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Are the Markets for Factories and Offices Integrated? Evidence from Hong Kong*

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Due to the relocation of manufacturing facilities from Hong Kong to Mainland China, it is widely believed that some vacant private factories have been used as offices in Hong Kong. Yet there is no direct and systematic evidence to support this speculation. In fact, according to MacGregor and Schwann (2003), industrial and commercial real estate shares some common features. Our research attempts to investigate empirically the price and volume relationship between industrial and commercial real estate, using both aggregate and disaggregate data from the industrial and commercial property markets in Hong Kong. The study was built on the observation that economic restructuring and geographical distance will affect the substitutability (and thus the correlation) of different types of property, and utilizes commonly used time series techniques for analysis. Policy implications are discussed.

Keywords

aggregation bias; geographical distance; industrial real estate; substitutability

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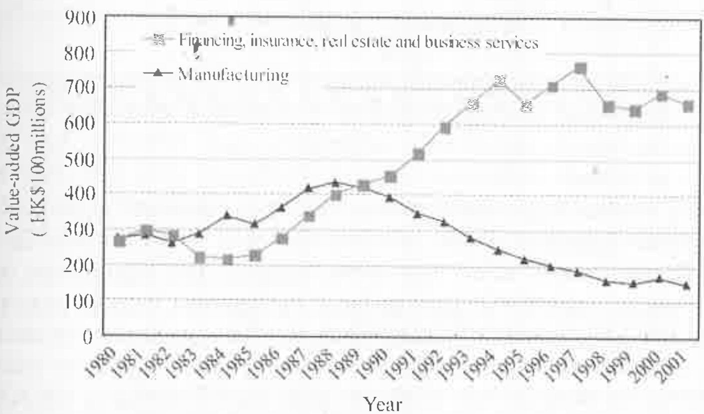
Introduction

Recent literature on economic development has formally established that as an economy develops, the relative share of its manufacturing industry will diminish and its service industry counterpart will increase.[1] Hong Kong may be an interesting example of this general phenomenon. As shown in Figure 1, the value-added GDP of Hong Kong's manufacturing industry declined substantially relative to its service industry after 1990. From 1980 to 1997, the employment share of Hong Kong's service sector rose from 42.1% to 79.3%, while the share of manufacturing fell from 45.9% to 9.8% (Tao and Wong, 2002). A lot of production operations have moved to China, which is the hinterland of Hong Kong, in view of its lower land and labor costs. Sung (2005, chpt. 4) reported that Hong Kong manufacturers employ about 10 million workers in Guangdong, but fewer than 233,000 in Hong Kong. Sung (1995, chpt. 5) further indicated that 88% of Hong Kong's foreign direct investment flow (FDI) went to the Mainland from 1998 to 2002. In fact, after reviewing a lot of evidence, Sung (2005, p.92) concluded that "the bulk of Hong Kong's trade with the Mainland is intra-industry trade generated by Hong Kong's investment in the Mainland."[2] It is then not surprising that the demand for factory building decreases significantly.

Figure 1: Value-added GDP of manufacturing and finance, insurance, real estate, and business services in Hong Kong (1980-2001)



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[1] Among others, see Echevarria (1997), Kongsamunt et al. (2001), and Ngai and Pissarides (2004) for theoretical explanations and empirical evidence.

[2] Among others, see Sung (1998) for a history of how business in Hong Kong moved to China.

On the other hand, the rapid expansion of the service sector in Hong Kong has generated increasing demand for office space (Jayantha et al., 2001). On top of the possibility of developing new land for commercial real estate, it seems natural to re-develop industrial real estate into office buildings, especially in a dense city like Hong Kong. However, due to legal constraints, it can be very costly to do so.[3] Furthermore, the ownership of a typical industrial building in Hong Kong is fragmented – a factory building may contain as many "owners" as the number of units. This makes re-development even more difficult. Therefore, it is plausible that some vacant private factories were used as offices in Hong Kong, either legally or illegally. As shown in Figure 2a, the vacancy rates of office and factory units seem to co-move. More direct and systematic evidence, such as property price analysis, is needed to support the speculation that factories were used as offices as the economy developed.

Figure 2a: Vacancy rates of office and private factory in Hong Kong (1980-2000)

According to MacGregor and Schwann (2003), the demand for real estate is derived from aggregate output demand, and any fluctuations in the real output should directly affect real estate returns. The equilibrium in the national capital market will tend to force the regional rates of return to a common risk-adjusted rate of return. Thus, the first hypothesis for our study is that office and factory buildings became closer substitutes after the restructuring of Hong Kong's economy from manufacturing to services. In fact, office property, or commercial real estate,[4] has some similarities to

[3] On top of the construction costs involved, real estate developers typically need to pay the government a large sum of money as a premium for changing the use of a plot of land if the intended use was not allowed in the land lease. Developers may also need approval from the town planning authority, which is sometimes described as a black-box process.

[4] In this study, "commercial real estate" is used interchangeably with "office property". Generally, commercial real estate includes offices, industrial, and retail buildings, but retail buildings were excluded from this study due to their different characteristics.

industrial real estate in many aspects. For example, they both serve as production inputs; they are often investment vehicles for institutional investors; and they are both directly affected by general economic conditions, such as interest rates, land supply, and government regulations. As the demand for factory continuously decline and the counterpart for office continuously increases, some real estate developers may choose to re-develop the factory buildings into office. However, the process will take time and substitution between factory and office should take place. Property price indices (aggregate data) from 1979 to 2002 were used for analysis.

The second hypothesis for our study is that office and factory buildings are good substitutes, and that geographical distances will affect the substitutability and thus the correlations of industrial and commercial properties. Due to the importance of property location, it is possible that a stronger substitution effect results if both property types are located in the same district or in an adjacent district.[5] To check for possible aggregation bias[6], district level transaction data for 11-year periods (1992-2002) will be used for our analysis.[7] The geographical distances were measured in terms of the proximity of districts.

We will repeat the exercise on the trading volume to examine if the industrial and commercial real estate may interact in non-price dimensions.[8] In fact, most previous studies on comparing the markets for different types of property focused on price co-movements and ignored the trading volume counterpart, so this paper can be treated as an extension in this regard.[9]

Clearly, several testable implications can be developed from the assertion that industrial real estate is effectively used as commercial real estate. First, the returns of industrial and commercial real estate should be positively correlated, and even significant Granger causalities should be observed. Second, their correlation increases as the economy develops. Third, the geographical distances will influence the significance of correlations. In

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[5] This would be the case for many location models, such as the "monocentric model". See Hanushek and Yilmaz (2005) for a review of the literature. For a textbook treatment, see DiPasquale and Wheaton (1996).

[6] There has been much discussion about aggregation bias in the recent literature in economics. Among others, see Hanushek et al. (1996), Bostic et al. (2005), and the references therein.

[7] The dataset of EPRC has been used in several previous studies, such as by Leung et al. (2002) and Leung and Feng (2005).

[8] Trading volume can be interpreted as a proxy for the degree of heterogeneity in investors' opinions and beliefs (Ito and Lin, 1993), or an indicator of either liquidity or illiquidity (Huang and Wang, 2004). In finance, Chowdhry and Nanda (1991) showed that cross-market trading is a source for trading volume correlation across markets. Ito and Lin (1993) used this approach to empirically investigate the causality of trading volumes in the U.S. and Japanese stock markets. Lo and Wang (2000) reviewed the literature.

[9] For instance, see Wheaton (1999).

particular, the correlations should be the most significant in the same districts, less so in neighboring districts, and the least significant for non-neighboring districts. This seems to have a very different focus on the existing literature, which is predominantly about the pricing and return determination of industrial real estate (see Appendix I for a summary of literature on industrial properties). More importantly, the aggregate and disaggregate analyses allowed us to check whether their results were consistent with each other. This has important implications on estimation problems such as aggregation bias.

Notice that this paper has a very different focus than the existing literature. Authors have examined many topics, including the price relationship between the commercial and residential property market (He and Webb, 2000; Kan et al., 2004); supply constraints on rental changes (Jones and Orr, 1999); excess returns (Brown and Chau, 1997); and the common features of commercial real estate (MacGregor and Schwann, 2003). None of the studies, however, has examined the price or volume relationships between the industrial and commercial real estate markets.

