Journal Pre-proof

Macroprudential policy and the real estate market: Effectiveness and repercussions

Shu-hen Chiang, Chien-Fu Chen

PII: S1049-0078(23)00072-6
DOI: https://doi.org/10.1016/j.asieco.2023.101652
Reference: ASIECO101652

To appear in: *Journal of Asian Economics*

Received date: 6 March 2022
Revised date: 28 April 2023
Accepted date: 16 August 2023

Please cite this article as: Shu-hen Chiang and Chien-Fu Chen, Macroprudential policy and the real estate market: Effectiveness and repercussions, *Journal of Asian Economics,* (2023) doi:https://doi.org/10.1016/j.asieco.2023.101652

Macroprudential policy and the real estate market: Effectiveness and repercussions

Shu-hen Chiang
Department of Finance
Chung-Yuan Christian University
Taoyuan City 320, Taiwan
E-mail: shchiang@cycu.edu.tw

Chien-Fu Chen[1]
Department of Economics
National Dong Hwa University
Hualien County 974301, Taiwan
E-mail: cfc@mail.ndhu.edu.tw

[1] Department of Economics, National Dong Hwa University.
Address: No. 1, Sec. 2, Da Hsueh Rd., Shoufeng, Hualien 974301, Taiwan (ROC).
Corresponding author: Tel: 886-3- 8905548; Fax: 886-3-890-0192.E-mail: cfc@mail.ndhu.edu.tw. We would like to thank an anonymous reviewer for constructive comments and suggestions, and the editors for editorial assistance.

Abstract

Macroprudential policies to counter the housing bubble has been widely implemented to maintain financial stability. However, few attempts have been made to address the (un)intended externalities, namely, the "bubble-thy-neighbor" spillovers of Forbes *et al.* (2016). A loan-to-value (LTV) policy adopted in a local rather than the overall housing market in Taiwan provides an opportunity to investigate the transmission from the bubbles to spillovers under time-varying econometric frameworks. The empirical results show that the LTV policy has been very effective in eliminating local housing bubbles, while the information regarding exorbitant housing prices in regulated areas had increasing ripple effects on other unregulated areas.

Keywords: Housing price; Macroprudential policy; Housing Bubbles; Externalities

1. Introduction

It has recently become more and more difficult for central banks to maintain financial stability in a closely interconnected world that faces ever more complex financial debates and crises. Although the traditional view argues that monetary policy should focus on the goal of price stability or the dual mandate through interest rate adjustments (Bernanke and Gertler, 2001), it has been proved that the interest rate tool is insufficient when it comes to handling asset price bubbles (Shi *et al.*, 2014; Kuttner and Shim, 2016; Martin *et al.*, 2020). To resolve the asset price bubble, many countries have started to vest their central banks with more powers and responsibilities for macroeconomic management by means of so-called macroprudential policies, which can select various formal and informal regulations to safeguard the overall financial system according to different financial environments and occasions.

Intriguingly, the rising significance of real estate assets to financial vulnerability finds its origin in two distinct characteristics. The first is that overheated housing markets are mainly caused by credit expansion (Agnello *et al.*, 2017), especially bank mortgage lending (Jorda *et al.*, 2015). The other is the imperfect nature of real estate, for example, the indivisibility of assets, the huge capital, low liquidity and no short sales (Wachter, 2015; Duca *et al.*, 2019) during the period of the recession. Combining these two factors must seriously deteriorate the balance sheets of banks and eventually cause the financial system to crash (Reinhart and Rogoff, 2008; Geanakoplos *et al.*, 2012; Kivedal, 2013). Due to the paramount importance of housing assets to financial stability, at the heart of the macroprudential policies is the desire to actively manage the status of the housing market via monitoring and controlling the flow of mortgage credit into the housing market and hence the loan-to-value (LTV) ratio is generally regarded as the most common measure among the several macroprudential toolkits.[2]

In the last decade, a new and burgeoning literature has been devoted to the effectiveness of the macroprudential policies, such as its ability to slow down the rapid

[2] In fact, there are various toolkits in macroprudential policy, such as caps on LTV and debt-service-to-income (DSTI) ratios.

growth of housing prices (Claessens, 2015; Galati and Moessner, 2018). These studies can be categorized according to three levels, namely, the international, regional and national aspects. Based on the Bank for International Settlements (BIS) and the Global Macroprudential Policy Instruments (GMPPI) survey conducted by the International Monetary Fund (IMF), macroprudential policies, such as those involving the LTV or DSTI ratio, have been effective in curbing housing prices and mortgage credit in the international context (Lim *et al.*, 2011; Claessens *et al.*, 2013; Kuttner and Shim, 2016; Cerutti *et al.*, 2017a, b; Akinci and Olmstead-Rumsey, 2018; Morgan *et al.*, 2019; Richter *et al.*, 2019; Meuleman and Vennet, 2020). Similar conclusions have also been reached in regard to regional analysis (Vandenbussche *et al.*, 2015; Jorda *et al.*, 2015; Zhang and Zoli, 2016; Carreras *et al.*, 2018) and specific-country research (Shi *et al.*, 2014; Tillmann, 2015; Jung and Lee, 2017; Gelain *et al.*, 2018; Klingelhofer and Sun, 2019). It should be noted, from what has been said above, that macroprudential tools to counter increasing housing prices are generally acknowledged to be valid.

However, there remain two unsettled questions that are related to housing bubbles and also follow-up externalities. The former is inherently an old problem: even though economists by and large admit that housing bubbles have been closely associated with a high likelihood of a financial crisis, they nevertheless argue that the identification of bubbles is the most challenging work (Blanchard *et al.*, 2010; Crowe *et al.*, 2013; Galati and Moessner, 2013; Ambrose *et al.*, 2013). Accordingly, previous studies regarding the effectiveness of macroprudential policies mostly focus on verifying whether combating upward housing prices is attributable to macroprudential policies. However, this inclination towards a reluctance to evaluate asset price bubbles gives rise to a fallacy that high housing prices caused by high incomes may not synonymous with housing bubbles. Let us return to the definition of the bubble based on an immense deviation of the housing price from a fundamental value (such as income) so that the price-to-income (P/I) ratio is widely applied to evaluate the housing bubbles.[3] We therefore claim that the (P/I) ratio, instead of the housing price is sufficient to fairly evaluate the effectiveness of macroprudential policies. The latter gives rise to a new debate: since the macroprudential policies are to adapt new regulations in a specific field, (un)intended externalities (spillovers) to other fields are inevitable consequences. However, past studies almost failed to grasp the by-product of the macroprudential policies until the work of Forbes *et al.* (2016) which analyzed the externalities from capital controls of a nation to other related countries. As mentioned by Forbes (2019), "There has been less progress, however, in terms of understanding the ramification of these leakages and spillovers." While a great deal of effort has been made on inter-sectoral spillovers, little is known about interregional spillovers, except for the studies by Forbes *et al.* (2016) and McCann and O'Toole (2019).[4] Judging from the above, it is clear that two interesting issues, housing bubbles and spillovers as the "complete" reactions of the real estate market to macroprudential policy, are rarely mentioned. Thus, we have decided to touch upon these topics by introducing the (P/I) ratio into housing bubbles as well as evaluating the degree of the externalities of housing prices from regulated to unregulated areas in order to fully pursue the effect of the macroprudential policies on the real estate market.

Meanwhile, the most distinguishing feature of the macroprudential policy is that it dynamically manages the status of the real estate market, thereby resorting to time-varying econometric methods, instead of traditional time-series analysis. This is an especially useful way of taking a closer look at the dynamic evaluations of the housing

[3] Another important indicator for housing bubbles is the price-to-rent (P/R) ratio, but the lack of rent data forces us to focus attention on the (P/I) ratio.

[4] Inter-sectoral spillovers can be found in Jimenez *et al.* (2017) for regulatory arbitrage between regulated and unregulated banks; Forbes *et al.* (2017) for negative spillovers of regulated banks; Cizel *et al.* (2019) for the credit substitution between the bank and nonbank sectors and Rubio (2020) for the difference between domestic regulated banks and foreign unregulated branch banks.

bubble as well as externalities in the face of a series of macroprudential regulations. According to the rolling window approach that is often used for calculation in time-varying econometrics, we first use a generalized version of the sup augmented Dickey-Fuller (GSADF) test to examine the (P/I) ratio to see the rise and fall of the multiple bubbles over time by Phillips *et al.* (page 1043, 2015), who stated: "Recent work on econometric detection mechanisms has shown the effectiveness of recursive procedures in identifying and dating financial bubbles in real time." As long as the episodes of the housing bubbles are identified, we can immediately assess the relative effectiveness of the various LTV recommendations. On the other hand, in compliance with Diebold and Yilmaz (2012), a time-varying spillovers index (hereafter referred to as the DY spillover method) is applied to scrutinize the time-varying externalities to other regions. To sum up, we believe that the dynamic processes from housing bubbles to housing price spillovers caused by variations in the LTV ratio over time can capture the direct (effectiveness against housing bubbles) and indirect (follow-up externalities of intercity housing prices) effects of macroprudential policies upon the real estate market.

Finally, as Laufer and Tzur-Ilan (2021) pointed out, the above-mentioned studies regarding the identification of the effect of macroprudential policy are considerably challenging on the grounds that they mostly applied cross-country panel estimations, which are very likely affected by a serious heterogeneity problem in that the macroprudential policies are applied across different countries and times. That is the reason why a macroprudential policy in Taiwan is selected due to its special policy design, where an LTV policy is executed only in a specific area so that an economy is clearly divided into regulated and unregulated areas.[5] In other words, differing from past experiences of macroprudential policies on a nationwide basis (Galati and

[5] Another example of a local LTV policy can be found in the case of New Zealand. We thank a reviewer for giving us this information.

Moessner, 2013; Rubio, 2020), Taiwan's case provides a "pure" experimental environment for addressing questions about externalities to avoid the unidentifiable source of the spillovers. By using quarterly housing price data across four cities in Taiwan, we first identify the episodes of the bubbles in Taipei city and New Taipei city as two regulated cases and then compute the time-varying housing price spillovers from regulated cities to other unregulated cities. It is important to note that the estimation results indicate that macroprudential regulations efficiently removed the bubble, while housing price spillovers apparently encouraged the transmission of these spillovers from regulated to other unregulated cities. These unintended spillovers may further result in new systemic risk from regulated to unregulated housing markets.

