estate prices originate from idiosyncratic shocks of the real estate market. In a broader examination, Goodhart and Hofmann (2001) implement a fixed-effects panel data model on a sample of 17 industrialized countries over the period 1970-2006 and conclude that short-term interest rates and inflation affect significantly the evolution of house prices in the U.K. In a similar context, Katrakilidis and Trachanas (2013) observe asymmetric long-run effects of inflation and output shocks to Greek house prices depended on the sign of the shock. They conclude that in the short-run house prices react immediately to a positive inflation shock, while at longer horizons upward movements in house prices are dominated by downward changes in consumer prices. Overall, despite the contradictory results of the extant literature, the

relevant literature does find the existence of a significant effect between macroeconomic shocks and house prices.

Much of the empirical analysis of the housing market assumes a linear relationship between variables with time invariant parameters between macroeconomic fundamentals and housing supply or demand. However, it is reasonable to assume that the linkage between fundamentals and the housing market exhibit nonlinearities and parameters are time varying. One may question the relevance of linear models with time invariant parameters in the analysis of the joint dynamics. Such types of models may not be able to capture the instability of the parameters and uncertainty. Furthermore, the recent empirical literature highlights that macroeconomic and financial variables are affected by structural breaks. In this paper we examine the relationship between house prices and the macro-economy for the U.S. and the U.K by means of a structural VAR model with time-varying parameters (TVP-VAR), spanning the period 1830 to 2016 and 1845 to 2016 respectively. We estimate a time-varying VAR set-up with drifting coefficients and stochastic volatilities. This follows the work of Cogley and Sargent (2005) and Canova and Gambetti (2010). The TVP-VAR model with constant volatility may result in biased estimates. The TVP-VAR model with stochastic volatility avoids this misspecification issue by accommodating the simultaneous relations among variables as well as the heteroscedasticity of the innovations. This gain in flexibility comes at the expense of a more complicated estimation structure. The estimation of the model requires using Markov-Chain Monte-Carlo (MCMC) methods with Bayesian inference.

The use of a time varying model allows the coefficients to evolve over time, adjusting to structural breaks in the dataset such as the Great Depression (1930s), the Great Inflation (1970s), the Great Moderation (1980s through mid-2000s), and the Great Recession (late-2000s). Accordingly, the model allows for possible stochastic volatility in the innovations. More specifically, we examine the response of real house prices to shocks on real output, price level and monetary policy variables, and use the conditional and unconditional evolution of volatility and correlation to uncover possible trends in the housing sector.

The relevant literature that examines the relationship of asset prices to macroeconomic variables with the use of TVP-VAR models is limited. Among them

are Simo-Kengne et al. (2015) who study the effect of stock and house prices on U.S. consumption, and Koop et al. (2009), Korobilis (2013) and Simo-Kengne et al. (2016) study the time-varying effects of monetary policy on house prices (among other variables).

The innovation introduced by the current analysis is twofold: Unlike most previous studies that consider the role of house price fluctuations in explaining movements in business cycles, and primarily consumption, we focus explicitly on the opposite direction, i.e., the effect of macroeconomic conditions on the real estate market. More specifically, we build on the previous works that primarily focuses on the role of monetary policy on the housing market, and to a very limited degree on the importance of other possible macro shocks in driving house prices. More importantly, our analysis is based on unique data sets for the U.S. and U.K. covering over 150 years of data (specifically, 1830-2016 for the U.S. and 1845-2016 for the U.K.), with results derived from a time-varying framework. These are the longest possible spans of data that can be used related to house prices for these two economies, and hence, allows us to study the evolution of these two countries, and in particular, their respective housing markets in response to various macroeconomic shocks in a time-varying fashion. To the best of our knowledge, this is the first attempt to study the time-varying impact of not only monetary policy shocks, but also other macroeconomic shocks, for the U.S. and U.K. using over a century of historical data.

In the next sections, we present the basic structure of the TVP-VAR model and the identification method of the structural shocks. Thereafter, our empirical findings and the conclusions based on our findings are discussed.

2.   Methodological issues

Our work is motivated by Cogley and Sargent (2005) and Canova and Gambetti (2010) who train a TVP-VAR model with Bayesian methods to allow for time-varying VAR coefficients with stochastic volatility on the innovations. We consider a reduced VAR model:

$$\theta_t(L)x_t = e_t \tag{1}$$

with $x_t = \{\Delta y_t, \Delta p_t, \Delta \mathrm{ir}_t, \Delta hp_t\}$ representing an n-vector of endogenous variables

(namely output growth, inflation (π), changes in interest rate and real housing returns) at each point of time t, each θ_{jt} in $\theta_t(L) = I - \theta_{1t}L - \cdots - \theta_{1t}L^1$ is a matrix of time-varying coefficients and e_t is a vector of zero mean VAR errors with a time-varying covariance matrix R_t. The coefficients in (1) evolve according to:

$$\theta_t = \theta_{t-1} + u_t \tag{2}$$

with θ_t denoting the vector that stacks all parameters in $\theta_t(L)$ and u_t a Gaussian white noise process with zero mean and constant covariance matrix Q, independent of ε_t at all leads and lags. We model the time variations of innovations $R_t = E(e_t e_t') = F_t D_t F_t'$, where F_t is a lower diagonal matrix with ones in the main diagonal and D_t a diagonal matrix. In order to provide flexibility to our model we drop the typical homoscedasticity assumption and allow for the existence of stochastic volatility on the VAR errors. In order to achieve this we compute the covariance matrix R_t as follows:

Let's assume that γ_t is a vector containing all the elements of F_t^{-1} below the diagonal, stacked by rows. Then to include stochastic volatility, γ_t follows (3):

$$\gamma_t = \gamma_{t-1} + \zeta_t \tag{3}$$

In a similar vein, σ_t is a vector of diagonal elements of D_t stacked by rows and follows (4):

$$log\sigma_t = log\sigma_{t-1} + \xi_t \tag{4}$$

where ζ_t and ξ_t are Gaussian white noise processes with zero mean and (constant) covariance matrices Ψ and Ξ, respectively. In order to be able to estimate our model we make a few modest assumptions: a) we assume that Ψ has a block diagonal structure, i.e. all covariances between coefficients belonging to different equations are zero, b) that Ξ is diagonal and c) that ζ_t, ξ_t and u_t are all mutually independent. Details on the Bayesian estimation of the system are reported in the Appendix.

Following the typical structural shock literature related to monetary VARs with asset prices (see for example, Bjørnland and Leitemo (2009), Bjørnland and Jacobsen, (2010, 2013)), the vector of VAR innovations e_t is a (time-varying) linear

transformation of the underlying "structural" shocks $\varepsilon_t = \left\{\varepsilon_t^y, \varepsilon_t^\pi, \varepsilon_t^{ir}, \varepsilon_t^{hp}\right\}'$. The model satisfies $E(\varepsilon_t \varepsilon_t') = I$, with ε_t^y representing a technological shock, ε_t^π an inflation (price) shock, ε_t^{ir} the effect of a monetary policy- finance (shock) and ε_t^{hp} a supply/demand shock of the housing market. Thus, $e_t = \varphi_t \varepsilon_t$, where φ_t is a nonsingular matrix that satisfies $\varphi_t \varphi_t' = R_t$. Given this normalization scheme, changes in the contributions of different structural shocks to the volatility of innovations to variables are captured by changes in φ_t. Let the companion form of (1) be:

$$X_t = \Theta_t X_{t-1} + He_t \tag{5}$$

where $X_t = (x_t', x_{t-1}', \dots, x_{t-l+1}')'$, $H = (I, 0, \dots, 0)'$ and Θ_t is the companion-form matrix derived from the autoregressive coefficients of (1). A local projection of (5) yields:

$$\frac{\partial x_{t+k}}{\partial e_t} = s_{n,n}\left(\Theta_t^k\right) \qquad \forall t, k = 0, 1, 2, \dots \tag{6}$$

where $s_{n,n}(\cdot)$ is the selector function that selects the n rows and columns of a matrix. The application of the chain rule yields the following impulse response at an arbitrary *k-th* horizon:

$$\frac{\partial x_{t+k}}{\partial \varepsilon_t} = \frac{\partial x_{t+k}}{\partial e_t}\frac{\partial e_t}{\partial \varepsilon_t} = s_{n,n}\left(\Theta_t^k\right)\varphi_t \qquad \forall t, k = 0, 1, 2, \dots \tag{7}$$

We are interested in the identification of level responses and thus of the cumulative responses to each variable. We define $\overline{\Theta}_t^k = \sum_{j=0}^k \Theta_t^j$ where the level response of each variable to each shock at k periods is the accumulated response of the differenced series from period zero to period k: $M_{t,k} = \sum_{j=0}^k s_{n,n}\left(\Theta_t^j\right)\varphi_t$. From the properties of the selector function we obtain $M_{t,k} = s_{n,n}\left(\overline{\Theta}_t^k\right)\varphi_t$. Letting $k \to \infty$ defines the time-varying matrix of long-run cumulative multipliers that indicate the long-run effect of each shock on the variable of interest.

Our identification method of structural shocks follows a Blanchard and Quah (1989) type with long-run restrictions on the innovations in order to decompose the

responses into permanent and transitory shocks. The identification of the structural shocks is based on well-documented macroeconomic hypotheses. First, according to the long-run neutrality of money approach, an increase or decrease in money supply cannot affect the (real) output. Moreover, according to the natural rate hypothesis, the single source of non-stationarity in real output stems from disturbances to aggregate supply and thus from technological advancements. Thus, we restrict exogenous changes of an inflationary shock to have no long-run effect on output, placing inflation second in the VAR. We also assume that output and inflation react with a lag to monetary policy shocks whereas the monetary policy-maker responds immediately to output and inflation shocks. Thus, the interest rate variable comes third in the ordering of the TVP-VAR system. Moreover, given that demand shocks in the housing market are basically transitory shocks uncorrelated to permanent shocks (Gattini and Hiebert, 2010), the matrix of cumulative long-run multipliers is a lower triangular matrix. Thus, for the definition of $M_{t,k}$ we use:

$$M_t M_t' = s_{n,n}(\overline{\Theta}_t^\infty) R_t \left(s_{n,n}(\overline{\Theta}_t^\infty) \right)' \tag{8}$$

with M_t obtained from the Cholesky decomposition of (8). Given M_t we can solve for φ_t and obtain the structural impulse responses of each shock according to the ordering $\varepsilon_t = \left\{ \varepsilon_t^y, \varepsilon_t^\pi, \varepsilon_t^{ir}, \varepsilon_t^{hp} \right\}'$:

$$\frac{\partial x_{t+k}}{\partial \varepsilon_t} = s_{n,n}(\Theta_t^k) \left(s_{n,n}(\overline{\Theta}_t^\infty) \right)^{-1} M_t \qquad \forall t, k = 0,1,2,\dots \tag{9}$$

Recursive substitution on (7) allows each variable to be written as a time-varying moving representation driven by the underlying structural disturbances. If $x_{i,t}$ represents a distributed lag process for each variable contingent of shock j, we have:

$$x_{i,t} = \mu_t^i + \sum_{k=0}^\infty [\overline{N}_{t,k}]_{i,j} \varepsilon_{t-k}^j \tag{10}$$

for $i = \{\Delta y_t, \Delta \pi_t, \Delta ir_t, \Delta hp_t\}$, $\varepsilon_{t-k}^j = \left\{ \varepsilon_{t-k}^y, \varepsilon_{t-k}^\pi, \varepsilon_{t-k}^{ir}, \varepsilon_{t-k}^{hp} \right\}$ and $\overline{N}_{t,k} = s_{n,n}(\Theta_t^k)$. From (10) we see that the time-varying unconditional variance of $x_{i,t}$ is decomposed into the contribution of each shock to the variance of each variable according to the following:

$$var_t(x_{i,t}) = \sum_{k=0}^{\infty} \left[s_{n,n}(\Theta_t^k)\varphi_t \right]_{i,j}^2 \tag{11}$$

and the time varying covariance of $x_{i,t}$ and $x_{q,t}$ conditional on each shock j is given by:

$$covar_t(x_{i,t}, x_{q,t}) = \sum_{k=0}^{\infty} \left[s_{n,n}(\Theta_t^k)\theta_t(1)M_t \right]_{i,j} \left[s_{n,n}(\Theta_t^k)\theta_t(1)M_t \right]_{q,j} \tag{12}$$

Time-varying unconditional and conditional correlations are given tractably from (11) and (12).