It should be noticed that while this paper focuses on Hong Kong, its economic lesson may apply to many other cities, especially those that have experienced rapid economic changes over the last few decades. An economic transformation from manufacturing to services inevitably shifts the demand for factory and office buildings. Can and should the government intervene and smooth out such process? Clearly, allowing for the market to re-develop that real estate is a possibility. This, however, is a costly option, and for many Asian cities, the risk may be too big to bear, and thus may hinder their economic transformation. Alternatively, governments may allow firms to use factories as office buildings, and hence minimize transaction costs. This seems to be a costless policy choice, at least in the short run. In fact, the entrepreneurs in Hong Kong may have secretly converted industrial real estate into office buildings. For investors, this may reduce the diversification benefits of investing across property types. This paper attempts to provide a preliminary yet formal analysis on this issue. Policy implications will be discussed in the concluding section.

The organization of this paper is simple. The dataset and econometric method will be described. Then we will present the results. The last section concludes.

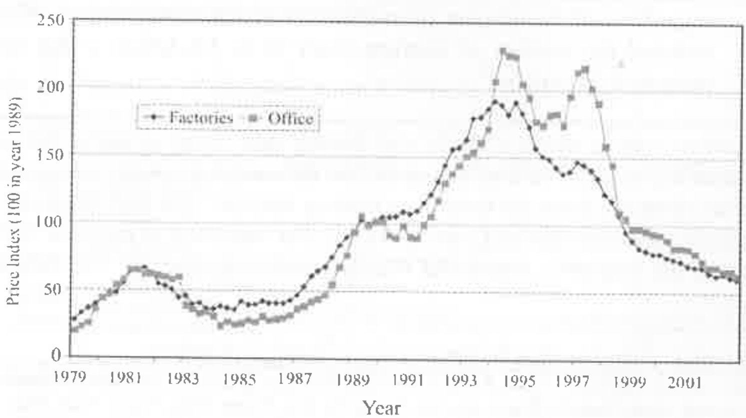
Data Description and Econometric Method

The analysis is divided into two parts. The first part uses aggregate data to analyze the co-movements of office and industrial real estate prices in the light of the economic restructuring in Hong Kong. This tests whether office and industrial properties become closer substitutes of each other as the economy develops. The second part uses disaggregate district-level data to analyze the effect of geographical distances on the co-movements of their prices as well as their trading volumes. This tests whether office and industrial properties are more substitutable for each other when they are geographically closer to each other.

Aggregate analysis

In the aggregate analysis, the quality-adjusted price indices of office and industrial properties in Hong Kong were collected from the Rating and Valuation Department of the Hong Kong Government. Quarterly data was available from 1979Q1 to 2002Q4 (Figure 2b). As discussed in the introduction, there appeared to be a structural change in 1990, as the value-added GDP of Hong Kong's manufacturing industry declined substantially relative to its service industry after this year (Figure 1). We therefore segregated the sample into two periods: 1979-1990 and 1991-2002, and conducted a simple test on whether there was an increase in the correlation and Granger causality between the two types of property.

Figure 2b: Price indices of offices and factories in Hong Kong (1979-2002)



District-level analysis

In the district-level analysis, individual transaction data on industrial and commercial property are obtained from the Economic Property Research Centre (EPRC), which gathers transaction records from the Land Registry of the Hong Kong Government. The dataset consists of all sales and purchases records for each individual property in Hong Kong from 1992 to 2002. It includes the name and district of the property, building completion dates, transaction prices, as well as the floor area.[10]

Since this study will examine whether geographical distances will affect the correlations of industrial and commercial properties, district level data is used.[11] There are at least two reasons for using district level data. On one hand, it is clear that the location preferences and the characteristics of different property types vary widely across sub-areas within Hong Kong, and relying solely on aggregate data will ignore the heterogeneity of different sub-areas. On the other hand, using building level data will result in too few observations in each sub-market for each time period. Therefore, district level data was chosen to eliminate the heterogeneity problem as much as possible, but still allowed enough locational variations to test the geographical distance effects properly. The criteria for sample selection and classification are as follows:

1) First we selected buildings that have complete information of transaction. The buildings were grouped at geographical districts by quarterly frequency.
2) In order to ensure a positive degree of freedom of series in the statistical test, we selected the districts that had at least four transactions for both industrial and commercial properties during the sampling period. In other words, districts that had fewer than four transactions in one property market were discarded, regardless of the number of transactions in the other market. This reduced the number of districts from 18 to 12, which is the full sample in our study.[12]

Following Leung et al. (2002) and Leung and Feng (2005), this study employs the realized rate of return as the detrended property price, and the number of transactions per quarter as trading volume. For each property type, the district-specific realized rate of return is a weighted average of the unit prices of the properties transacted within a particular district. The details are

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[10] For further information about the EPRC, please see Leung et al. (2002).
[11] There are 18 districts in Hong Kong: Central & Western, Wan Chai, Eastern, Southern, Yau Tsim Mong, Sham Shui Po, Kowloon City, Wong Tai Xin, Kwun Tong, Tsuen Wan, Tuen Mun, Yuen Long, Northern, Tai Po, Sai Kong, Shatin, Kwai Tsing, and the outlying islands. The district boundaries are defined by the government.
[12] Wei (2004) also discussed the results of different sub-samples. Due to the space limit, we did not include the details of those analyses. It sufficed to say that they were similar to the full sample and interested readers may consult Wei (2004).

shown in Appendix II.

To assess the distance effect, we do not measure the actual distance between districts, but perform analysis separately for offices and factories located: 1) in the same district; 2) in adjoining districts; and 3) in non-adjoining districts. According to the above criteria, there are three sample groups in both the sales and rental markets. Table 1a and Table 1b contain the summary statistics for the sample in the sales market and rental market, respectively. There are 12 districts in the sales market and 14 districts in the rental market.[13] Notice that in general, the correlation between the industrial real estate in District A and the office in District B, denoted as corr(indust(A), office(B)), is different from the correlation between the industrial real estate in District B and the office in District A, denoted as corr(indust(B), office(A)). Thus, for the 12 districts in the sales market, we will have 12 by 12 (i.e., 144) correlations. Similarly, for 14 pairs of districts in the rental market, we will have 14 by 14 (i.e., 196) correlations.

Table 1a: Number of districts in each sample group in the sales market

Districts		Industrial real estate market	Commercial real estate market	Total No. of observations	
Full sample (total No. of transactions ≥4)		12	12	144	
Same Districts		N.A.	N.A.	12	
Different districts	Neighboring districts	N.A.	N.A.	42	132
	Non-Neighboring districts	N.A.	N.A.	90	

Note: N.A. denotes that it is not applicable.

Table 1b: Number of districts in each sample group in the rental market

Districts		Industrial real estate market	Commercial real estate market	Total No. of observations	
Full sample (total No. of transactions ≥4)		14	14	196	
Same districts		N.A.	N.A.	14	
Different districts	Neighboring districts	N.A.	N.A.	53	182
	Non-Neighboring districts	N.A.	N.A.	129	

Note: N.A. denotes that it is not applicable.

[13] The six districts excluded from the full sample for the sales market was: Wan Chai, Wong Tai Sin, North, Tai Po, Sai Kung and Islands; and the four districts excluded from the full sample for the rental markets were: Wan Chai, Wong Tai Sin, Sai Kung and the outlying islands.

Tables 2 and 3 provide the number of transactions in the sale and rental markets for both industrial and commercial properties.[14] Compared to commercial properties (i.e., office), industrial properties are more active in the sales market, but less active in the rental market. This may be explained by the owner-occupied feature of most industrial buildings (Wheaton and Toto, 1990). In Hong Kong, some commercial properties are exclusively for rental (Feng, 2003). Thus, the sales portion of the industrial market is larger, while the rental portion of is smaller than the commercial property counterpart. (Due to the space limit and the similarity between the results of the sales and rental markets, the main text will only discuss the sales market. The results of the rental market are available upon request).

Tables 2-4 summarize the total number of transactions in each district, the efficient sampling period, and the number of zero transaction periods for each district.[15] The trading volume varies significantly across districts. As shown in Figure 3, the vast majority of buildings do not have a lot of transactions.