Overall, we pay special attention to the dynamic response of the real estate market to macroprudential regulations. The main contributions of this paper are threefold. First, we emphasize that the (P/I) ratio, instead of housing price is the best indicator for identifying housing bubbles. Second, macroprudential polices are especially noteworthy in the case of Taiwan, on the grounds that an LTV policy in a special area within a nation can give us a glimpse of the secret background of the housing price spillovers between regulated and unregulated areas. Third, unlike the existing literature that focuses on a single aspect, we can provide a full story that encompasses current bubble symptoms (the GSADF test) as well as the follow-up externalities to other regions (the DY spillover method) over time.

The remainder of this paper is organized as follows. In Section 2, the macroprudential policy in Taiwan is first introduced and then the data regarding housing prices and household income are described. Section 3 outlines the time-varying bubble test as well as the DY spillover method. In Section 4, the empirical results are reported to develop several policy implications. Finally, a review of the conclusions is provided in Section 5.

2. Macroprudential Regulations and Data Description

In this section, we will briefly review the macroprudential policy implemented in Taiwan during the 2010-2016 period. Moreover, the relevant data for housing prices and household income are described and analyzed.

2.1 Background and content of the macroprudential policy in Taiwan

The Taipei Metropolitan Statistical Area (MSA) is Taiwan's largest MSA with more than six million inhabitants and includes Taipei city as the central city and New Taipei city as its suburban area. Following the outbreak of the severe acute respiratory syndrome (SARS) in 2003, housing prices persistently increased until the collapse of Lehman Brothers on September 13, 2008. However, housing prices once again started to rise in 2009 and the amount of the increase was even greater than that during the earlier 2003-2008 period. In the second half (October) of 2009, Fai-nan Perng, as the governor of the central bank in Taiwan, persuaded the commercial banks to make more conservative decisions regarding mortgage lending, while at the same time repeatedly delivering a public warning in relation to the unreasonably high housing prices in the Taipei MSA. However, these caveats seemed to be invalid. Subsequently, in June 2010, after a meeting of the central bank's Board of Directors, Perng officially announced that a selective credit control policy, namely, the LTV policy as one of the macroprudential tools, would be implemented. In this case, stricter housing mortgage credit control with a maximum LTV ratio would only be enforced in the Taipei MSA for two reasons. The first reason was that the central bank argued that the macroprudential policies were more effective in preventing housing bubbles than adjusting the interest rate, and the second was that at that time the overheated housing market was concentrated in Taipei, rather than being a serious issue throughout the island. In contrast to the other macroprudential policy measures, the Central Bank of Taiwan (CBT) decided to regulate a specific sector (housing) as well as a specific location (Taipei MSA) with an upper limit on mortgage credit as shown in Figure 1.

In Figure 1, the macroprudential policies in the Taipei MSA were enforced by three waves using the LTV measure. The first wave was announced in June 2010 whereby the regulated areas would include all 12 districts of Taipei city and 10 districts of New Taipei city with a total of 29 districts. These districts were concentrated around the core of the Taipei metropolitan area. At the same time, the population of these 10 districts accounted for 77.53% of the total population of New Taipei city. The most concrete measure within this new policy was that when banks extended housing mortgages for property located in these regulated regions, the amount of the bank loan had to strictly follow a new LTV ratio, which could not exceed 70%.[6] Shortly afterwards, on December 31, 2010, the second wave of the LTV policy extended the boundary to three more remote districts of New Taipei city. At that time, the LTV ratio was further lowered to 60% in all regulated areas. After two and a half years, the CBT launched the third wave of the LTV policy in June 2014 so that four suburban districts in New Taipei city were additionally included in the regulated areas in order to ensure the effectiveness of the policy against housing bubbles in the Taipei MSA. The populations of the regulated districts in the second and third waves accounted for 88.08% and 95.44% of the total population of New Taipei city, respectively. To sum up, the authorities gradually broadened the scope of the regulated areas associated with a stricter LTV ratio. The process of implementing the LTV measures in Taiwan can be summarized as shown in Table 1, which fully reflects the changing characteristics of the macroprudential

[6] Generally speaking, an LTV ratio of 80% or even 90% is normal for bank lending in Taiwan.

policies.

As time progressed, this LTV policy was in force for more than 5 years until March 2016. However, the application of this macroprudential tool continues to provoke a great deal of controversy. The most frequently voiced criticism is concerned with how to prove the existence of housing bubbles in the Taipei MSA and another debate is whether this policy has resulted in excessive liquidity in other cities due to housing price spillovers that have eventually led to a nationwide housing frenzy. These two questions are totally consistent with the direct (housing bubbles) and indirect (housing price externalities) impacts of the macroprudential policies, as mentioned earlier.

2.2 Data sources and description

We first provide a brief introduction to the four major cities in Taiwan, namely, Taipei, New Taipei, Taichung and Kaohsiung, respectively. As far as their urban populations are concerned, New Taipei city and Taipei city are the first and fourth largest cities, while Taichung and Kaohsiung are currently the second and third most populous cities. Moreover, Taipei city and New Taipei city are both located in the northern part of Taiwan, while the Taichung and Kaohsiung cities are located in the central and southern regions of Taiwan, respectively, as shown in Figure 2.

Next, we collect actual housing price transactions and the housing price index from the Sinyi Real Estate Development (SRED) Company for the following reasons. First, the SRED company is the largest real estate agency in Taiwan as well as the first such firm to be publicly listed on the Taiwan stock exchange (TWSE). Second, based on the low-frequency quarterly housing data, the fact that the SRED company is the first company to publish housing price data every quarter since 1996 under its own housing transaction platform and the first housing price index since 1991 is very useful when implementing related time-varying estimations of bubbles and spillovers. Third, this housing price index is calculated in accordance with existing and second-hand housing transactions, which account for more than 70% of total housing transactions, so this company's housing price information can represent the status of Taiwan's housing market. Based on the above, this housing price index has been widely used in past academic research, e.g., Chien, 2010 and Chen *et al.*, 2011.

The important point to note is that the housing price series are the trimmed mean values of transaction prices after deleting the highest and lowest prices at the 5% level in order to avoid possible outliers. As shown in Figure 3, the highlight is the much higher housing prices in Taipei city than the ones in the other three cities. In other words, the highest housing prices associated with the fastest growth rates can be found in the Taipei MSA including Taipei city and New Taipei city. Finally, the annual data on household income are obtained from the Directorate-General of Budget, Accounting and Statistics.[7]

By combining the housing price and household income data, the (P/I) ratios can be computed as shown in Figure 4, from which it is obvious that the highest value is still in Taipei city and even the ratio for New Taipei city is also apparently higher than the ones for Taichung and Kaohsiung as two unregulated areas. Judging from the above, we can easily understand why the central bank decided to implement a macroprudential tool, namely, the LTV ratio, solely in the Taipei MSA.

In addition, we have selected the housing price index as shown in Figure 5. This index is calculated using the Laspeyres index with a base of 100 in this city itself since the first quarter of 2001. At the same time, this housing price index is a constant quality

[7] In Taiwan, the data on rents can only be obtained from Taipei city, while the housing rent data for the other three cities are very limited (Teng *et al.*, 2017). Thus, we only apply the (P/I) ratio to estimate the possibility of housing bubbles for all cities. As suggested by a reviewer, besides using the (P/I) ratio, we also use the (P/R) ratio to detect the episodes of housing bubble in Taipei city, which are almost the same as those based on the (P/I) ratio. The bubble test results of the (P/R) ratio are available from the authors upon request.

index based on a hedonic model. Compared to housing price transactions data, there are some benefits from this housing price index. For instance, there are more observations with data available for 1991, rather than 1996, to give us a good chance of estimating the time-varying spillovers for a specific window size. Moreover, by using the housing price index with a base year we can further compute the individual housing returns, which are consistent with the requirement of the DY spillover method that data must be stationary. From Figure 5, it can be seen that when the LTV ratio was implemented in the Taipei MSA after 2010, there were similar trends in terms of the housing price indices among all four cities. This result enables us to wonder whether the LTV policy may generate conspicuous housing price spillovers between regulated and unregulated cities due to capital flight.

3. Time-varying estimations of the bubbles and spillovers

An overheated housing market always covers two critical concepts: the bubble and spillovers, respectively. Coincidentally, these two topics in real estate economics can precisely respond to the full impact of macroprudential policies upon real estate markets. We therefore utilize two subsections here to represent the bubbles and housing price spillovers in the dynamic empirical models.

3.1 Identification of the bubbles using a new ADF test

A standard asset pricing model based on an economic fundamental (income or rent) is often quoted to assess reasonable housing prices through the use of the (P/I) or (P/R) ratio. However, empirical works based on income (Gallin, 2006; Mikhed and Zemcik, 2009) or rent (Clark, 1995; Gallin, 2008; Plazzi *et al.*, 2010) have shown that there is little evidence of a housing bubble. In fact, the "no bubble" phenomenon also occurs in relation to other asset prices like the stock market (Campbell and Shiller, 1987; Diba and Grossman, 1987, 1988). Evans (1991) made an excellent conjecture that if a bubble is characterized by periodic collapses, the evidence for there being no bubble is very reasonable on the grounds that traditional time-series econometrics require the long-term data to obtain reliable parameters.

In particular, following the GFC event of 2008, the goal of the macroprudential policies is to serve as a surveillance mechanism against housing bubbles. Although many economists have still subjectively presumed that a dynamic detection of the housing bubble is an impossible task, some constructive progress in econometrics has recently been achieved in efficiently identifying the bubbles in real-time updates. A typical case is a rolling-window ADF strategy, where the argument put forward by Evans (1991) inspired Phillips *et al.* (2011) to introduce a rolling-window calculation to grasp the characteristics of periodically collapsing bubbles, including the origin and termination of the bubble. However, one may note that these tests are intended to examine the (P/I) or (P/R) ratio, rather than housing prices alone (Engsted *et al.*, 2016; Pavlidis *et al.*, 2016). Based on the significance of the bubbles, the GSADF test is widely applied to identify the time-varying bubbles in relation to different types of assets, such as stock markets (Phillips *et al.*, 2015), commodity futures markets (Etienne *et al.*, 2014), the art market (Kraussl *et al.*, 2016), international housing markets (Pavlidis *et al.*, 2016), and the Australian housing markets (Shi *et al.*, 2020b). More recently, Shi and Phillips (2023) have argued that many economic variables, which may affect housing prices, must be considered in advance by means of the endogenous instrumental variables-based (IVX) method, in which case the housing bubble can be fairly detected.