3.   Data and Empirical Results

3.1   The Data

We compile a dataset of annual time series for the U.S. and U.K. spanning the periods of 1830-2016 and 1845-2016 respectively, which includes real Gross Domestic Product (*y*), Consumer Price Index (*p*), nominal short term interest rate (*ir*), and real house prices (*hp*), with the latter obtained by deflating the nominal house prices with the consumer price index. All variables for the U.S. were sourced from the Global Financial Database. While data for the U.K. is derived from the database called the Three Centuries of Data (Version 2.3), maintained by the Bank of England[1]. An advantage of using a relatively long sample is the ability to examine how economies, and especially the housing market of these two countries, have evolved over time covering almost their entire modern economic history. All data except interest rates are transformed into logarithms. Conventional unit root tests fail to reject the existence of unit roots for all variables in levels, but not in first differences.[2] Hence, we work with growth rate of output, inflation, changes in interest rate and real housing returns, as indicated by: $\Delta y_t, \Delta p_t, \Delta \text{ir}_t, \Delta hp_t$, respectively.

3.2   Empirical findings

We train a TVP-VAR model and estimate the conditional and unconditional deviations and correlations as well as the Impulse Responses of a shock on output,

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[1] http://www.bankofengland.co.uk/research/Pages/datasets/default.aspx
[2] We use standard unit-root tests: Augmented-Dickey-Fuller (ADF)(1981), Phillips-Perron (PP) (1988), Dickey-Fuller with Generalised-Least-Squares-detrending (DF-GLS) (Elliott et al. , 1996), and the Ng-Perron modified version of the PP (NP-MZt) (2001) tests to confirm that the (log-)levels of the variables under consideration follow an integrated process of order 1 or are I(1) processes. All unit root tests are available from the authors upon request.

inflation and interest rate on house prices. Given the time-varying nature of the model there is no need to test for the existence of structural breaks (Korobilis, 2013). We choose a lag length of two based on the SIC criterion applied to a VAR with constant parameters over time.

In Figure 1, we report the coefficients for the house prices (fourth) equation. Given the time-varying nature of our model and the Bayesian estimation that provides the entire posterior distribution of the coefficients, we report both posterior median values and 68% intervals instead of the typical t-test and F-test statistics. [3]
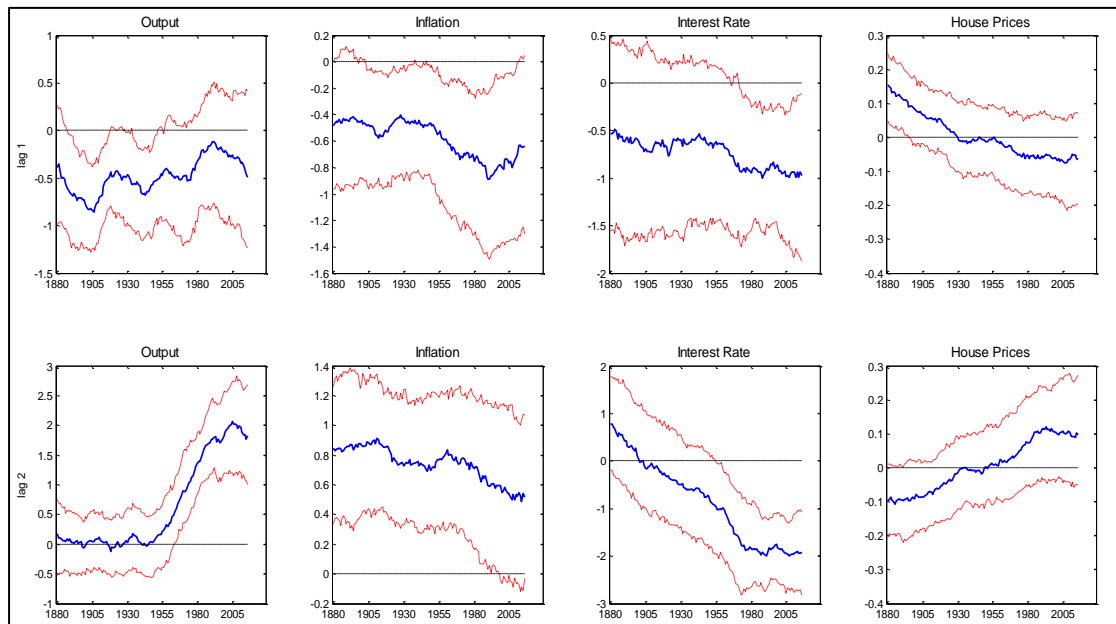
Figure 1: U.S. Posterior median coefficients estimates and their 68% intervals for house prices. We report Lag 1 and Lag 2.

As we observe from figure 1, the time-varying coefficients of the first lag for output are mostly statistically insignificant, while the parameters for the second lag are significant in the post-1960 period. In fact, output coefficients exhibit the highest effect on house prices with the maximum value of the median value reaching 2. In other words, a unit increase in output increases houses prices after 2 years by two units. In contrast, inflation parameters are statistically significant for both lags, but the negative values in the median value of the first lag are mostly compensated in half by the positive values of the second lag. Thus, inflation appears to have a small positive effect on house prices. The median values of the interest rate coefficients for the first

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[3] Estimates for output growth, inflation and interest rate equations are reported in the Appendix.

lag are negative and slightly declining with a value around -0.5, while the second lag has statistically significant coefficients in the post 1960 period and stabilizes around -2 on the Great Moderation period and onwards. This finding is expected and is consistent with the literature, because an increase of the interest rate deteriorates financing of construction investments. This negative relationship is at a maximum in the Volcker administration period, where the focus of monetary policy shifted from growth to restraining inflation. The coefficients of house prices are almost all statistically insignificant. Overall, the key drivers in the evolution of U.S. house prices appear to be the lagged values of output and interest rates, with an almost symmetric and opposite effect.

The situation is different for the U.K. Results reported for the UK in Figure 2 show that both the output growth and inflation coefficients are statistically insignificant in both lags. This finding is strikingly different from the extant literature, since earlier studies detect a predominance of inflation shocks in the housing market (Tsatsaronis and Zhu, 2004). The difference in our empirical findings could be attributed to the time-varying nature of our model that allows for the detection of "local" trends in the sample. Earlier studies based on the constant parameter SVAR model failed to capture this feature since it is commonly smoothed out in long-span datasets. The interest rate coefficients have the right sign and indicate that the monetary policy is the main driver of evolution of house prices. Moreover, the coefficients of the first lag of house prices are statistically significant and larger than the other coefficients through time, implying a persistence of house price, consistent with arguments in Terrones and Otrok (2004). Thus, U.K. prices emerge to be more persistent than U.S. house prices, while monetary policy is of key importance to both real estate markets.
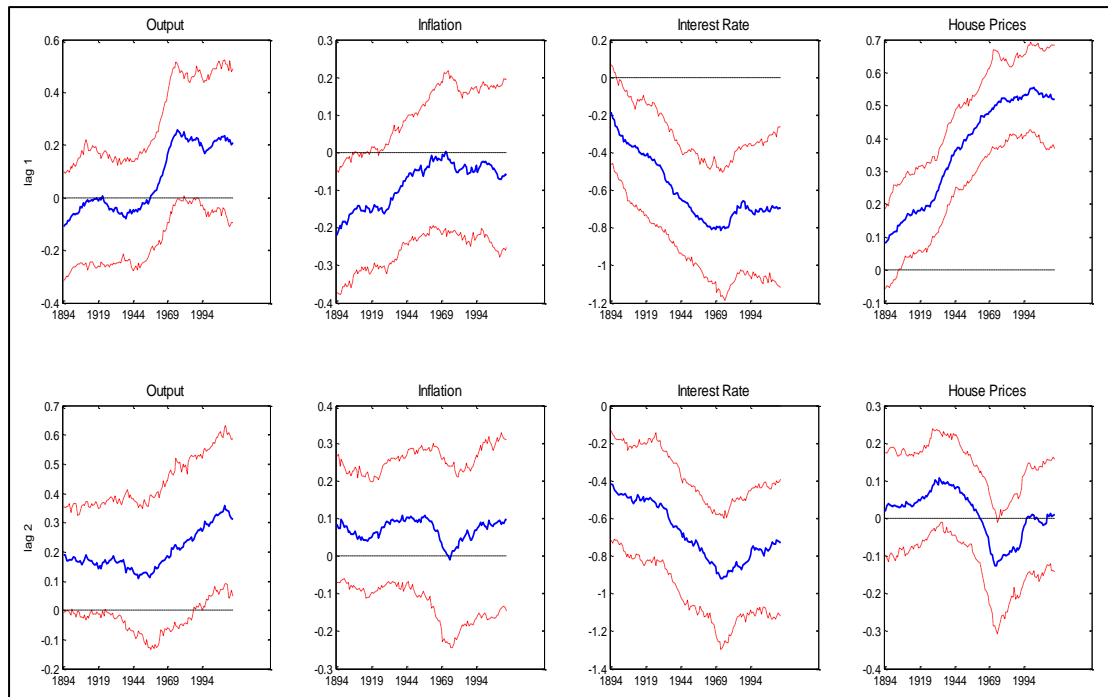
Figure 2: U.K. Posterior median coefficients estimates and their 68% intervals for house prices. Lag 1 and Lag 2.

3.2.1 Impulse Response analysis

Although the analysis of the time-varying coefficients provides valuable information on the existence of a causal relationship among house prices and fundamentals, it lacks the perspective of a time evolution of structural shock - an assessment of the response of the housing market to a change in fundamentals over time. In this vein, we examine the time-varying response of house prices to a structural shock in fundamentals, permanent or transitory. The permanent shocks on output, inflation and interest rate are coded as "technological shock", "price shock" and "financial (money) shock", respectively. As in Demary (2010), the aforementioned shocks are allowed to have a permanent effect on house prices, while supply and demand fluctuations in the housing market have only a transitory shock on house prices. As in Matsyama (1999) we treat all changes in the regulatory framework as a technology shock. For instance, an increase or decrease in the time required to obtain a building permit, changes in the various zoning laws, changes in the tax system that might encourage or discourage home ownership, shifts in demographics and availability of land can affect the housing market.

In figures 3 and 4, we report the impulse response functions (IRF) for the U.S. and the U.K real estate market, respectively. Given the time-varying nature of our model, we have to add one more axis to the IRF plots that corresponds to the date of

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the imposition of the shock. As it is obvious from the IRFs, all shocks are short-lived up to approximately 5 years ahead and have zero effect beyond that point. Given the inability to plot confidence intervals in the two plots (as the figures would become unreadable), we splice 2D graphs for each IRF for 1, 2, 3 and 5 years ahead, depicted in figures 5 and 6 for the U.S. and the UK respectively.
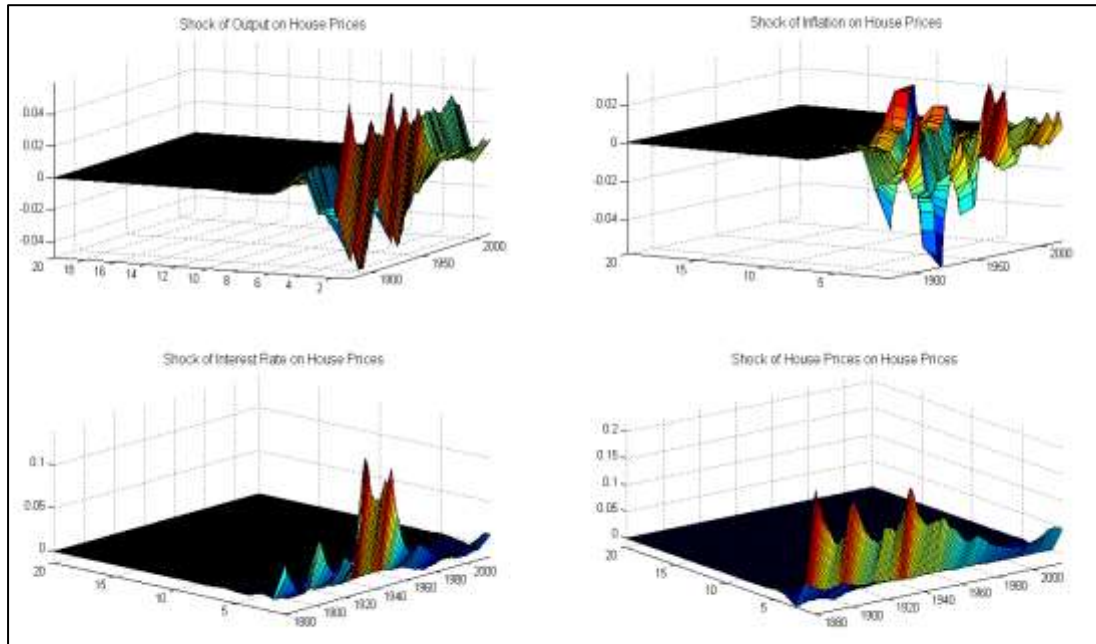