Table 2: Number of transactions in each district and region (sales market)

	Region	District	Transactions (Industrial real estate market)			Transactions (Commercial real estate market)		
All of Hong Kong	Hong Kong Island	Central and Western	98	4736	41759	4664	10047	21330
		Wan Chai	0			3332		
		Eastern	4218			1970		
		Southern	420			81		
	Kowloon	Yau Tsim Mong	460	14648		8359	10027	
		Shan Shui Po	2429			334		
		Kowloon City	1182			572		
		Wong Tai Sin	1765			2		
		Kwun Tong	8812			760		
	New territories	Tsuen Wan	6020	22375		733	1256	
		Tuen Mun	2513			141		
		Yuen Long	306			90		
		North	897			3		
		Tai Po	151			3		
		Sai Kung	0			0		
		Sha Tin	5649			87		
		Kwai Tsing	6839			199		
		Islands	0			0		

[14] Following Feng (2003), each contract renewal was treated as a transaction.

[15] Following Feng (2003), the effective sampling period is defined as the number of periods between the first and last periods with transaction records; and the zero transaction period measures the number of zero transaction periods within the effective sampling period.

Table 3: Number of transactions in each district and region (rental market)

	Region	District	Transactions (Industrial real estate market)			Transactions (Commercial real estate market)		
All of Hong Kong	Hong Kong Island	Central and Western	20	651	4895	2125	4128	8786
		Wan Chai	0			1752		
		Eastern	571			239		
		Southern	60			12		
	Kowloon	Yau Tsim Mong	365	2297		2615	3510	
		Shan Shui Po	354			289		
		Kowloon City	169			493		
		Wong Tai Sin	250			0		
		Kwun Tong	1159			113		
	New territories	Tsuen Wan	919	1947		315	1148	
		Tuen Mun	98			14		
		Yuen Long	57			12		
		North	20			353		
		Tai Po	31			17		
		Sai Kung	0			0		
		Sha Tin	416			268		
		Kwai Tsing	406			169		
		Islands	0			0		

Table 4: Granger causality of office and industrial property prices

	COM→IND	IND→COM
1979-1990	Yes	No
1991-2002	Yes	Yes

Note: → denotes the former granger causes the latter at the 5% level.

The time series of property price are not stationary but property returns are, and the latter are used for the analysis. Figure 3b provides the distribution of quarterly average returns for each district in the sales market. The average rate of returns in both industrial and commercial properties displays asymmetric distribution in the sales market, with the peak (the largest frequency) at an interval of 0-0.1, and assigns more weight to the left.

Figure 3a: Distribution of the quarterly trading volume in the sales market

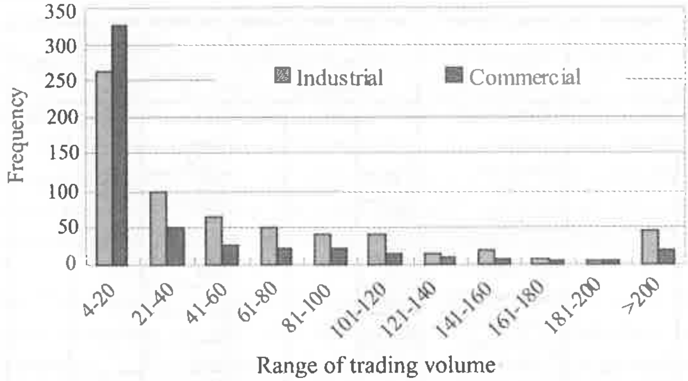
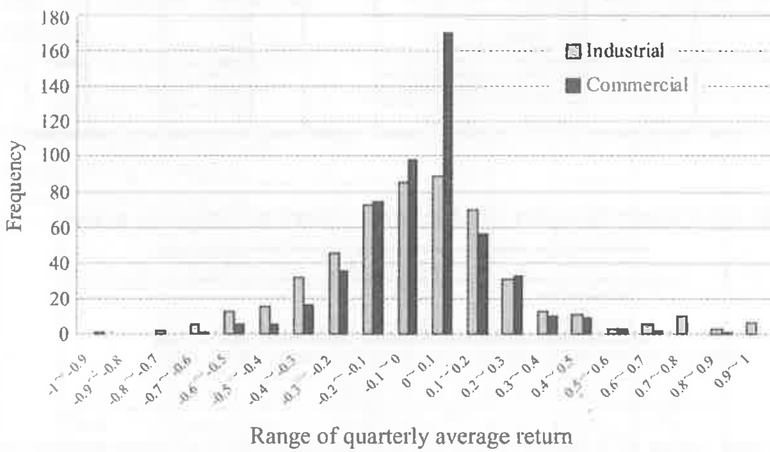


Figure 3b: Distribution of the quarterly average return in the sales market



In terms of econometric tools, this paper employs the ADF test to detect non-stationarity, partial correlation to measure the co-movement, bootstrapping to correct for small sample bias, and the Granger test to detect statistical causality. Since these are standard tools in applied work, we provide only a quick review in the appendix and refer interested readers to econometrics textbooks such as Greene (2000).

Empirical Results

Aggregate results

We performed ADF tests on the price index data and found that both the series of industrial and office prices were non-stationary. As a result, their rates of return, which were stationary, were used instead.

Our analysis showed that the correlations between offices and factories were positive and significant in both sub-periods. This confirmed that industrial and office properties share some common characteristics. In particular, the correlation during 1979-1990 was 0.4, whereas the correlation during 1991-2002 was 0.7. Based on a *t*-test (after Fisher's transformation), the increase in correlation proved to be significant at the 5% level. This supported the hypothesis that the co-movements between offices and factories became stronger as the economy transformed from manufacturing to servicing.

Further analysis was performed using Granger causality tests. The results are shown in Table 4. During 1979-1990, the Granger causality was unidirectional from office to industrial property. After 1990, a feedback relationship was found. This reinforced the correlation results that office and factories became more integrated after Hong Kong's economic transition. Therefore, the notion of an increased substitutability between offices and factories is supported by aggregate data.

Table 4a: Correlation of prices in the sales market: Downtown vs. suburb

	Office prices (downtown)	Office prices (suburb)
Factory prices (downtown)	−0.12	0.28
Factory prices (suburb)	−0.14	0.44*

Note: * denotes that it is significant at the 95% confidence level.

Table 4b: Significant test of the correlation of prices in the sales market

Sample	Positive*	Negative*	Insignificant	Total
Full sample	10 (6.94%)	5 (3.47%)	129 **(89.58%)**	144 (100%)
Same districts	0 (0.00%)	1 (8.33%)	11 **(91.67%)**	12 (100%)
Neighboring districts	4 (9.52%)	1 (2.38%)	37 **(88.09%)**	42 (100%)
Non-Neighboring districts	6 (6.67%)	3 (3.33%)	81 **(90.00%)**	90 (100%)

Notes: 1. * denotes that it is significant at the 95% confidence level.
2. Figure in parentheses is the corresponding percentage of the total number.

Table 4c: Test granger causality of prices in the sales market

	COM→IND	IND→COM	Two-way causality	Neither	Total
Full Sample	12 (8.33 %)	8 (5.56%)	1 (0.69%)	123 **(85.42%)**	144 (100%)
Same districts	0 (0.00%)	0 (0.00%)	0 (0.00%)	12 **(100%)**	12 (100%)
Neighboring districts	2 (4.76%)	3 (7.14%)	0 (0.00%)	37 **(88.10%)**	42 (100%)
Non-Neighboring districts	10 (11.11%)	5 (5.56%)	1 (1.11%)	74 **(82.22%)**	90 (100%)

Among districts with significant causality	**COM→IND (+)**	**COM→IND (-)**	**IND→ COM (+)**	**IND→ COM (-)**	**Two-way causality**	**Total**
Full sample	9 **(42.86%)**	3 (14.29%)	7 (33.33%)	1 (4.76%)	1 (4.76%)	21 (100%)
Same districts	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Neighboring districts	2 **(40%)**	0 (0.00%)	2 **(40%)**	1 (20%)	0 (0.00%)	5 (100%)
Non-Neighboring districts	7 **(43.75%)**	3 (18.75%)	5 (31.25%)	0 (0.00%)	1 (6.25%)	16 (100%)

Notes: 1. → denotes the former granger causes the latter only.
2. (+), (-) denotes the positive and negative causality.

