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ORIGINAL ARTICLE

Connected markets through global real estate investments

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Abstract

This study focuses on the possibility of higher risk in commercial real estate markets due to the "linked ownership" network, which is measured by the common holdings of properties in different urban real estate markets by the same investor. Using data from 2007 to 2016, our results show that commonality in ownership can explain the significant comovement in international office market performance and add additional information to other matrices constructed by geographic distance, mergers and acquisitions capital flow, currency unit, and even overlapping occupiers located in those cities. The transmission mechanism is most pronounced and persistent during the global financial crisis period.

1 | INTRODUCTION

With financial globalization, international real estate investment has boomed. Private, institutional, and listed real estate investors, such as occupational pension funds, insurance companies, and sovereign wealth funds, increasingly hold global real estate portfolios by acquiring private real estate directly or through fund structures in multiple countries (Andonov, Eichholtz, & Kok, 2015; Andonov, Kok, & Eichholtz, 2013). For example, in 2015, over 10% of properties and over 30% of REITs held by CalPERS were international assets and over 50% of the properties held by TIAA Real Estate were located outside the United States. Other large funds, such as CalSTRS and Blackstone, also held a significant proportion of their portfolios in global real estate. There has emerged a significant body of

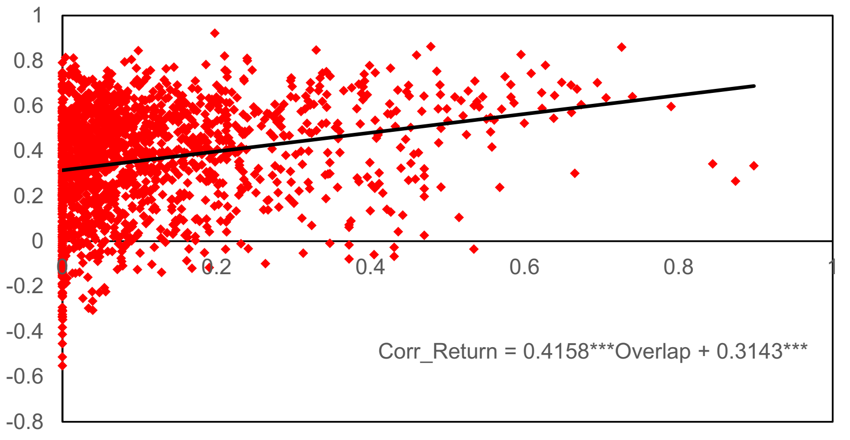

FIGURE 1 Linked ownership and office market comovement [Color figure can be viewed at wileyonlinelibrary.com]
Note. Linked ownership is defined as the share of offices purchased by investors who also invest in properties in the other cities (see Section 3). The bilateral office market comovement is the correlation coefficient of the office total return between each pair of cities. Data used for 58 cities (see Section 4). The slope of the fitted line is significant at the 1% level.

the literature discussing the costs and benefits of investing internationally (Falkenback, 2009; Lizieri, 2009; Lizieri & Pain, 2014; Lizieri, Reinert, & Baum, 2011; Newell, Adair, & Mcgreal, 2010; Worzala & Sirmans, 2003).

This paper focuses on one specific network associated with global investment strategies—the network based on "linked ownership" of properties. On the one hand, internationally diversified real estate investment strategies have become increasingly popular: Based on an MSCI survey, in 2013, 21% of US private commercial real estate investments were foreign investments (Aussant, Hobbs, Liu, & Shepard, 2014). In the City of London, foreign ownership rose from around 4% in the mid-1980s to 45% at 2006 to over 65% by 2014 (Lizieri & Kutsch, 2006; Lizieri & Mekic, 2018). The globalization of ownership means that professional investors based in one city typically have exposure to real estate assets in other cities. On the other hand, those investments are dramatically concentrated in a small number of major cities and markets: Real Capital Analytics Inc. (RCA) data show that 67% of the value of major global office transactions 2007–2014 occurred in just 20 cities (Lizieri & Mekic, 2018). Innovations in real estate investment make it easier to acquire a global real estate portfolio, with capital from a range of investors pooled to acquire prime real estate assets. As a result, the real estate in different cities and countries can be owned by the same investor or fund manager, forming a "linked ownership" network. This "linked ownership" network reflects the flow of international capital and creates invisible connections between cities: shocks between markets can be transmitted via those global real estate investments. This might be because real estate portfolio holders in the market where the crisis initiates may undertake actions to liquidate their investments in other markets; face collateral write-downs, forcing down asset prices; or have issues refinancing or raising debt capital. Figure 1 is revealing in this regard: it plots the relationship between overlapping ownership and comovements in international office markets for each pair in our sample of 58 cities. Linked ownership is defined as the share of offices in one city owned by investors who also have investments in the other city.[1] The figure reveals

[1]Detailed definition is in Section 3.1.

TABLE 1 Factors driving office market comovement

	C.	Linked ownership	Country	Contin.	Dist.	Corr_IR	Corr_Exch.	MA	GFCI
Coef.	0.132	0.184***	0.162***	−0.01	0.057	0.095***	0.027**	0.094	0.010**
Std. error	(0.151)	(0.052)	(0.029)	(0.027)	(0.067)	(0.023)	(0.014)	(0.093)	(0.005)

Note. This table reports factors associated with office market comovement. The dependent variable is the bilateral office market comovement: the correlation coefficient of the office total return between each pair of cities. Data used for 58 cities (see Section 4). The dependent variable is the correlation of returns between pairs of cities. Independent variables include linked ownership, which is defined as the share of offices purchased by investors who also invest in properties in the other cities (see Section 3); a dummy for whether the two cities are in the same country (Country) and continent (Contin.), the distance of the two cities (Dist.), the correlation coefficient of interest rate of each pair of the county of the cities (Corr_IR), the correlation coefficient of exchange rate of each pair of the county of the cities (Corr_IR), the competitiveness of the city (GFCI), measured by the global financial center ranking, the marge and acquisition flow between each pair of cities (MA). We report the standard error in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

that the higher the linked ownership between two cities, the higher the comovement of their office market performance. A 1% increase in linked ownership is related to a .41% increase in the correlation coefficient, in which the slope is significant at 1% level.

Although real estate markets, especially direct real estate investment markets, are generally more local and heterogeneous (Eichholtz, 1996; McAllister, 1999), comovement may still occur across international real estate markets, both in private and public markets. Previous literature documented a variety of drivers, such as economic and financial integration (Bardhan, Edelstein, & Tsang, 2008; Eichholtz, Gugler, & Kok, 2011; Milcheva & Zhu, 2016; Milcheva & Zhu, 2017), country and continental factors (Eichholtz & Huisman, 2001; Eichholtz, Huisman, Koedijk, & Schuin, 1998), as well as economic factors such as currency risks (Liu & Mei, 1998; Ziobrowski, Ziobrowski, & Rosenberg, 1997) and interest rate risks (Eichholtz & Huisman, 2001; Quan & Titman, 1999). To test whether linked ownership can add additional information to all these documented factors, we regress the correlation coefficient of office market returns of each pair of cities on the linked ownership as well as other variables, including whether the two cities are in the same country and continent, the distance between the two cities, the correlation coefficient of interest rate movements of each pair of cities (countries), the correlation coefficient of exchange rate of each pair of cities (countries), the competitiveness of the city, measured by the global financial center ranking, and the merger and acquisition flow between each pair of cities.[2] As shown in Table 1, the linked ownership variable remains significant, confirming that the linked ownership channel should not be ignored when investors try to understand potential comovement across international real estate markets.

Therefore, in this paper, we attempt to provide detailed analyses on the relationship between this "linked ownership" network and the performance of commercial office markets of 58 global cities. Based on a dynamic spatial panel model, we find a significant comovement in office market performance captured by linked ownership between cities, while controlling for the different levels of rental growth, income growth, market transparency, and economic structure. The commonality in ownership can add additional information in capturing the office market comovement to other matrices constructed by geographic distance, similarity in openness, legal system, currency unit, cross-city merger and acquisition flows, and even overlap in occupation—for example, accounting for the proportion of global firms located in many of the cities. Our findings can provide empirical evidence on the "dark

[2]We use the M&A flow between each pair of cities to measure the economic and finance openness. Most previous literature uses the ratio of exports plus imports to the GDP and the ratio of FDI to the GDP as the measure of openness. However, it is difficult to collect the data regarding the trade and FDI flow at the city level, and we use the merger and acquisition flow as a proxy.

side" of diversification. It is well known that diversification can reduce the risks of individual portfolios. For instance, Eichholtz (1996) shows that international diversification reduces the risk of a real estate portfolio more than that of common stock and bond portfolios. However, after the financial crisis, more concerns arise on the positive relationship between diversification and the systemic risk: the reduction of the risks at the individual level may be at the cost of more risk sharing between entities due to similar portfolio positions. Diversification can result in more overlap among the portfolio of investors, thereby transferring risks among institutions and facilitating spillover effects. As Slijkerman et al. (2013) state: "diversification lowers the risk of isolated shocks for a financial entity, but may simultaneously increase the systemic risk." Füss and Ruf (2017) also show that, via the location of headquarter and branches, the expected capital shortfall of financial institutions can explain the return comovements among financial center office markets. Their results highlight that diversification through seemingly uncorrelated assets may fail due to the correlated risks. Our results focus on the similarity in the asset portfolio, which is reflected by the linked ownership network. We find that the overlapping the asset portfolio is positively related to comovement across international office markets. Consistent with the finding with Füss and Ruf (2017), our results also confirm that investors should be aware that, due to similar geographic diversification strategies, the benefits of diversification may actually be reduced, especially during crisis periods, when it is needed most.

Further, our paper studies the comovement in office performance across 58 cities. Most research on real estate market comovement is focused on public listed real estate markets and/or at the aggregate national level. D'Arcy and Lee (1998) show that in addition to country-type diversification, city-level diversification can also benefit investors. However, there has been limited work at city level examining concentration of flows, correlation, and performance, but that has largely been confined to office markets and focused on a few global financial centers (see, e.g., Jackson et al., 2008; Lizieri & Pain, 2014), which, as global investors seek new markets and sectors, needs to be extended. Our study shows that the comovement of office market returns may extend beyond country and/or continent and also beyond the class of cities (primary or secondary city). For instance, based on our impulse response results, when the London office market experiences a shock, Dublin and Madrid respond more strongly than other British cities; some North American and Asian cities, such as New York, Washington, Hong Kong, or Shanghai, have larger reactions than some European cities, such as Vienna, Prague, and Berlin. Linked to the extent of coownership, global financial centers are still the most influential cities. The 10 most influential cities include London, Paris, New York, San Francisco, Los Angeles, Washington DC, Tokyo, Boston, Seattle, and Seoul. A one-standard-deviation negative office price shock in London, for example, generates a significant change in the remaining 57 cities with an average drop of 0.65 percentage point one quarter after the shock. Thus, the influence of a major city can spread more widely, not only to domestic secondary cities but also to foreign secondary cities. Therefore, country-level diversification and primary–secondary city diversification may not be sufficient.

The rest of the paper is presented as follows: Section 2 provides a discussion of theoretical underpinnings and a review of related research on this topic; Section 3 describes our data; Section 4 lays out the empirical strategy; the results are discussed in Section 5 followed by our concluding remarks in Section 6.

2 | PREVIOUS LITERATURE

There are a number of theoretical and empirical grounds for investors to diversify their assets internationally. One important concept is that global property markets should not move in tandem, with spatially fixed real estate prices being largely driven by local factors. Thus, investing in a global portfolio, in theory, offers the ability to limit the impact of any property downturn in a specific country or region, improving ex ante risk-adjusted returns. Some literature shows that an internationally diversified portfolio enables investors to achieve higher expected returns at lower risk (D'Arcy & Lee, 1998; Del Casino, 1986; Sweeney, 1989; Thomas & Lee, 2006). However, the benefits of diversification can be offset by higher risks, including currency risk (Newell & Webb, 1996; Thomas & Lee, 2006; Worzala, 1994; Ziobrowski et al., 1997), taxation risk (Newell & Worzala, 1995), barriers to international property investment (Lizieri & Finlay, 1995), political risks and transparency (Eichholtz et al., 2011), and other costs (McAllister, 1999).