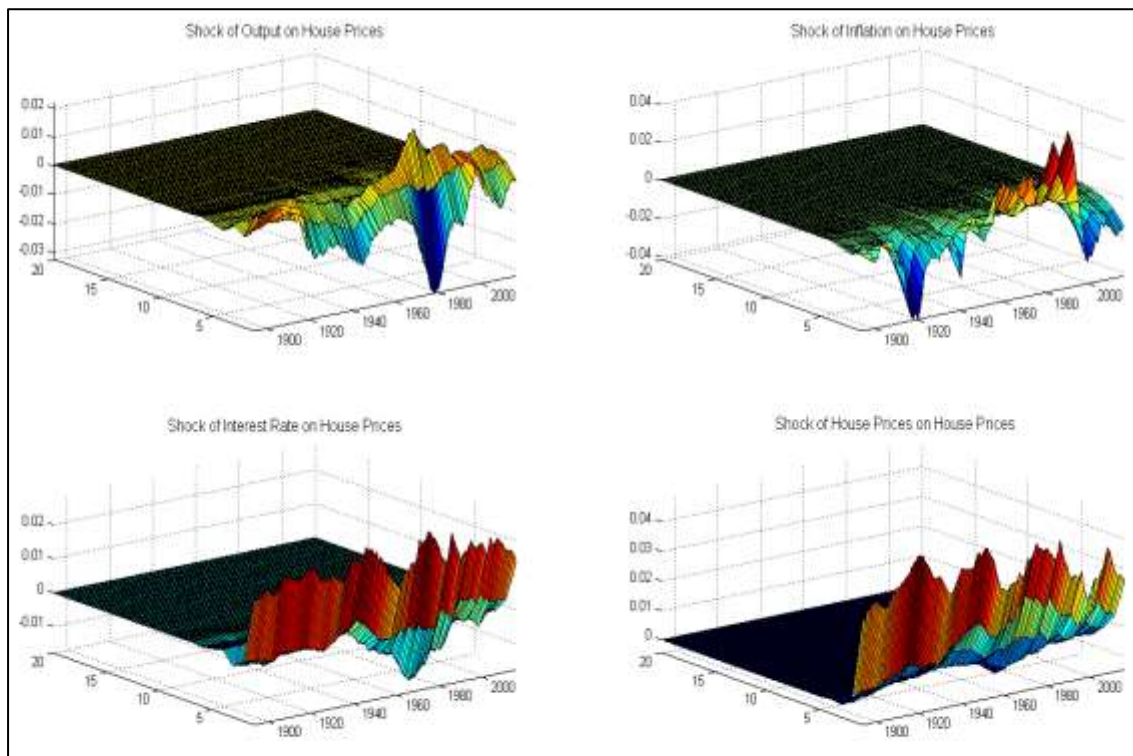**Figure 3:** Impulse Response Functions of the time-varying model for the U.S.

Figure 4: Impulse Response Functions of the time-varying model for the U.K

A technology shock (figure 5, subplots a-d) has a positive, significant and persistent impact in the long run on U.S. house prices, consistent with theory. Given the dual nature of the housing market as a consumption as well as an investment asset (Leung, 2004), a positive technology shock increases disposable income, shifting consumption up and eventually encouraging investment on the housing market. The response to a technology shock is realized within a two-year lag length that is consistent with the actual experience, given the time limitations in funding and completing a housing construction project. The response of house prices is found to be higher before WWII and smaller in the period after the Great Moderation (1984-2007), exhibiting two peaks around the 1900s and the 1930s; the period of the 1907 Panic and the Great Depression. This finding is interesting since it corroborates with the business cycle literature that supports the existence of high macroeconomic volatility during periods of increased macroeconomic uncertainty.

In contrast to the response of house prices to a technology shock, the response to an inflation shock (subplots e-h) is short-lived. In the first year (subplot e), the response is statistically significant before the Great Depression and during the WWII period. However, on the second year, after the imposition of the shock (subplot f) the response turns negative and significantly smaller in absolute terms. From that point and onwards, no response is statistically significant. The small negative response of house prices to a price shock follows the monetary literature, which states that an increase in inflation forces the monetary authority to react by increasing interest rates and reducing investments in the housing construction sector, aiming at the stabilization of prices (Demary, 2010; Katrakilidis and Trachanas, 2013). These findings corroborate with our previous results of the TVP-VAR coefficients regarding inflation and pinpoint the effectiveness of the inflation-targeted policies of the Federal Reserve on the stabilization of asset prices (Simo-Kengne et al., 2015).

Under a similar perspective, a money shock (figure 5, subplots i-l) induces a negative effect on house prices, since an increase of interest rates drives house prices downwards due to higher mortgage rates and lower demand in the real asset market. In terms of magnitude, the monetary policy effect is higher in the post 1970s period. Interestingly, the response of house prices to transitory idiosyncratic shocks of the housing market (subplots m-p) is very small, positive and statistically significant only
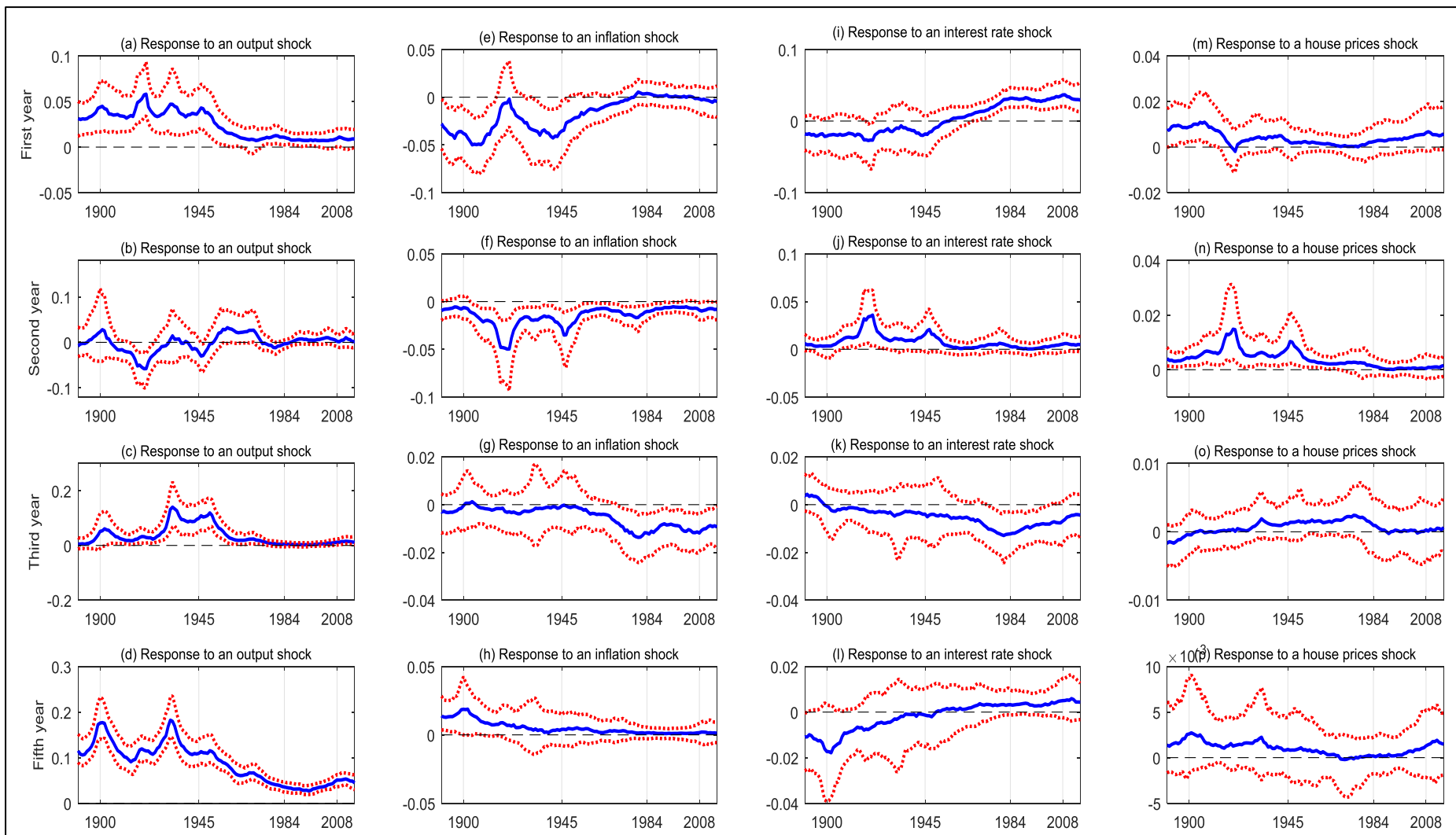
Figure 5: Horizon dependent Impulse Response Functions of the time-varying model for the U.S with 16th and 84th (1 std) percentiles for house prices.

on the second year (subplot n) and only to the pre 1970s period. Given the economic changes following the Great Depression and the WWII period, these transitory shocks in house demands have no long-run effect to the house prices and could be attributed to supply shocks in the housing market.

Overall, our results corroborate with the literature on the significance of technology shocks in the long run (Kahn, 2008; Gattini and Hiebert, 2010) and the negative effect between money shocks and house prices (Demary, 2010). However, we do not find a significant autoregressive effect of house prices in line with Del Negro and Otrok (2007), Gattini and Hiebert (2010) and Terrones and Otrok (2004). This difference could be attributed to our time-varying approach and the different identification scheme that we use, which makes it possible to unveil local trends in the house prices that are typically smoothed out in time-invariant approaches with long-span data sets used in the majority of the previous studies.

Regarding the U.K. housing market depicted in figure 6, the response of house prices on technology, money and idiosyncratic house prices shocks is qualitatively similar to that of the U.S. market. In fact, the technology shocks appear to have a positive effect earlier than in the U.S. market from the third year (figure 6, subplot c) after the imposition of the shock and retain their significance up to the fifth year (subplot d). The effect of technology shocks on house prices is stronger and more persistent in the case of the U.K. The long-term effect of the money shock (figure 6, subplot h) is positive, significant and higher than the corresponding U.S. effect (figure 5, subplot h), implying a tighter supervision of the housing market by the monetary authority. Interestingly, price shocks (subplot l) have a significant positive effect on house prices in the long run, in line with the notion that house assets could be used to hedge inflation (Demary, 2010; Brooks and Tsolacos, 1999).