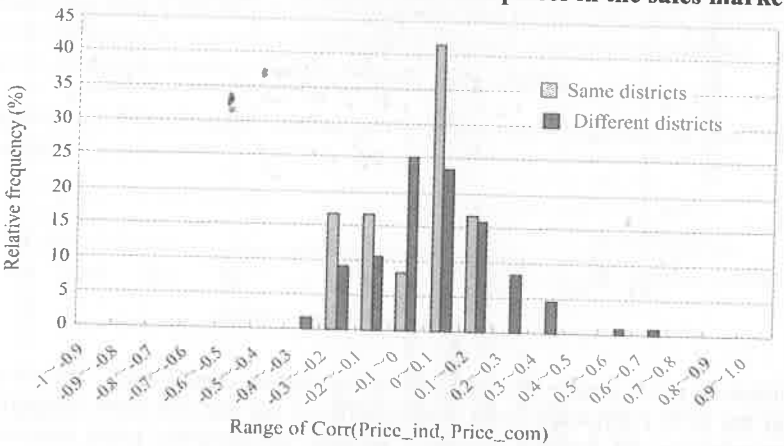
District-level results

Despite finding a significant regime shift, there are reasonable doubts for the results based on aggregate data. On top of the aggregation bias mentioned before, it is also clear that the time series, especially those of the sub-samples, were too short for more sophisticated tools, such as endogenous structural break tests or regime-switching tests. The detrending procedures employed earlier may not be "powerful" enough to eliminate those kinds of "non-stationarity," and hence, the Granger tests could be biased. Thus, it seems justified for us to re-examine the co-movement of the two markets in a district-level. Due to space limits, however, this section will mainly report the empirical results of the sales market. Wei (2004) showed that the results of the rental market are similar.

We begin our analysis by examining the correlation of prices between the industrial and commercial properties located: 1) in the same district; 2) in adjoining districts (i.e., district-pair, which share a common boundary); and 3) in non-adjoining districts.[16] The distributions of price correlation for properties located in the same district and those located in different districts (including both adjoining and non-adjoining districts) are exhibited in Figure 4a. It is clear that there are weak price correlations between industrial and commercial properties in the sales market for both sub-samples. Figure 4b further distinguishes the correlation of prices for properties located in adjoining and non-adjoining districts in the sales market. The distribution of these two sub-samples are asymmetric, with the peak at the 0~0.1 interval. However, the main message remains the same. The correlations between office and industrial prices were weak irrespective of the property location. This is even so if we pool the districts into larger areas (suburb v. downtown) to avoid the small sample problem (Table 4a).[17]

Figure 4c provides a straightforward way to investigate the substitution effect of industrial and commercial properties. We plot the price correlations of different districts in the commercial property sales market against the corresponding price correlations of districts in the industrial and commercial property sales markets. Intuitively, if industrial and commercial properties are good substitutes of each other, then the slope of the line should be positive. The flat fitted line indicates that there is no clear price substitution effect between the industrial and commercial properties.

Figure 4a: Distribution of correlation between prices in the sales market



[16] The terms "adjoining" and "neighboring" will be used interchangeably.
[17] "Downtown" includes Yau Tsim Mong, Central and Western, and Wan Chai districts which constitute more than a half of the office space. The rest belong to the "suburb". Since Hong Kong is a small city, there is no "rural" area in Hong Kong. Thanks to an anonymous referee for this suggestion.

Figure 4b: Distribution of correlation between prices among different districts in the sales market

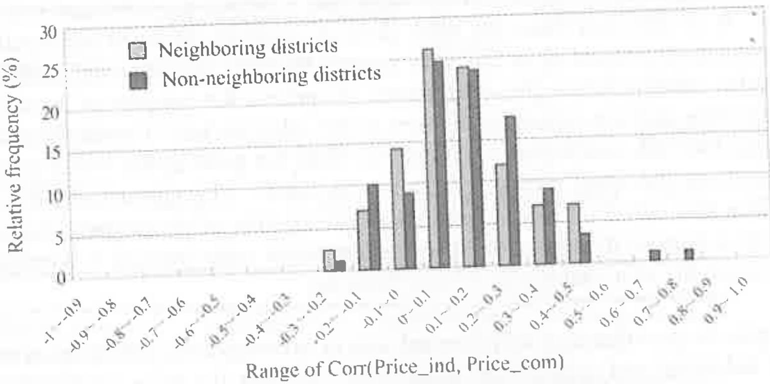


Figure 4c: Relationship between correlations of prices among different districts in the sales market

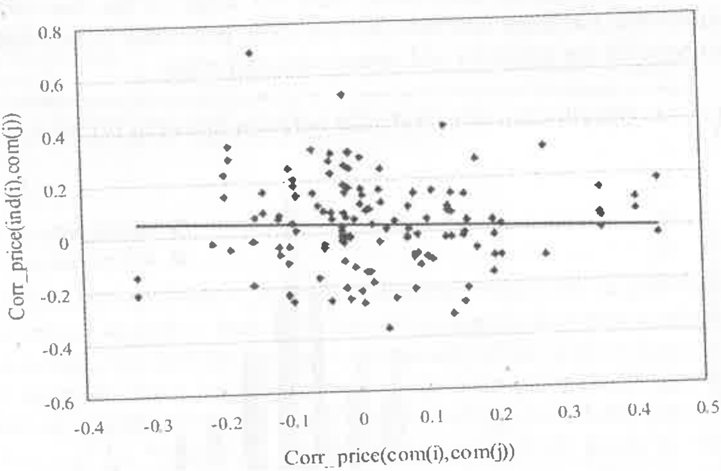
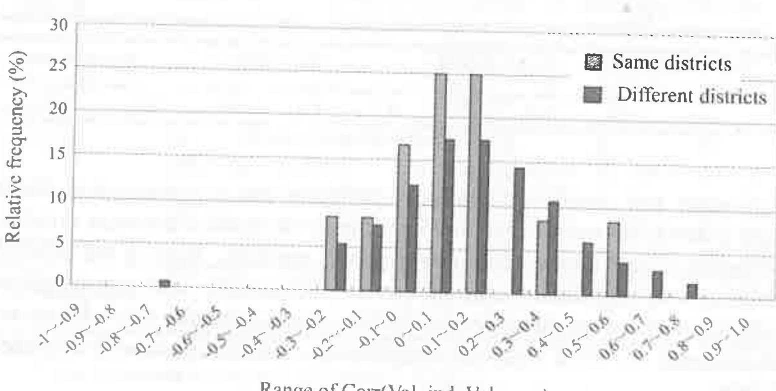


Table 4b gives a more precise result of correlation significance. It shows that at the 95% confidence level, nearly 90% of the districts have insignificant correlations for the full sample. For the sub-samples, price correlations appear to be most insignificant for the same districts, less so for the non-neighboring districts, and the least insignificant for the neighboring districts. It seems that the substitution effect, if any, is restricted to the own district. Among the significant correlations, positive correlations dominate in the full sample and sub-sample of neighboring districts and non-neighboring districts, while in the sub-sample of same districts, negative correlation is found.

It is well known that the co-movement needs not be contemporary, and hence, we allow for a lead-lag in the time horizon. Granger causality tests are conducted to formally assess the lead-lag relationship between the comercial and industrial property prices. Table 4c shows that for the full sample and sub-samples of neighboring districts and non-neighboring districts, over 80% of the districts do not display any causality between the price of industrial and the commercial properties. Causality within the same district is not found neither. Among the districts with significant causality, positive causality running from commercial property price to industrial property price is dominant.

However, co-movements of two markets may not occur in prices. It can be argued that, due to many possible market imperfections or price rigidity, markets interact in the form of "trading volume co-movement".[18] Figure 5a displays the distribution of correlation between trading volumes in the sales market. The peak of same district samples and different districts samples are from 0-0.2. Relative to the correlation of property prices, it seems that the proportion of positive correlation is higher. Figure 5b shows that the correlations among neighbor districts and non-neighbor districts are not significantly different, casting doubt on the hypothesis that geographical distance is important in determining the co-movements of industrial and commercial real estate. Figure 5c presents a data-plot of the correlation between the office in two different districts on the one hand, and the corresponding correlation between a factory in one of the districts and an office in the other district. If the offices in the two districts are good substitutes, and if the office and factory are also good substitutes, one would expect there to be a positive relationship between the two correlations. The figure, however, shows a weakly negative relationship.