Let us start with a random walk with an asymptotically negligible drift of the (P/I) ratio as in our case in (1):

$$(P/I)_t = dT^{-\eta} + (P/I)_{t-1} + \varepsilon_t, \varepsilon_t \sim iid(0, \sigma^2) \quad (1)$$

where (P/I) is the ratio of the housing price to income, T is the total sample interval, ε_t is an iid random error with mean zero and variance σ^2, and $\eta > 1/2$ is used to control the magnitude of the intercept, namely, d. A transient dynamics is further inserted to investigate the extent of the bubble using a rolling-window calculation from r_1 to r_2: the regression from the sample starts from the r_1^{th} fraction of the total sample (T) and ends at the r_2^{th} fraction due to $r_2 = r_1 + r_w$, where r_w is the fractional window size. This empirical regression model is therefore expressed as (2):

$$\Delta(P/I)_t = \alpha_{r_1,r_2} + \beta_{r_1,r_2}(P/I)_{t-1} + \sum_{i=1}^{k} \varphi_{r_1,r_2}^{i} \Delta(P/I)_{t-i} + \varepsilon_t \quad (2)$$

To examine the housing bubble, we calculate the unit roots by using the null hypothesis: $\beta_{r_1,r_2} = 0$ against the alternative hypothesis: $\beta_{r_1,r_2} > 0$.

$$ADF_{r_1}^{r_2} = \frac{\hat{\beta}_{r_1,r_2}}{se(\hat{\beta}_{r_1,r_2})} \quad (3)$$

That is to say, this is a right-tailed statistic for the degree of mild explosiveness. A recursive estimation procedure based on (3) on subsamples of the (P/I) ratio can be used to compute the test statistic since r_0 is the smallest sample window fraction. This new test statistic, which is proved to have much better estimation power in the presence of periodically collapsing bubbles, is referred to as the supremum ADF (SADF) test statistic as in (4):

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2} \quad (4)$$

According to the critical value, the value of the SADF statistic being larger than the critical value implies that an explosive event starts to emerge, while its value being lower than the critical value stands for the end date of this exuberance. In other words, the SADF test proposed by Phillips *et al.* (2011) can not only confirm the existence of the housing bubble, but it can also discover the duration of the bubble.

However, Phillips *et al.* (2015) argued that the SADF test may suffer from low power and inconsistency as a result of failing to detect more than one bubble. Thus, they proposed the GSADF test to determine the multiple bubbles and multiple episodes of bubbles through the application of a new date-stamping strategy with a double recursion using a recursive backward sup ADF (BSADF) regression operation, namely, a flexible window to change both the starting and ending points, instead of having a fixed starting point from the SADF. The GSADF statistic is shown as in (5):

$$\mathrm{GSADF}(\mathrm{r}_0) = \sup_{\mathrm{r}_2 \in [\mathrm{r}_0, 1], \mathrm{r}_1 \in [0, \mathrm{r}_2 - \mathrm{r}_0]} \mathrm{ADF}_{\mathrm{r}_1}^{\mathrm{r}_2} = \sup_{\mathrm{r}_2 \in [\mathrm{r}_0, 1]} \mathrm{BSADF}_{\mathrm{r}_2}(\mathrm{r}_0) \quad (5)$$

Similarly, the GSADF test is still a right-tailed test. That is, rejecting the null hypothesis is equivalent to supporting explosive behavior. Besides, we must notice that the critical values of the SADF and GSADF tests must be obtained by case-by-case simulations due to the nonstandard limiting distribution.

3.2 Time-varying spillovers

Another issue when faced with an overheated housing market is related to externalities or spillovers among local housing markets.[8] Over the past few decades, there have been at least two strands of the literature on housing price spillovers. The first strand has involved applying causality tests to trace back to source cities in many national cases (Liu *et al.*, 2008; Costello *et al.*, 2011; Chen *et al.*, 2011; Yunus and

[8] Externalities, spillovers and ripple effects are interchangeably used in economics, finance and real estate research, respectively.

Swanson, 2013; Brady, 2014) and China is also no exception (Chiang, 2014; Gong *et al.*, 2016). The second strand originated from Meen (1999), who argued that regional housing price relativities should be stable variables in the long run based on spillover behaviors among regions. Cook (2003) for the UK, Stevenson (2004) for Ireland, Lee and Chien (2011) for Taiwan, Balcilar *et al.* (2013) for South Africa and Lee *et al.* (2016) for China all found that housing price relativities are stable, thereby proving the existence of spillovers among local housing markets.

The above studies on housing price spillovers among housing markets all relied on traditional time-series econometrics. Diebold and Yilmaz (2012) argued that the financial market surely varies over time and so they applied the vector autoregressive (VAR) model using a rolling-window approach to display new time-varying spillovers. In fact, their time-varying estimation of spillovers has been recently applied in many economic and financial fields (Zhou, 2012; Tsai, 2015; Chiang *et al.*, 2017; Tsai and Chiang, 2019; Zhang and Fan, 2019; Chen and Chiang, 2020). As an alternative, Hurn *et al.* (2022) combined two ideas including the time-varying Granger causality test from Shi *et al.* (2020a) and the IVX method from Shi and Phillips (2023) to further explore the sentiment-driven spillovers. We here adopt the spillover estimation approach of Diebold and Yilmaz (2012).

In fact, Diebold and Yilmaz (2009) first brought up the idea that forecast error variance decomposition (FEVD), which is defined as the ratio of the variance of a specific variable (x) to the shock of another variable (y), is similar to the concept of spillovers from y to x, and so they calculated FEVD from the VAR model to create a new spillover index. A main advantage of the DY spillover indices is that they reveal the size and direction of spillovers simultaneously. More importantly, it is generally believed that spillovers among different areas is a classic example of agnostic data-based empirics through the use of Cholesky decomposition as a specific identification, where FEVD depends on the ordering of the variables which is referred to as the "variable ordering" problem. To correct for this drawback, a generalized VAR (GVAR) methodology, which is robust to Cholesky identification, is used to calculate the degree of spillovers.

First, we consider a VAR (p) model of housing returns (HR) with N cities and p lags as in (6).[9]

$$HR_t = \sum_{i=1}^{p} \mathrm{A}_i HR_{t-i} + \varepsilon_t\, , \varepsilon_t \sim (0, \Sigma) \tag{6}$$

where ε is a random error with a zero mean and covariance matrix, Σ, and A_i is the impact of the lagged variable (HR_{t-i}). Based on a GVAR system, we can compute the H-step-ahead FEVD by $\varphi_{ij}^{g}(H)$ with g on behalf of the GVAR model as:

$$\varphi_{ij}^{g}(\mathrm{H}) = \frac{\Sigma_{jj}^{-1} \sum_{h=0}^{H} [(\mathrm{A_h}\Sigma)_{ij}]^2}{\sum_{h=0}^{H} (\mathrm{A_h}\Sigma \mathrm{A_h'})_{ii}} \tag{7}$$

According to the non-unity sum of FEVD in a GVAR model, the normalization of (7) can be operated by a new version of FEVD ($\tilde{\varphi}_{ij}^{g}$) to sum up to 1 as follows:

$$\tilde{\varphi}_{ij}^{g}(H) = \frac{\varphi_{ij}^{g}(H)}{\sum_{j=1}^{N} \varphi_{ij}^{g}(H)} \tag{8}$$

Since the magnitude of the FEVDs can represent the effects of spillovers, the first spillover index is constructed by the total spillover index (TSP^{g}), as:

[9] VAR and generalized VAR methods both assume that all variables must be stationary. To meet this requirement, housing returns are used to calculate the spillover index in this paper.

$$TSP^g(H) = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \tilde{\varphi}_{ij}^g(H)}{\sum_{i,j=1}^{N} \tilde{\varphi}_{ij}^g(H)}, \text{ where } \sum_{i,j=1}^{N} \tilde{\varphi}_{ij}^g(H) = N \quad (9)$$

The total spillover index is calculated based on the average value of the aggregation of the spillovers regardless of whether they are from or to other cities through the use of the FEVD of the housing return in a specific city minus itself. Thus, the value of the total spillover between zero and unity can show the "average" level of spillovers over all cities. Generally speaking, a higher value of the total spillover index reflects more active spillovers across cities and hence higher systemic risk (Diebold and Yilmaz, 2014).

Moreover, we can learn more about the impacts of macroprudential policies from regulated to unregulated areas based on the directions of the spillovers, that is to say, the directional spillover index for market i "from" other markets as in (10) by $SP_{i.}^g$, and the directional spillover index for market i "to" other markets as in (11) by $SP_{.i}^g$.

$$SP_{i.}^g(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\varphi}_{ij}^g(H)}{\sum_{i,j=1}^{N} \tilde{\varphi}_{ij}^g(H)} = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\varphi}_{ij}^g(H)}{N} \quad (10)$$

$$SP_{.i}^g(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\varphi}_{ji}^g(H)}{\sum_{i,j=1}^{N} \tilde{\varphi}_{ji}^g(H)} = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\varphi}_{ji}^g(H)}{N} \quad (11)$$

Besides, we can simply obtain a net index, referred to as the "net" spillover index (NSP_i^g), as in (12) through the application of the spillovers to other markets in (11) minus the spillovers from other markets in (10). Compared to other cities, a positive net spillover index indicates that this city is a provider, whereas a negative value of this index can show that this city is a receiver:

$$NSP_i^g(H) = SP_{.i}^g(H) - SP_{i.}^g(H) \tag{12}$$

Furthermore, it is interesting to note that Diebold and Yilmaz (2012) proposed another index to examine net spillovers between two specific markets by means of a "net pairwise" spillover index (SP_{ij}^g) as in (13). A highlight of this index is that it lets us know more about the net spillovers of a city "to" or "from" another city, rather than other cities.

$$SP_{ij}^g(H) = \left[\frac{\tilde{\varphi}_{ji}^g(H)}{\sum_{i,k=1}^N \tilde{\varphi}_{ik}^g(H)} - \frac{\tilde{\varphi}_{ij}^g(H)}{\sum_{i,k=1}^N \tilde{\varphi}_{ik}^g(H)}\right] = \left[\frac{\tilde{\varphi}_{ji}^g(H) - \tilde{\varphi}_{ij}^g(H)}{N}\right] \tag{13}$$

Through the operational process of total, directional, net and net pairwise spillovers, it is clear that the DY spillover index can be used to comprehensively trace the evolution of housing price spillovers among urban housing markets as the macroprudential regulations were announced one after another. In addition, we wish to introduce the rolling window calculation into all kinds of spillovers in order to probe into the dynamic evolution of spillovers. The steps involved in the rolling-window approach are outlined as follows. First, we choose a rolling window size, for example, *m*. Second, supposing that the number of increments between successive rolling windows is one quarter, we then partition the entire data set into $K = T - m + 1$ subsamples. The first rolling window contains observations from 1 to *m*, the second rolling window contains observations from 2 to $m + 1$, and a similar pattern continues until the final quarter T. Third, by estimating the model in (6) using each rolling window subsample, we can obtain a variance decomposition in (7) and then calculate a value of the spillover index, for example, the total spillover index in (9), the directional spillover index in (10) or (11), the net spillover index in (12) and the net pairwise spillover index in (13). Finally, we can plot each value of the spillover index over the rolling window to see how the estimates change over time, so that the parameters might be time varying.