Overall, most of the previous literature finds that international real estate investment provides diversification benefits, despite the aforementioned costs (Sirmans & Worzala, 2003).[3] For instance, using listed real estate equity return as the proxy for commercial real estate performance, Eichholtz et al. (1998) find continental factors in Europe and in North America, but no dominant continental factor in the Asia-Pacific region. The authors therefore suggest cross-continent diversification for European and American real estate investors. Considerable literature documents the costs and benefits of the country-level diversification. For example, using ICAP property data in 22 real estate markets in 21 countries from 1987 to 1997, Case et al. (2000) confirm a relatively low correlation coefficient in the property return, ranging from .33 to .44 for all property types. The authors also find that cross-border correlations are partially due to a common exposure to fluctuations in the global economy. Eichholtz et al. (2011) find that international property companies underperform local property companies from 1996 to 2001, which is attributable to the political environment, the level of economic integration, and the transparency of the real estate market in target countries. But since 2001, the underperformance disappeared.

City-level diversification is less studied. Arnold and Kavanaugh (1988) investigate the JLW property index in London, Paris, and Sydney with US NCREIF index from 1978 to 1987. The authors find that US real estate is positively correlated with returns in Sydney and Paris, but negatively correlated with investments in the City of London. The difference in individual real estate markets provides substantial diversification benefits in a portfolio context. D'Arcy and Lee (1998) investigate three types of diversification strategies: country, property-type, and city-type diversification and define city-type diversification into two categories, a major financial center in a country and a secondary city in the country. They show that in addition to across country diversification, city type also provides diversification benefits.

Although abundant literature investigates the level of comovement across regional real estate markets, the underlying channel of comovement has not been completely understood, especially at the city level. Several channels have been documented in the literature, including global and continental factors (Eichholtz, 1996; Ling & Naranjo, 2002), financial market integration (Bardhan et al., 2008; Eichholtz et al., 2011), the convergence and integration in (European) real estate markets (Case et al., 2000; Lizieri, Mcallister, & Ward, 2003), interconnectedness across market via factors that include migration (Holly, Pesaran, & Yamagata, 2011), cross-border investing and capital flows (Milcheva & Zhu, 2017; Milcheva & Zhu, 2016; Zhu & Milcheva, 2016). However, nearly all these studies are conducted at the national level. This paper attempts to study the sources of comovement in the real estate market at the city level.

[3]More evidences regarding the diversification benefits/costs are found in securitized real estate. For example, Eichholtz (1996), Conover, Friday, and Sirmans (2002), Liu and Mei (1998), and many others show that an internationally diversified portfolio of real estate securities enables investors to achieve higher expected returns at lower risk. However, Liu, Hartzell, and Hoesli (1997) and Stevenson (2000) find no significant gains from extending an REIT portfolio into international markets.

Lizieri utilizes the concept of a "world city network" in his book "Towers of Capital" (Lizieri, 2009; Lizieri & Pain, 2014). Spatial clustering of global financial business occurs in a small number of major cities—the international financial centers (IFCs), acting as coordinating centers for an interlinked system of international financial flows (Firedmann, 1986; Lizieri & Pain, 2014). In these world cities, there exists an interlocking of occupation, ownership, and finance: firms that occupy space are often the same firms that acquire offices as investment assets and that provide finance for the creation of new office space. Shocks in international financial markets are transmitted to occupier, investment, and debt markets and can reinforce any tendency toward cyclical behavior.[4] This potential volatility can further be transmitted internationally via the globalization of real estate ownership. Globalization of financial activity has led to increasing functional specialization in IFCs, with many domestic-focused firms squeezed out of the occupier market by international financial and linked business and professional services firms who together articulate global transactions and flows of finance.

Using city-level office market performance data, pioneering work by Füss and Ruf (2017) focuses on the network created by the financial integration. They find that the comovement of office market performance can be explained by the commonality of banks that locates in those cities, weighted by the systemic capital shortfalls for those banks. This paper proposes a different channel to theirs, that is, the network built upon linked investment ownership of assets across markets.

3 | METHODOLOGY

3.1 | The "linked ownership" network

We define linked ownership as where a single real estate owner or fund manager owns real estate in two cities. The greater the extent of coownership in a pair of cities, the more they are "linked by ownership." Such a linked ownership network reflects the flow of capital, and could potentially affect real estate market performance within and across markets. For example, if a real estate investor suffers losses in value in one city, this may lead to forced sales of their assets in another city, or lead to analysts marking down asset values in those cities due to concerns about asset quality or the validity of appraisals.[5] If that investor is leveraged at portfolio level, then the damage to collateral and loan to value ratios may lead to adverse action by lenders or asset liquidation, creating market and funding liquidity spiral effects of the type identified by Brunnermeier and Pedersen (2009). With a greater degree of ownership interconnectedness between cities, there is a greater risk of spillover effects.

The concept of ownership is not without definitional problems. As Lizieri and Mekic (2018) note, real estate ownership is a complex concept: many smaller professional investors use fund structures for their international (and even domestic) commercial real estate investment strategies. RCA data will typically record the fund manager or general partner as the buyer or seller (although joint venture acquisitions may be recorded separately). It could be argued that if one such fund gets into difficulty, it is the end investors who suffer rather than the fund manager: and that other funds may be unaffected and not suffer sales pressure. It seems to us, however, that there are still likely to be spillover effects, for example, on the ability to refinance or raise new debt and equity and on external valuations of

[4]IFCs satisfy Grenadier (1996) criteria for the existence of deep property cycles: an undiversified employment structure, long lags between starts and completions in development, and barriers to entry for developers due to scale of investment required.

[5]This has resonances in the arguments of Kaminsky et al. (2003) on financial contagion across markets.

fund value and performance benchmarking.[6] Joint ownership of properties, for example, through limited partnerships, causes further issues, not least as shares of ownership and responsibilities are not always transparent. These are important nuances, but the general principle should still apply.[7] Cross-market impacts will be influenced by what Lizieri and Mekic describe as "effective control": the role of the promoter, fund manager or general partner, assembling equity and debt capital—which is what will be recorded on RCA. Direct purchasers, whether they be institutional investors, sovereign wealth funds, High Net Worth Individuals (HNWI), or owner occupiers, will be individually identified, as is appropriate. As a robustness check, we excluded the 100 largest real estate funds and reconstructed the weight matrix. On average, 18% of transactions were made by these firms. The share reaches the highest level in 2015, amounting to 21.2%. We constructed a weight matrix by excluding transactions by the 100 real estate asset managers. The results are robust to this change (see Appendix 3).

Another concern is that RCA include transactions made by conventional firms not only for investment purpose, but also for use as headquarters or branch offices. Because our office return data are based on commercial properties for investment purposes, there could be a mismatch in the two types of dataset. We checked those office transactions made by Fortune 500 firms in our sample (excluding CBRE and JLL). The average share of transactions by value is only 3.89%. In 2007, the share was 5.84%, but dropped to only 0.67% in 2009. In 2015, the share rose to 5.06%. The weight matrix remains robust after we exclude transactions purchased by Fortune 500 companies (Appendix 3).

We use the following rules to identify the "linked ownership" network between city i and j. In general, the weight from city i to city j is defined as the proportion of the properties located in city i that are owned by investors with stakes in city j[8]:

$$w_{i,j,t} = \frac{1}{L_t} \sum_{h=1}^{L_t} q_{i.l,j,h,t}, \tag{1}$$

with $l = 1, 2, ..L_t$ and L_t is the total number of properties in city i. $j = 1, 2, ..H_t$ and H_t is the total number of properties in city j at period t. $w_{i,j,t}$ measures the dependence of city i on city j. In other words, it shows the potential influence of city j on city i. $q_{i.l,j,t}$ is a dummy variable with value of 1 if property l in city i and property h in city j owned by the same investors, and 0 otherwise:

$$q_{i.l,j,h,t} = \begin{cases} 1 & \text{if property l in city } i \text{ and property } h \text{ in city } j \text{ owned by the same investor} \\ 0 & \text{otherwise} \end{cases}, \tag{2}$$

A complete index would require a full ownership census for all the cities being assessed, which is not currently feasible. Instead, we examine patterns of linked ownership from a time series of transactions in a wide range of global markets as a proxy for overall ownership.

Let us assume that three properties locate in city A, A1, A2, and A3, and two properties are in city B, B1, and B2. Among the six pairs of properties, A1 is acquired by the same investors as property B1

[6]As an example, consider spillover effects across separate global funds offered by the same fund manager during the global financial crisis with debt and collateral write-downs in one fund triggered by problems in another, possibly with different investor base and market exposure.

[7]We are grateful for the helpful discussion with our RERI mentors on this point. We would note that the "fund manager" effect would reduce the likelihood of finding common patterns: if they were found, this would strengthen the result.

[8]We allow for turnover in portfolio holdings in our analysis, since the ownership linkage between cities is recalculated on a periodic basis. While private real estate holding periods tend to be relatively long, it is possible that finite life funds will enter a city and subsequently liquidate their holdings within our sample period.

and B2; therefore, there are two solid lines. So, $\sum_{l=1}^{L_t} q_{i.l,j,h,t} = 1$. As $L_t = 3$, $w_{i,j,t} = \frac{1}{L_t} \sum_{l=1}^{L_t} q_{i.l,j,h,t} = \frac{1}{3}$. One-third of the properties in city A are owned by investors with an interest in City B, and one-third is the strength of dependence of city A on B. In the same way, $\sum_{h=1}^{H_t} q_{j,h,i,l,t} = 2$. As $H_t = 2$, we have $w_{j,i,t} = \frac{1}{H_t} \sum_{h=1}^{H_t} q_{j,h,i,l,t} = 1$, which measures the dependence of city B on A. All the properties in city B are owned by an investor with an interest in city A. Thus, the measure is asymmetric between pairs of cities. In terms of cross-city transmission, a shock in city A is likely to have more of an impact in city B than a shock in city B is on city A (where two-thirds of the properties are held by investors with no stake in B).

3.2 | Determinants of the "linked ownership network"

We utilize a gravity model[9] to explain the overlap in ownership between cities (*i* and *j*), which takes the form:

$$w_{i,j} = G\frac{M_i^{\beta_1} M_j^{\beta_2}}{D_{i,j}^{\beta_3}}, \tag{3}$$

where $w_{i,j}$ is overlap ratio between city *i* and *j*. *G* is a constant and *M* is a vector of the economic mass of each city. We consider city-level GDP, unemployment rate, population yield and vacancy as well as national-level exchange rate, consumer price index (CPI), and interest rate. *D* is the distance between city *i* and *j*. We consider not only geographic distance, but also cultural affinity, legal system and currency unit, economic openness, as well as other economic and financial interconnectedness between cities, such as location of global firms and cross-city mergers and acquisitions. Equation (3) is solved by quasi-maximum likelihood (ML) estimation.

3.3 | The "linked ownership network" and the comovement of office markets

To quantify the relationship between ownership overlap and comovement in international office markets, we apply a spatial panel regression:[10]

$$y_{i,t} = \rho \sum_{j=1,j\neq i}^{N} w_{i,j,t} y_{j,t} + \varphi y_{i,t-1} + \sum_{k=1}^{K} \gamma_k X_{i,k,t} + \sum_{k=1}^{K} \zeta_k X_{i,k,t-1} + \delta Z_t + \alpha C_i + u_{i,t}, \tag{4}$$

where $y_{i,t}$ is the office total return in time *t* for the *i*th city. $w_{i,j,t}$ is the weight between cities *i* and *j* at period *t*. The definition of $w_{i,j,t}$ is described in Section 3.1. $\sum_{j=1,j\neq i}^{N} w_{i,j,t} y_{j,t}$ captures the weighted

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[9]As a reviewer suggested, as a complement to the gravity model, a spatial interaction model could model the overlap in the ownership while considering the spatial interaction between the two cities, such as capital flows. We leave this model for future research.