This fact is not observable in the U.S. market and probably stems from the different evolution of the U.K. housing market. Due to land limitations in the U.K., the housing supply is smaller than that of the vast U.S. housing market, assuring higher prices and smaller price fluctuations. Higher prices drive U.K. households to invest earlier and for more years in a residence than a corresponding U.S. household (Bouchouicha and Ftiti, 2012). This wealth effect can be observed in the large U.K.
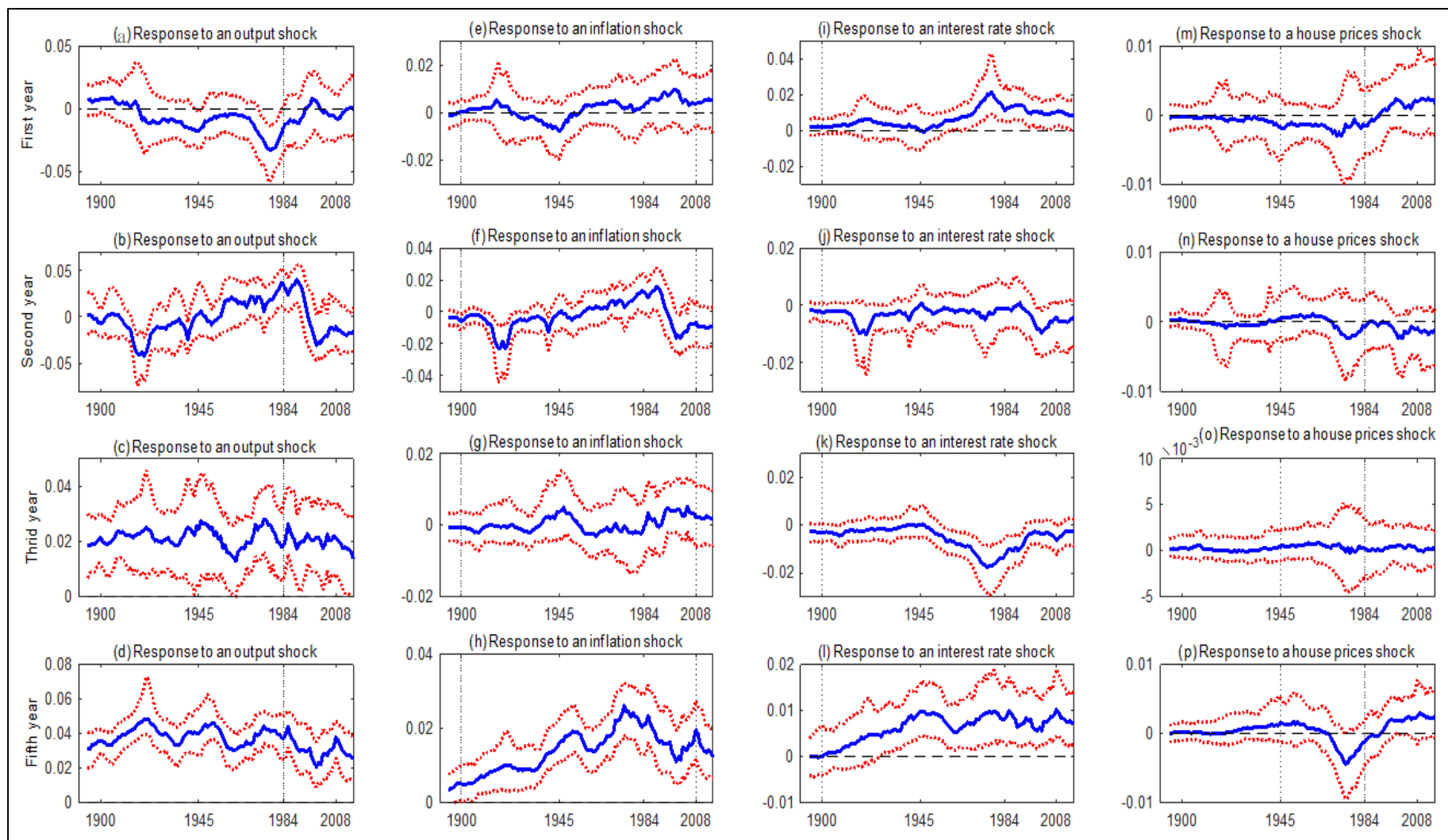
Figure 6: Horizon dependent Impulse Response Functions of the time-varying model for the U.K with the 16th and 84th (1 std) percentiles for house prices.

cities. Thus, investment in U.K. housing is used to hedge inflation, which is not the case in the U.S. market.

3.2.2 Volatility and Correlation

In the extant literature on macroeconomic research, a pivotal point is the effect of the fiscal and monetary policy on the volatility of economic macroeconomic fundamentals. In the finance literature, the historical risk when investing in an asset is assumed to be its historical volatility. Hence, in the boundaries of this paper, the evolution of house price volatility could provide valuable information on the evolution of the real estate market conditioned on macroeconomic shocks. Given the time-varying nature of our approach, we are able to examine the time evolution of both the conditional and the unconditional house prices volatility on each type of shock. In figure 7, we report the conditional and unconditional standard deviations from the response of U.S house prices to the three permanent macroeconomic shocks.[4]
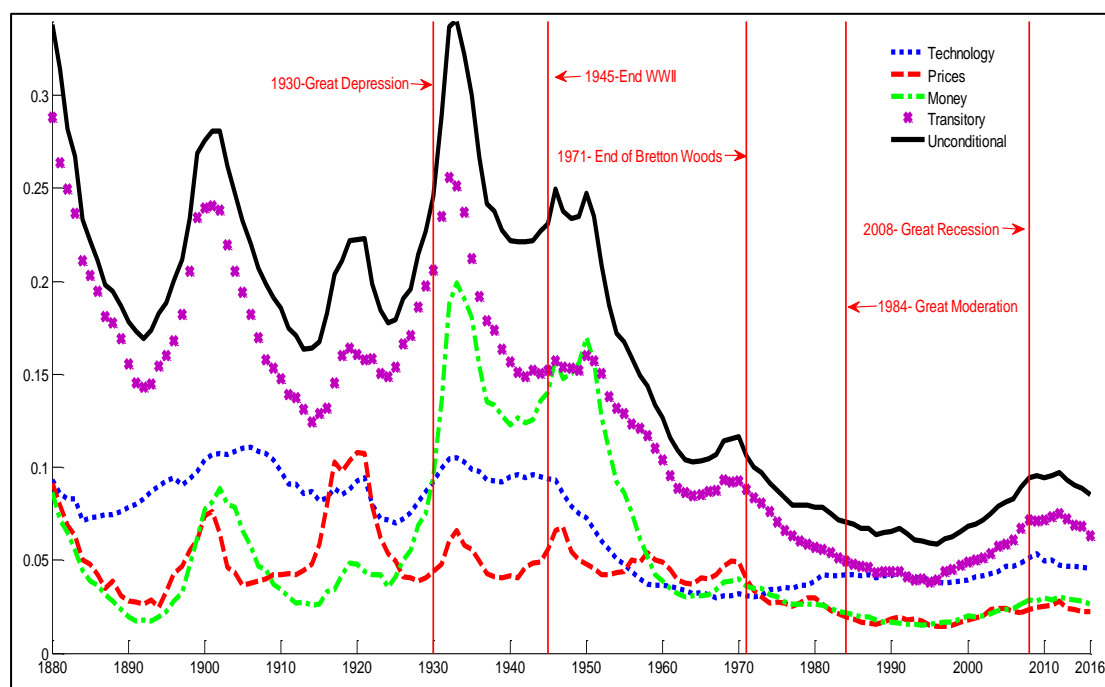
Figure 7: Unconditional and conditional standard deviations for the U.S. The solid (black) line depicts the unconditional standard deviation, the dotted (blue) is the conditional deviation on a technology (output) shock, the dashed (red) line the conditional deviation of a prices (inflation) shock, the line-dotted (green) line the conditional shock on a money (interest rate) shock and the line marked with an x (purple) the conditional deviation on the transitory shock

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[4] We examine standard deviations instead of variances, since house prices are expressed in US and GBP, respectively. Thus, variances would have no physical meaning.

As we observe, the (unconditional) volatility of house prices for the U.S. rises significantly in the pre-1945 period with significant spikes during the banking Panic of 1907, the period of the Great Depression and the early years after the end of WWII. The volatility drops significantly during the 1960s and 1970s and bottoms out during the period of the Great Moderation. Beyond that point, it increases again with the boom of the housing market in the 2000s and falls in the Great Recession period, eroding almost all the gain in the stabilization of prices achieved during the Great Moderation period. As reported in figure 7, most of these price fluctuations were sparked by significant economic events and changes in policy (and so the term "Great"). The most significant components of volatility are transitory demand shocks in the market. In contrast, money shocks exhibit two significant spikes during the Great Depression period and the 1960s. After these periods, the contribution of the conditional volatility of the money shock is small and probably insignificant, implying a small effect of monetary policy on the U.S. housing market.

The technological shock (output) is the second most important (permanent) factor, with its contribution peaking during the Great Depression and the Great Moderation periods. During the Great Depression period, a decrease in output led to an increase in house price volatility, as a result of high macroeconomic uncertainty. During periods of high macroeconomic uncertainty, downward movements in investment and in disposable income affect asset prices negatively. In contrast, during the Great Moderation period, the inflation targeted policies of the Federal Reserve achieved a stabilization of prices. Moreover, technological innovations introduced in the housing construction industry after the 1970s reduced construction costs. These factors led to a decrease in the fluctuation of house prices.

Table 1 summarizes our main conclusions from figure 7 in a quantitative manner. It reports posterior standard deviations of TVP–VAR estimates at key points in time and facilitates a numerical comparison of house price volatility between different time periods. The difference in the volatility between two consecutive periods is measured as the percentage decline in standard deviation from the local peak in the period and the local trough. Given the Bayesian nature of the model, we compute the lower bound for each peak and the upper bound for each trough on the 16th to 84th intervals. When the lower bound on the preceding peak exceeds the upper bound on the following trough, we interpret that as evidence of a statistically

significant reduction in the standard deviation since the confidence bounds associated with peak and trough do not overlap one another. [5]

Table 1: Changes in volatility over different time periods for U.S. house prices					
	1880-1930 vs 1930-1945	1930-1945 vs 1945-1971	1945-1971 vs 1971-1984	1971-1984 vs 1984-2008	1984-2008 vs 2008-2016
Technology Shock	-67.93	389.22*	-80.70*	9.90	-43.30
Price Shock	-69.14*	19.56	-33.13*	-53.16	-42.28
Money Shock	34.56	33.34*	-90.16*	0.64*	-71.25
Transitory Shock	-34.82*	-29.12*	-49.12*	-12.10*	-64.10
Unconditional	-98.81*	117.77	69.71	91.86	-61.60

Notes: All number are percentages. Statistically significant changes at the 5% level of significance (the lower bound of the preceding peak exceeds the upper bound of the following trough) are marked with an asterisk. Negative values denote reductions in volatility.

We find a statistically significant drop in house price volatility between 1945-1971 and 1971-1984 conditioned on macroeconomic shocks, with the largest reduction noticeable for the technology and money shocks. We also observe some sporadic events of change in volatility for the other periods. What is interesting is that while we observe a significant increase in post-war volatility conditioned on the technology shocks, the changes in volatility of the Great Moderation and after period are statistically non-existent for all fundamentals' shocks. This finding implies that despite the 2008 financial crisis the volatility of house prices has remained similar, suggesting small changes in the structure of the market and its dynamic relationship with the macroeconomy.

The posterior estimates of conditional and unconditional correlations of macro shocks with house prices (along with the confidence intervals) are shown in figure 8. We depict the conditional to macro shocks correlations of output growth to house prices in subplots (a) to (c) and the corresponding unconditional correlation to subplot (d). While subplots (a) and (b) reveal statistically insignificant correlations, we detect a positive and significant correlation near unity when we condition the correlation on money shocks (subplot c). If we combine the findings from figures 7 and 8, we argue that money shocks drive volatility and correlation during the period spanning the Great Depression until WWII. The unconditional correlation (subplot d) is close to