4. Estimation Results

In this section, the housing bubbles are detected in regulated areas and then the time-varying housing price spillovers over four cities are estimated to determine possible subsequent effects of this policy between regulated and unregulated areas. Finally, some critical policy implications are discussed.

4.1 Detecting the existence and episodes of housing bubbles

The SADF and GSADF tests are both proposed to detect the existence of these bubbles with their durations from start to finish. Given that the (P/I) ratios have been obtained from the 1996-2017 period using quarterly data and the minimum window size is 17 based on total 88 observations according to Phillips *et al.* (2015), the first window extends from the first quarter of 1996 to the first quarter of 2000. Compared to SADE test, the GSADF test can further detect multiple bubbles, so we only report the empirical results of the GSADF statistic in Figures 6 and 7 in Taipei city and New Taipei city, respectively. More specifically, we highlight five critical time points, including the start (October 2009), three waves of LTV measures (June 2010; December 2010; June 2014) and the end (March, 2016) from Table 1 to provide a key to understanding the effectiveness of the macroprudential policies.

From Figure 6 for Taipei city, we can see the episodes of the housing bubbles based on the GSADF test for the 2009-2016 period (the shaded area), which almost overlaps the interval that existed for the macroprudential regulations. As far as the three waves of LTV measures are concerned, the first wave of the LTV policy was really effective against the housing bubbles by lowering the (P/I) ratio, but this effect lasted for only 3 months and then the (P/I) ratio rose again leading to a reemergence of the bubble. Thus, after 6 months, the second wave of the LTV measure was immediately fulfilled to counter the increasing (P/I) ratio and the possible appearance of a housing bubble. However, the second wave could not suppress the upward (P/I) ratio until September 2011, so that the time lag was extended by 9 months. What is worse, the second wave never removed the bubbles. The third and final wave that was announced by June 2014 appeared to be another successful case, where continuously lowering the (P/I) ratio eventually eliminated the housing bubbles over a period of one and a half years until 2016, when the macroprudential regulations just ended. For New Taipei city in Figure 7, it was found that the implementation periods of the LTV ratio were almost consistent with the housing-bubble episodes. However, based on relative effectiveness of three-wave LTV measures, the only discrepancy based on the experience of Taipei city is that there was no effect in terms of lowering the (P/I) ratio and countering the bubbles during the first wave of the LTV policy.

As discussed above, we summarize the main findings as follows. First, the existence and episodes of multiple housing bubbles are detected as shaded areas, regardless of Taipei city or New Taipei city. Second, between the two regulated cities, it is clear that the level of the overheated market in Taipei city was far higher than the one in New Taipei city. This result explains why the LTV policy was implemented in all areas of Taipei city but not in all districts of New Taipei city. Third, the duration of execution of the macroprudential policies is almost in agreement with the duration of the housing bubbles over two regulated cities. That is to say, the macroprudential policies completely revolved around the housing-bubble debate. Finally, although there were heterogeneous impacts of the three waves of LTV measures, the accumulated impacts from the first to the third round of the LTV measures eventually resolved the housing bubbles in 2016 as the last year of the macroprudential policies. It is therefore concluded that the policy effectiveness can be identified by the coincidence of the timing of the policy and the timing of the bubble (Eisenberg, 2003; Zheng *et al.*, 2023).

However, the timing of the policy is not sufficient to further ensure a causal relationship between the macroprudential policies and a suppression of housing price appreciation, which is effective in attacking the housing bubbles. We thus plan to apply a difference-in-differences (DID) analysis to investigate this causal relationship by using the two regulated cities (Taipei and New Taipei) as the treatment group in contrast to two unregulated cities (Taichung and Kaohsiung) as the control group. We estimate the DID estimator $\hat{\delta}$ as in (14) in order to evaluate the impacts of the macroprudential policies on the housing price appreciation.

$$DHP_{it} = \alpha_0 + \alpha_1 MP_i + \alpha_2 TIME_t + \delta(MP_i \times TIME_t) + \varepsilon_{it} \tag{14}$$

where DHP_{it} is the growth rate of housing prices for city i in period t, MP_i is a dummy variable that equals 1 for the treatment group and 0 for the control group, and $TIME_t$ is a dummy variable that equals 1 in the periods in which the LTV policy was implemented and 0 in other periods.

In addition, we also include important macroeconomic variables, which may affect housing price appreciation to set up another DID regression as in (15):

$$DHP_{it} = \alpha_0 + \alpha_1 MP_i + \alpha_2 TIME_t + \delta(MP_i \times TIME_t) + \boldsymbol{\beta}'\boldsymbol{X}_t + \varepsilon_{it} \tag{15}$$

where $\boldsymbol{X}_t$ refers to the control variables that are the determinants of the housing price, i.e., the growth rate of GDP ($GROWTH$), inflation rate ($INFLATION$), and interest rate (IR).

The estimation results are shown in Table 2. In this table, the effectiveness of macroprudential policies in Taiwan is confirmed based on the significantly negative effect of this policy on housing price appreciation and hence the resolution of the housing bubbles.[10]

4.2 Time-varying housing price spillovers

The "bubble thy neighbor" term coined by Forbes *et al.* (2016) represents a convincing argument in that it additionally considers the importance of externalities of housing prices from regulated to other unregulated areas during the implementation periods of macroprudential policies. We believe that a novel approach by Diebold and Yilmaz (2012) can fully respond to the extent of the impact of the externalities of regulated cities on other cities by tracing the dynamic process of spillovers over time.

We first estimate a static version of the total spillovers, which are calculated based on FEVDs under a GVAR model over the total sample period covering 1991-2017 with 108 observations as shown in Table 3.[11] First, we can see that the total spillovers across the four cities amount to 31.5%, and so systemic risk is not too high. Second, the highest spillovers to other cities are those to New Taipei and Taipei as the Taipei MSA, followed by Taichung and Kaohsiung. At the same time, there are similar orders based on spillovers from other cities. This result reveals that the strongest degree of interaction is that within the Taipei MSA. Thirdly, by comparing the "contribution to others" with the "contribution from others," it is clear that the greatest net spillovers to other cities are those for the Taipei and New Taipei cities (two regulated cities), while negative net spillovers appear in Taichung and Kaohsiung (two unregulated cities), respectively. This result leads us to wonder whether there may be externalities from regulated cities

[10] We would like to our gratitude for an anonymous reviewer for suggesting the use of the difference-in-differences analysis.
[11] That the number of lags equals 1 is determined by the Schwarz Bayesian criterion (SBC).

to other unregulated cities. Finally, Kaohsiung is a special case as it has the lowest spillovers to other cities (2.80%) and from other cities (21.20%). That is to say, this city is a relatively isolated housing market.

Moreover, we apply a rolling window approach with 48 quarters, namely, 12 years, as our window size to estimate all of the parameters from the GVAR models. We obtain time-varying total spillovers in (9) across four cities from the first quarter of 2003 to the fourth quarter of 2017.[12] Figure 8 shows that the total spillovers across the four cities are clearly volatile and changeable: after the 2008 GFC event, total spillovers began to abruptly increase from 25% to 35% in 2009 due to rising systemic risk and then up to 45% in the period of the first LTV regulation beginning June 2010. In other words, the first stage of the increase in total spillovers stemmed from the 2008 GFC, while the second stage of higher total spillovers was caused by the first LTV policy in 2010 but the subsequent second and third rounds of the LTV measures could not efficiently reduce total spillovers. Furthermore, even though the LTV policy stopped being implemented in 2016, the strong spillovers in 2017 still make us cautious about the possibility of a backlash against the macroprudential regulations. We therefore conclude that the macroprudential regulations may increase, or at least not help reduce, systemic risk based on the high level of total spillovers after 2008.

To further investigate the sources of spillovers between regulated and unregulated areas, we need to consider directional spillovers, that is, spillovers “from” and “to” other cities as shown in Figure 9. First, there are increasingly high spillovers from regulated cities, especially Taipei city to other cities. Second, it is found that spillovers “from” other cities exhibit upward trends in two unregulated cities (Taichung and

[12] Compared to the GSADF tests used in the univariate analysis for the (P/I) ratio, the DY spillover method under a GVAR model requires a larger window size. That is, more data are needed to estimate all related parameters.

Kaohsiung). In other words, spillovers "from" other cities are found in unregulated cities, while spillovers "to" other cities prevail over the regulated areas, including the Taipei and New Taipei cities. Thus, it is concluded from the LTV policy adopted in the Taipei MSA that unregulated cities are receivers, while regulated cities are transmitters based on the viewpoint of spillovers. This result really enables us to worry about the possibilities of the "bubble thy neighbor" argument by Forbes *et al.* (2016).