[10]We also use alternative models to measure the spatial dependence, including a Spatial Durbin model ($y_{i,t} = \rho \sum_{j=1,j\neq i}^{N} w_{i,j,t} y_{j,t} + \varphi y_{i,t-1} + \sum_{k=1}^{K} \gamma_k X_{i,k,t} + \sum_{k=1}^{K} \lambda_k \sum_{j=1,j\neq i}^{N} w_{i,j,t} X_{j,k,t} + \delta Z_t + \alpha C_i + u_{i,t}$), and a Spatial Lag model without lagged exogenous variables ($y_{i,t} = \rho \sum_{j=1,j\neq i}^{N} w_{i,j,t} y_{j,t} + \varphi y_{i,t-1} + \sum_{k=1}^{K} \gamma_k X_{i,k,t} + \delta Z_t + \alpha C_i + u_{i,t}$). The results in terms of impulse response and spatial dependence intensity are robust. Detailed results are in Appendix 3.

average office performance in neighboring cities. As $j \neq i$, the performance of the domestic market is excluded in $\sum_{j=1,j\neq i}^{N} w_{i,j,t}y_{j,t}$. $\sum_{j=1,j\neq i}^{N} w_{i,j,t}y_{j,t}$ is also called the spatial lag term. ρ is the spatial dependence coefficient. It captures the average impact of performance in foreign cities on the domestic market. $y_{i,t-1}$ is the lagged endogenous variable, and φ is the time-dependence coefficient. $X_{i,k,t}$ is for the kth control variable for city i at period t. We consider a set of city-specific variables, such as vacancy rate, GDP, population, unemployment rate, office transaction volume, and global financial status; and a set of country-specific variables, such as credit supply, interest rate, stock market performance, CPI change, account balance, as well as the ratio of trade to GDP and FDI to GDP ratio for economic and financial integration (Bardhan et al., 2008). To control for global comovement, we also include global variables, including oil price change and VIX change. C_i and Z_t stand for city and year dummies, respectively. δ and α are the corresponding coefficients.

Equation (4) can be represented in matrix form as:

$$Y_t = \rho W_t Y_t + \varphi Y_{t-1} + X_t \gamma + X_{t-1} \zeta + Z\delta + C\alpha + u_t, \tag{5}$$

where Y_t is a vector of office returns. W_t is the weight matrix, with zero diagonal elements and nonzero off-diagonal elements. X_t is a matrix of control variables. Assuming that the infinite sums are well defined, by continuous substitution, Equation (5) can be represented as:

$$y_t = \sum_{p=0}^{\infty} A_{t-p}^{p} V_{t-p} \left(X_t \gamma + X_{t-1} \zeta + Z_t \delta + \alpha C + u_t \right), \tag{6}$$

where $V_t = (I - \rho W_t)^{-1}$ and $A_t = \varphi V_t = \varphi (I - \rho W_t)^{-1}$. Since $(I - \rho W_t)^{-1} = I + \rho W_t + \rho^2 W_t^2 + \rho^3 W_t^3 + \cdots$, Equation (6) implies a spatial multiplier effect (Anselin, 2006; LeSage & Pace, 2009). Any unexpected shocks in one city will also affect the remaining cities through the spatial relationship among those cities. Not only do the first-order "neighbors," ρW_t, get affected (the direct spillover effect), but the "neighbor's neighbors" are also impacted through that spatial multiplier effect through $\rho^2 W_t^2$, $\rho^3 W_t^3$, etc. (the indirect spillover effect). In the end, the change can have a feedback effect on the city of origin of the shock (the feedback effect). In this way, the response spreads to immediate neighbors and higher orders of neighbors in (ownership) space.

The average impulse response in the next P periods after the shock over the observation period is calculated (following Pesaran & Shin, 1998) as:

$$\begin{bmatrix} \Psi_{1,1,P} \\ \vdots \\ \Psi_{1,1,P} \end{bmatrix} = \frac{1}{T} \sum_{t=1}^{T} \sum_{p=0}^{P} A_{t+p}^{P} V_{t+p} \Omega_e \begin{bmatrix} \sigma_1^{-1} \\ \vdots \\ 0 \end{bmatrix}, \tag{7}$$

where σ_1^{-1} is the standard deviation related to the error of the shock variable. $\Psi_{1,1,P}$ is the response of the office market in the jth city to the shock in the city 1. Since Ω_e is assumed to be a diagonal matrix—that is, the error terms are independent from each other—the cross-border transmission of a city-specific shock entirely occurs through the spatial structure of V. Based on Equation (7), the average spillover effect of a one-standard-deviation office market shock in the ith country in period P is:

$$\Psi_{i,P}^{imp} = \frac{1}{N-1} \sum_{j=1,j\neq i}^{N} \Psi_{i,j,P} \tag{8}$$

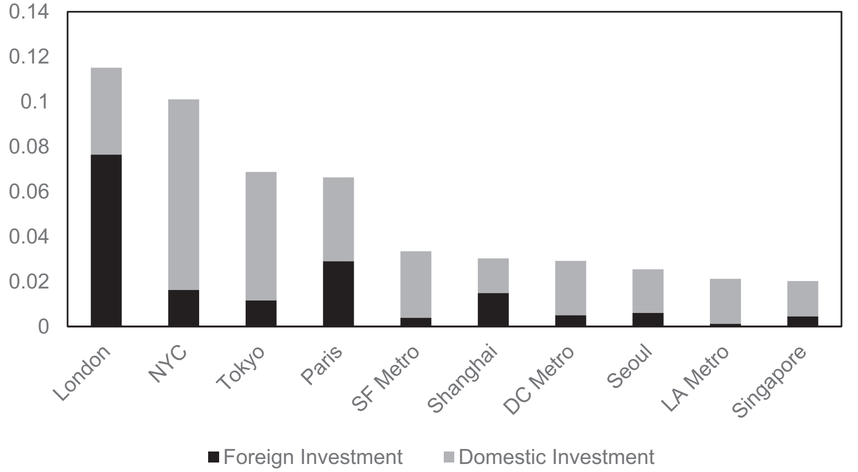


FIGURE 2 Share of transactions in value in ten largest office markets (mean activity over 2007–2016) [Color figure can be viewed at wileyonlinelibrary.com]
Note. This graph illustrates the share of transactions by value of the ten largest markets from 2007 to 2016. The unit of the y-axis is 1. Black bars show the share based on foreign investments and gray bars show the share based on domestic investments.
Source. © Real Capital Analytics Inc.

The average response of the ith country in period P to a foreign country shock is:

$$\Psi_{i,P}^{res} = \frac{1}{N-1} \sum_{j=1, j \neq i}^{N} \Psi_{j,i,P}. \tag{9}$$

4 | DATA

Data for major global office transactions were supplied by RCA.[11] We collected 16,576 real estate transactions between 2007 and 2016, located over 210 cities and 57 countries. Over 80% of transactions are concentrated in the largest 58 cities, which are all included in our sample.[12] Figure 2 shows the share of transactions by value of the 10 largest markets over the period between 2007 and 2016: two European cities (London and Paris), four Asian cities (Tokyo, Shanghai, Seoul, and Singapore), and four US cities (New York, San Francisco, Washington DC, and Los Angeles). These 10 markets account for over 51% of total major transactions recorded in RCA. Among those transactions, foreign capital plays a remarkable role. On average, for the 58 cities, 38% of the transactions are acquisitions by foreign

[11]We acknowledge that focusing only on the office market is narrow because investors can invest in more than one real estate type and different segments can be cointegrated. However, focusing on one sector allows clearer measurement of common movement; the office sector remains the largest sector for global real estate estimation and data for the sector are more widely available and transparent. Based on BNP's (2019) report, in 2018, Office presented 45% of investment volume of commercial real estate in Europe and is characterized by a large share of mega deals. We would hope to extend the sectoral analysis in future research.

[12]We note that since our data have a minimum size constraint, this will somewhat bias our sample toward larger markets (and larger, professional, investors). However, the concentration figures reported here are consistent with those of other authors. Appendix 1 reports the name, country, and the share of the share of transactions by value for each city.

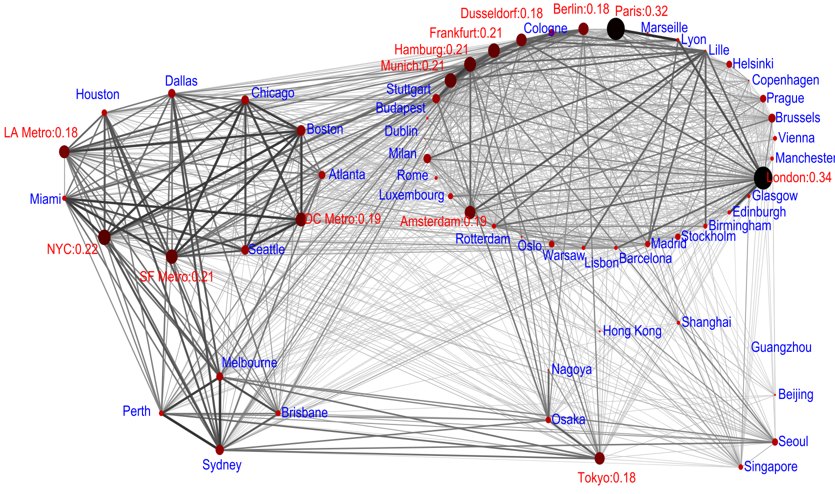


FIGURE 3 Average overlap of ownership across the 58 cities over the period 2007–2016 [Color figure can be viewed at wileyonlinelibrary.com]

Note. This figure visualizes the average overlap of ownership across the 58 cities over the period 2007–2016. The degree of overlap between cities is represented by the width of the line. The size and the color of the circle in each city show the degree of centrality of each city. The degree of centrality is measured as the average proportion of properties in other cities that are owned by investors with stakes in this city. The larger and darker the circle, the more central the city is in term of the coownership in the office market.

investors. In the 10 largest cities by activity, foreign investors contributed up to 35% of the capital. With such significant foreign capital inflows into their office markets, it is likely that there will be properties in any two cities in different countries that are owned by the same investor. London has the largest foreign investment share, amounting to 66% (consistent with the findings of Lizieri & Mekic, 2018), followed by Shanghai (49%) and Paris (42%).

Figure 3 visualizes the average overlap of ownership across the 58 cities over the period 2007–2016. The degree of overlap between cities is represented by the width of the line. Nearly all cities are connected to *some* other cities, implying that there is obvious ownership interconnection between cities all over the world. There are two obvious clusters in terms of ownership overlapping. One is within the United States (LA metro, DC metro, NYC, Boston, SF metro) and the other is in Europe (a London, Paris, Frankfurt, Munich cluster). The size of the circle shows the degree of centrality of each city. The degree of centrality is measured as the average proportion of properties in other cities that are owned by investors with stakes in this city. London has the highest level of overlap to other cities. An average of 34% of the properties in the other 57 cities are owned by the investors who have also invested in London office market. Paris and New York are the second and third most highly connected cities. Two U.S. cities (New York and San Francisco) and five European cities (Paris, London, Hamburg, Munich, and Frankfurt) have overlap ratios greater than 20%. Asian cities, such as Beijing, Hong Kong, Shanghai, and Guangzhou, have much lower connectivity.[13]

As shown in Table 2, on average, 10% of office buildings have owners with interests in offices in the other cities. The maximum overlap ratio is 97%, which runs between San Francisco and Seattle. Second, cities within the same country tends to have higher overlap ratios, emphasizing that geography and proximity still matter. The overlap ratio for cities within the same country is 38.7%, which is much

[13] Appendix 2 reports the degree of centrality for all 58 cities.