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[5] In the Appendix we report in detail the standard deviation for all local extrema, along with the year in which those extrema occurred and the lower and upper bounds for all troughs and peaks.
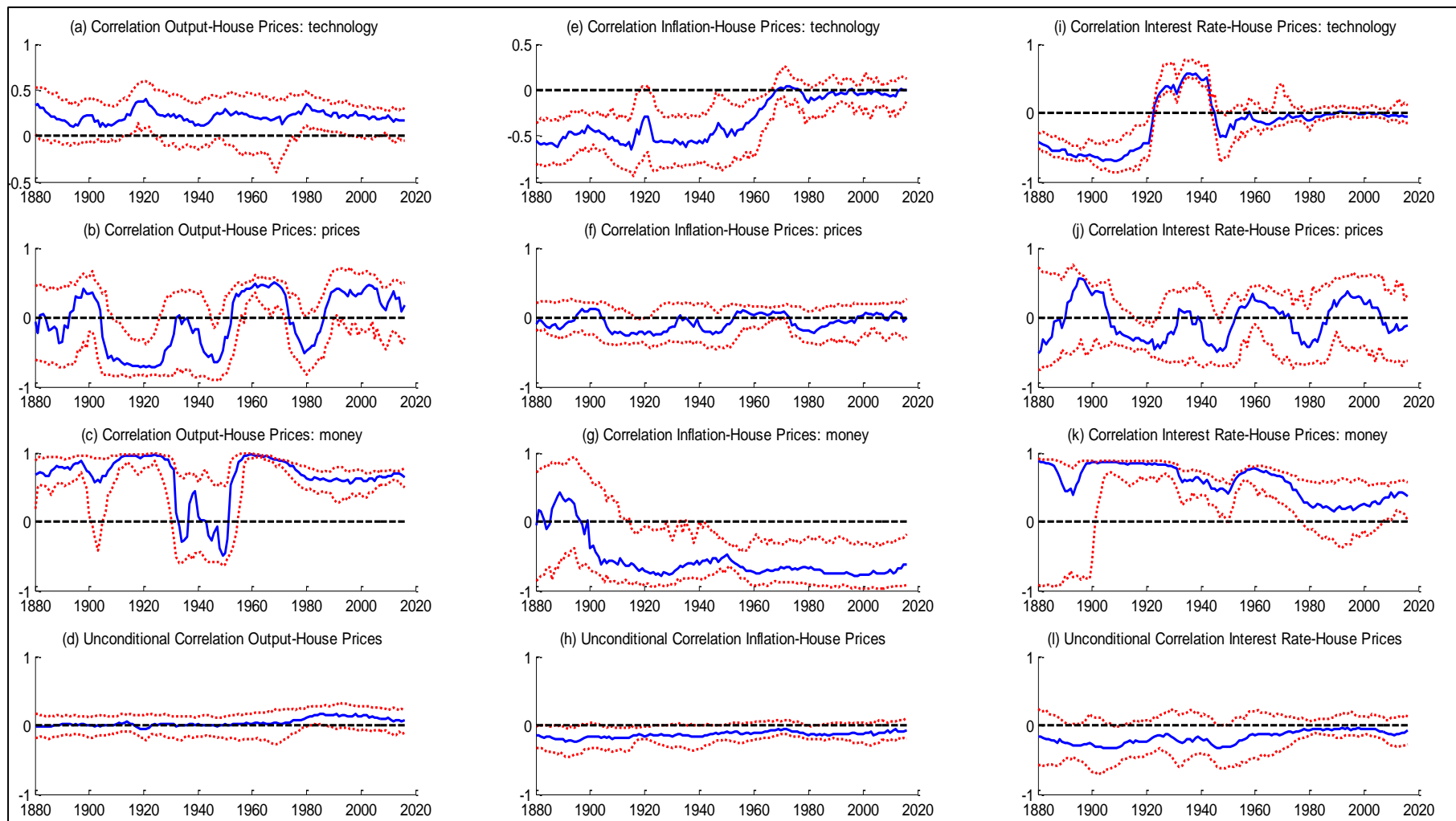
Figure 8: Unconditional and conditional correlation on the macro shocks for the U.S with the corresponding 16th and 84th percentiles.

zero, implying that the effect of money shocks is dampened by the opposite and quantitatively similar combined effect of prices and technology shocks over time.

In subplots (e) to (h), we depict the conditional and unconditional correlations among house prices and inflation. As we observe, conditioned on the technology (subplot e) and the money shock (subplot f) there is a negative correlation between inflation and house prices that is statistically significant in the post 1970s period. Inflation targeted policies in the post-Great Moderation period stabilized prices, while interest rate changes (money shocks) became the main policy instrument driving the economy. Especially for house prices, a lowering inflation rate in the post-1984 period constitutes the main reason for the small correlation with output (conditioned on the technological shocks- subplot e), while also reflects the importance of money shocks in shaping preferences of real estate investors. Interestingly, the correlations of house prices to interest rates shown in subplots (i) to (k) reveal no statistically significant relationship after 1984. This finding suggests that although the money shock does not affected house prices directly (as we also infer from the analysis of the IRFs), it can affect house prices correlation indirectly through changes in output growth and inflation, a pattern that is obvious due to our time-varying coefficients and missed by earlier studies (Musso et al., 2011).

In figure 9, we report the conditional and unconditional volatilities for the U.K. house prices. As we observe, throughout time, price volatility is smaller than the corresponding U.S. values. The unconditional deviation exhibits two significant peaks; a) during the 1920s period and the post WWII economic recession and b) during the period 1970-1980, an era of general economic and social turbulence in the U.K. Especially in the period 1970-1980 the U.K. economy exhibited a supply (technological) shock that increased the volatility of most macroeconomic variables. Interestingly, the period with the lowest variability is the post Great Recession period presumably due to the quantitative easing program of the Bank of England that stabilized the economy and the small but positive output growth rates. A close examination of figure 9 reveals that the conditional volatility on monetary policy shocks follow almost identically the fluctuations of the unconditional volatility (we return to this observation in more detail later when we examine the conditional and unconditional correlations).
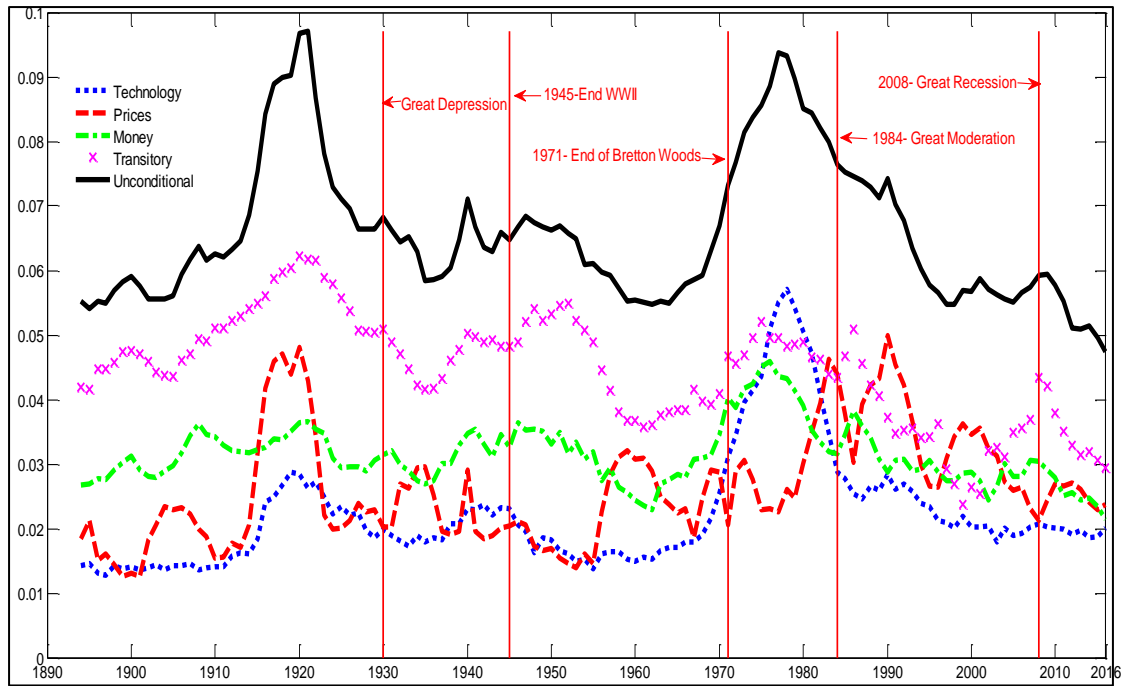
Figure 9: Unconditional and conditional standard deviations for the U.K. The solid (black) line depicts the unconditional standard deviation, the dotted (blue) is the conditional deviation on a technology (output) shock, the dashed (red) line the conditional deviation of a prices (inflation) shock, the line-dotted (green) line the conditional shock on a money (interest rate) shock and the line marked with an x (purple) the conditional deviation on the transitory shock.

The effect of a transitory housing market shock accounts for the largest part of volatility until the 1970s and falls significantly thereafter, pointing to structural changes to the economy that produced the earlier fluctuations in house prices. The technology shock has the lowest contribution in all periods apart from the period 1970-1985. Thus, price volatility can be attributed to price and money shocks. Especially in the period after the 1984, the effect of the technology shock is small and declining. Most of the variation in the post-2008 period stems from transitory and inflation-monetary policy shocks with a declining trend.

In Table 2, we summarize the volatility fluctuation differences over different time periods. In order to keep our results comparable with those of the U.S. market, we keep the same time splits. Despite the existence of large percentage changes in volatility, only three changes are statistically significant, presumably due to smaller volatility values in comparison to the U.S. The only interesting finding is the reduction in volatility between the pre and post 1984 period. These fluctuations in volatility could be attributed to a supply increase in the post 1984 period in the

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housing market (transitory shock) and the volatility of the English economy during the 1970-1980 period that affects the output growth rate (technology shock).

Table 2: Changes in volatility over different time periods for U.K. house prices					
	1880-1930 vs 1930-1945	1930-1945 vs 1945-1971	1945-1971 vs 1971-1984	1971-1984 vs 1984-2008	1984-2008 vs 2008-2016
Technology Shock	-59.84	171.31	62.71	-61.92*	-79.56
Price Shock	-68.43	62.98	39.95	12.18	-79.74
Money Shock	-12.41	103.58	-17.22	-3.67	-35.26
Transitory Shock	-54.69	104.78	-54.87	214.10*	-48.51
Unconditional	-98.16*	624.31	-64.53	188.90	-66.95

Notes: All number are percentages. Statistically significant changes (the lower bound of the preceding peak exceeds the upper bound of the following trough) at the 5% level of significance are marked with an asterisk. Negative values denote reductions in volatility.

Our analysis of the time-varying correlation of house prices with macroeconomic variables (figure 10) reveals some interesting facts. Conditioned on price shocks, the correlation between output growth rate and house prices becomes high and significant for the period 1950-1980 (subplot b), about the same period where price volatility spikes. Given the high inflation during that period (surpassing 20% at 1975), this finding reveals the important role of inflation on the investing decisions on the U.K. real estate market. Secondly, conditioning on money shocks (subplot c), the correlation becomes high and significant. Again, this is an indication that monetary policy drives the co-movement between output growth and house prices as an instrument to hedge inflation. The (combined) unconditional correlation shown in subplot (d) is zero for almost the entire sample, with a small exception over 1980s, a period of considerable volatility on all economic sectors.

In subplots (e) - (h) we report the correlation of inflation to house prices. The significant negative correlation conditioned on technology shocks during the period 1960-1990 (subplot e) implies that investment on housing can hedge inflation-boosting growth. This effect is also obvious for the money shock (subplot f). The unconditional correlation is again insignificant (subplot h). In subplots (i) to (k) we focus on the conditional correlation among interest rates and house prices. Apparently, the high and statistically significant correlation between monetary policy and housing prices conditioned on the money shock (subplot k) and the unconditional correlation (subplot l) after the 1960s, reveals the significant role of interest rates to house prices.
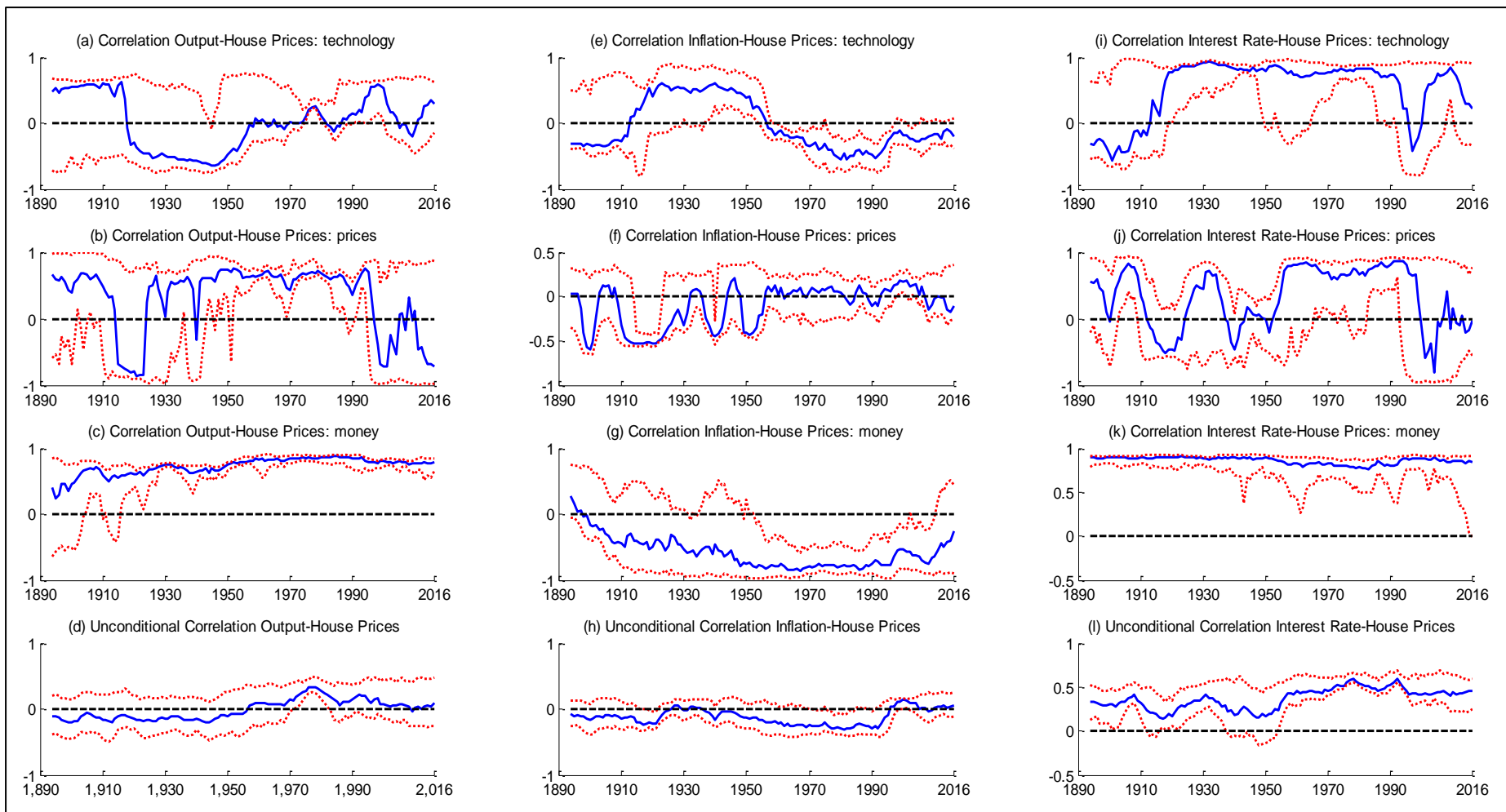
Figure 10: Unconditional and conditional posterior median correlations on the macro shocks for the U.K with the corresponding 16th and 84th percentiles.

