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Dynamics between Direct Industrial Real Estate and the Macroeconomy: An Empirical Study of Hong Kong

Daniel Lo [1,*], Yung Yau [2], Michael McCord [1] and Martin Haran [1]

[1] Faculty of Computing, Engineering and the Built Environment, Ulster University, Newtownabbey BT37 0QB, UK
[2] Department of Sociology and Social Policy, School of Graduate Studies, Lingnan University, Hong Kong
* Correspondence: d.lo@ulster.ac.uk

Abstract: Pricing of direct industrial real estate (DIRE) has long been under-researched due to the paucity of analysable data. Compared to other types of real estate, DIRE has often been regarded as more inefficient because of information asymmetry amongst market players stemming from a lack of market transparency. Therefore, pricing of DIRE usually does not follow a random walk and should be more predictable than other types of real estate. Along this line of reasoning, this study empirically investigates the causal relationships between the price-to-rent ratio of DIRE and macroeconomic attributes using cointegration and causality techniques. More specifically, we employ data on the market of Hong Kong to investigate the lead-lag relationships between the price-to-rent ratio of DIRE and a wide spectrum of macroeconomic and financial indicators, including inflation, money supply, national income, exchange rates, performance of housing market and other economic indicators specific to the industrial sector. The results of our statistical tests reveal significant evidence that DIRE is generally moving in syncs with other segments of the economy over time in terms of long-term cointegration. Further, DIRE tends to lag behind the overall macroeconomy in terms of Granger causation with the price-to-rent ratio exhibiting varying lengths of time lag with the macroeconomic determinants. The findings of the study carry important implications for informing property valuation practices and industrial land policy, particularly in designing urban revitalization programmes aimed at optimising industrial land use.

Keywords: price-to-rent; industrial real estate; macroeconomics; market efficiency; Granger causality; Hong Kong

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1. Introduction

Direct industrial real estate (DIRE) is often characterised by low liquidity and transparency, and high physical heterogeneity and information asymmetry between market participants. Undertaking the valuation of DIRE is therefore a decidedly challenging exercise, not least when the market is sluggish with a paucity of transactions, or when special-purpose properties of rare structural features and functionality are concerned. Nonetheless, numerous studies have been conducted to explore the determinants of pricing with respect to the price and rent of DIRE at the property level, with the majority of research endeavours centred around how they can be explained by property attributes such as building age and structural design [1,2], proximity to labour market, accessibility or distance to infrastructure and economic centres [3–5], and industrial agglomeration [1,3,6]. As far as property valuation is concerned, the price-to-rent ratio has frequently been employed by real estate practitioners, traders, and policy makers to assess whether a given property market is overheated by, for instance, comparing the ratios cross-sectionally and contemporaneously with other similar markets, or temporally with the historical trends of the subject market [7] In the context of residential real estate, a significant deviation of the price-to-rent ratio from its long-term historical trends usually signals a decline in housing affordability or excessive speculative activity within the market, and a consequent mean reversion to its equilibrium value would likely occur. For commercial real estate, including DIRE, the price-to-rent ratio could indeed reveal useful information about the behaviours of market players and the interaction between the property market and the macroeconomy, including the legal and regulatory environment: a high price-to-rent ratio may imply market players anticipating a shortage of new supply in the foreseeable future, whilst a low ratio value may be indicative of a surging demand for rental properties resulting from, for example, a stamp duty increase.

An extensive body of literature has been directed at examining the dynamics between the ratio and the macroeconomy, with the majority of them focusing primarily on residential real estate and, to a lesser extent, the commercial office sector. Of particular societal relevance and importance are the branches of studies that delve into topics in relation to "buy versus rent" [8], generation rent [9,10], affordability [11,12] and the role of macroeconomics in the determination of price/rent of office real estate [13] However, relatively few scholarly works have given a thorough empirical account of the price-to-rent ratio of DIRE and its relationships with its underpinning macroeconomic determinants that shape the property market landscape. A more integrative and nuanced conceptualization of the dynamics between DIRE and the wider economy is of paramount importance in formulating industrial policy and guiding economic transformation on one hand and informing valuation practices of DIRE on the other. Against this backdrop, this study attempts to explore and dissect the macroeconomic and financial determinants of the price-to-rent ratio of DIRE using data from the Hong Kong market. More specifically, it is positioned to examine the long-term cointegration and causal relationships between the ratio and a wide spectrum of macroeconomic indicators, including attributes related to the general economic conditions, forex market, manufacturing sector, and other external economic factors with a purpose to enhance the empirical understanding of the market drivers of DIRE. Previous studies [14–16] in residential and commercial real estate (including the retail and warehouse subsectors) have illuminated that macroeconomic attributes can be used to explain the pricing behaviours of traders within a property market with the price-rent dynamics critically dependent on the liquidity, transparency, and/or efficiency of an economy. For example, Duca and Ling [14] observe that the capitalisation rate behaves differentially during periods of market boom and bust, with capital availability/liquidity being one of the key factors affecting the pricing of the market across the real estate industries of retail, industrial warehouse, apartment, and commercial office. Given the more inefficient nature of DIRE relative to other property sectors, we contend that the price-to-rent dynamics should be more pronounced and hence more noticeable with respect to the general macroeconomic conditions. In addition, since increasing the supply of DIRE is, in many circumstances, a technically more cumbersome and time-consuming process in view of, for example, town planning procedures, we therefore further posit that the price/rent interaction of DIRE could be less instantaneously responsive to changes in the market fundamentals of the economy.