TABLE 2 Summary statistics of variables

	Mean	Std	Max	Min	75%	50%	25%
Ownership Overlap Ratio							
Average of 58 Cities	0.104	0.144	0.924	0	0.145	0.047	0
Within the same country	0.387	0.209	0.924	0	0.531	0.394	0.233
Cross border	0.086	0.118	0.903	0	0.123	0.041	0.000
10 cities with highest transaction volume	0.118	0.176	0.930	0	0.161	0.043	0
10 cities with lowest transaction volume	0.067	0.151	1.000	0	0.049	0	0
10 cities with highest GDP	0.125	0.192	0.924	0	0.176	0.030	0
10 cities with lowest GDP	0.046	0.127	1.000	0	0.023	0	0
10 cities with highest GFCI ranking	0.110	0.174	1.000	0	0.138	0.031	0
10 cities with lowest GFCI ranking	0.104	0.180	0.924	0	0.128	0	0
Office Market Performance							
Quarterly Total Return (%)	2.187	5.19	0.239	−0.392	0.045	0.018	0.011
Yield (%)	5.52	1.14	8.75	2.83	6.16	5.41	4.82
Vacancy Rate (%)	10.704	4.728	23.325	0.575	14.125	10.325	7.050
Economic fundamentals							
City Level							
Unemployment Rate (%)	6.829	3.372	23.1	1.63	8.51	6.03	4.39
Log of Population	15.128	0.889	17.397	13.082	15.676	14.913	14.476
Log of GDP	10.752	0.438	11.491	8.894	10.983	10.800	10.588
Offices of 100 Global Firms	124	74	368	0	164	116	67
Log of GFCI score	5.734	0.912	6.693	4.605	6.482	6.376	4.605
Cross-City mergers and acquisitions (Million USD)	68.891	875.64	61,926	0	0.754	0	0
Country Level							
Log of CPI index	4.761	0.331	5.481	4.377	4.776	4.605	4.567
Log of Exchange Rate	1.030	1.651	7.635	−0.275	0.772	0.333	0.123
Log of Stock	6.845	0.972	9.537	3.880	7.358	6.967	6.547
Long-term rate (%)	3.046	1.580	11.177	−0.0265	4.13	2.929	1.815
Transparency Rank	12.30	10.38	49	1	18	10	3
Balance of International Trade (% of GDP)	0.623	4.882	23.89	−13.55	4.411	−0.651	−2.912
Geographic Location							
Log of Distance	8.232	1.241	9.837	3.550	9.140	8.881	7.122
Same Country	0.059	0.235	1	0	0	0	0
Cultural Index	7.214	6.170	31.833	0	11.833	5.333	2
Same Legal system	0.261	0.439	1	0	1	0	0

higher than the overlap ratio for cross-border cities, which is just 8.6%. Third, larger cities tend to show higher overlap ratios. In Table 2, for the ten largest office markets in terms of their transaction volume, the average overlap ratio is 11.8%, while for the ten smallest markets, the average overlap ratio is only 6.7%. If we group the cities according to their GDP, the 10 cities with the highest GDP have an average overlap ratio of 12.5%, while the 10 cities with the lowest GDP have a ratio of only 4.6%. Fourth, cities with stronger, more competitive financial centers exhibit slightly higher overlap ratios. If we sort the cities according to the Global Financial Centres Index (GFCI),[14] top financial centers have a higher overlap ratio than those ranked at the bottom.

Our office market performance data come from Property Market Analysis LLP (PMA), who report the performance of office market in 61 cities globally.[15] After removing missing data, 58 cities are left for analysis. Over the period 2007–2016, PMA report average annual total returns of 8.8%, with a standard deviation of 20.8%. The average yield is 5.5% and the mean vacancy rate is 10.7%, reflecting the post-GFC difficulties. The explanatory variables were collected from a variety of sources. Appendix 5 reports the data sources.

5 | RESULTS

5.1 | Determinants of linked ownership

In the first stage of our analysis, we run a gravity model to explain the drivers of the overlap in ownership. The ownership overlap ratio is the dependent variable. The results are reported in Table3. The signs of the significant parameters seem reasonable and intuitive. The ownership overlap ratio increases significantly with a drop in the geographic distance between pairs of cities. Being in the same country increases the likelihood of linked ownership. Apart from that, cultural similarity and similarity in investment and financial freedoms play a significant role in colocation of investment. Cities with stronger commonality in cultural and investment and finance policies tend to have a higher overlap in the ownership. Having common currency also significantly increases the overlap ratio, as this removes foreign exchange risk and the costs of hedging, which might otherwise discourage investments. It should be noted that the transaction price of offices are in USD, so some of the impact of currency risk may have already been priced in the office value. The degree of overlap in the global firms as occupiers established in the pair of cities is also highly related to commonality in ownership of properties, which provides support for the "Towers of Capital" thesis (Lizieri, 2009; Lizieri & Pain, 2014). The spatial clustering of global financial business acts to create coordinating centers for an interlinked system of international financial flows (Friedmann, 1986; Lizieri & Pain, 2014). However, merger and acquisition (M&A) flows fail to explain ownership overlap. It could be that M&A in all sectors may be too broad a measure to capture the capital flows into the office sector. Regarding push and pull factors, consistent with the existing literature, we find that cities with higher yield, higher GDP, more population, lower interest rates, lower vacancy rate, lower unemployment rate, higher liquidity (proxied by higher transaction volume), lower exchange rate of local currency, and lower inflation tend to be more attractive to investors.

5.2 | Linked ownership and the comovement in international office markets

In this section, we seek to explain the comovement in office total returns across cities. Table 4 reports our baseline results. Model 2 is a panel model without a spatial term, while Models 3–5 regress real

[14]The GFCI index represents the global city index rank, which is a ranking of the competitiveness of financial centres published each year since 2007.

[15]PMA's prime capital value estimates are based on transaction data on rents and cap rates that are used to value a representative synthetic building and are used for investment strategy and performance benchmarking by many large professional investors. Füss and Ruf (2017) summarize the strength of the PMA data. PMA data reflect the market-to-market value of the commercial real estate, and are not subject to biases due to appraisal smoothing, the difference in valuation techniques internationally, and time-varying market liquidity.

TABLE 3 Results of gravity model

	Model 1: Gravity Model	
Constant	−15.874***	(1.489)
Log of Distance$_{i,j}$	−0.2071***	(0.0224)
Same Country$_{i,j}$	0.5044***	(0.0662)
Cultural Distance$_{i,j}$	−0.0388***	(0.0040)
Same Legal System$_{i,j}$	−0.0408	(0.0480)
Same Currency Unit	0.2244***	(0.0624)
Overlap in Firms	0.7513***	(0.1319)
Transparency Distance	−6.3013***	(1.9546)
Log of M&A flows	0.0022	(0.0061)
GFCI distance	−1.2792	(1.1259)
Yield $_{i,t}$	17.617***	(2.822)
Yield $_{j,t}$	4.930*	(2.882)
Vacancy $_{i,t}$	−0.0290***	(0.0046)
Vacancy $_{j,t}$	0.0060	(0.0052)
Unemployment $_{i,t}$	−0.0098	(0.0065)
Unemployment $_{j,t}$	−0.0164**	(0.0070)
Log PoP $_{i,t}$	−0.0481	(0.0415)
Log PoP$_{j,t}$	0.2878***	(0.0436)
Log GDP $_{i,t}$	0.36779***	(0.0747)
Log GDP $_{j,t}$	0.8526***	(0.0836)
Log Volume $_{i,t}$	−0.0138	(0.0434)
Log Volume $_{j,t}$	0.3199***	(0.0388)
Log Exchange $_{i,t}$	−0.0596***	(0.0176)
Log Exchange $_{j,t}$	−0.0246	(0.0167)
Log CPI $_{i,t}$	0.0577	(0.0886)
Log CPI $_{j,t}$	−0.4704***	(0.0830)
ir $_{i,t}$	0.0359	(0.0282)
ir $_{j,t}$	−0.1184***	(0.0308)
Year dummies	Yes	
Ave. no. of city	58	
No. of Period	10	
No. of observations (Pair of Cities* Period)	33,060	
Quasi-LL	9,877	

Note. This table reports the gravity model estimated by quasi-maximum likelihood estimation. The dependent variable is the ownership overlap ratio. Independent variables include dummy variables for same country, same currency, same legal system, and difference in cultural, transparency rank for the countries of the two cities, merger and acquisition flows, overlap in the global firms, global financial center index (GFCI) difference, city level office market yield, vacancy, transaction volume, GDP, unemployment rate and population as well as country level CPI, interest rate, and exchange rate. We report the standard error in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

TABLE 4 Spatial panel regressions

	Model 2: Panel Model	Model 3: Spatial Panel Model	Model 4: Spatial Panel Model + Distance Decay Model	Model 5: Spatial Panel Model + Crisis Dummy
ρ		0.4617***		
		(0.0768)		
ρ (overlap > 15%)			0.2922***	
			(0.0524)	
ρ (15% > overlap > 5%)			0.0165	
			(0.0605)	
ρ (overlap < 5%)			−0.0218	
			(0.0612)	
ρ_tranquil				0.2444***
				(0.0926)
ρ_crisis				0.3645***
				(0.0909)
Δ Total Return (t−1)	0.3202***	0.2828***	0.2909***	0.2931***
	(0.0203)	(0.0209)	(0.0208)	(0.0205)
Δ Log Population	−1.0475	−1.0965	−0.9573	−0.9603
	(0.7633)	(0.7578)	(0.6616)	(0.6565)
Δ Unemployment rate	−0.0057***	−0.0045***	−0.0044***	−0.0040***
	(0.0016)	(0.0016)	(0.0016)	(0.0016)
Δ Log GDP	0.0054	0.0002	0.0011	0.0032
	(0.0146)	(0.0144)	(0.0145)	(0.0144)
Δ Vacancy	−0.0048***	−0.0037***	−0.0039***	−0.0035***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Log Volume	0.0107***	0.0113***	0.0104**	0.0101**
	(0.0046)	(0.0046)	(0.0046)	(0.0046)
Log GICS	−0.0146	−0.0078	−0.0114	−0.0100
	(0.0198)	(0.0196)	(0.0197)	(0.0196)
Δ Long-term Rate	0.0012	0.0009	0.0014	0.0003
	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Δ log CPI	−0.1268	−0.1265	−0.0767	−0.0829
	(0.1744)	(0.1727)	(0.1734)	(0.1723)
Δ log exchange rate	0.0186	0.0172	0.0157	0.0181
	(0.0241)	(0.0239)	(0.0240)	(0.0238)
Δ Log stock	0.0639***	0.0391***	0.0466***	0.0335***
	(0.0123)	(0.0128)	(0.0129)	(0.0128)
Account Balance	−0.0470	−0.0465	−0.0482	−0.0487
	(0.0514)	(0.0509)	(0.0510)	(0.0507)
Trade of GDP	0.1106***	0.1189***	0.1245***	0.1104***
	(0.0241)	(0.0239)	(0.0241)	(0.0239)

(Continues)

TABLE 4 (Continued)

	Model 2: Panel Model	Model 3: Spatial Panel Model	Model 4: Spatial Panel Model + Distance Decay Model	Model 5: Spatial Panel Model + Crisis Dummy
FDI of GDP	0.0057	0.0067	0.0068	0.0068
	(0.0068)	(0.0067)	(0.0067)	(0.0067)
Δ Log Population (t−1)	0.8075	0.9006	0.6999	0.7313
	(0.5716)	(0.5661)	(0.5721)	(0.5652)
Δ Unemployment rate (t−1)	−0.0049***	−0.0035***	−0.0038***	−0.0033**
	(0.0015)	(0.0015)	(0.0015)	(0.0015)
Δ Log GDP (t−1)	−0.0185	−0.0223	−0.0227	−0.0229
	(0.0146)	(0.0145)	(0.0146)	(0.0144)
Δ Vacancy (t−1)	−0.0051***	−0.0041***	−0.0044***	−0.0040***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Log Volume (t−1)	0.0025	0.0017	0.0029	0.0024
	(0.0045)	(0.0045)	(0.0045)	(0.0045)
Log GICS (t−1)	0.0120	0.0065	0.0099	0.0080
	(0.0207)	(0.0205)	(0.0206)	(0.0205)
Δ Long-term Rate (t−1)	0.0005	−0.0001	0.0004	−0.0011
	(0.0018)	(0.0018)	(0.0018)	(0.0018)
Δ log CPI (t−1)	0.2621	0.1641	0.2451	0.0912
	(0.1683)	(0.1673)	(0.1673)	(0.1675)
Δ log exchange rate (t−1)	0.0034	0.0073	0.0053	0.0079
	(0.0239)	(0.0237)	(0.0238)	(0.0236)
Δ Log stock (t−1)	0.0310***	0.0211***	0.0258***	0.0080
	(0.0091)	(0.0091)	(0.0091)	(0.0096)
Account Balance (t−1)	0.0706	0.0701	0.0678	0.0700
	(0.0505)	(0.0500)	(0.0501)	(0.0498)
Trade of GDP (t−1)	−0.0970***	−0.1083***	−0.1076***	−0.0977***
	(0.0242)	(0.0240)	(0.0241)	(0.0241)
FDI of GDP (t−1)	−0.0066	−0.0063	−0.0061	−0.0063
	(0.0067)	(0.0066)	(0.0066)	(0.0066)
Δ oil	0.0087	0.0068	0.0069	0.0058
	(0.0196)	(0.0059)	(0.0059)	(0.0059)
Δ VIX	−0.0056	0.0029	0.0027	−0.0034
	(0.0223)	(0.0064)	(0.0064)	(0.0065)
City dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Ave. no. of City	58	58	58	58
No. of period	39	39	39	39

(Continues)

TABLE 4 (Continued)

	Model 2: Panel Model	Model 3: Spatial Panel Model	Model 4: Spatial Panel Model + Distance Decay Model	Model 5: Spatial Panel Model + Crisis Dummy
No. of observations (City* Period)	2,204	2,204	2,204	2,204
Adj. R^2	0.4346	0.4526	0.4492	0.4570

Note. The dependent variable in Models 2–5 is the total return of offices. ρ is the spatial dependence coefficient. W is constructed using observed linked ownership ratio. Control variables include change in lagged return, change in population, change in unemployment rate, change in GDP, change in long-term interest rate, change in CPI, change in credit supply, global financial center rank, vacancy rate, log of transaction volume, change in exchange rate, account balance, trade to GDP, FDI to GDP, global oil price change, and change in VIX index. Population, unemployment rate, GDP, global financial center score, and vacancy rate are at city level. Interest rate, CPI, credit supply, exchange rate, and account balance are at national level. Oil price and VIX are at the global level. We report standard errors in brackets. ***, **, and * denotes 1%, 5%, and 10% significance level, respectively.

estate total returns on the change in returns of "connected" cities. Model 3 includes only one matrix. In Model 4, we use three weight matrices. Matrix 1 includes only cities with overlap ratios larger than 15%. That means, each weight between a pair of cities has at least 15% of properties that are owned by the same owner. If the overlap ratio is below 15%, the weights are set as zero. Matrix 2 is defined in the same way as matrix 1. The only difference is that the weight includes cities with an overlap ratio between 15% and 5%. If the overlap ratio is above 15% or below 5%, the weight between the two cities is set as zero. In the same way, we define matrix 3 as before but with the overlap ratio less than 5%.