Figure 5a: Distribution of correlation between volumes in the sales market



[18] See Lo and Wang (2000) for more discussion on this.

Figure 5b: Distribution of correlation between volumes among different districts in the sales market

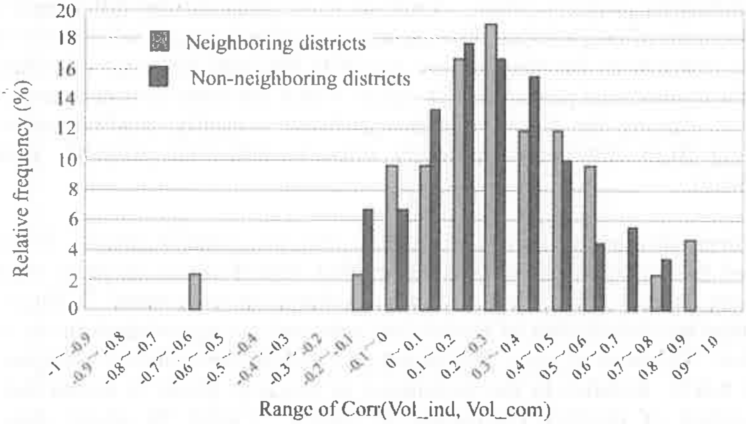
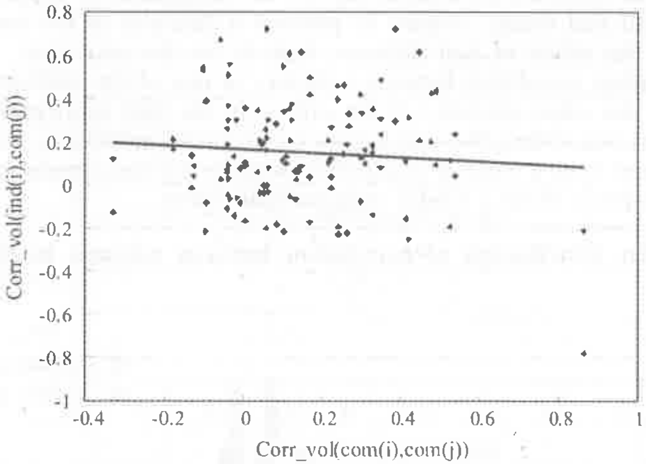


Figure 5c: Relationship between correlations of volumes among different districts in the sales market



Significant test results of volume correlation are summarized in Table 5. Most districts do not display any significant correlation between volumes in the industrial and commercial property sales markets. Among the 20% of the districts with significant correlations in full sample and non-neighboring districts, positive relationships prevailed. Similar results were found in the sub-samples of same districts, neighboring districts, and non-neighboring districts.

Table 5: Significant test of the correlation of volumes in the sales market

Sample	Positive*	Negative*	Insignificant	Total
Full sample	27 (19.44%)	0 (0.00%)	117 **(81.25%)**	144 (100%)
Same districts	2 (16.67%)	0 (0.00%)	10 **(83.33%)**	12 (100%)
Neighboring districts	7 (16.67%)	0 (0.00%)	35 **(83.33%)**	42 (100%)
Non-Neighboring districts	18 (20.00%)	0 (0.00%)	72 **(80.00%)**	90 (100%)

Notes: 1. * denotes that it is significant at the 95% confidence level.
2. Figure in parentheses is the corresponding percentage of the total number.

Again, to allow for cross-period rather than contemporary co-movement in trading volumes, we perform the Granger causality test and report the results in Table 6. Over 50% of the full sample and over 60% of the same districts and neighboring districts display significant causalities, except for the non-neighboring districts, in which 50% of the districts display insignificant causalities. Same districts and neighboring districts show larger proportions of significant causalities than non-neighboring districts. Among the districts with significant statistics, the dominant relationship is that commercial property trading volumes positively Granger causes industrial property trading volumes.

Table 6: Test granger causality of volumes in the sales market

	COM→IND	IND→COM	Two-way causality	Neither	Total
Full sample	41 (28.47%)	29 (20.14%)	9 (6.25%)	65 **(45.14%)**	144 (100%)
Same districts	4 (33.33%)	2 (16.67%)	2 (16.67%)	4 (33.33%)	12 (100%)
Neighboring districts	14 (33.33%)	10 (23.81%)	2 (4.76%)	16 (38.10%)	42 (100%)
Non-neighboring districts	23 (11.11%)	17 (5.56%)	5 (1.11%)	45 **(50.00%)**	90 (100%)

Among districts with significant causality	**COM→IND** (+)	(-)	**IND→ COM** (+)	(-)	**Two-way causality**	**Total**
Fullsample	39 **(49.37%)**	2 (2.53%)	27 (34.18%)	2 (2.53%)	9 (11.39%)	79 (100%)
Same districts	3 **(37.5%)**	1 (12.50%)	2 (25.00%)	0 (0.00%)	2 (25.00%)	8 (0.00%)
Neighboring districts	13 **(50.00%)**	1 (3.85%)	9 (34.61%)	1 (3.85%)	2 (7.69%)	26 (100%)
Non-Neighboring districts	23 **(51.11%)**	0 (0.00%)	16 (35.56%)	1 (2.22%)	5 (11.11%)	45 (100%)

Notes: 1. → denotes the former granger causes the latter only.
2. (+), (-) denotes the positive and negative causality.

Wei (2004) reported that during the same sampling period, the results of the rental market were similar to the sales market. There is neither significant contemporary correlation nor causality between the rents of industrial and commercial properties. Positive correlations of rent prevail when significant correlations exist. Again, there is no clear relationship between industrial and commercial property substitution. For trading volumes, most districts illustrated insignificant correlation and no causality.

Concluding Remarks

This study attempts to investigate the substitutability between industrial properties and offices. In particular, we studied the co-movements of prices and trading volumes. We distinguished between the sales and rental markets. Wei (2004) examined the robustness of the results by focusing on different sub-samples and obtained the same conclusions. First, there is a clear co-movement between the prices of offices and factory buildings in the aggregate data. It was particularly strong during the sub-period of 1991-2002 in the sense that two-way Granger causality was detected. Second, the district level analysis shows a different picture. A majority of the districts displayed no significant contemporary correlation of prices or trading volumes between industrial and commercial properties, either for the sales or rental markets. For those districts that displayed significant correlations, positive value was the norm[19]. These district level results remain largely the same even if we pool the districts into larger areas (suburb v. downtown).

In addition, most districts had no price or rental causalities between the industrial and commercial property markets. The results in trading volume were different. Over half of the districts displayed significant causalities of trading volumes in the sales markets. Where causality existed, it was mainly on the positive side, running from commercial property prices leading industrial property prices in the sales market; but running either way causality in the rental market. Finally, geographical distances had no effect on prices in the sales market, but had an influence on volume in the sales market. In the rental market, the distance effect is weak for both rents and volumes. The sharp contrast of the results in the aggregate and district levels suggests the presence of aggregation bias. Researchers and policymakers should be cautious about such bias, and further analysis is clearly needed.

How should we interpret these findings? One possible explanation is market segregation. Firms that use factory buildings differ from firms that use office

[19] There was only one significant negative correlation of prices, and it was in Yuen Long. Similarly, the only one significant negative rental correlation was in Tai Po. Yuen Long and Tai Po are both major industrial bases in Hong Kong.

buildings. Clearly, industrial buildings provide some facilities that some firms, such as photo shops, some garment manufacturers, etc would need and commercial buildings fail to provide. Also, firms that occupy office buildings may also be reluctant to use factory buildings for a variety reasons. For instance, trading companies with mailing addresses in industrial buildings could be perceived as being in poor financial condition ("signaling effect"). Or firms in some sectors, such as the financial sector, frequently need to do business with other firms of the same sector or some public agents, and hence prefer to stay near each other ("clustering effect"). Therefore, market segregation may reflect the functional differentiation, financial constraint variations, and location preferences of different sectors and firms, which, in turn, have an impact on the price relationship between the industrial and commercial property markets.