Indeed, the primary motivation of the current study lies in the rather unique vicissitude of the Hong Kong manufacturing market and its industrial property sector over the past century, which makes the city an interesting subject upon which to conduct research. Since the "Reform and Openness" initiatives of China, designed and launched by Deng Xiaoping in 1979, the industrial sector of Hong Kong as a whole has witnessed a process of gradual, but inevitable, de-industrialisation with a constant outflow of manufacturing jobs, facilities, and investments to the mainland, particularly to the Pearl River Delta region, due to the imbalances and disparity of land supplies, production costs, and supplies of labour between the two places. The rapid and large-scale modernisation across China has concomitantly marked the end of the era of "Made in Hong Kong" when the city was once hailed as the Pearl of the Orient under the effective and efficacious governance and forward-looking leadership of the British colonial government based on the principles of laissez-faire capitalism and rule of law. During the colonial time, Hong Kong was, astoundingly, one of the world's leading exporters in many industries such as clothing and textile, plastics, toys, and electronics, despite the city's relatively small population and lack of natural resources. With the de-industrialisation of the city came the debilitation of its industrial real estate sector. The significance of the sector has shrunk substantially both in terms of output and labour force over the past four decades. Vacant, dilapidated, under-utilised, and poorly maintained decades-old industrial buildings scatter across the city, with some being converted—lawfully or unlawfully—to structures for residential and/or non-industrial uses. In 2010, the government of Hong Kong launched a scheme known as the "Revitalisation of Industrial Buildings", with an objective to optimise land use in order to meet the incessantly changing needs of the society. To facilitate the growth and development of new industries such as testing and certification services, cultural and creative industries, and environmental industries as promoted in the Policy Address in 2009–2010 (See: https://www.policyaddress.gov.hk/09-10/eng/index.html, accessed on 1 August 2022), the government introduced a number of measures to increase industrial land supply by, for instance, putting forward a tailor-made lease modification system, which provided favourable terms and conditions to land users/owners to redevelop their existing properties or apply for a wholesale conversion of the buildings with a land premium determined by their most suitable use. Hundreds of applications under the scheme have been approved, with millions of square metres of industrialised land being revitalised or created.

The remainder of the paper is organised as follows. Section 2 discusses the literature on the relationships between the price-to-rent ratio and macroeconomic attributes, covering not only the industrial property sector, but also the residential and commercial property markets. Section 3 presents the research methods of the study, providing an in-depth discussion on the Johansen cointegration test and the Granger causality model. Section 4 presents the key research findings, followed by an analysis of the results. The last section concludes the study.

2. Literature Review

From the perspective of price discovery, the dynamics between property price and rent as well as their cross-sectional and temporal associations with other macroeconomic determinants can indeed be explained by the DiPasquale and Wheaton model (or the DW model) [17]. Pertinently, property such as other asset classes can be viewed as an investment, with its price equal to the summation of all future discounted incomes that can be derived. The demand for real estate and the total housing stock jointly determines the level of rent. When the demand increases due to an exogenous shock, for instance, rent should increase as a result, given that the amount of housing stock remains largely the same in the short term. The surging rent should, on average, translate into a higher price of property through a process known as capitalisation. The rate of capitalisation, commonly termed "investment yield", indicates the opportunity cost that investors require to invest in the assets. Four economic attributes are encapsulated in the DW model, which governs the fashion in which the yield is determined, namely, long-term interest rate, expected growth rate of rental income, the risk associated with the generation of rental income, and government policy.