We see that the spatial coefficient is significantly positive and takes the value of 0.4617 in Model 3. In all cases, Model 3 also achieves higher adjusted R^2 and lower Bayesian information criterion (BIC) than the model without spatial considerations (Model 2). In Model 4, the matrix based on ownership overlap ratios higher than 15% has the highest coefficient at 0.2922. When the overlap ratio is lower than 15%, the spatial dependence coefficient drops to 0.0165, and becomes insignificant. The decrease in the spatial dependence intensity with different overlap ratios implies that comovement in office market performance declines with decreasing common ownership. From an investment perspective and intuitively, this implies that diversification benefits will be greater in markets with lower levels of linked ownership.

In all these models, we control for drivers of office market performance at city, national, and global levels. The control variables have the expected signs, but not all are significant. Lagged total returns have a significant effect on current performance, confirming the stickiness of property prices. A 1 percentage point increase in the previous return is associated with an increase in the price in the next period by around 0.3 percentage points, economically as well as statistically significant. As expected, a lower local vacancy rate, in both contemporaneous and past periods, is related to a higher office return. At the city level, the unemployment rate, also in both contemporaneous and past periods, has a significant negative impact on office performance.[16] Liquidity can also be an important driver of office market performance. Our results confirm that in more liquid markets with higher office transaction volume, the total return is significantly higher. Office market returns also increase with contemporaneous and past performance of the local equity market, demonstrating common movement between different asset classes, as might be expected given the cyclical events experienced over the time span of the dataset employed. Exchange rate movement, however, has no significant impact on office performance.[17]

[16] We would note that these are short-run impacts and there is limited empirical evidence that economic growth variables have a long-run effect on real estate rents and values.

[17] We note that office capital value is reported in USD, offsetting currency effects.

Market integration, which is measured by the import and export to GDP ratio, can significantly boost the office market in the contemporaneous period, but the impact becomes negative one period later.

We also investigate whether spatial dependence changes during times of market distress. During the GFC, comovement may increase due to the drying up of liquidity. Given the relatively short crisis period, we decided not to split the data and run the model separately in each phase. Instead, we allow for phase-dependent spatial linkages. It should be noted that we have allowed the spatial weights to change over time; therefore, the increase in the coefficient is purely due to the increase in the intensity, rather than to change in the weight itself. We use a crisis dummy to analyze whether the spatial coefficient changes significantly during the late 2007–2009 financial crisis.[18] Incorporating these modifications, Equation (4) becomes:

$$Y_t = \left(\rho_0 + \rho_p Crisis\right) W_t Y_t + \varphi Y_{t-1} + X_t \gamma + X_{t-1} \zeta + Z\delta + C\alpha + u_t, \tag{10}$$

where ρ_0 is the coefficient of spatial dependence in the normal period and ρ_p captures the change of the coefficient in the crisis period from 2007Q4 to 2009Q4. The results are shown in Model 5 of Table 4. During the crisis period, the spatial coefficient rises from 0.2444 to 0.6098. The increase is both statistically and economically significant, confirming that the comovement becomes more serious over the period with low market liquidity and strong capital shortfall but nonetheless still exist outside the crisis phase.

5.3 | Robustness analyses

To make sure that the linked ownership network is the best way to capture the investment relationships in our cities and that the spatial weight matrix does not capture other linkages or global comovements, we add alternative weight matrices into our spatial panel model (Asgharian et al., 2013; Milcheva & Zhu, 2015). The idea of this exercise is to see if the presence of another spatial link among returns can weaken the impact of integration through common ownership. We construct additional weight matrices based on distance; on cultural similarity whether the two cities are in the same country, whether the two cities have the same legal system as well as similarity in investment and financial policy. As Lizieri and Pain (2014) and Füss and Ruf (2017) show, the performance of office markets can also be connected via their "common occupiers." In the spirit of Globalization and World City ranking (GaWC), but using the location of 100 leading firms in accounting, banking, financial, advertising, and other firms, we construct a weight matrix according to the proportion of same bank or the same financial insurance company between pairs of cities. The commonality in global firms also reflects the financial and economic interconnectedness between cities. We also construct a weight matrix based on the stock of M&A flows across each pair of cities. In this way, we control for the interconnectedness between cities due to general economic activities. Thus, Equation (4) becomes:

$$Y_t = \rho W_t Y_t + \rho_{\text{alternative}} W_t^{\text{alternative}} Y_t + \varphi y_{t-1} + X_t \gamma + X_{t-1} \zeta + Z\delta + C\alpha + u_t. \tag{11}$$

[18]It was suggested to us that real estate reacted more slowly to the GFC and that the crisis phase should be pushed backward to as late as 2010. While some markets (notably the United States) did fall late, some of this was an appraisal effect masking earlier falls, alongside possible client pressure (Crosby, Devaney, Lizieri, & Mcallister, 2018). In the United Kingdom, the IPD (valuation-based) capital value index peaked in July 2007 and fell 11% by year end and a further 10% in H1 2008; by Q3 2010, it was recovering. IPD/MSCI appraisal-based figures show falls in many countries (including the United States, contrasting with NCREIF) in 2008. REIT indices around the world fell very substantially in 2008, given further confirmation to our periodization.

The results are reported in Table 5. In all cases, the spatial dependence coefficient measured by linked ownership remains significant and of comparable magnitude, ranging from 0.4008 to 0.5000.[19] This shows that our measure of the ownership network between cities is not weakened, when alternative weight matrices are included, such as geographic distance. Intriguingly, the network effects driven by linked ownership of office buildings can add additional information in explaining comovement of office market performance to those networks built on the occupiers of the buildings—the global firms occupying space in world cities and capital flows of mergers and acquisitions.

The main concern in the spatial econometric model is that the foreign variable ($\sum_{j=1,j\neq i}^{N} w_{i,j,t}y_{j,t}$) may be endogenous to the domestic variable ($y_{i,t}$). The endogeneity may arise for two reasons. First, $y_{i,t}$ may be correlated with $y_{j,t}$, but $w_{i,j,t}$ is assumed to be exogenous to $y_{i,t}$. In this case, the ordinary least squares (OLS) estimator for the spatial coefficient may be biased. According to Kelejian and Prucha (1998), $y_{i,t}$ in the past periods and exogenous variables ($X_{i,k,t}$) can be used as the instruments to address the correlation between $y_{j,t}$ and $y_{i,t}$. The baseline model is reestimated using this approach.[20] Results based on alternative estimates are also reported in Table 6. As shown in Table 6, the OLS estimator for the spatial coefficient appears upward biased based on the instrumental variable (IV) approach. The ML and Bayesian estimator for the spatial coefficient yield very similar results, but higher than the IV estimator, and close to those of the OLS approach.

The second kind of endogeneity comes from the correlation between $w_{i,j,t}$ and $y_{i,t}$. In other words, the assumption of "exogenous weights" may be violated, especially for economic or financial weights. As investors may strategically select which cities to invest, real estate market performance and the ownership overlap ratio can be endogenously related. For instance, opportunistic funds may be attracted by cities with higher investment yields, such as cities in some emerging countries, but other risk-averse investors may be interested in well-developed real estate markets, such as London. As a result, different types of investors may cluster in some cities due to the real estate market performance of these cities. This bilateral relationship may result in endogeneity and lead to biased results. We follow Piras and Kelejian (2014) and use instruments including geographic distance, being in the same country, cultural distance, being in the same legal system, being in the same currency unit, the overlap ratio of international firms, a distance measure of real estate investment transparency, and year dummies. We argue that these instruments should be (largely) exogenous to the real estate market. We first regress the ratio of properties owned by the same investors between each pair of cities on these IVs. Considering the overlap ratio is nonnegative, we use Tobit regression rather than OLS used by Piras and Kelejian (2014).

[19] As mentioned by Asgharian et al. (2013), the problem associated with multiple weight matrices is that these matrices may be correlated and result in potential multicolinearity. Indeed, as shown in Table 3, distance, the legal system, the overlap in firm locations, etc., can each explain the overlap in terms of property ownership to a certain degree. The potential multicollinearity problem may lead to an overestimation of the standard errors and result in a low t statistic for the coefficients. Although coefficient for all the alternative matrices becomes insignificant when two matrices are included, we would not interpret this result as demonstrating that the linked ownership is the only linkage between cities, because when only one matrix (such as distance, overlap in 100 Global firms, etc.) is included, each of them can significantly explain the comovement (however, our ownership matrix shows the highest coefficient).

[20] The problem with using lagged dependent variables as the instrument has been documented in the literature. Lagging an explanatory variable can achieve causal identification only when '(i) serial correlation in the potentially endogenous explanatory variable, and (ii) no serial correlation among the unobserved sources of endogeneity' (Bellemare, Masaki, & Pepinsky, 2017). In other words, the assumption of "no dynamics among unobservables" must be held. When this assumption is not satisfied, the estimated coefficient may be inefficient and inconsistent. Using Bayesian and ML estimators can avoid this problem. The results are presented in Table 6. The spatial dependence coefficient here is even higher than for the IV estimate. The reason might be because we have included as many exogenous variables as possible. Hence, the probability of "dynamics among unobservable" is limited.