Furthermore, we can obtain the results for the net spillovers in the four cities to know whether a city is a provider or receiver of spillovers according to spillovers "to" other cities minus spillovers "from" other cities. As shown in Figure 10, a city with positive (negative) net spillovers implies that it is a provider (receiver) of spillovers. We can see that only regulated areas (Taipei and New Taipei) give rise to positive net spillovers to other cities, while unregulated areas (Taichung and Kaohsiung) receive spillovers from other cities due to negative net spillovers. More importantly, with Taipei city being at the heart of the LTV policy it is shown that significantly increasing net spillovers to other cities comes along with more and more strict LTV ceiling ratios, while Kaohsiung is the greatest receiver of net spillovers from other cities during the regulated period (2010-2016). This result indicates that net spillovers arising from regulated to unregulated cities apparently increased due to the accumulated effects of the three waves of LTV policies on these regulated areas. However, the net spillovers between a specific city and other cities may mix regulated and unregulated cities. Taking Taipei city as an example, when considering its net spillovers, it is necessary to compare Taipei with the other three cities (Taichung, Kaohsiung and another regulated city, namely, New Taipei city). We must consider the net pairwise spillovers in further detail to clarify the spillovers between regulated and unregulated areas.

Finally, we employ "pairwise," i.e., "one-on-one" net spillovers in Figure 11, where a positive value of pairwise net spillovers stands for net spillovers from the former to the latter, while a negative value implies net spillovers from the latter to the former. From the left side of Figure 11, it is clear that Taipei city exhibits strongly increasing spillovers to the other three cities. What is most important is that increasing spillovers from Taipei city to two unregulated cities based on the "Taipei-Taichung" and "Taipei-Kaohsiung" cases is especially significant since the LTV policy was enforced in June 2010, while another regulated city (New Taipei city) also generates mildly strong spillovers to the two unregulated cities. Finally, we conjecture that, since Taichung is closer to the Taipei MSA, there is evidence of net spillovers from Taichung to Kaohsiung.

To sum up, there is sufficient evidence to prove the existence of follow-up reverse impacts of macroprudential policies, namely, externalities in the form of increasing housing prices from regulated to other unregulated areas due to capital flight, and this is especially noteworthy in the case of Taipei city as the core of macroprudential policies based on the net pairwise spillover index. When policy-makers attempt to adopt macroprudential policies, they must consider its complex influences on the overall economy, rather than dealing with housing bubbles alone.

4.3 Policy implications

Although most studies on the effectiveness of macroprudential policies have only focused on whether or not to efficiently reduce high housing prices, Forbes *et al.* (2016) proposed a "bubble-thy-neighbor" viewpoint to highlight subsequent repercussions or leaks of macroprudential policies through the application of the concept of externalities. In this paper, the (P/I) ratio is first proposed to check the status of housing bubbles. At the same time, a special LTV policy between regulated and unregulated groups in Taiwan is employed to further explore housing price spillovers. We therefore conclude that this macroprudential policy is effective in leaning against the housing bubbles in regulated areas, while this policy has resulted in apparently increasing housing price spillovers from regulated to unregulated cities and has eventually raised new questions about systemic risk.

As discussed above, there are surprisingly complicated and mixed impacts of macroprudential policies upon the real estate market in that macroprudential policies may be effective in dealing with direct targets (avoiding housing bubbles and credit growth), but is often associated with unintended spillovers or leakages as the "bubble-thy-neighbor" phenomenon. These mixed findings indicate that even though this policy has proved to be very effective in fighting against bubbles, its subsequent negative impacts on other regulated areas or countries still make it difficult to determine whether macroprudential policies are really appropriate for the real estate market and financial stability. Thus, how to reduce unintended spillovers to other unregulated areas is our concern: we suggest that the best buffer against externalities to other unregulated areas is to strengthen the cooperation mechanisms with other unregulated regions on the grounds that better communication and cooperation among all related areas can internalize possible repercussions or externalities to make the real effect of macroprudential policies on the financial stability become more valuable. In fact, similar advice about a policy coordination program, for example, international macroprudential policies, is also proposed by Agenor *et al.* (2021).

5. Conclusions

Following the GFC that took place in 2008, the adoption of macroprudential policies to dynamically counteract high housing prices became a critical part of the efforts made to mitigate macroeconomic volatility and maintain financial stability. However, based on the existing literature, how to identify the bubbles as well as the follow-up externalities of housing prices from the real estate markets in a real-time manner is open to question and hence is the initial motivation of this paper.

To fill the gap left by past studies, our contribution can be summarized by means of several points. First, we argue that the (P/I) ratio, rather than the often-used housing price is a reasonable indicator for housing bubbles. Second, a special macroprudential policy, where a lower LTV ratio is implemented in regulated areas within a nation, is very useful in comprehensively investigating spillovers from regulated to unregulated areas. Third, we introduce two kinds of time-varying econometric methods to monitor housing bubbles and housing price spillovers over time to investigate the dynamic effects of macroprudential regulations. Fourth, the empirical results in the case of Taiwan illustrate that this LTV policy has been highly effective against the housing bubbles of regulated cities based on the (P/I) ratio, but it has also given rise to a new systemic risk from the housing market on account of significant increases in housing price spillovers from regulated cities to other unregulated cities. Finally, we would like to emphasize that the integrated effect of the macroprudential policies covering housing bubbles and subsequent externalities may be mixed. Thus, how to establish further cooperation among related areas to minimize unintended spillovers is the most appropriate strategy when implementing macroprudential policies.

References

Agenor, P., Jackson, T., Kharroubi, E., Gambacorta, L., G. Lombardo, and L. A. Pereira da Silva (2021). Assessing the gains from international macroprudential policy cooperation. *Journal of Money, Credit and Banking*, 53, pp. 1819-1866.

Akinci, O. and J. Olmstead-Rumsey (2018). How effective are macroprudential policies? An empirical investigation. *Journal of Financial Intermediation* 33, pp. 33-57.

Agnello, L., V. Castro, and R. M. Sousa (2017). Economic activity, credit market conditions and the housing market. *Macroeconomic Dynamics* 22, pp. 1769-1789.

Ambrose, B.W., P. Eichholtz, and T. Lindenthal. (2013). "House prices and fundamentals: 355 years of evidence. *Journal of Money, Credit and Banking* 45, pp. 477-491.

Balcilar, M., A. Beyene, R. Gupta, and M. Seleteng (2013). 'Ripple' effects in South African house prices. *Urban Studies* 50, pp. 876-894.

Bernanke, B. S. and M. Gertler (2001). Should central banks respond to movement in asset prices? *American Economic Review* 91, pp. 253-257.

Blanchard O., G. Dell'Ariccia, and P. Mauro (2010). Rethinking macroeconomic policy. *Journal of Money, Credit and Banking* 42, pp. 199-215.

Brady, R. R. (2014). The spatial diffusion of regional housing prices across U.S. states. *Regional Science and Urban Economics* 46, pp. 150-166.

Campbell, J. Y. and R. J. Shiller. (1987). Cointegration and tests of present value models. *Journal of Political Economy* 95, pp. 1062-1088.

Carreras, O., E. P. Davis, and R. Piggott. (2018). Assessing macroprudential tools in OECD countries within a cointegration framework. *Journal of Financial Stability* 37, pp. 112-130.

Cerutti, E., S. Claessens, and L. Laeven. (2017a). The use and effectiveness of macroprudential policies: New evidence. *Journal of Financial Stability* 28, pp. 203-224.

Cerutti, E., J. Dagher, and G. Dell'Ariccia. (2017b). Housing finance and real-estate booms: A cross-country perspective. *Journal of Housing Economics* 38, pp. 1-13.

Chen, C. and S. Chiang. (2020). Time-varying spillovers among first-tier housing markets in China. *Urban Studies* 57, pp. 844-864.

Chen, P., M. Chien, and C. Lee. (2011). Dynamic modeling of regional house price diffusion in Taiwan. *Journal of Housing Economics* 20, pp. 315-332.

Chiang, S. (2014). Housing markets in China and policy implications: Co-movement or ripple effect. *China & World Economy* 22, pp. 103-120.

Chiang, M., T. Sing, and I. Tsai. (2017). Spillover risks in REITs and other asset markets. *Journal of Real Estate Finance and Economics* 54, pp. 579-604.

Chien, M. (2010). Structural breaks and the convergence of regional house prices. *Journal of Real Estate Finance and Economics* 40, pp. 77-88.

Cizel, J., J, Frost, A., Houben and P. Wierts. (2019). Effective macroprudential policy: Cross-sector substitution from price and quantity measures. *Journal of Money, Credit and Banking* 51, pp. 1209-1235.

Claessens, S. (2015). Important questions for housing markets and housing policy. *Journal of Money, Credit and Banking* 47, pp. 419-421.

Claessens, S., S. Ghosh, and R. Mihet. (2013). Macroprudential policies to mitigate financial system vulnerabilities. *Journal of International Money and Finance* 39, pp. 153-185.

Clark, T. E. (1995). Rents and prices of housing across areas of the United States: A cross-section examination of the present value model. *Regional Science and Urban Economics* 25, pp. 237-247.

Cook, S. (2003). The convergence of regional house prices in the UK. *Urban Studies* 40, pp. 2285-2294.

Costello, G., P. Fraser, and N. Groenewold. (2011). House prices, non-fundamental components and interstate spillovers: The Australian experience. *Journal of Banking and Finance* 35, pp. 653-669.

Crowe, C., G. Dell'Ariccia, D. Igan, and P. Rabanal. (2013). How to deal with real estate booms: Lessons from country experiences. *Journal of Financial Stability* 9, pp. 300-319.

Diba, B. T. and H. I. Grossman. (1987). On the inception of rational bubbles. *Quarterly Journal of Economics* 87, pp. 697-700.

Diba, B. T. and H. I. Grossman. (1988). Explosive rational bubbles in stock prices? *American Economic Review* 78, pp. 520-530.

Diebold, F. X. and K. Yilmaz. (2009). Measuring financial asset return and volatility spillovers, with application to global equity markets. *Economic Journal* 119, pp. 158-171.

Diebold, F. X. and K. Yilmaz. (2012). Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of Forecasting* 28, pp. 57-66.

Diebold, F. X. and K. Yilmaz. (2014). On the network topology of variance decompositions: Measuring the connectedness of financial firms. *Journal of Econometrics* 182, pp. 119-134.