Overall, from the analysis of impulse responses, conditional and unconditional volatility and correlations we conclude that monetary policy are an important determinate of house prices in the U.K. Although this finding is not new to literature (Brooks and Tsolacos, 1999), our time-varying examination provides new insight into period dependent inferences on the evolution of house prices conditioned on monetary policy shocks.

3.2.3 VAR with time-invariant coefficients

As already pointed several times in this paper, most of the empirical literature exploits models with time-invariant coefficients. In order to compare our work to previous studies, we train a time-invariant VAR(2) model and estimate impulse responses of house prices to macroeconomic shocks.[6] All responses for the U.S. market are shown in figure 11. They are constructed based on the identification scheme of long-run restrictions also used on the TVP-VAR model.
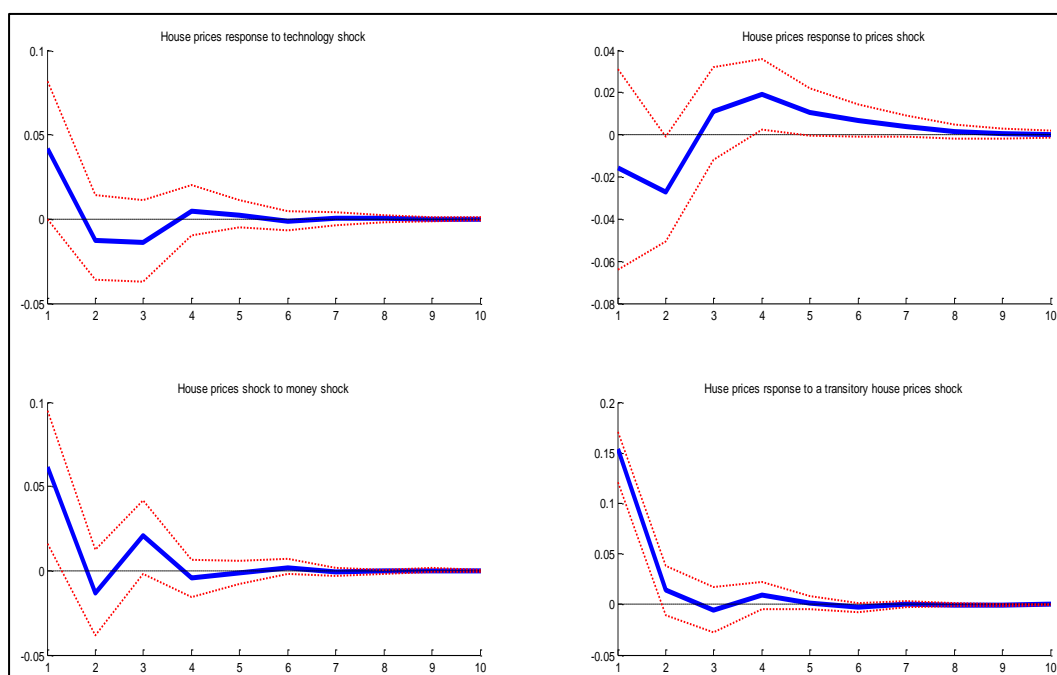

Figure 11: Impulse responses of house prices to macroeconomic shocks with 1 standard deviation band for the U.S.

All responses of house prices are small and statistically insignificant from zero, with the exception of the transitory house prices shock that exhibits a positive but short-lived effect. Thus, the use of constant coefficients as in Musso *et al.* (2011)

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[6] All inverse roots of the AR characteristic polynomial lie inside the unit circle, thus the system is stable. Detailed characteristics of the VAR models are not reported here due to space limitations; they are considered typical in the literature and are not relevant to our analysis. They are available from the authors upon request.

and Del Negro and Otrok (2007) overstates the transitory effect of supply/demand shocks in the housing market and is not able to uncover time-varying phenomena based on the actual economic conditions on each point in time, since they are smoothed-out during the estimation of the VAR model.

In figure 12, we report the corresponding IRFs for the U.K. market. The results are quantitatively similar to the U.S. market, rendering the constant coefficient analysis not suitable for our cause.
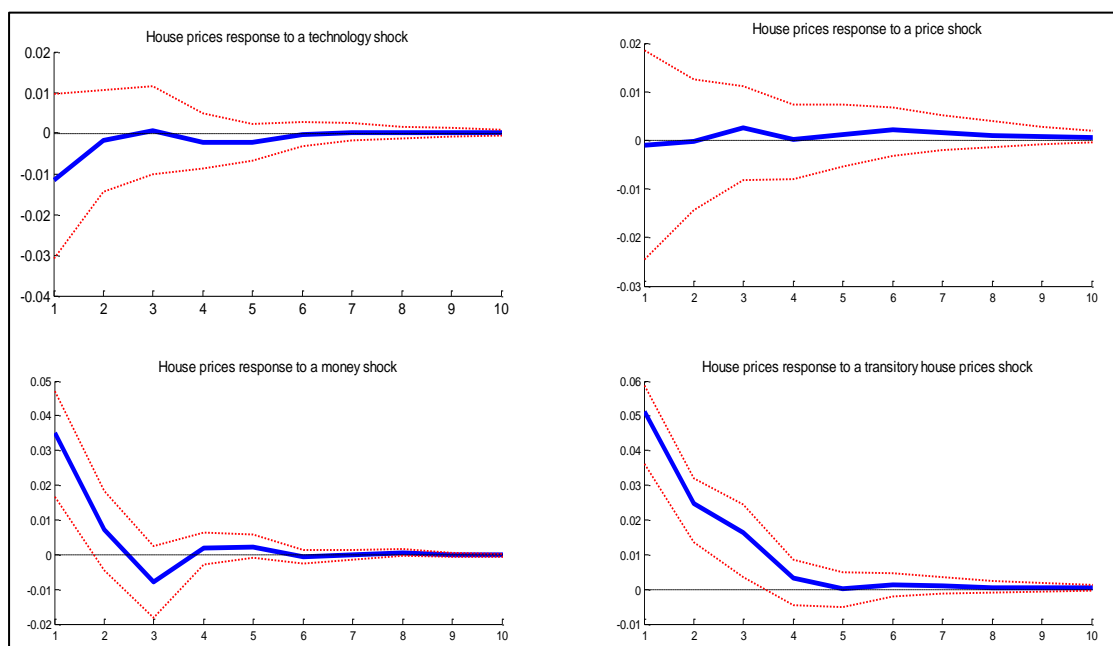

Figure 12: Impulse responses of house prices to macroeconomic shocks with 1 standard deviation bands for the U.K.

4. Conclusions

In this paper, we study the dynamic relationship of the U.S. and the U.K. housing market with the macroeconomy, focusing on the effect of macroeconomic shocks on the evolution of house prices. In the process, we build a time-varying VAR model over the periods of 1830 to 2016 and 1846-2016 for the U.S. and U.K. respectively, by including real house prices, output growth, real central bank interest rates and inflation incorporating stochastic volatility. We examine the dynamic evolution of the coefficients of the models, the impulse responses of house prices on the macroeconomic shocks and the conditional and unconditional volatility and correlation of house prices to fundamentals. Regarding the U.S. housing market, our

empirical findings corroborate to previous literature on the importance of technology shocks on house prices and the existence of a small and negative relationship between monetary policy and the housing sector. However, we reject the importance of transitory supply shocks of the housing market on house prices, reported in earlier studies. This divergence can be attributed to the time-varying nature of our approach that associates each shock with the specific economic conditions that prevail over the time of its imposition. The empirical findings on the U.K. housing market emphasize on the importance of monetary policy on the housing sector, with the effect of the technological shocks on house prices being unimportant. Overall, the time-varying character of our approach adhere to the main economic phenomena that drive house price, describe adequately the contribution of each macroeconomic variable and provide a deep understanding on the dynamic relationship of the housing market and the economy.

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Appendix

<u>Appendix A: Estimation of the TVP-VARs models</u>

Our estimation procedure draws directly from Canova and Gambetti (2010).

1. <u>Priors</u>

Let z^T dente the sequence of z's up to time T. Let γ be the vector containing the non-zero elements of F^{-1} that are different from one and are stacked in rows and Ξ a vector including all the Ξ_i. The transition density is assumed to be

$$p(\theta_t|\theta_{t-1},\Omega) \propto I(\theta_t)f(\theta_t|\theta_{t-1},\Omega)$$

$$p(\theta_t|\theta_{t-1},\Omega) = N(\theta_{t-1},\Omega)$$

Where $I(\theta_t)$ is an indicator function selecting non-explosive draws of θ_t for y_t. We assume the hyperparameters and the initial states are independent so that the joint prior is simply the product of the marginal densities. Following Cogley and Sargent (2005) we assume:

$$P(\theta_0) \propto I(\theta_0)N(\bar{\theta},\bar{P})$$

$$P(\Omega) = \text{IW}(\bar{\Omega}^{-1},T_0)$$

$$P(\log\sigma i_0) = \text{N}(\log\bar{\sigma}_i, 10)$$

$$P(\gamma) = \text{N}(0,10000 \times I_4)$$

$$P(\Xi_i) = \text{IG}(\frac{0.01^2}{2},\frac{1}{2})$$

Where $\bar{\theta},\bar{P}$ are OLS estimates of the VAR coefficients and their variances obtained with the initial sample, $\bar{\Omega} = \lambda\bar{P}$, T_0 is the number of observations in the initial sample (40 observations), $\bar{\sigma}_i$ is the estimate of the variance of the residual in equation i obtained using the initial sample. The hyperparameter λ is set to 0.0005 for all parameters except for the constant terms of output growth, inflation and interest rate. For these constants, it is set to 0.001.

2. Posteriors

To draw realizations from the posterior density we use the Gibbs sampler. Each iteration is composed of four steps and, under regularity conditions and after a burn-in period, iterations on these steps produce draws from the joint density.