TABLE 5 Spatial panel regression with alternative matrix

	Model 6: Distance	Model 7: Same Country	Model 8: Similar Cultural	Model 9: Same Currency	Model 10: Same Legal System	Model 11: Similar Transparency	Model 12: Overlap in 100 Global Firms	Model 13: Merger and Acquisition Flow
ρ	0.4942***	0.4303***	0.4936***	0.4008***	0.4658***	0.5000***	0.4400***	0.4355***
	(0.0964)	(0.0804)	(0.0872)	(0.0836)	(0.0870)	(0.0925)	(0.0939)	(0.0812)
ρ_distance	−0.0849							
	(0.1248)							
ρ_country		0.0487						
		(0.0668)						
ρ_cultural			−0.0025					
			(0.0025)					
ρ_currency				0.0883				
				(0.0660)				
ρ_legal					−0.0205			
					(0.0784)			
ρ_trans.						−0.1054		
						(0.1169)		
ρ_same firm							0.0317	
							(0.1207)	
ρ_MA								0.0297
								(0.0530)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.4524	0.4525	0.4525	0.4529	0.4522	0.4525	0.4522	0.4523
Adj. R^2_alternative	0.4445	0.4438	0.4443	0.4460	0.4436	0.4436	0.4457	0.4437

Note. The dependent variable is the total return of offices. ρ is the spatial dependence coefficient. The first $W(\rho)$ is constructed using the observed linked ownership ratio. The alternative weight matrix is constructed based on distance (Model 7), similar in culture (Model 8), same legal system (Model 9), same currency unit (Model 10), similarity in real estate transparency (Model 11), and overlap in 100 global firms (Model 12). Control variables include change in lagged return, change in population, change in unemployment rate, change in GDP, change in long-term interest rate, change in CPI, change in credit supply, global financial center rank, vacancy rate, log of transaction volume, change in exchange rate, account balance, trade to GDP, FDI to GDP, global oil price change, and change in VIX index. Population, unemployment rate, GDP, global financial center score, and vacancy rate are at city level. Interest rate, CPI, credit supply, exchange rates, and account balance are at national level. Oil price and VIX are at global level. We report standard error in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

TABLE 6 Spatial panel regression with alternative estimate

	Model 14: OLS	Model 15: ML	Model 16: Bayesian	Model 17: Instrumented Weights (Piras & Kelejian, 2014)
ρ	0.5838***	0.5186***	0.5618***	0.4293***
	(0.0561)	(0.0424)	(0.0289)	(0.0858)
Control Variables	Yes	Yes	Yes	Yes
City dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Adj. R^2	0.4737	0.4630	0.4644	0.4495

Note. This table reports the spatial panel model using different estimates. The dependent variable is the total return of offices. ρ is the spatial dependence coefficient. W is constructed using the observed linked ownership ratio. Only in Model 17, the weight is constructed based on predicted weights according to the instrumented weights method proposed by Piras and Kelejian (2014). Control variables include change in lagged total return, change in population, change in unemployment rate, change in GDP, change in long-term interest rate, change in CPI, change in credit supply, global financial center rank, vacancy rate, log of transaction volume, change in exchange rate, account balance, global oil price change, and change in VIX index. Population, unemployment rate, GDP, global financial center score, and vacancy rate are at city level. Interest rate, CPI, credit supply, exchange rate, and account balance are at national level. Oil price and VIX are at the global level. We report the standard error in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

Wooldridge (2002) suggests the Tobit regression in the first stage when the endogenous variable is left-censored. The results for the first-stage regression are presented in Appendix 4. All the instruments are significant with an expected sign. The F test for the relevance of the instruments is also significant at the 1% level.[21] In the second-stage regression, we run the regression again with the estimated weights. The results are reported in Model 17, Table 6. The spatial coefficient remains significant. However, the standard error becomes larger, which implies the decrease in efficiency of this estimate. Overall, we can conclude that the concern about endogenous weights does not change the main finding of this paper: linked ownership has a direct impact on the correlation between market returns.

5.4 | Impulse response analysis

The advantage of a spatial model is that it allows us to investigate how a change in the dependent variable in one market transmits throughout the spatial system to other markets. Due to the dynamic nature of the spatial framework, applied return variations in one country will affect the returns in countries with a high overlap in the property ownership. The resulting movements in those markets will, in turn, affect their "neighboring" markets, and so on. For transmission of spatial shocks, we calculate the impulse responses that follow a one-standard-deviation city-specific foreign shock. Figure 4 shows the average spatial effect of a one-standard-deviation shock to the office market globally, excluding the response in the city where the shock originally arises. The impulse response is based on Model 3, which reports the overall spatial dependence during the entire observation period.

[21] Ideally, we should also test the exogeneity of these instruments. The standard method is Sargan–Hansen test. However, as is the case in this paper, data often have a different dimension in the first- and second-stage models, and hence, we are not able to perform the Sargan–Hansen test here. The exogeneity test for instrumented weights in the spatial econometric models should be a topic for future research. Additionally, we also carefully select instruments that should be exogenous to city office market performance, such as variables based on the geographic location of the city and variables based on the overall economy of the cities.

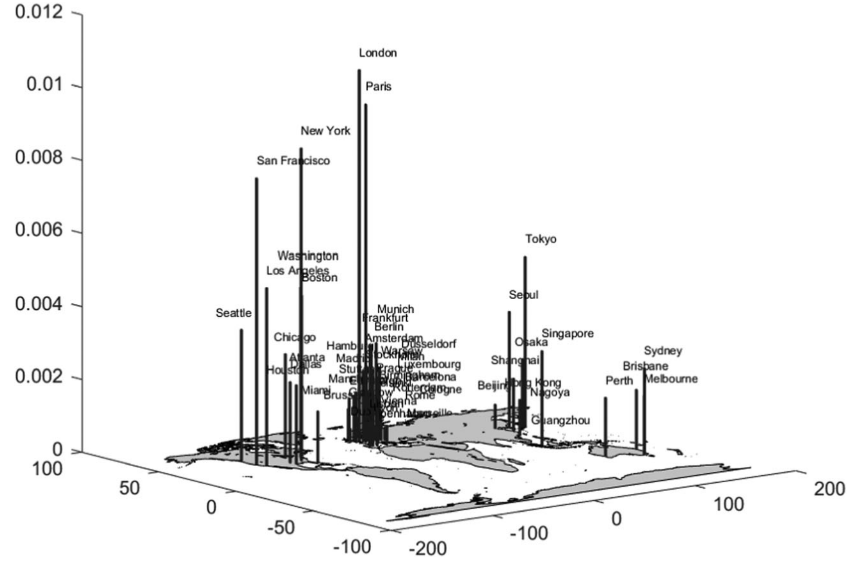
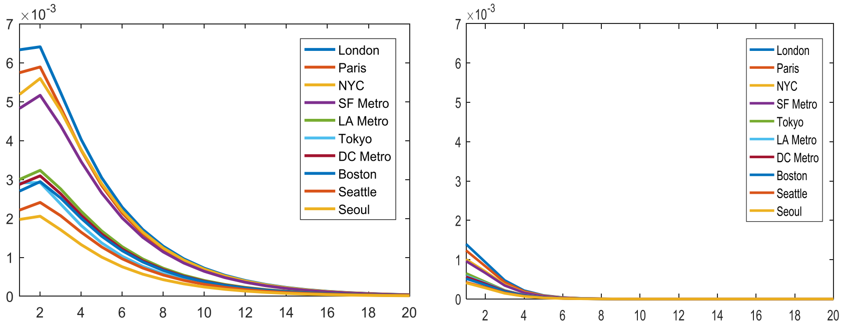


FIGURE 4 Average cumulative response of global office markets to a one-standard-deviation city-specific shock 20 quarters after the shock [Color figure can be viewed at wileyonlinelibrary.com]
Note. This graph illustrates the average response in the other cities when the office return in one city is changed by one standard deviation. It shows the total response 20 quarters after the shock, on the average of the responses in the remaining cities (excluding the city where the shock originally arise).

London appears to be the dominant driver, as a shock to London office market generates the strongest impact. A one-standard-deviation shock to the London office market will change the office total returns in each of the remaining 57 cities by an average of 0.36 percentage point one quarter after the shock. The impact drops to 0.17% in the next two quarters and to less than 0.1% from the fourth quarter. After 20 quarters, the change cumulates to 1.02%, on average across the 57 office markets. Tokyo and New York are also important drivers, with an average cumulative impact of 0.47% and 0.85%, respectively. These results are determined by our ownership spatial matrix—the overlap ratios—hence, they are unsurprising given that the cities above have high overlap ratios with other markets. The 10 most influential cities based on their impact are London, Paris, New York, San Francisco, Los Angeles, Washington DC, Tokyo, Boston, Seattle, and Seoul.[22]

Figure 5 distinguishes comovement during the crisis phase and more tranquil periods. It illustrates the average response of the remaining countries to a shock in those 10 cities that yield the strongest impact. The coefficient is based on Model 5. It is clear that the response is much more pronounced and persistent during the crisis period. In the crisis period, the effect is highest in the second quarter after the shock. A one-standard-deviation office price shock in London will result in an average of 0.63 percentage point change on each of the remaining cities one quarter after the shock. This impact rises slightly to 0.64 percentage point two quarters after the shock. After the third quarter, the effect declines: impacts are rapid. After five quarters, the impact drops by half. After 10 quarters, the impact becomes marginal. Up to the 20th quarter, the response cumulates to 3.41 percentage points. It should

[22]Concerns may arise that the spatial correlation coefficient is dominated by these 10 cities. Accordingly, we excluded them and reran the spatial model using the remaining 48 cities. The spatial coefficient decreases from 0.46 to 0.31, but remains statistically significant. Based on this result, we argue that the autocorrelation is not completely dominated by the 10 most influential cities.



Panel A: Crisis Period *Panel B: During Post-crisis Period*

FIGURE 5 Average response of global office markets to a one-standard-deviation city-specific shock in 10 dominant cities during crisis and tranquil periods [Color figure can be viewed at wileyonlinelibrary.com]
Note. This graph illustrates the average response in the other cities when the office return in the 10 dominant cities is changed by one standard deviation during the crisis and tranquil periods. It shows the response from the first to the 20th quarter after the shock, on the average of the responses in the remaining cities (excluding the city where the shock originally arises).

be noted that the mean quarterly price appreciation is 2.2%, as shown in the summary statistics. We argue that the transmission of shocks is thus economically significant.

We also show the impact during the more tranquil period (Figure 5b). A one-standard-deviation shock to the London office market will result in only an average 0.14 percentage points increase in each foreign city one quarter after the shock. During the crisis period, interdependence increased dramatically, derived, for example, by price pressure generated in part by forced sales by professional investors due to liquidity problems. This asymmetric impact suggests that downside risks are most pronounced in interconnected markets, with implications for investment strategy.

Figure 6 shows the impact of a one-standard-deviation decrease in office prices in the London market up to 20 quarters after the shock during the crisis period. Panel A illustrates the cumulative responses. The strongest response to a London office market shock occurs in Dublin, with office returns dropping by a total of 5.16% after 20 quarters. This can be explained by the high overlap in ownership between Dublin and London. Also, we see strong joint exposure with Birmingham and with Madrid, and hence, strong spillover effects of a total of 3.93% and 4.11%, respectively. Hong Kong also has a distinct response, amounting to 3.82% in total. Overall, European cities have the strongest response, followed by Asian cities, while US cities seem to be least affected, confirming regional effects found in other studies.

To provide a more detailed analysis on the spillover effect, we decompose the response into that part trigged by the direct spatial effect (the spillovers to the first-order neighbors), indirect effect (the spillovers to higher-order neighbors), and the feedback effect (the spillovers back to the city of origin of the shock). Panel B of Figure 6 illustrates the responses in the London, Dublin, Madrid, and Birmingham office markets from the 1st to the 20th quarter after the shock. The solid line shows the total response, and the dashed line represents the response based only on the direct spatial effect. The difference between the solid and dash line reflects the degree of indirect spatial effect for Dublin, Madrid, and Birmingham as well as the feedback effect for London itself.

In general, we see visible responses due to the spatial multiplier effect. Shocks spill over to the higher order of neighbors (the neighbors' neighbors), which makes the response become stronger and more persistent. In Dublin, the office returns would drop by about 1.51% in total one-quarter after the