On the other hand, market segregation does not explain why we observed a significant amount of trading volume causalities in the sales market. Also, the fact that in most cases, the commercial property market volumes positively Granger causes the industrial property market volumes in the sales market suggests at least some informational spillover between the two types of property. It is possible that there are always some vacancies in the two markets, and when there is any news, the markets adjust the "occupying rates" instead of the prices. Alternatively, it can also be interpreted as indirect evidence for some search-matching theories, when some declining firms will need to leave (more expensive) commercial buildings and move to (less expensive) industrial buildings to continue the operations. The created vacancies are later filled up by improving firms, which now move out from the industrial buildings into office buildings.[20] Unfortunately, no district level vacancy rate data is available, and we are not aware of any theory that simultaneously explains: (1) why property markets should adjust vacancy rates but not prices, and (2) why office market trading volume should Granger cause the factory counterpart. Clearly, more theoretical work along these lines is needed.[21]

It is premature to draw detailed policy recommendations from this study. However, the lack of price correlation or causality between factory buildings and offices may suggest that the substitutability between the two kinds of property in Hong Kong has previously been overstated. It follows that any change in the economic environment may impact "factory-users" and "office-

[20] Among others, see Rogerson et al. (2005) for a review of the search theory.

[21] Another limitation of our study is that we only observed private factories, but not government factory estates due to the lack of public factory data. This may not be an important limitation, though, as government factories are typically not converted into office buildings, and the vacancy rate of some government factories are as high as 50%. See " Vacant units in factory buildings", Hong Kong Government Press Release, 2004-2-25.

users" very differently. Under some conditions, it may lead to an "overreaction" in prices or rents, as well as an "excessive cleansing of firms" during recessions. Future town planning and land use legislation should take this into account. In light of these considerations, further analysis on the role of government in sectoral re-allocation, especially in the property markets, should also be welcome.

References

Asabere, P. K and F. E Huffman (1991). Zoning and industrial land values: The case of Philadelphia, *American Real Estate and Urban Economics Association Journal*, **19**, 2, 154-160.

Bailey, M. J., R. F. Muth, and H. O. Nourse (1963). A regression method for real estate price index construction, *Journal of the American Statistical Association*, **58**, 933-942.

Barber, C., D. Robertson, and A. Scott (1997). Property and inflation: The hedging characteristics of U.K. commercial property, 1967-1994, *Journal of Real Estate Finance and Economics*, **15**, 1, 59-76.

Benjamin, J. D, E. N. Zietz, and G. S. Sirmans (2003). The environment and performance of industrial real estate, *Journal of Real Estate Literature*, **11**, 3, 279-323.

Roy T. Black, Marvin L. Wolverton, John T. Warden, Robert H. Pittman (1997). Manufacturing versus distribution: Implicit pricing of real property characteristics by submarket, *Journal of Real Estate Finance and Economics*, **15**, 3, 271-285.

Bostic, R., S. Gabriel, and G. Painter (2005). Housing wealth, financial wealth, and consumption: New evidence from micro data, Univ. of Southern Calif., mimeo.

James Boyd, Winston Harrington, Molly K. Macauley (1996). The effects of environmental liability on industrial real estate development, *Journal of Real Estate Finance and Economics*, **12**, 1, 37-58.

Brown, G. R. and K W Chau (1997). Excess returns in the Hong Kong commercial real estate market, *The Journal of Real Estate Research*, **14**, 1-2, 91-105.

Case, B. and J. M. Quigley (1991). The dynamic of real estate prices, *Review of Economics and Statistics*, **22**, 50-58.

Case, B., H. O. Pollakowski, and S. M. Wachter (1991). On choosing among house price index methodologies, *AREUEA Journal*, **19**, 3, 286-307.

Case, K. E. and R. J. Shiller (1987). Prices of single family homes since 1970: New index for four cities, *New England Economic Review*, Sept/Oct, 45-56.

Chowdhry, B. and V. Nanda (1991). Multimarket trading and market liquidity, *Review of Financial Studies*, **4**, 3, 453-511.

Clapp, J. M. and C. Giaccott (1992). Estimating price indices for residential property: A comparison of repeat sales and assessed value methods, *Journal of the American Statistical Association*, **87**, 418, 300-306.

Dickey, D. and W. Fuller (1979). Distribution of the estimators for autoregressive time series with a unit root, *Journal of the American Statistical Association*, **74**, 427-431.

DiPasquale, D. and W. Wheaton (1996). *Urban Economics and Real Estate Markets*. New Jersey: Prentice Hall.

Dombrow, J., J.n R. Knight, and C. F. Sirmans (1997). Aggregation bias in repeat-sales indices, *Journal of Real Estate Finance and Economics*, **14**, 75-88.

Echevarria, C. (1997). Changes in sectoral composition associated with economic growth, *International Economic Review*, **38**, 2, 431-452.

Efron, B. (1979). Bootstrap methods: Another look at the Jackknife, *Annals of Statistics*, **7**, 1-26.

Englund, P., J. M. Quigley, and C. L. Redfearn (1998). Improved price indexes for real estate: measuring the course of Swedish housing prices, *Journal of Urban Economics*, **44**, 171-196.

Greene, W. (2000). *Econometric Analysis*, 4th ed. New York: Prentice Hall.

Grissom, T. V., D. J. Hartzell, C. H. Liu (1987). An approach to industrial real estate market segmentation and valuation using the arbitrage pricing paradigm, *American Real Estate and Urban Economics Association Journal*, **15**, 3, 199-219.

Halvorsen, R. and H. O. Pollakowski (1981). Choice of functional form for hedonic price equation, *Journal of Urban Economics*, **10**, 37-49.

Hanushek, E., S. Rivkin, and L. Taylor (1996). Aggregation and the estimated effects of school resources, *Review of Economics and Statistics*, **78**, 611-627.

Hanushek, E. and K. Yilamz (2005). When Alonso meets Tiebout, Hoover Inst., Stanford Univ., mimeo.

He, L. T, J. R Webb (2000). Causality in real estate markets: The case of Hong Kong, *Journal of Real Estate Portfolio Management*, **6**, 3, 259-271.

Huang, J. and J. Wang (2004). Transactions Cost, Liquidity and Asset Prices, MIT, mimeo.

Ito, T. and W. L. Lin (1993). Price volatility and volume spillovers between the Tokyo and New York stock markets, *NBER Working Paper* 4592.

Jackson, T. O. (2001b). The effects of environmental contamination on real estate: A literature review, *Journal of Real Estate Literature*, **9**, 91-116.

Jackson, T. O. (2001c). Environment risk perceptions of commercial and industrial real estate lenders, *Journal of Real Estate Research,* **22**, 3, 271-288.

Jackson, T. O. (2002). Environmental contamination and industrial real estate prices, *Journal of Real Estate Research*, **23**, 1/2, 179-199.

Jayantha, W. M., S. S. Y. Lau, and S. Ganesan (2001). The impact of a rapidly expanding service sector on private office property: The case of Hong Kong, *Review of Urban and Regional Development Studies,* **13**, 3, 221-243

Jones, C., A. Orr (1999). Local commercial and industrial rental trends and property market constraints, *Urban Studies,* **36**, 2, 223-237.

Kain, J. F., and J. M. Quigley (1970). Measuring the value of housing quality, *Journal of American Statistical Association*, **65**, 532-548.

Kan, K., S. K. S. Kwong, and C. K. Y. Leung (2004). The dynamics and volatility of commercial and residential property price: Theory and evidence, *Journal of Regional Science*, **44**, 1, 95-123

Kongsamunt, P., S. Rebelo, and D. Xie (2001). Beyond balanced growth, *Review of Economic Studies*, **68**, 869-882.

Leung, C. K. Y. and S. K. S. Kwong (2000). Price volatility of commercial and residential property, *Journal of Real Estate Finance and Economics*, **20**, 25-36.

Leung, C. K. Y. and D. Feng (2005). What drives the property price-trading volume correlation? Evidence from a commercial real estate market, *Journal of Real Estate Finance and Economics*, **31**, 241-255.

Leung, C. K. Y., G. C. K. Lau, and Y. C. F. Leung (2002). Testing alternative theories of the property price-trading volume correlation, *Journal of Real Estate Research*, **23**, 253-263.

Lo, A. W. and J. Wang (2000). Trading volume: Definitions, data analysis, and implications of portfolio theory, *Review of Financial Studies*, **13**, 2, 257-300.