Duca, J. V., L. Popoyan, and S. M. Wachter. (2019). Real estate and the Great Crisis: Lessons for macroprudential policy. *Contemporary Economic Policy* 37, pp. 121-137.

Eisenberg, D. (2003). Evaluating the effectiveness of policies related to drunk driving. *Journal of Policy Analysis and Management* 22, pp. 249-274.

Engsted, T., S. J. Hviid, and T. Q. Pedersen. (2016). Explosive bubbles in house prices? Evidence from the OECD countries. *Journal of International Financial Markets, Institutions and Money 40*, pp. 14-25.

Etienne, X. L., S. H. Irwin, and P. Garcia. (2014). Bubbles in food commodity markets: Four decades of evidence. *Journal of International Money and Finance* 42, pp. 129-155.

Evans, G. W. (1991). Pitfalls in testing for explosive bubbles in asset prices. *American Economic Review* 81, pp. 922-930.

Forbes, K. (2019). Macroprudential policy: What we've learned, don't know and need to do. *AEA Papers and Proceedings* 109, pp.470-475.

Forbes, K., M. Fratzscher, T. Kostka, and R. Straub. (2016). Bubble thy neighbour: Portfolio effects and externalities from capital control. *Journal of International Economics* 99, pp. 85-104.

Forbes, K., D. Reinhardt, and T. Wieladek. (2017). The spillovers, interactions and (un)intended consequences of monetary and regulatory policies. *Journal of Monetary Economics* 85, pp. 1-22.

Galati, G. and R. Moessner. (2013). Macroprudential policy: A literature review. *Journal of Economic Surveys* 27, pp. 846-878.

Galati, G. and R. Moessner. (2018). What do we know about the effects of macroprudential policy? *Economica* 85, pp. 735-770.

Gallin, J. (2006). The long-run relationship between house prices and income: Evidence from local housing markets. *Real Estate Economics* 34, pp. 417-438.

Gallin, J. (2008). The long-run relationship between house prices and rents. *Real Estate Economics* 36, pp. 635-658.

Geanakoplos, J., R. Axtell, J. D. Farmer, P. Howitt, B. Conlee, J. Goldstein, M. Hendry, N. M. Palmer, and C. Yang. (2012). Getting at systemic risk via an agent-based model of the housing market. *American Economic Review* 102, pp. 53-58.

Gelain, P., K. Lansing, and G. J. Natvik. (2018). Explaining the boom-bust cycle in the U.S. housing market: A reverse-engineering approach. *Journal of Money, Credit and Banking* 50, pp. 1751-1783.

Gong, Y., J. Hu, and P. J. Boelhouwer. (2016). Spatial interrelations of Chinese housing markets: Spatial causality, convergence and diffusion. *Regional Science and*

Urban Economics 59, pp. 103-117.

Hurn, S., S. Shi, and B. Wang. (2022). Housing networks and driving forces. *Journal of Banking and Finance*, 134, 106318.

Jimenez, G., S. Ongena, J. Peydro, and J. Saurina. (2017). Macroprudential policy, countercyclical bank capital buffers and credit supply: Evidence from the Spanish dynamic providing experiment. *Journal of Political Economy* 125, pp. 2126-2177.

Jorda, O, M. Schularick, and A. M. Taylor. (2015). Betting the house. *Journal of International Economics* 96, pp. S2-S18.

Jung, H. and J. Lee. (2017). The effects of macroprudential policies on house prices: Evidence from an event study using Korean real transaction data. *Journal of Financial Stability* 31, pp. 167-185.

Kivedal, B. K. (2013). Testing for rational bubbles in the US housing market. *Journal of Macroeconomics* 38, pp. 369-381.

Klingelhofer J. and R. Sun. (2019). Macroprudential policy, central banks and financial stability: Evidence from China. *Journal of International Money and Finance* 93, pp. 19-41.

Kraussl, R., T. Lehnert, and N. Martelin. (2016). Is there a bubble in the art market? *Journal of Empirical Finance* 35, pp.99-109.

Kuttner, K. and I. Shim. (2016). Can non-interest rate policies stabilize housing markets? Evidence from a panel of 57 economies. *Journal of Financial Stability* 26, pp. 31-44.

Laufer, S. and Tzur-Ilan, N. (2021). The effect of LTV-based risk weights on house prices: Evidence from an Israeli macroprudential policy. *Journal of Urban Economics* 124, 103349.

Lee, C., C. Lee, and S. Chiang. (2016). Ripple effect and regional house prices dynamics in China. *International Journal of Strategic Property Management* 20, pp. 397-408.

Lee, C. and M. Chien. (2011). Empirical modeling of regional house prices and the ripple effect. *Urban Studies* 48, pp. 2029-2047.

Lim, C., F. Columba, F. Columba, A. Costa, P. Kongsamut, A. Otani, M. Saiyid, T. Wezel, and X. Wu. (2011). Macroprudential policy: What instruments and how to use them? Lessons from country experiences. IMF Working Paper WP/11/238.

Liu, C., Z. Luo, L. Ma, and D. Picken. (2008). Identifying house price diffusion patterns among Australian state capital cities. *International Journal of Strategic Property Management* 12, pp. 237-250.

Martin, C., N., Schmitt and F. Westerhoff (2020). Housing markets, expectation formation and interest rates. *Macroeconomic Dynamics*, forthcoming.

McCann, F. and C. O'Toole (2019). Cross-border macroprudential policy spillovers and bank risk-taking. *International Journal of Central Banking* 15, pp.267-311.

Meen, G. (1999). Regional house prices and the ripple effects: A new interpretation. *Housing Studies* 14, pp.733-753.

Meuleman, E. and R. V. Vennet (2020). Macroprudential policy and bank systemic risk. *Journal of Financial Stability* 47, pp. 100724.

Mikhed, V. and P. Zemcik. (2009). Do house prices reflect fundamentals? Aggregate and panel data evidence. *Journal of Housing Economics* 18, pp. 140-149.

Morgan, P. J., P. J. Regis, and N. Salike. (2019). LTV policy as a macroprudential tool and its effects on residential mortgage loans. *Journal of Financial Intermediation* 37, pp. 89-103.

Pavlidis, E., A. Yusupova, I. Paya, D. Peel, E. Martinez-Garcia, A. Mack, and V. Grossman. (2016). Episodes of exuberance in housing markets: In search of the smoking gun. *Journal of Real Estate Finance and Economics* 53, pp. 419-449.

Phillips, P. C. B., Y. Wu, and J. Yu. (2011). Explosive behavior in the 1990s Nasdaq:

When did exuberance escalate asset values: *International Economic Review* 52, pp. 201-226.

Phillips, P. C. B., S. Shi, and J. Yu. (2015). Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *International Economic Review* 56, pp. 1043-1078.

Plazzi, A., W. Torous, and R. Valkanov. (2010). Expected returns and expected growth in rents of commercial real estate. *Review of Financial Studies* 23, pp. 3469-3519.

Reinhart, C. M. and K. S. Rogoff (2008). Is the 2007 US sub-prime financial crisis so different? An international historical comparison. *American Economic Review* 98, pp. 339-344.

Richter, B., M. Schularick, and I. Shim. (2019). The costs of macroprudential policy. *Journal of International Economics* 118, pp. 263-282.

Rubio, M. (2020). Cross-country spillovers from macroprudential regulation: Reciprocity and leakage. *Journal of International Money and Finance* 103, 102134.

Shi, S., S. Hurn, and P. C. B. Phillips. (2020a). Causal change detection in possible integrated systems: Revisiting the money-income relationship. *Journal of Financial Econometrics* 18, pp. 158-180.

Shi, S., J. Jou, and D. Tripe. (2014). Can interest rates really control house prices? Effectiveness and implications for macroprudential policy. *Journal of Banking and Finance* 47, pp. 15-28.

Shi, S. and P. C. B. Phillips. (2023). Diagnosing housing fever with an econometric thermometer. *Journal of Economic Surveys* 37, pp. 159-186.

Shi, S., A. Rahman, and B. Wang. (2020b). Australian housing market booms: Fundamentals or speculation? *Economic Record* 96, pp. 381-401.

Stevenson, S. (2004). House price diffusion and inter-regional and cross-border house price dynamics. *Journal of Property Research* 21, pp. 301-320.

Teng, H., C. Chang, and M. Chen. (2017). Housing bubble contagion from city centre to suburbs. *Urban Studies* 54, pp. 1463-1481.

Tillman, P. (2015). Estimating the effects of macroprudential policy shocks: A qual VAR approach. *Economic Letters* 135, pp. 1-4.

Tsai, I. (2015). Spillovers effect between the regional and the national housing markets in the UK. *Regional Studies* 49, pp. 1957-1976.

Tsai, I. and S. Chiang. (2019). Exuberance and spillovers in housing markets: Evidence from first- and second-tier cities in China. *Regional Science and Urban Economics* 77, pp. 75-86.

Vandenbussche, J., U. Vogel, and E. Detragiache. (2015). Macroprudential policies and housing prices: A new database and empirical evidence for central, eastern and southeastern Europe. *Journal of Money, Credit and Banking* 47, pp. 343-377.

Wachter, S. (2015). The housing and credit bubbles in the United States and Europe: A comparison. *Journal of Money, Credit and Banking* 47, pp. 37-42.

Yunus, N. and P. E. Swanson. (2013). A closer look at the U.S. housing market: Modeling relationships among regions. *Real Estate Economics* 41, pp. 542-568.

Zhang, D. and G. Fan. (2019). Regional spillovers and rising connectedness in China's urban housing prices. *Regional Studies* 53, pp. 861-873.

Zhang, L. and E. Zoli. (2016). Leaning against the wind: Macroprudential policy in Asia. *Journal of Asian Economics* 42, pp. 33-52.

Zheng, S., H. Li, and H. Sun. (2023). Crisis lifecycle, policy response and policy effectiveness. *Public Management Review* 25, pp. 286-312.

Zhou, X. (2012). Volatility spillovers between the Chinese and world equity markets. *Pacific-Basin Finance Journal* 20, pp. 247-270.