- Step 1: $p(\theta^T|y^T,\gamma,\sigma^T,\Xi,\Omega)$

Conditional on $(\theta^T|y^T,\gamma,\sigma^T,\Xi,\Omega)$ the unrestricted posterior of the states is normal. To draw from the conditional posterior we employ the algorithm of Carter and Kohn (1994). The conditional mean and variance of the terminal state θ^T is computed using standard Kalman filter recursions while for all the other states the following backward recursions are employed:

$$\theta_{t|t-1} = \theta_{t|t} + P_{t|t}P_{t|t}^{-1}\left(\theta_{t+1} - \theta_{t|t}\right)$$

$$P_{t|t-1} = P_{t|t} - P_{t|t}P_{t+1|t}^{-1}P_{t|t}$$

Where $p(\theta_t|\theta_{t+1},y^T,\gamma,\sigma^T,\Xi,\Omega)\sim N\left(\theta_{t|t+1},P_{t|t+1}\right)$

- Step 2: $p(\gamma|y^T,\theta^T,\sigma^T,\Xi,\Omega)$

Given that σ^T and y^T are known ε_t is known and since u_t is a standard Gaussian white noise, we have $D_t^{-1/2}F^{-1}\varepsilon_t = u_t$ or $D_t^{-1/2}\varepsilon_t = D_t^{-1/2}(F^{-1} - I)\varepsilon_t + u_t$. We can rewrite the ith equation as $z_{it} = -w_{it}\gamma_i + u_{it}$ where $z_{it} = \varepsilon_{it}/\sqrt{\sigma_{it}}$, $w_{it} = \left[\varepsilon_{1t}/\sqrt{\sigma_{1t}},\dots,\varepsilon_{i-1,t}/\sqrt{\sigma_{i-1,t}}\right]$ and γ_i is the column vector formed by the non-zero elements of the ith row of $F^{-1} - I$. Given the normal prior, the posterior is $\gamma_i = N(F_{1,i},V_{1,i})$ where $F_{1,i} = V_{0,i}\left(V_{0,i}^{-1}\gamma_{0,i} + w_i'z_i\right)$ and $V_{1,i} = \left(V_{0,i}^{-1} + w_i'w_i\right)$ with $V_{0,i}$ and $\gamma_{0,i}$ the prior variance and mean, respectively. Drawing for $i = 2,3,4$ we obtain a draw for γ.

- Step 3: $p(\sigma^T|y^T,\theta^T,\gamma,\Xi,\Omega)$

The elements of σ^T are drawn drawn using the univariate algorithm by Jacquier, Polson and Rossi (2004) along the lines described in Cogley and Sargent (2005) (see Appendix B.2.5 for details).

- Step 4: $p(\Xi_i|y^T,\theta^T,\gamma,\sigma^T,\Omega), p(\Omega|y^T,\theta^T,\gamma,\sigma^T,\Xi)$

Conditional on $y^T,\theta^T,\gamma,\sigma^T$ and under conjugate priors, all the remaining hyperparameters, can be sampled in a standard way from Inverted Wishart and Inverted Gamma densities (Gellman et al., 1995). We perform 20000 repetitions, discard the first 5000 draws and, for inference, we keep one every 10 of the remaining draws to break the autocorrelation of the draws.

Appendix B: TVP-VAR parameters

Figure A1, A2 and A3 present graphically the time-varying coefficients for the output growth, inflation and interest rate equations in the VAR for the U.S. while figures A4, A5 and A6 present the respective coefficients for the U.K.
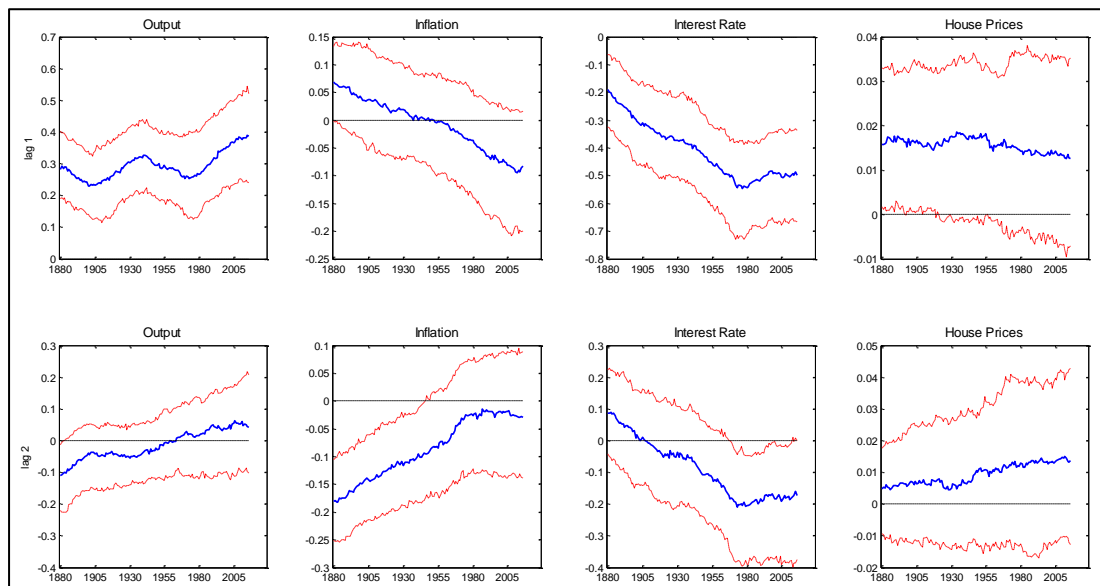

Figure A1: U.S. Posterior median coefficients estimates and their 68% intervals for output growth equation.
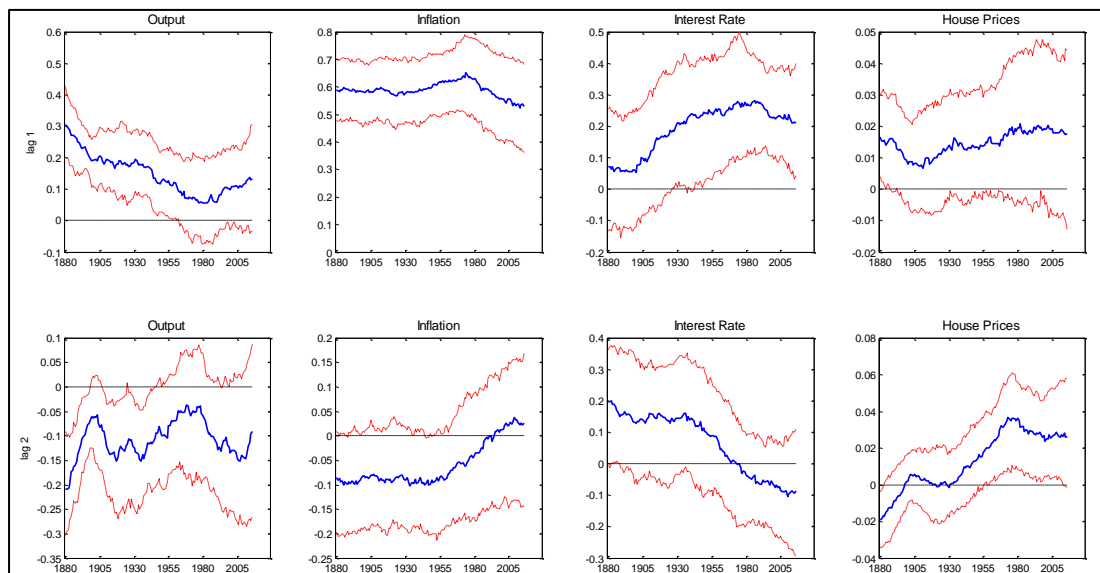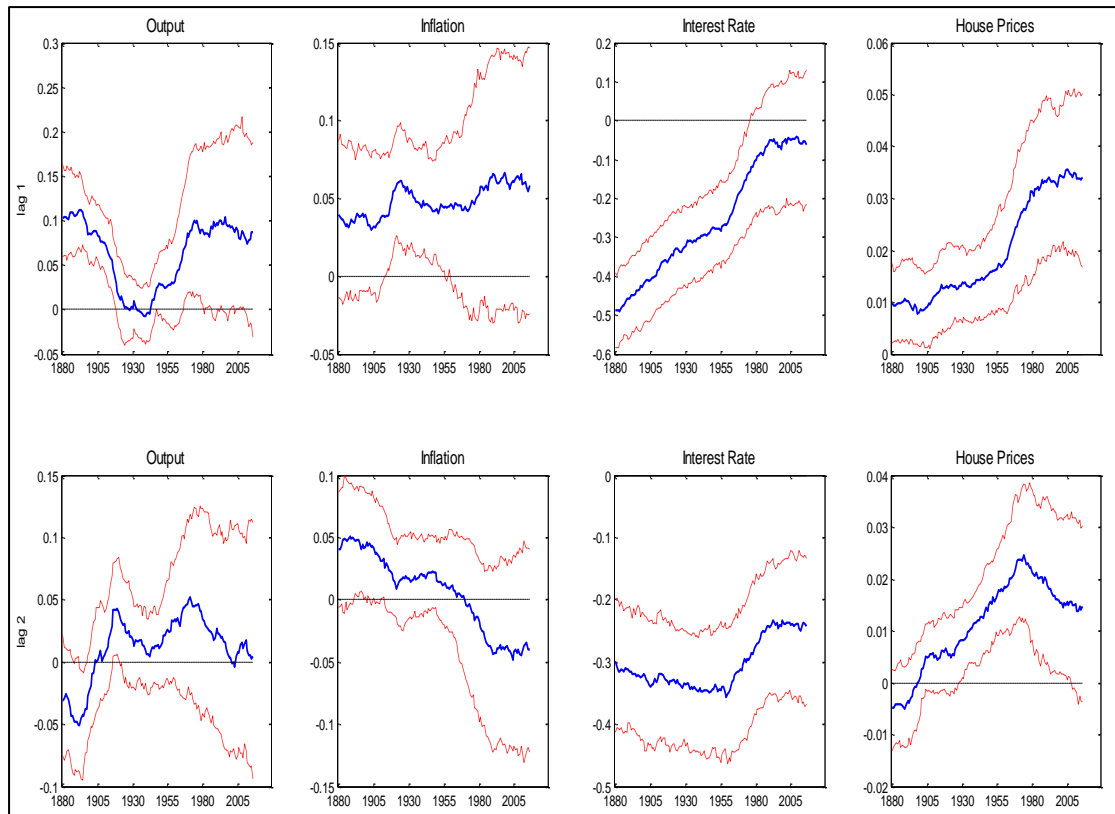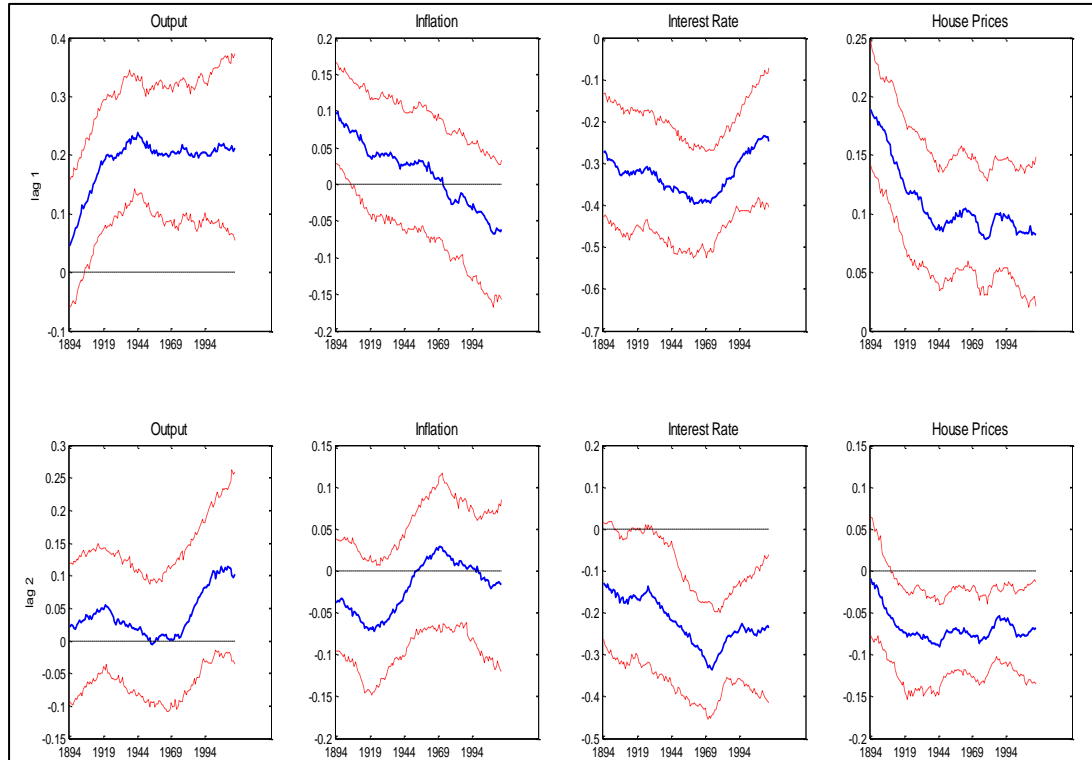

Figure A2: U.S. Posterior median coefficients estimates and their 68% intervals for inflation equation.