Macgregor, B. and G. M Schwann (2003). Common features in UK commercial real estate returns, *Journal of Property Research*, **20**, 1, 23-48.

Meese, R.A. and N.E. Wallace (1997). The construction of residential housing prices indices: A comparison of repeat-sales, hedonic-regression, and hybrid approaches, *Journal of Real Estate Finance and Economics*, **14**, 51-73.

McDonald, J. F. and D. P. McMillen (2000). Employment subcenters and subsequent real estate development in suburban chicago, *Journal of Urban Economics*, **48**, 135-157.

Ngai, R. L. and C. A. Pissarides (2004). Structural change in a multi-sector model of growth, LSE, Mimeo.

Pace, R. K. (1993). Nonparametric methods with application to hedonic models, *Journal of Real Estate Finance and Economics*, **7**, 3, 185-204.

Rogerson, R., R. Shimer, and R. Wright (2005). Search-theoretic models of the labor market: A survey, *Journal of Economic Literature*, forthcoming.

Quigley, J. M. (1995). A Simple hybrid model for estimating real estate prices indices, *Journal of Housing Economics*, **4**, 1-12.

Simons, R. A. (1994). Industrial real estate mortgage default experience of the New York state job development authority second loan program: A preliminary investigation, *Journal of the American Real Estate and Urban Economics Association*, **22**, 4, 631-646.

Sims, C. A. (1972). Money, income and causality, *American Economic Review*, **62**, 4, 540-552.

Sivitanidou, R and P Sivitanides (1995). Industrial rent differentials: The case of greater Los Angeles, *Environment and Planning A*, **27**, 7, 1133-1146.

Somerville, C. T. (1999). The industrial organization of housing supply: Market activity, land supply and the size of homebuilder firms, *Real Estate Economics*, **27**, 4, 669-694.

Sung, Y. W. (1998). *Hong Kong and South China: The Economic Synergy*. Hong Kong: City University of Hong Kong Press.

Sung, Y. W. (2005). *The Emergence of Greater China: The Economic Integration of Mainland China, Taiwan and Hong Kong*. Hampshire: Palgrave.

Tao, Z. and Wong, Y. C. R. (2002). Hong Kong: From an industrialised city to a centre of manufacturing-related services, *Urban Studies*, **39**, 12, 2345-2358.

Thompson, B. and S. Tsolacos (1999). Rent adjustments and forecasts in the industrial market, *Journal of Real Estate Research*, **17**, 1-2, 151-167

Tse, R. Y. C., Y. H. Chiang, and J. Raftery (1999). Office property returns in Shanghai, Guangzhou, and Shenzhen, *Journal of Real Estate Literature*, **7**, 197-208.

Wang, P. (2000). Market efficiency and rationality in property investment, *Journal of Real Estate Finance and Economics*, **21**, 2, 185-201.

Wei, P. (2004). The correlation of industrial and commercial real estate prices in Hong Kong, Chinese University of Hong Kong, unpublished thesis.

Wheaton, W. (1999). Real estate "cycles": Some fundamentals, *Real Estate Economics*, **27**, 2, 209-230.

Wheaton, W. and R. G. Torto (1990). An investment model of the demand and supply for industrial real estate, *American Real Estate and Urban Economics Association Journal*, **18**, 4, 530-547.

Vacant units in factory buildings, Hong Kong Government Press Release, Feb.25, 2004. http://www.info.gov.hk/gia/general/200402/25/0225186.htm.

Appendix 1: Reviews on industrial property attributes

	Wheaton and Torto, 1990	Asabere and Huffman, 1991	Sivitanidou and Sivitanides, 1995	Black and. Wolverto, 1997	Thompson and Tsolacos, 1999	McDonald and McMille, 2000	Thomas O. Jackso, 2002
DATA							
Time period	1972-1989	1980	1990	1987-1995	1978:1-1997:4	1990-1996	1995-1999
Location	US	US	US	US	UK	US	US
Frequency	Annual	Monthly		Annual	Quaterly	Annual	Annual
Sample size	130,000	100	461	331	80	14,289	102
Dependent variables	**Industrial space stock**	**Log of sale prices of vacant lot**	**Log of industrial property rents**	**Log of industrial property prices**	**Index of national industrial rents adjusted for inflation**	**Industrial development in quarter section**	**Log of industrial property prices**
Independent variables							
PHYSICAL							
Building size			(-7.37)***	(3.94)***			(5.09)***
Office area				(3.45)***			
Site area		(6.148)**		(2.02)*			(3.69)**
Dock-high doors				(4.56)***			(4.01)*
Crane				(3.96)***			
Air-conditioning				(1.92)*			
Age			(-6.30)***	(-3.60)***			(-1.44)
Absorption rate					(2.3)**		
LOCATIONAL							
Distance to the CBD		(-4.686)**		(-2.58)***		(3.53)***	
Distance to the airport			(-6.33)***			(3.32)***	
Distance to the freeway interchange			(3.58)***			(2.43)*	
Rail				(0.79)		(1.16)	
Distance to the shopping mall			(2.39)*				
Distance to the nearest employment sub center						(2.194)*	
Percent of housing abandoned in the neighborhood		(-3.025)**					

(Continued)

	Wheaton and Torto, 1990	Asabere and Huffman, 1991	Sivitanidou and Sivitanides, 1995	Black and. Wolverto, 1997	Thompson and Tsolacos, 1999	McDonald and McMille, 2000	Thomas O. Jackso, 2002
REGIONAL							
Education			(5.42)***				
Crime			(-1.96)*				
Agriculture						(6.342)***	
Business services			(3.75)***				
Water						(2.119)*	
Parks and open space						(1.474)	
Total zoned land for Ind.use			(-3.15)***				
Percentage of total zoned land for Ind. use		(-2.129)*	(-4.55)***				
Residential zoning		(-0.599)					
Growth on nonresidential development			(6.48)***				
TENANT TYPE							
Multi-tenancy			(2.71)***				
ECONOMIC VARIABLE							
Manufacturing wage				(2.96)***			
Manufacturing employmen	(3.12)*						
Wholesale employmen	(4.66)*						
Capital cost	(-2.65)*						
Union win ratio				(-1.54)			
Time of sale		(1.833)*		(-2.60)***			
Net rents			(-1.98)*				
Income		(2.873)*					
GDP					(2.7)**		
Adjusted *R*	0.83	0.403		0.55	0.47		0.886

* Significant at the 0.01 level; ** Significant at the 0.05 level; *** Significant at the 0.10 level

Appendix II: Measurement of Prices and Volume

In terms of measurement, this paper follows the works of Leung et al. (2002) and Leung and Feng (2005). This study employed the realized rate of return as the detrended property price, and the number of transactions per quarter as trading volume.

The realized rate of return is a weighted average value in quarterly frequency using transaction value as the weight. The transaction value was calculated as the product of unit price and construction area. Intuitively, the larger the value successfully transacted, the more representative the trading would be. First, the weighted average price per quarter is obtained in order to calculate the realized rate of return. The formulas are described as follows:

$$W_i = \frac{P_{ij} Q_{ij}}{\sum_j P_{ij} Q_{ij}}, \quad \sum_i W_i = 1, \quad \sum_i W_i P_i = \overline{P},$$

where i is the index of district, j is the number of transactions of the i-th district per quarter, P is the price per square foot, Q is the construction area, W is the ratio of the dollar value on the transaction date to the total dollar value transacted within a quarter, and $\overline{P}$ is the weighted average price per quarter.

Deflated by the quarterly composite consumer price index (1990=1), the realized rate of return, or the percentage change of the real price, is derived as follows:

$$P^* = \frac{\overline{P}}{\text{CPI}}, \quad \text{ROR}_t = \frac{P_t^* - P_{t-1}^*}{P_{t-1}^*} * \frac{1}{D},$$

$$D = n + 1 \ \text{ if zero-transaction period} = n \quad (n \geq 0).$$

Where $P*$ is the real price per quarter of a certain district, ROR_t is the realized rate of return per quarter of that district, adjusting for zero-transaction duration D. This study will focus on the effective sampling period,[22] which begins with the first period with non-zero ROR and ends with the last non-zero ROR period. The effective sampling period is a convenient tool not only because it precludes uninformative zero-ROR or zero transactions in the time series, but also because it can be utilized to compare the industrial and commercial property time series for more reliable correlation analysis. If both time-series have different effective sampling

[22] For more discussion of the effective sampling period, see Leung and Feng (2005).

periods, we select the shorter effective sampling period for the calculation of correlation. In the following tables, the dramatic variations of the effective sampling period for each district between the industrial and commercial property markets are depicted.