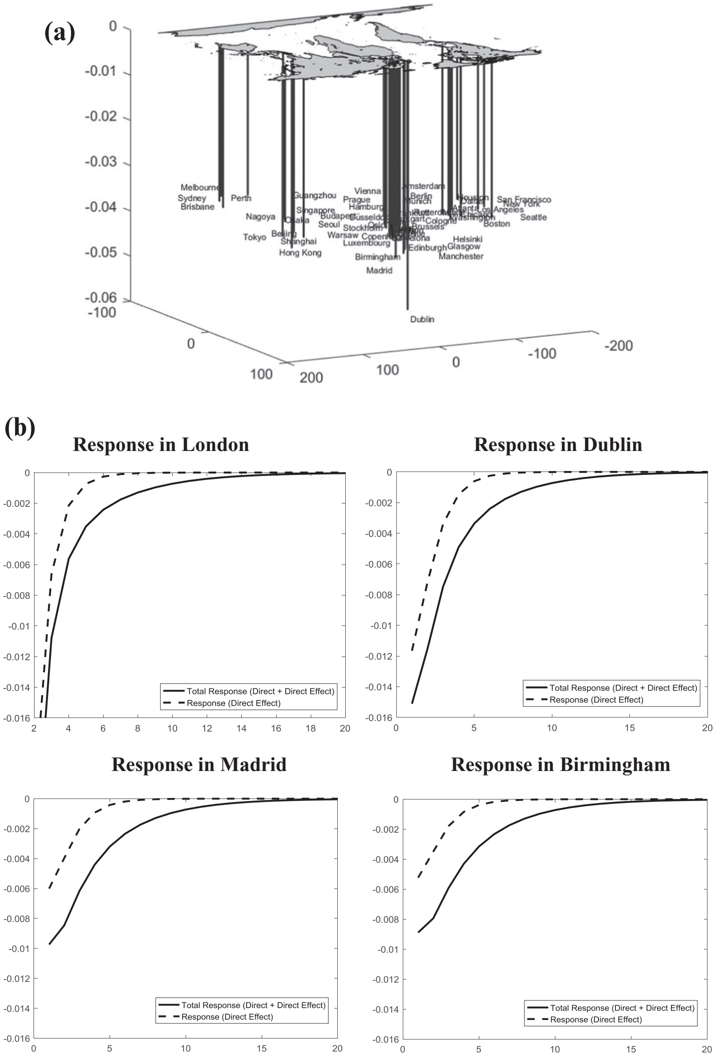
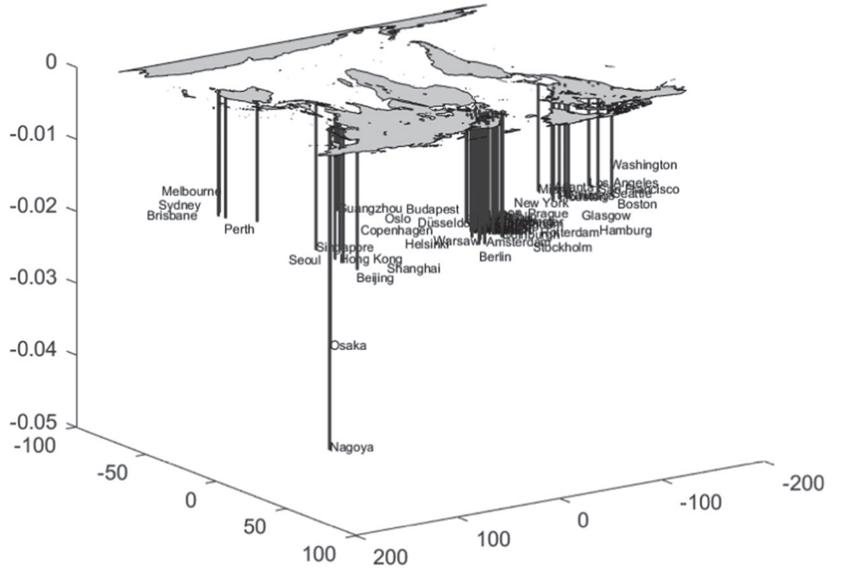


FIGURE 6 Response to a one-standard-deviation decrease in London office total returns during the crisis period: Panel A: cumulative response of global office markets up to 20 quarters after the shock and Panel B: decomposition of responses in London, Durbin, Madrid, and Birmingham [Color figure can be viewed at wileyonlinelibrary.com]

Note. Panel A of this graph illustrates the average response in the other cities when the office return in London drops by one standard deviation during the crisis period, respectively. It shows the total response 20 quarters after the shock, on the average of the responses in the remaining 57 cities (excluding London). Panel B of this graph presents the decomposed response in London, Dublin, Madrid, and Birmingham. The solid line shows the total response, and the dashed line represents the response based only on the direct spatial effect. The difference between the solid and dash line reflects the degree of indirect spatial effect for Dublin, Madrid, and Birmingham as well as the feedback effect for London.

(a) Tokyo



(b) New York

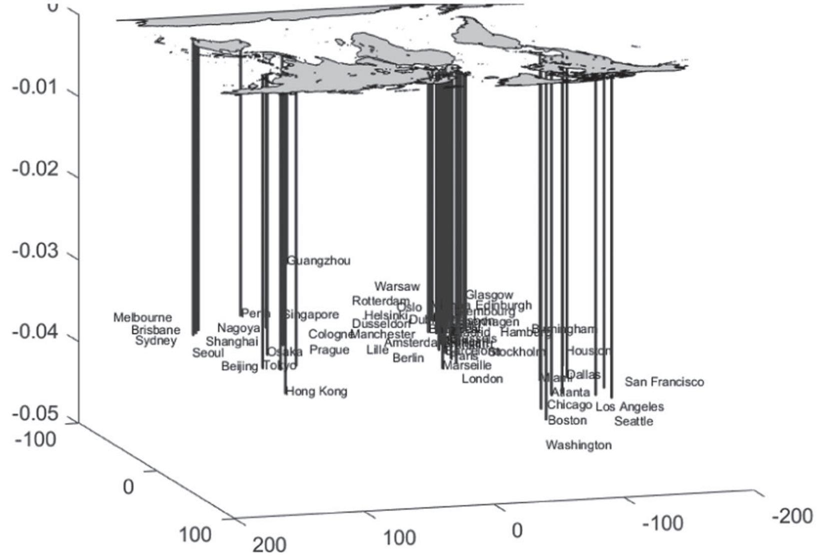


FIGURE 7 Cumulative response of global office markets to a one-standard-deviation decrease in Tokyo and New York Office returns 20 quarters after the shock during crisis period [Color figure can be viewed at wileyonlinelibrary.com]

Note. This graph illustrates the average response in the other cities when the office return in Tokyo and New York drops by one standard deviation during the crisis period, respectively. It shows the total response 20 quarters after the shock, on the average of the responses in the remaining 57 cities (excluding Tokyo and New York, respectively).

shock, and 23% of the total response is due to this indirect effect. From the second to the fourth quarter after the shock, the indirect spatial effect would contribute 37%, 54%, and 70%, respectively, of the total response. After the first year, the direct spatial effect (the spillover to the first-order neighbors) drops to close to zero. The persistence of the response is largely attributable to this indirect spillover effect. On average, up to 20 quarters after the shock, 52% of the cumulative response in Dublin can be explained by the indirect spatial effect. A similar conclusion can be drawn for Madrid and Birmingham. Nearly 70% of the cumulative response in the office returns in these two cities is triggered by the indirect spatial effect. Regarding the London office market, the spatial multiplier effect increases the cumulative response by 21% on average up to 20 quarters after the shock. Due to spatial dependence captured by linked ownership, the response in London office returns rises by 0.0039, 0.0046, 0.0042, and 0.0035, respectively, from the first to the fourth quarter after the shock. The transmission of the one-time shock finally feeds back to the city of origin of the shock and reinforces the response there.

As shown in Figure 7a, the impact of Tokyo office market is mainly focused on Asian cities, with domestic cities Nagoya and Osaka showing the strongest decrease, amounting to 1.60% and 0.94% in the first quarter after the shock, respectively. The cumulative effect is 4.26% and 2.89% in 20 quarters after the shock, respectively. The weakest effect is observed for North American cites. In response to a 1% shock in New York office market (Figure 7b), the Washington office market reacts strongest, driven by the high linked ownership of space in the two cities. North American cities respond more pronouncedly and European cities react least to the shock in New York. This illustrates the continued importance of regional factors despite the growth of pan-continental investment strategies.

6 | CONCLUSIONS

In this paper, we have assessed the relationship between the commonality in property ownership and the comovements across 58 global office markets over the period of 2007–2016 using a dynamic spatial panel model. Office market shocks can have spillover effects on other cities through the channel of the global investment of real estate investors, over and above standard return drivers: an invisible network coming from commonality in ownership, which reflects the flow of international capital. While controlling for city level, country level, and global factors, we find that commonality of ownership is significantly positively related to the comovement of office market returns. It can add more information to traditional measures of economic and financial integration. Markets with a larger proportion of properties owned by the same investors show stronger office market return linkages. For instance, given the large exposure of investors to London and to other cities, when London office market are adversely affected, investors may have to liquidate their investments in other markets, and thereby affect the demand and supply in those other cities.

We show that a one-standard-deviation shock to the office return in London will generate a significant shift in office returns in the other cities, amounting to 1.02% during the crisis period, with a maximum impact of 2.31% in Dublin. We also show that commonality of property owners adds additional information next to other spatial linkages—such as geographic distance, similarity in culture and transparency, and even the overlap in occupiers (global firms). The results remain robust after we correct for the self-selection issue in the weights. An important task for future work will be to further investigate the channels by which the ownership network influences common movement. These results have potentially important policy implications for real estate investors seeking global diversification in their property strategies. The strong clustering of investment in a relatively small set of cities contributes to the pattern of shared ownership we identify. Our results show that it is these markets that are most prone to near-simultaneous shocks transmitted from one market to another. By implication, there will be stronger comovements in those cities, reducing diversification gains, with movements most pronounced in the tails of the distribution. To minimize such downside risks, investors should consider seeking less connected markets, subject to liquidity and scale constraints.

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APPENDIX 1: CITIES, COUNTRIES, AND SHARE OF TRANSACTIONS BY VALUE

City	Country	Share	City	Country	Share
London	United Kingdom	11.51%	Osaka	Japan	0.58%
NYC	United States	10.11%	Dallas	United States	0.58%
Tokyo	Japan	6.88%	Brussels	Belgium	0.50%
Paris	France	6.64%	Dusseldorf	Germany	0.50%
SF Metro	United States	3.35%	Warsaw	Poland	0.45%
Shanghai	China	3.03%	Birmingham	United Kingdom	0.36%
DC Metro	United States	2.92%	Copenhagen	Denmark	0.34%
Seoul	South Korea	2.55%	Prague	Czech Republic	0.30%
LA Metro	United States	2.13%	Dublin	Ireland	0.30%
Singapore	Singapore	2.02%	Miami	United States	0.29%
Chicago	United States	1.95%	Guangzhou	China	0.27%
Hong Kong	Hong Kong, China	1.86%	Cologne	Germany	0.26%
Boston	United States	1.85%	Rome	Italy	0.26%
Beijing	China	1.73%	Barcelona	Spain	0.26%
Sydney	Australia	1.56%	Manchester	United Kingdom	0.25%
Frankfurt	Germany	1.47%	Perth	Australia	0.24%
Stockholm	Sweden	1.43%	Lyon	France	0.23%
Seattle	United States	1.20%	Helsinki	Finland	0.21%
Munich	Germany	1.02%	Luxembourg	Luxembourg	0.21%
Houston	United States	0.97%	Rotterdam	Netherlands	0.21%
Madrid	Spain	0.92%	Stuttgart	Germany	0.20%
Amsterdam	Netherlands	0.90%	Nagoya	Japan	0.15%
Melbourne	Australia	0.89%	Lisbon	Portugal	0.13%
Berlin	Germany	0.82%	Edinburgh	United Kingdom	0.12%
Milan	Italy	0.76%	Glasgow	United Kingdom	0.11%
Hamburg	Germany	0.75%	Budapest	Hungary	0.08%
Atlanta	United States	0.74%	Marseille	France	0.06%
Brisbane	Australia	0.68%	Lille	France	0.02%
Oslo	Norway	0.64%			
Vienna	Austria	0.61%			

APPENDIX 2: DEGREE OF CENTRALITY OF THE CITIES

City	Centrality	City	Centrality	City	Centrality	City	Centrality
London	33.6%	Seattle	13.1%	Osaka	8.6%	Glasgow	4.4%
Paris	32.4%	Milan	13.0%	Madrid	8.3%	Rome	4.3%
NYC	22.2%	Stuttgart	12.9%	Luxembourg	8.0%	Lyon	4.3%
Hamburg	21.0%	Chicago	12.8%	Brisbane	7.7%	Budapest	2.6%
Munich	20.7%	Dallas	12.3%	Perth	7.3%	Hong Kong	2.0%
Frankfurt	20.7%	Brussels	12.2%	Singapore	7.2%	Marseille	2.0%
SF Metro	20.6%	Melbourne	11.7%	Miami	6.6%	Beijing	1.9%
DC Metro	19.5%	Atlanta	11.3%	Rotterdam	6.4%	Oslo	1.9%
Amsterdam	18.8%	Prague	10.4%	Birmingham	6.4%	Lille	1.8%
LA Metro	18.3%	Cologne	10.0%	Vienna	6.0%	Copenhagen	1.4%
Dusseldorf	18.1%	Seoul	9.9%	Lisbon	5.4%	Nagoya	1.3%
Berlin	17.7%	Helsinki	9.6%	Manchester	5.2%	Dublin	0.6%
Tokyo	17.6%	Warsaw	9.2%	Edinburgh	5.1%	Guangzhou	0.1%
Boston	14.7%	Houston	8.8%	Barcelona	5.1%		
Sydney	14.3%	Stockholm	8.7%	Shanghai	4.9%		

Note. The numbers reported are computed as $c_i = \frac{1}{N-1} \sum_{j=1,j\neq i}^{N} w_{i,j}$, where $w_{i,j}$ is the proportion of properties in city i that are owned by investors who also invest in city *j*. For example, an average of 29.33% of the properties in the other 57 cities is owned by the investors who also own property in Paris.