Table 1: Content of the macroprudential policies within the Taipei MSA

LTV policies	Regulated areas	LTV limits (time)
Start: moral suasion		October 2009
First wave	Taipei city and 10 districts of New Taipei city	70% (June 2010)
Second wave	Taipei city and 13 districts of New Taipei city	60% (December 2010)
Third wave	Taipei city and 17 districts of New Taipei city	60% (March 2014)
End		March 2016

Note: The third wave was actually expanded to an outer area, namely, four districts of Taoyuan county.

Table 2: Difference-in-differences regressions

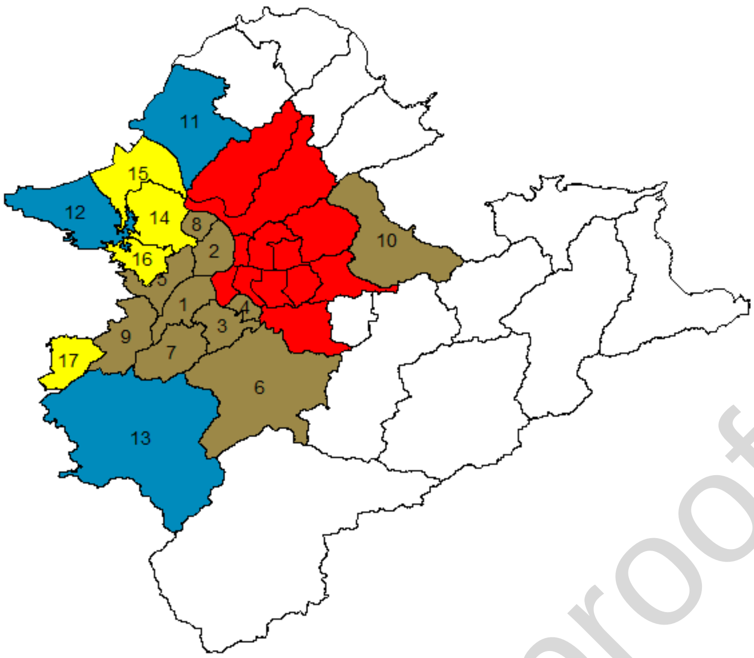
	DHP	DHP
Constant	0.570**	6.743**
	(0.205)	(2.254)
MP	1.703**	1.694**
	(0.232)	(0.265)
$TIME$	0.905*	−0.886
	(0.412)	(0.922)
$MP \times TIME$	−1.787**	−1.779**
	(0.534)	(0.561)
$GROWTH$		0.056
		(0.069)
$INFLATION$		0.229
		(0.148)
IR		−2.573**
		(0.747)

Notes: The numbers in parentheses are standard errors. The symbols ** and * denote significance at the 1% and 5% level, respectively.

Table 3: Total spillovers during 1991-2017

Unit: %

	Taipei City	New Taipei City	Taichung City	Kaohsiung City	Contribution **from** others
Taipei City	65.37	26.99	7.57	0.07	34.60
New Taipei City	27.94	59.96	11.10	1.00	40.00
Taichung City	13.94	14.73	69.61	1.72	30.40
Kaohsiung City	5.59	9.29	6.23	78.89	21.20
Contribution **to** others	47.50	51.00	24.90	2.80	126.20
Contribution including own	112.80	111.00	94.50	81.70	31.50



Note: The red region is Taipei city with 12 districts. The brown and red regions are the regulated regions during the first wave of the LTV policy. The second and third waves additionally include the blue and yellow regions, respectively.

Figure 1: The Taipei MSA and its regulated locations

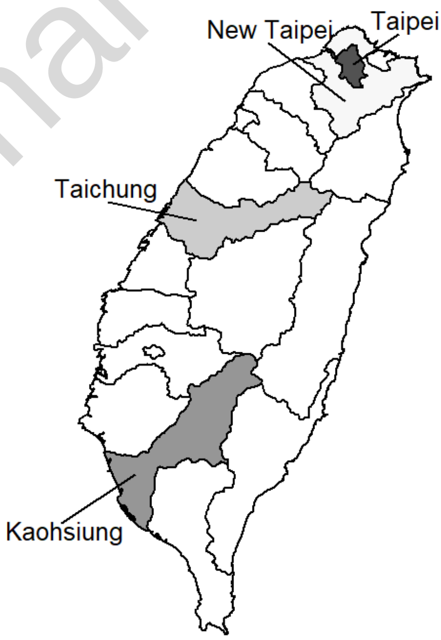
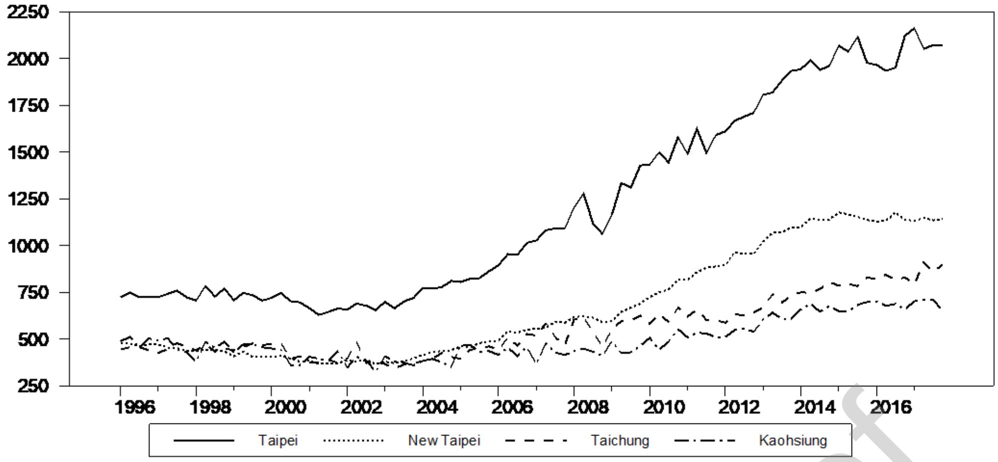


Figure 2: Locations of four cities in Taiwan



Note: Data are collected from SRED company and the unit is ten thousand NT dollars.

Figure 3: Housing prices in four cities in Taiwan (1996-2017)

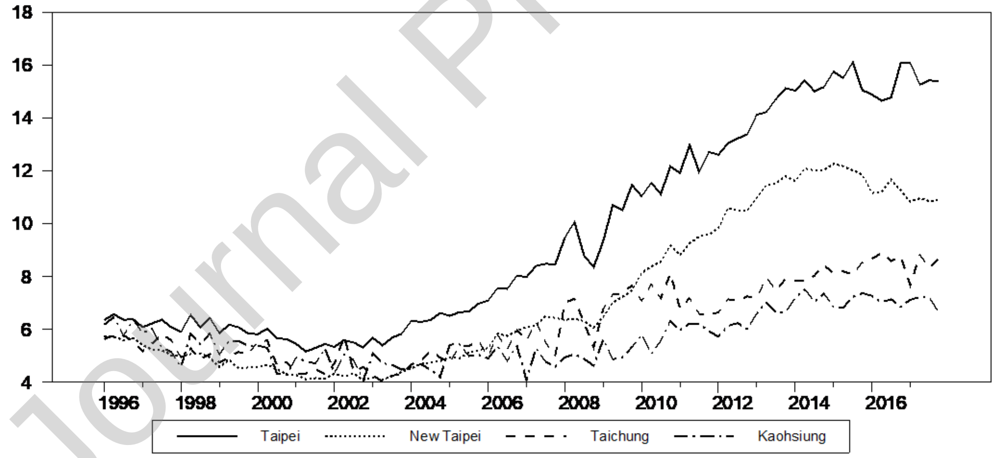


Figure 4: Housing price to income (P/I) ratio

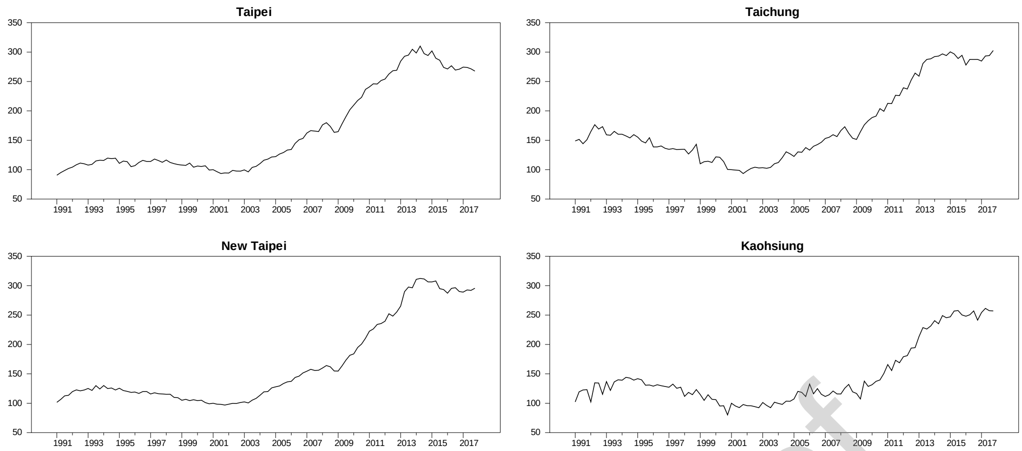
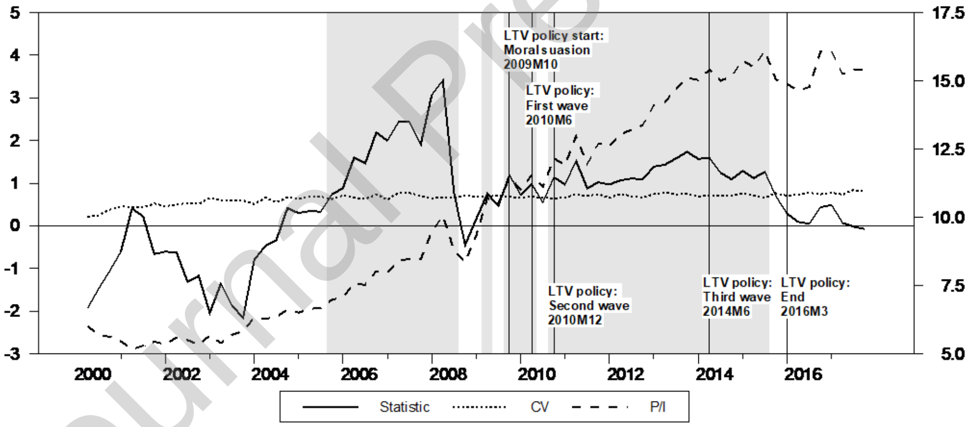
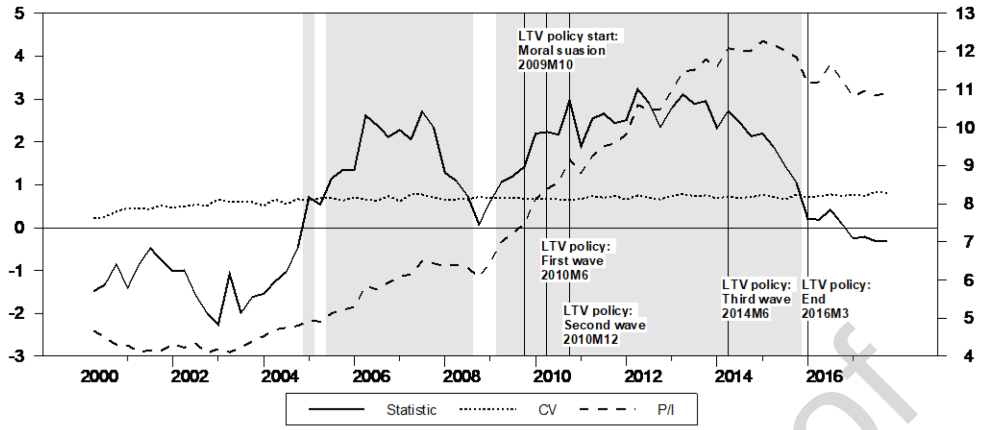