A large volume of research in the housing literature has been devoted to uncovering and explaining the joint dynamics of real estate prices and rents by employing different statistical methods and datasets. Pertinently, most of the attention within the literature on the price-to-rent ratio has so far been drawn to the residential real estate sector given its more transparent nature with relatively more readily available data for undertaking empirical analysis. For example, Sommer et al. [18] explored the linkages between property rents and prices for the US market using a dynamic equilibrium stochastic model of housing tenure choice. The results indicated that during the period of 1995 and 2005, over half of the growth in the price-to-rent ratio was a consequence of a higher per capita income, more relaxed lending requirements, and low interest rates. In a subsequent study, Kishor and Morley [19] examined market fundamentals that could affect the price-to-rent ratios of eighteen cities in the US. Their investigation was based upon Campbell and Shiller's analytical framework [20], which was, in turn, premised on the decomposition of the price-to-rent ratio into two components: an unobserved component, which is determined by the expected real estate return and the growth rate of real rental income, and a residual component, which explains the non-stationary temporal deviation of the ratio from its present value. The results discovered that large cities tend to have a present value component greater than that implied by the statistical model. In other words, large cities generally have a higher average price level relative to its rent counterpart.

Ayuso and Restoy [7] corroborated, using a general intertemporal asset pricing model, that residential market prices tend to mean-reverse to their long-term equilibrium over a long time horizon. Using data on the UK, US, and Spanish markets, their research findings displayed that the past overvaluation of the property sectors as reflected by high price-to-rent ratios are attributable to the slow adjustment of rents and inelasticity of housing supply in the presence of demand shocks. From a global economic perspective, Beltratti and Morana [21] revealed strong and persistent interlinkages between the housing markets of the G7 nations with their price fluctuations governed by some common global macroeconomic factors such as investment flows, productivity growth, global stock prices, and oil prices. Importantly, bidirectional causal linkages are evident between house prices and macroeconomic developments, with investment exhibiting a greater impact upon house price shocks relative to consumption and output factors. In relation to the dynamics between house price and rent, some existing empirical evidence in the housing literature suggested that they react to macroeconomic attributes in a differential manner. For instance, compared to rent, house price is more responsive to changes in short-term interest rates and the general productivity of the economy. On the other hand, rent is a lagging indicator of price and short-term interest rates [22].

In the context of the UK, Bracke [23], by evaluating the micro-spatial property price structure of London, illuminated that residential neighbourhoods of higher economic standing tend to be associated with higher price-to-rent ratios. Clark and Lomax [24] also utilised the British housing market transaction and rental price data and established a strong positive empirical relationship linking the degree of physical desirability of a neighbourhood and the price-to-rent ratio. Further, the study showed that detached and semi-detached houses, on average, display higher price-to-rent ratios relative to terraced houses and apartments. More recently, McCord et al. [25] and Lo et al. [8] explored the price-to-rent characteristics of the UK market for different property types, confirming that the detached sector tends to Granger-cause other submarkets in terms of pricing. It is further evident that the price-to-rent ratios of the detached sector are the largest as well as the most volatile. In their subsequent studies [15,16], they empirically revealed that GDP, money supply, foreign exchange markets, and the performance of the equity market are important drivers of the price-to-rent ratio. Further, Lo et al. [26] demonstrated how real estate pricing is intimately correlated with the efficiency of the market by examining the spatial autocorrelation structure of house prices in the UK.

Despite the DIRE sector being relatively under-researched, some studies in the literature did attempt to provide evidence-based investigations that are empirically insightful, dissecting the price–rent dynamics and the market fundamentals that underpin them. For instance, Ambrose [27] investigated 57 industrial real estate listings in Georgia, USA, for the period of 1986–1987 and observed that the industrial property market was indeed priced fairly rationally by investors through valuations that were based on building-specific and locational attributes. Further, industrial properties that were listed for sale were over 200% as large and had smaller finished space for office than properties for lease. In other words, traders in the market priced property attributes differently when they were buying than when they were leasing.