Figure A3: U.S. Posterior median coefficients estimates and their 68% intervals for interest rates equation.

Figure A4: U.K. Posterior median coefficients estimates and their 68% intervals for output growth equation.
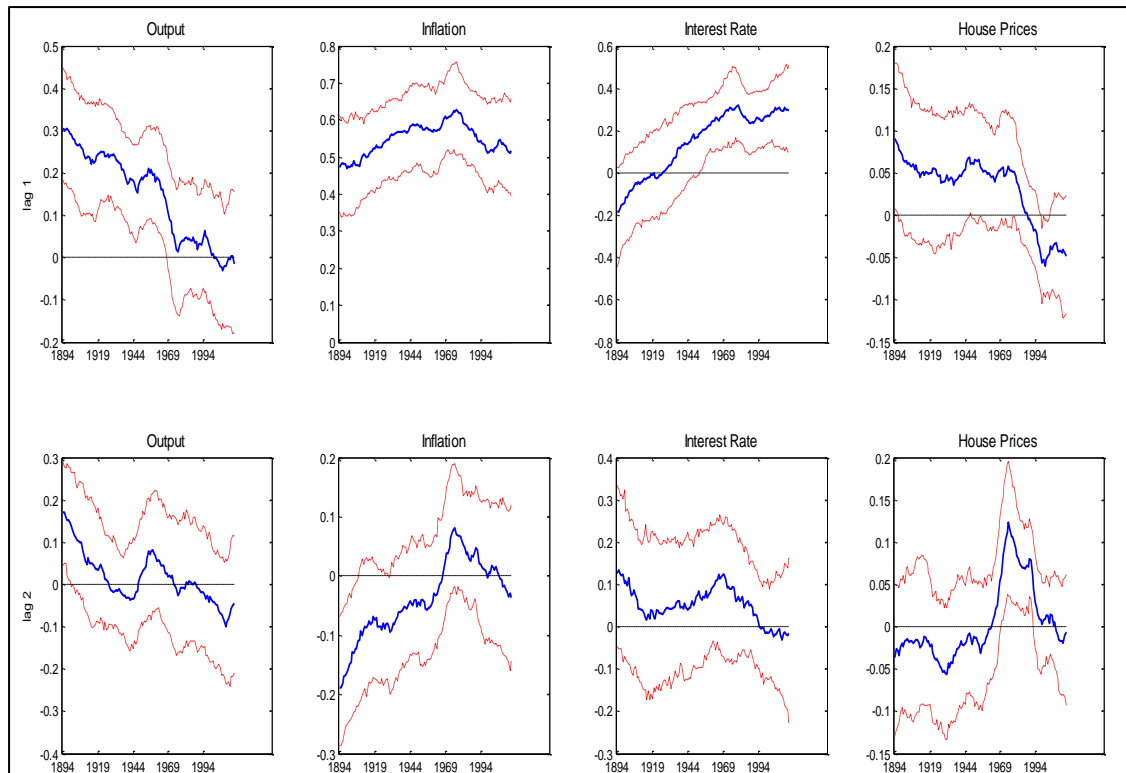
Figure A5: U.K. Posterior median coefficients estimates and their 68% intervals for inflation equation.
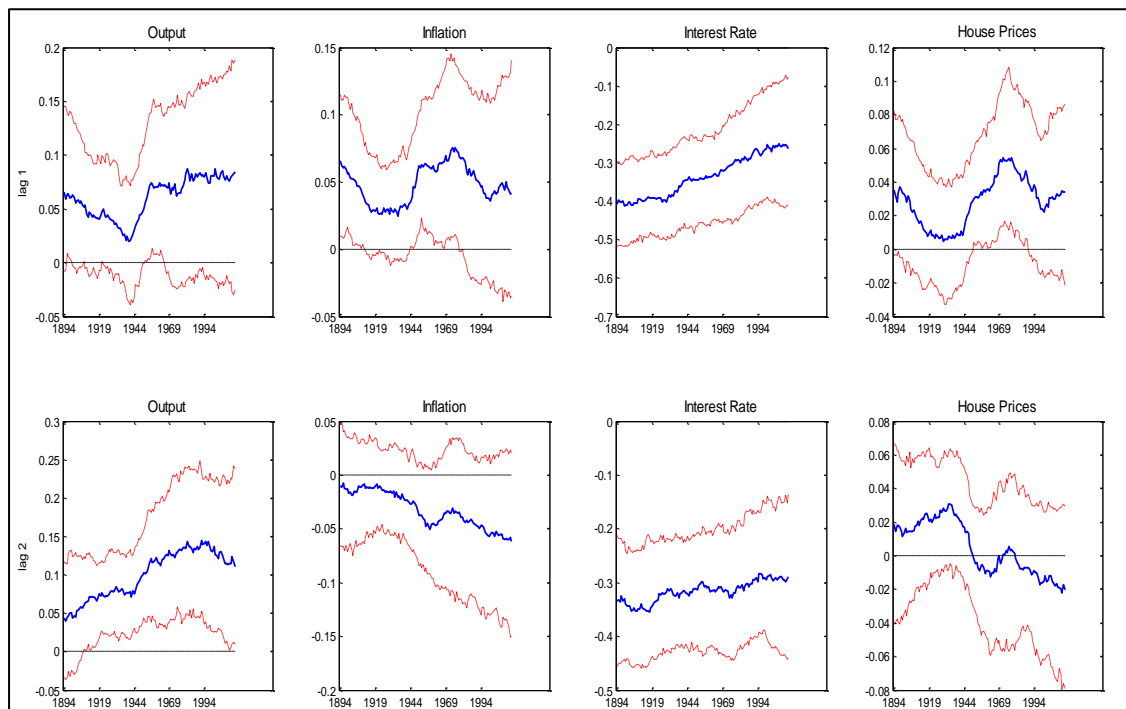

Figure A6: U.K. Posterior median coefficients estimates and their 68% intervals for interest rates equation.

Appendix C: Volatility evolution

Table A1: US volatility evolution		1880-1930	1930-1945	1945-1971	1971-1984	1984-2008	2008-2016
Technology Shock	Local peak	0.11 (1906) [0.1056]	0.11 (1933) [0.0973]	0.09 (1945) [0.0878]	0.04 (1984) [0.0409]	0.05 (2008) [0.0491]	0.05 (2009) [0.0497]
	Local trough	0.07 (1925) [0.0781]	0.09 (1930) [0.1095]	0.03 (1967) [0.0414]	0.03 (1972) [0.0403]	0.04 (1997) [0.0507]	0.05 (2016) [0.0618]
	Change		-67.93	389.22*	-80.70*	9.90	-43.30
Prices Shock	Local peak	0.11 (1920) [0.0910]	0.07 (1933) [0.0415]	0.07 (1947) [0.0593]	0.04 (1971) [0.0261]	0.02 (2005) [0.0160]	0.03 (2012) [0.0211]
	Local trough	0.03 (1894) [0.0867]	0.04 (1939) [0.0735]	0.04 (1964) [0.0878]	0.02 (1984) [0.0257]	0.01 (1996) [0.0323]	0.02 (2016) [0.0415]
	Change		-69.14*	19.56	-33.13*	-53.16	-42.28*
Money Shock	Local peak	0.09 (1930) [0.0500]	0.20 (1933) [0.1090]	0.17 (1950) [0.1051]	0.04 (1971) [0.0263]	0.03 (2008) [0.0243]	0.03 (2012) [0.0255]
	Local trough	0.02 (1891) [0.0431]	0.10 (1930) [0.1737]	0.03 (1963) [0.0605]	0.02 (1984) [0.0265]	0.02 (1994) [0.0184]	0.03 (2016) [0.0436]
	Change		34.56	33.34*	-90.16*	0.64*	-71.25
Transitory Shock	Local peak	0.29 (1880) [0.2361]	0..26 (1932) [0.2180]	0.16 (1950) [0.1328]	0.09 (1971) [0.0736]	0.07 (2008) [0.0560]	0.08 (2012) [0.0634]
	Local trough	0.12 (1914) [0.1667]	0.15 (1942) [0.1858]	0.09 (1964) [0.1086]	0.05 (1984) [0.0642]	0.04 (1995) [0.0527]	0.06 (2016) [0.0838]
	Change		-34.82*	-29.12*	-49.12*	-12.10*	-64.10*
Unconditional Volatility	Local peak	0.70 (1880) [0.9685]	0.29 (1945) [0.2876	0.30 (1971) [0.2982]	0.32 (1983) [0.3165]	0.35 (2008) [0.3514]	0.37 (2016) 0.3649]
	Local trough	0.29 (1930) [0.2852]	0.28 (1939) [0.3487]	0.29 (1946) [0.6116]	0.30 (1971) [0.6985]	0.32 (1984) [0.6985]	0.35 (2008) [0.6985]
	Change		-98.81*	117.77	69.71	91.86	-61.60

Notes: Changes are in percentages. Negative values denote reductions in volatility. Local peaks/troughs are extrema values of standard deviation for the sub-sample with the year of the extrema reported in parenthesis and the corresponding lowest value of the peak/ highest value of the local trough from the 16th-84th percentiles of the distribution in brackets. Statistically significant changes at the 5% level of significance are denoted with an asterisk.

		1880-1930	1930-1945	1945-1971	1971-1984	1984-2008	2008-2016
				Table A2: U.K. volatility evolution			
Technology Shock	Local peak	0.03 (1919) [0.0139]	0.02 (1942) [0.0147]	0.03 (1971) [0.0226]	0.06 (1978) [0.0488]	0.03 (1984) [0.0224]	0.02 (2008) [0.0140]
	Local trough	0.01 (1897) [0.0265]	0.02 (1933) [0.0303]	0.01 (1955) [0.0289]	0.03 (1984) [0.0483]	0.02 (2003) [0.0358]	0.02 (2014) [0.0345]
	Change		-59.84	171.31	62.71	-61.92*	-79.56
Prices Shock	Local peak	0.05 (1920) [0.0287]	0.03 (1935) [0.0080]	0.03 (1959) [0.0130]	0.05 (1983) [0.0240]	0.05 (1990) [0.0278]	0.03 (2012) [0.0103]
	Local trough	0.01 (1899) [0.0268]	0.02 (1942) [0.0353]	0.01 (1953) [0.0328]	0.02 (1971) [0.0444]	0.02 (2008) [0.0411]	0.02 (2008) [0.0411]
	Change		-68.43	62.98	39.95	12.18	-79.74
Money Shock	Local peak	0.04 (1921) [0.0160]	0.04 (1941) [0.0168]	0.04 (1971) [0.0341]	0.04 (1976) [0.0390]	0.04 (1986) [0.0309]	0.03 (2008) [0.0201]
	Local trough	0.03 (1894) [0.0528]	0.03 (1935) [0.0535]	0.02 (1962) [0.0470]	0.03 (1984) [0.0572]	0.02 (2002) [0.0395]	0.02 (2016) [0.0420]
	Change		-12.41	103.58	-17.22	-3.67	-35.26
Transitory Shock	Local peak	0.06 (1920) [0.0534]	0.05 (1930) [0.0404]	0.06 (1952) [0.0448]	0.05 (1975) [0.0428]	0.05 (1986) [0.0387]	0.04 (2008) [0.0305]
	Local trough	0.04 (1865) [0.0528]	0.04 (1935) [0.0535]	0.04 (1961) [0.0470]	0.04 (1984) [0.0572]	0.02 (1999) [0.0395]	0.03 (2016) [0.0420]
	Change		-54.69	104.78	-54.87	214.10*	-48.51
Unconditional Volatility	Local peak	0.09 (1894) [0.0896]	0.04 (1940) [0.0409]	0.05 (1971) [0.0469]	0.05 (1984) [0.0493]	0.06 (2008) [0.0561]	0.06 (2016) [0.0584]
	Local trough	0.04 (1926) [0.0393]	0.04 (1930) [0.0896]	0.04 (1945) [0.0896]	0.05 (1971) [0.0896]	0.05 (1985) [0.0831]	0.06 (2008) [0.0896]
	Change		-98.16*	624.31	-64.53	188.90	-66.95

Notes: Change are in percentages. Negative values denote reductions in volatility. Local peaks/troughs are extrema values of standard deviation for the sub-sample with the year of the extrema reported in parenthesis and the corresponding lowest value of the peak/ highest value of the local trough from the 16th-84th percentiles of the distribution in brackets. Statistically significant changes are denoted with an asterisk.

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