Figure 5: Housing price indices in four cities (1991-2017)



Note: The values of the GSADF test are measured on the left axis based on backwards SADF statistics. The (P/I) ratio is measured on the right axis. Critical values (CV) are based on 95% critical values of the GSADF test according to 2,000 simulations.

Figure 6: Detecting bubbles and their duration (shaded): Taipei City



Note: Please refer to Figure 6.

Figure 7: Detecting bubbles and their duration (shaded): New Taipei City

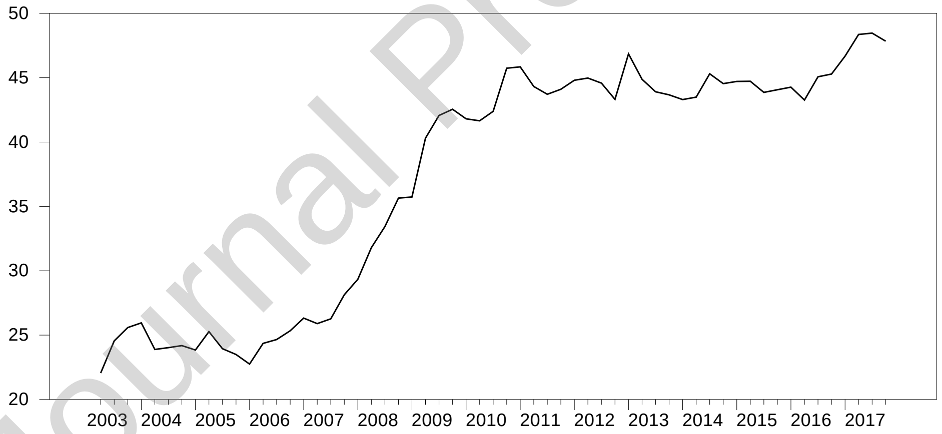
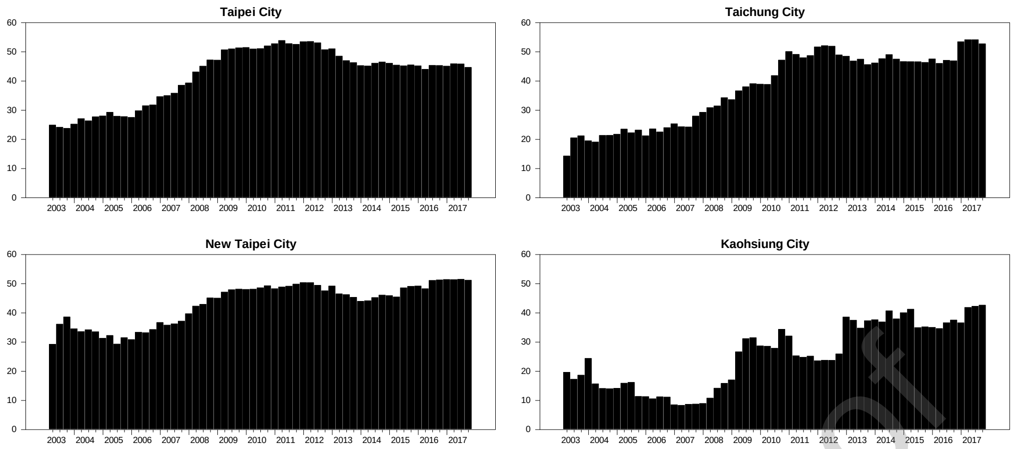


Figure 8: Total spillover effects

(a) Spillovers from other cities



(b) Spillovers to other cities

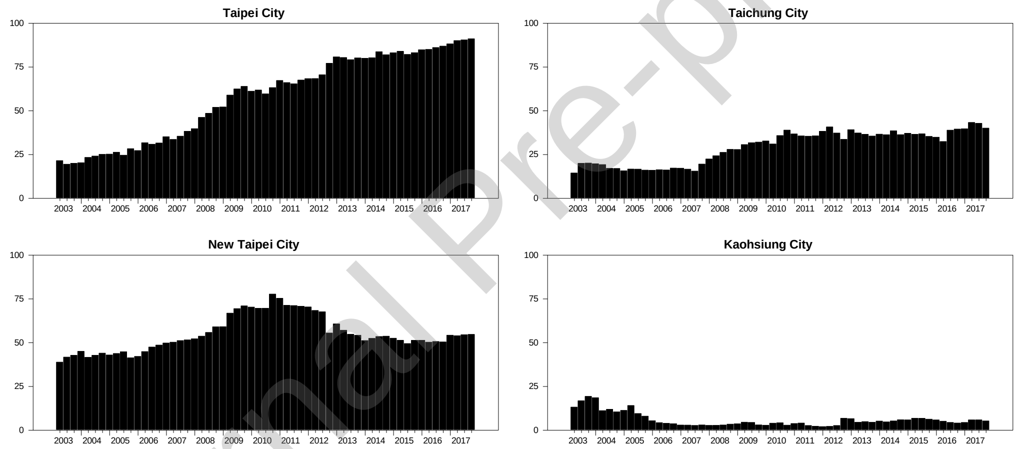


Figure 9: Directional spillovers

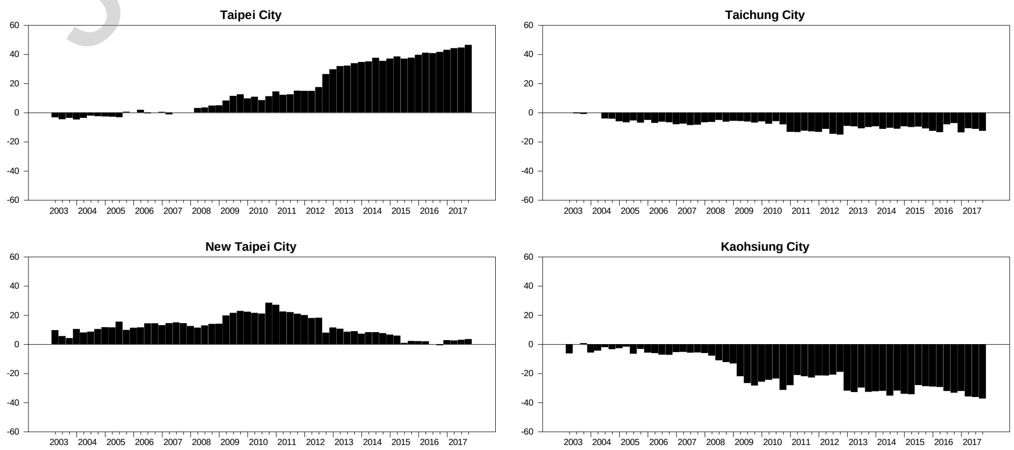


Figure 10: Net spillovers

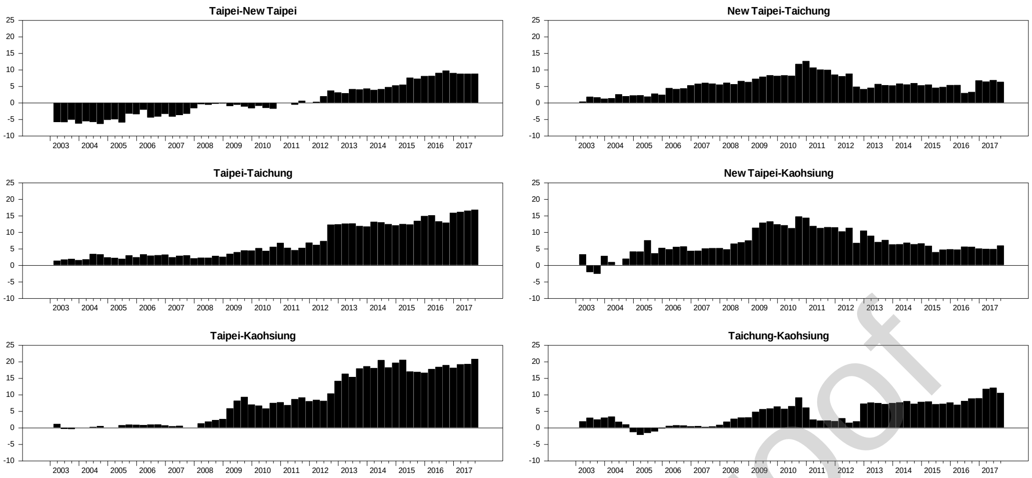


Figure 11: Net pairwise spillovers

Conflict of Intrest

The authors confirm that there are no conflicts of interest associated with this manuscript and there has been no financial support for this work that could have influenced its outcome.

Declaration of Competing Interest

The authors confirm that there was no funding received for this work and all authors contributed significantly to this manuscript.