APPENDIX 3: ALTERNATIVE SPECIFICATION OF SPATIAL PANEL MODELS

	Model: Spatial Durbin Model	Model: No Lagged Independent Variables	Model: RCA Transactions Excluding 100 RE Asset Managers and Fortune 500	Model: Excluding 10 most influential cities	Model: Excluding Fixed Effects
ρ	0.4466***	0.5618***	0.3991***	0.3137***	0.4921***
	(0.0859)	(0.0735)	(0.0733)	(0.1038)	(0.0420)
Δ Log Price $t-1$	0.3014***	0.2955***	0.2831***	0.3146***	0.2759***
	(0.0208)	(0.0208)	(0.0210)	(0.0236)	(0.0203)
Δ Log Population	−0.3700	−0.3500	−1.0729*	−1.0863*	−1.0994**
	(0.2347)	(0.2363)	(0.5586)	(0.5710)	(0.5445)
Δ Unemployment	−0.0033**	−0.0043***	−0.0043***	−0.0046***	−0.0044***
	(0.0015)	(0.0015)	(0.0016)	(0.0015)	(0.0015)
Δ Log GDP	−0.0109	−0.0133	0.0004	−0.0001	−0.0022
	(0.0141)	(0.0141)	(0.0145)	(0.0138)	(0.0142)
Δ Vacancy	−0.0012	−0.0015**	−0.0042***	−0.0033***	−0.0037***
	(0.0007)	(0.0007)	(0.0009)	(0.0008)	(0.0009)

(Continues)

	Model: Spatial Durbin Model	Model: No Lagged Independent Variables	Model: RCA Transactions Excluding 100 RE Asset Managers and Fortune 500	Model: Excluding 10 most influential cities	Model: Excluding Fixed Effects
Log volume	0.0144***	0.0140***	0.0112***	0.0122***	0.0109
	(0.0029)	(0.0028)	(0.0046)	(0.0052)	(0.0045)
GICS	0.0031	−0.0003	−0.0107	−0.0530	−0.0125
	(0.0080)	(0.0080)	(0.0196)	(0.0691)	(0.0194)
Δ Long-term Rate	−0.0016	0.0012	0.0009	0.0014	0.0011
	(0.0021)	(0.0020)	(0.0020)	(0.0020)	(0.0019)
Δ log CPI	−0.0874	−0.1888	−0.1312	0.0638	−0.1244
	(0.1723)	(0.1729)	(0.1729)	(0.1725)	(0.1613)
Δ log exchange rate	0.0160	0.0203	0.0156	0.0244	0.0197
	(0.0239)	(0.0241)	(0.0239)	(0.0248)	(0.0236)
Δ Log stock	0.0273**	0.0410***	0.0408***	0.0450***	0.0358***
	(0.0131)	(0.0127)	(0.0128)	(0.0123)	(0.0111)
Account Balance	−0.0302	0.0074	−0.0490	−0.0087	−0.0540
	(0.0413)	(0.0397)	(0.0510)	(0.0482)	(0.0504)
Trade of GDP	0.0145	0.0230***	0.1182***	0.1155***	0.0965***
	(0.0102)	(0.0099)	(0.0239)	(0.0227)	(0.0230)
FDI of GDP	0.0029	0.0034	0.0058	0.0055	0.0046
	(0.0047)	(0.0048)	(0.0067)	(0.0062)	(0.0066)
W Δ Log Population	1.8598*				
	(1.0075)				
WΔ Unemployment rate	−0.0149***				
	(0.0054)				
WΔ Log GDP	0.1770***				
	(0.0562)				
WΔ Vacancy	−0.0022				
	(0.0048)				
W Log volume	−0.0139*				
	(0.0072)				
W GICS	0.0002				
	(0.0035)				
WΔ Long-term Rate	−0.0026				
	(0.0029)				
WΔ log CPI	1.1767***				
	(0.3393)				

(Continues)

	Model: Spatial Durbin Model	Model: No Lagged Independent Variables	Model: RCA Transactions Excluding 100 RE Asset Managers and Fortune 500	Model: Excluding 10 most influential cities	Model: Excluding Fixed Effects
WΔ log exchange rate	−0.1882*				
	(0.0993)				
WΔ Log stock	0.0046				
	(0.0128)				
W Account Balance	0.1466				
	(0.1442)				
W Trade of GDP	−0.0361**				
	(0.0173)				
W FDI of GDP	−0.0856***				
	(0.0286)				
Δ Log Population (t−1)			0.8398	0.9493	0.8001
			(0.5668)	(0.5823)	(0.5572)
Δ Unemployment			−0.0036***	−0.0033**	−0.0025*
			(0.0015)	(0.0015)	(0.0015)
Δ Log GDP (t−1)			−0.0192	−0.0184	−0.0266*
			(0.0145)	(0.0139)	(0.0144)
Δ Vacancy (t−1)			−0.0044***	−0.0035***	−0.0040***
			(0.0009)	(0.0008)	(0.0009)
Log volume (t−1)			0.0015	−0.0032	−0.0002
			(0.0045)	(0.0051)	(0.0044)
GICS (t−1)			0.0096	0.0362	0.0108
			(0.0206)	(0.0676)	(0.0203)
Δ Long-term Rate (t−1)			−0.0001	−0.0002	0.0009
			(0.0018)	(0.0018)	(0.0017)
Δ log CPI (t−1)			0.1656	0.0427	0.0624
			(0.1676)	(0.1673)	(0.1446)
Δ log exchange rate (t−1)			0.0036	0.0093	0.0067
			(0.0237)	(0.0246)	(0.0235)
[illegible]			[illegible]***	[illegible]**	[illegible]
			(0.0091)	(0.0090)	(0.0089)
Account Balance (t−1)			0.0744	0.0600	0.0715
			(0.0500)	(0.0474)	(0.0495)
[illegible]			[illegible]***	[illegible]***	[illegible]***
			(0.0240)	(0.0228)	(0.0230)
FDI of GDP (t−1)			−0.0063	−0.0049	−0.0060
			(0.0066)	(0.0061)	(0.0065)

(Continues)

	Model: Spatial Durbin Model	Model: No Lagged Independent Variables	Model: RCA Transactions Excluding 100 RE Asset Managers and Fortune 500	Model: Excluding 10 most influential cities	Model: Excluding Fixed Effects
Δ oil	0.0182***	0.0122**	0.0079	0.0042	0.0090*
	(0.0062)	(0.0058)	(0.0059)	(0.0058)	(0.0053)
Δ VIX	0.0048	0.0003	0.0026	0.0030	0.0045
	(0.0066)	(0.0064)	(0.0064)	(0.0064)	(0.0051)
City dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	No
Ave. no. of City	58	58	58	58	58
No. of Period	39	39	39	39	39
No. of Observations (Cities * Period)	2204	2204	2204	2204	2204
Adj. R^2	0.4530	0.4321	0.4510	0.4320	0.4590

Note. This table reports the spatial panel model using IV estimation using the instrument proposed by (Kelejian & Prucha, 1998). The dependent variable in Models 2–5 is the return of office price. Model 6 uses total return as the dependent variable. ρ is the spatial dependence coefficient. W is constructed using the linked ownership ratio. Control variables include change in lagged return, change in population, change in unemployment rate, change in GDP, change in long-term interest rate, change in CPI, change in credit supply, global financial center rank, vacancy rate, change in exchange rate, global oil price change, and change in VIX index. Population, unemployment rate, GDP, global financial center score, vacancy rate are at city level. Interest rate, CPI, credit supply, and exchange rate are at national level. Oil price and VIX are at the global level. We report standard errors in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

APPENDIX 4: ALTERNATIVE SPECIFICATION OF SPATIAL PANEL MODELS

	Model: First-stage regression
Log of Distance$_{i,j}$	−0.0219***
	(0.0010)
Same Country$_{i,j}$	0.1853***
	(0.0042)
Cultural Distance$_{i,j}$	−0.0056***
	(0.0002)
Same Legal System$_{i,j}$	0.0080***
	(0.0023)
Same Currency Unit	0.0196***
	(0.0030)

(Continues)

	Model: First-stage regression
Overlap in Firms	0.1410***
	(0.0057)
Transparency Distance	−1.1467***
	(0.0651)
Log MA flow	0.0058***
	(0.0003)
GFCI distance	−0.3938***
	(0.0551)
Year dummies	Yes
Ave. no. of City	58
No. of Period	10
No. of Observations (Pair of Cities*Period)	33,060
Quasi-LL	5,526
R^2	0.2622
J Test	1,443***

Note. This table reports the first-stage regression results for linked ownership ratio on several instruments using Tobit regression (*Piras and Kelejian, 2014* and *Wooldridge, 2002*). The dependent variable is the ownership overlap ratio. Independent variables include dummy variables for same country, same currency, same legal system, and difference in cultural, transparency rank for the countries of the two cities, overlap in the global firms, merger and acquisition flows, and difference in the global financial center index (GFCI). We report the standard error in brackets. ***, **, and * denote 1%, 5%, and 10% significance level, respectively.

APPENDIX 5: DATA DESCRIPTION AND SOURCES

Variable	Description	Sources
City Level Data		
Total Return	Total Return on an annually reviewed prime & fully let property. Calculated as Capital Growth + Income Yield (net yield) – Capital Costs.	PMA
Yield	Quoted market yield on a fully let prime building, netted down. Net yields take into account acquisition costs as well as nonrecoverable costs.	PMA
Vacancy Rate	Total availability as a proportion of stock	PMA
Unemployment Rate	City-level unemployment rate. For cities where data are not available, using national unemployment rate to interpolate. City-level unemployment rate is annual data, and we use the national quarterly unemployment rate to interpolate.	OECD Metropolitan Database, OECD
Population	Total population in cities/metropolitan areas. For cities where data are not available, using country population growth rate to interpolate.	OECD Metropolitan Database, OECD

(Continues)

Variable	Description	Sources
GDP	GDP in cities/metropolitan areas. For cities where data are not available, using country GDP growth rate to interpolate. City-level GDP growth rate is per annual, and we use the national quarterly GDP growth rate to interpolate.	OECD Metropolitan Database, OECD
Offices of 100 Global Firms	Location of 100 global service firms (accountancy, advertising, banking/finance, insurance, law, and management consultancy) for each city.	GaWc database
GFCI score	The Global Financial Centres Index (GFCI) is a ranking of the competitiveness of financial centers published each year since 2007 by Z/Yen Group and based on over 29,000 financial center assessments from an online questionnaire together with over 100 indices from a variable database (The Long Finance Report). The higher the score, the more competitive the city is.	The Long Finance Report
Cross City Mergers and Acquisitions	All together 740,623 mergers, acquisitions, capital increase, buy-in and buy-out, as well as joint venture happened in the 29 countries over the period between 2000 and 2016	Zephyr database
Country Level		
CPI	CPI index	OECD database
Exchange Rate	National currency to special drawing right	OECD database
Stock Performance	MSCI stock price index	Datastream
Long-term Rate	ten-year government bond yield	Datastream
Transparency Rank	JLL ranks countries based on real estate transparency every 2 years. The transparency is quantified based on 139 variables relating to transaction processes, regulatory & legal frameworks, corporate governance, performance measurement, and data availability. Higher ranking implies higher transparency, which is associated with stronger investors and corporate real estate activities.	JLL global real estate transparency ranking
Balance of International Trade	Balance of payment of economic transactions of an economy with the rest of the world	World Bank Database
Trade of GDP	Import and Export to GDP	World Bank Database
FDI of GDP	FDI inflows and outflows to GDP	World Bank Database

(Continues)

Variable	Description	Sources
Cultural Index	Hofstede Scores designed to measure affinity across six distinct cultural dimensions. These factors include assessments of a society's attitudes and responses with respect to issues of: (1) Power Distance, (2) Individualism versus Collectivism, (3) Masculinity versus Femininity, (4) Uncertainty Avoidance, (5) Long-Term versus Short-Term Orientation, and (6) Indulgence versus Restraint.	Geert Hofstede's website
Same Legal system	The legal system is classified based on the following categories: Napoleonic, Germanic, Nordic, Anglo-American, Social, and Islamic law.	