Another strand of studies focused more exclusively on the efficiency of industrial property. Atteberry and Rutherford [28] utilised the hedonic valuation model to examine over 700 industrial property sales in Dallas, USA. They detected a significant time lag between past and current industrial real estate prices, seemingly suggesting that the industrial markets under investigation were not informationally efficient, since the current prices did not fully reflect the past price information. In a similar study, Chai [29] scrutinised the pricing of the warehouse sector and revealed that the general market conditions comove with income-generating industrial properties. More specifically, the demand for and supply of warehouses jointly determine the levels of vacancy rates, rents, and net operating income of the firms within the sector, which indeed echoed the propositions and assumptions of the DW model. Mueller [30] also reported similar empirical findings in line with the DW model, revealing that local demand and supply are key determinants affecting the rental growth rates of industrial real estate. On a different note, Wang et al. [31] observed that the value of an industrial property could be heavily influenced by the level of technology at both industry and national levels. They conjectured that technological progress could optimise production methods and, hence, improve energy efficiency at the property level, which would translate into higher property values. Further, new technological breakthroughs could stimulate more industrial development, creating even more demand for industrial land that could result in higher land prices.

Some studies have shed empirical light on the relationships between the price/rent performance of DIRE and macroeconomic attributes. Notably, Thompson and Tsolacos [32] probed into the British industrial property data and established that industrial property real rents or their growth rates are closely and positively related to the general productivity of the economy proxied by GDP, which determines the demand for manufacturing goods. Further, they found that real rents and construction costs collectively determine the supply. A later investigation by Jones and Orr [33], also utilising British data, further revealed that the supply attributes of industrial real estate are of higher elasticity than those of the retail sector. In subsequent studies, Benjamin et al. [1] and Jackson and White [34] both averred that price inflation and interest rates are two important determinants of real prices and rents of industrial property. In particular, the two factors would generally lead to a decline in the performance of industrial property in terms of price and rent, especially in times of economic slowdown.

Appositely, the interrelationships between price, rent, return, and macroeconomic determinants for income-generating property have been examined more rigorously within the commercial office and retail real estate sectors. Using global real estate data on the Asian, European, and American markets, de Wit and van Dijk [35] found that employment, vacancy rates, GDP, general price level, and stock are significant drivers of the returns on office space investments. A later study by Karakozova [36] further confirmed their results using the Finnish property market data, with findings pointing to GDP and the territory sector employment rates being significant drivers of direct commercial office returns, whilst pointing out that factors affecting industrial real estate returns have received little attention in the literature. In a similar vein, Lieser and Groth [37] explored demographic, social, economic, and institutional attributes that could have an impact on commercial property investment activity. The study is empirically insightful and comprehensive in that it covered forty-seven countries over a nine-year investigation period, showing within a panel data regression framework that economic factors (e.g., size of economy, GDP growth), depth and sophistication of capital markets (proxied by factors such as market liquidity, amount of initial public offering activity, and ease of accessibility to capital), political stability, and sociocultural characteristics (such as general human development levels and the control of bribery and corruption) all have a statistically significant impact on the financial performance of commercial real estate. In the context of retail real estate, Ho and Faishal bin Ibrahim [38] measured the degree of association between the sector and the macroeconomic environment, providing evidence that pro-growth policy and GDP growth tend to have a positive association with rents and returns.

Despite a plethora of quantitative investigations examining the dynamics between the pricing of commercial real estate and the macroeconomy in the literature, to the best of our knowledge, so far there has been no empirical study exclusively directed at exploring the relationships between the price-to-rent ratio of industrial real estate and sector-level and macroeconomic attributes. From a practical standpoint, it is crucial to understand how the interaction of industrial property price and rent responds to or influences different economic fundamentals within the sector and the wider economy. A better conceptualisation of how the pricing of DIRE with respect to key macroeconomic attributes is of significance, not only in terms of formulating company-level investment strategies, but also steering the direction of industrial real estate development within a city or nation at a macro policy design level through, for instance, introducing more pro-DIRE measures and regulations, encouraging more FDI and streamlining existing taxation policy to facilitate more efficient and effective industrial land use and development.

3. Methodology

Based on the economic and methodological rationales of previous empirical studies in the literature [14–16], we employ Johansen cointegration and Granger causality techniques to explore potential cointegration and causal relationships between the price-to-rent ratio of DIRE and an array of macroeconomic determinants deemed to display pricing dynamics with the real estate market of Hong Kong. The investigation period spans from 2010 Q1 to 2019 Q4, which was selected with a purpose to model a relatively stable market environment and investment climate, minimising noises caused by irrelevant exogeneous factors such as the global financial crisis during 2007/2008 and the recent outbreak of COVID-19 during 2019/2020.