Table II-a: Summary of statistics at the district level in the sales market

Variable list	Industrial real estate sales market			Commercial real estate sales market		
	max	min*	mean	max	min*	mean
Trading volume of each district	8812	98	2784	8359	2	1334
Efficient sampling period	44	43	43	44	9	41
Zero transaction period	4	0	1	35	0	9

*Note: Calculation of the minimum excludes the district with no transaction record

Table II-b: Summary of statistics at the district level in the rental market

Variable list	Industrial real estate rental market			Commercial real estate rental market		
	max	min*	mean	max	min*	mean
Trading volume of each district	1159	20	332	2620	12	502
Efficient sampling period	44	31	42	44	25	39
Zero transaction period	27	0	10	30	0	10

*Note: Calculation of the minimum excludes the district with no transaction record

In this study, the number of transactions per quarter was used as a measurement of trading volume. This proxy is widely employed in the real estate literature because it avoids the possible disturbing effect of the heterogeneous features of properties and idiosyncratic tastes of traders.[23]

[23] For a detailed discussion of the trading volume, please see Leung et al. (2002).

Appendix III: A Review of the Econometric Tools

ADF test

Before calculating correlation coefficients, a test for series stationary is needed to avoid spurious results. The Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests for the presence of a unit root are used as a formal test for stationary. Specifically, consider a first-order autoregressive process:

$$y_t = \alpha_1 y_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim \text{idd}(0, \sigma^2) \qquad \text{(III.1)}$$

Subtracting y_{t-1} from each side of equation (1) we obtain:

$$\Delta y_t = (\alpha_1 - 1) y_{t-1} + \varepsilon_t \qquad \text{(III.2)}$$

or

$$\Delta y_t = \gamma y_{t-1} + \varepsilon_t \qquad \text{(III.3)}$$

To find out if series { y_t } has a unit root, a t-test can be constructed with the null hypothesis $\gamma = 0$ (which is the same as $\alpha_1 = 1$). The usual t distribution is inapplicable under this null hypothesis, but Dickey and Fuller (1979) tabulated the appropriate τ ("tau") statistics. Because under non-stationary, the statistics computed are not asymptotically or normally distributed, but distributed according to the Dickey-Fuller distribution, which is skewed to the left.

A more general specification of Equation (III.3) which is often used in practice is:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \alpha_2 t + \varepsilon_t \qquad \text{(III.4)}$$

That is, constant and time trend terms are included. Again, the null hypothesis is that $\gamma = 0$ (i.e., { y_t } contains a unit root, so it is non stationary). However, if the error term ε_t is autocorrelated, then Equation (III.4) is modified by adding lagged difference terms, and the test is known as the Augmented Dickey-Fuller (ADF) test:

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \alpha_2 t + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t,$$

where

$$\gamma = -\left(1-\sum_{i=1}^{p}\alpha_i\right), \quad \beta_i = \sum_{j=i}^{p}\alpha_j \qquad \text{(III.5)}$$

The lagged difference terms $\sum_{i=2}^{p}\beta_i \Delta y_{t-i+1}$ are added to capture the autocorrelated omitted variables that would enter the error term. However, the true order of the autoregressive process is usually unknown, so that it is important to select the appropriate lag length. Including too many lags will reduce the power of the test to reject the null hypothesis. On the other hand, too few lags will not appropriately capture the actual error process and result in an over-rejection of the null when it is true. There are several ways to determine the proper number of lagged differences; and we will employ the most commonly used ones – the Akaike information criterion (AIC) and Schwartz Bayesian criterion (SBC) – in our study.

The partial autocorrelation function

Stationary time series may be autocorrelated. To prevent spurious results, it is necessary to pre-whiten the series by removing the autocorrelation of the series. The partial autocorrelation function (PACF) is used to detect the autocorrelation of the series.

The partial autocorrelation function measures the correlation between two observations, y_t and y_{t-s}, once the effect of the intervening values y_{t-1} has been removed. To get the partial autocorrelation function, first consider an AR (1) process $y_t = \alpha_1 y_{t-1} + \varepsilon_t$, subtracting the mean of $y(\mu)$ for each observation from both sides, we have a new AR (1) equation:

$$y_t{}^* = \phi_{11} y_{t-1}{}^* + e_t \qquad \text{(III.6)}$$

Where: e_t = an error term,

$y_t{}^* = y_t - \mu$.

Because the error process may not be a white noise, the symbol $\{ e_t \}$ is used for clarity. Since there is no intervening value, the first order autocorrelation coincides with the autoregressive parameter ϕ_{11}. Now consider the AR (2) process:

$$y_t{}^* = \phi_{11} y_{t-1}{}^* + \phi_{22} y_{t-2}{}^* e_t \qquad \text{(III.7)}$$

Here the ϕ_{22} coefficient measures the correlation between y_t and y_{t-2} once the effect of y_{t-1} has been removed. Repeating this process for all additional lags yields the partial autocorrelation function. Usually, with sample size n, $n/4$ lags are used to obtain the sample PACF.

PACF can aid in identification of an AR(p) process. In the AR(p) process, there is no direct correlation between y_t and y_{t-s} for $s>p$. In other words, all values of ϕ_{ss} will be zero for $s>p$. Therefore, the PACF for an AR(p) process should cut to zero for all lags greater than p. The PACF coefficients can be test under the null hypothesis of AR(p) model (i.e., all $\phi_{p+i,p+i}$ are zero), the variance of $\phi_{p+i,p+i}$ is approximately T^{-1}.

Bootstrap technique

In the traditional analysis, the statistically significant tests of the time series are conducted under the normality assumption. However, for the small samples, this assumption may not hold. In our study, the bootstrap method (Efron, 1979) is used.

The bootstrap technique estimates statistics from a small limited data sample by repetitively random re-sampling of the small data. Then the parameter of interest for the population can be approximated from the bootstrapped sample data. In addition, confidence intervals and the sampling error can be calculated. These estimates completely summarize the information about the parameters, and do not require unwarranted assumptions about the data. Therefore, the bootstrap technique is a powerful tool to estimate population statistics and confidence intervals from small samples without assuming anything about the underlying distribution of the data.

The Granger causality test

The correlation coefficient in our study is a conventional tool for summarizing the contemporaneous relationship. The relationship between two time series, however, is not necessarily contemporaneous. Thus, the Granger causality test is used as a formal tool to assess the lead-lag relationship between two time series.

Defined by Granger (1969) and Sim (1980), causality is supposed when the lagged values of a variable, x_t, have explanatory power in the regression of a variable, y_t, on lagged values of y_t and x_t. The procedure to test whether x_t causes y_t is as follows:

First, running two regressions for null hypothesis " x_t does not cause y_t ":

Unrestricted regression:

$$Y_t = \sum_{i=1}^{m} \alpha_i Y_{t-i} + \sum_{i=1}^{n} \beta_i X_{t-i} + \varepsilon_i \qquad \text{(III.8)}$$

Restricted regression:

$$Y_t = \sum_{i=1}^{m} \alpha_i Y_{t-i} + \mu_i \qquad \text{(III.9)}$$

Last, use the sum of squared residuals from (4.8) and (4.9) to calculate an F statistic and test whether the group of coefficients $\beta_1, \beta_2, \beta_3, \ldots, \beta_n$ are significantly different from zero. If they are, we can reject the null hypothesis that " x_t does not cause y_t ".

The *F*-statistic is defined as:

$$F = \frac{(N-k)(\text{ESS}_R - \text{ESS}_{UR})}{q(\text{ESS}_{UR})} \qquad \text{(III.10)}$$

Where ESS_R and ESS_{UR} are the sums of squared residuals in the restricted and unrestricted regression, respectively; N is the number of observations; k is the number of estimated parameters in the unrestricted regression; and q is the number of parameter restrictions. The statistic is distributed as $F(q, N-k)$. Because the Granger causality tests are very sensitive to the choice of lag length, the Akaike information criterion (AIC) will be used to choose the proper periods of lag.