We explore the short- and long-term relationships between the price-to-rent ratios of the industrial real estate market, and a basket of its economic determinants, which can be categorised into five groups of variables, as follows:

Group 1—General macroeconomic attributes

The first group of attributes comprises (i) inflation (I), (ii) employment rate (ER), (iii) GDP growth (GDP), and (iv) stock market performance (HSI). We posit that the industrial real estate market should, to certain extent, perform in tandem with the general economy. For example, industrial land price should possibly move in sync with the general price level of goods and services, as reflected by the inflation rate; the general productivity or overall strength of the economy as signalled by the employment rate, GDP growth, and the performance of the stock market should have a positive association with the industrial sector. However, their causal relationships, we surmise, might be statistically ambiguous, which would require further empirical inquiry.

Group 2—Liquidity-related attributes

The four attributes encompassed in this group are (i) the exchange rate of RMB/HKD (RMB), (ii) (inverse of) DXY (DXY), (iii) M3 money supply (M3), and (iv) foreign direct investment (FDI). According to the Quantity Theory of Money, asset prices increase with the amount of money or liquidity of capital being circulated within an economy, the holding velocity of money, and the level of real output constant. Accordingly, we hypothesise that (i) money supply, as represented by M3, should be positively associated with industrial land price in the long run; (ii) when there is an increase in the exchange rate between RMB and HKD, a higher volume of capital-chasing local assets will flow from China to Hong Kong as HKD-denominated assets will become more financially appealing from the perspective of Chinese investors, driving real estate asset prices up; (iii) along the same line of thought, when DXY, which measures the strength of the USD, appreciates, the HKD, through the linked exchange rate mechanism, should appreciate in the short term against other international currencies. Hence, when the inverse of DXY increases, we should expect a larger amount of international capital pouring into the Hong Kong economy, propelling the prices of its assets, including those of industrial real estate assets; (iv) likewise, when there is an increased amount of foreign direct investment within the economy, we should also expect industrial property prices to surge.

Group 3—Housing market attributes

We consider this category of attributes, consisting of (i) average residential property price (RHP) and (ii) residential price-to-rent ratio (PtR_R), to detect any temporal linkages between the housing market and the DIRE market in terms of pricing. Several studies (e.g., [39,40]) in the literature have documented temporal co-movement between the two sectors of real estate. The associations between them could be plausibly due to the underlying market fundamentals they share in common, causing their price/rent characteristics to trend in a similar fashion over time.

Group 4—Industrial sector-specific attributes

It is logical to assume that the price-to-rent ratio of the industrial property market should be correlated to the performance and characteristics of the manufacturing sector and the DIRE. Briefly, if the manufacturing sector is in expansion with growing return and profitability, the demand for industrial space should plausibly increase, impacting the pricing of industrial real estate. To account for the size, profitability, productivity, and revenue of the manufacturing sector of Hong Kong, we incorporate the following attributes specific to the manufacturing sector in our models: (i) value added (VA), (ii) number of industrial establishments (IE), (iii) total workforce (W), (iv) operating expenses (OE), and gross sales (S).

Group 5—External economic factors

Lastly, we posit that the steadfast growth of the manufacturing sector in mainland China over the past decades, particularly in provinces geographically proximate to Hong Kong such as Guangdong, should have a quantitative and spatial impact on the overall development of the city's industrial sector, consequentially shrinking its industrial real estate. Therefore, we encompass the rate of change in the volume of manufacturing output of Guangdong (GD) in our models to evaluate whether the Hong Kong industrial real estate sector is affected by its neighbouring region in terms of pricing. An inverse operation is performed on the variable given that it is expected to be inversely correlated to the DIRE in Hong Kong.

The abovementioned variables are measured on a quarterly basis. In addition, the price-to-rent time series are analysed for three administratively defined districts, namely, Hong Kong Island (HKI), Kowloon (K), and the New Territories (NT), to determine whether there is any spatial heterogeneity across the industrial real estate market with respect to the macroeconomic attributes. Table 1 below provides detailed descriptions of the variables examined in our analysis.

Empirical Models

We undertake stationarity tests on the time series prior to examining any potential cointegration and causal relationships between two variables. Failure to detect and account for the non-stationarity of a time series could produce spurious empirical results [41] In our study, we employ the Augmented Dickey Fuller (ADF) unit root test to detect whether a unit root is found within a given time series, with the general equation of the test given by:

$$\Delta Y_t = \alpha + \beta T + \varnothing Y_{t-1} + \sum_{i=1}^{k} \partial \Delta Y_{t-i} + \varepsilon_t \tag{1}$$

where Y_t denotes the level of the time series; α is an intercept term; T is a temporal trend; k represents the number of time periods (i.e., the lag length) for achieving white noise governed by the Schwarz Information Criterion (SIC); and ε_t is an error term, which is a mean of zero and finite variances.

Cointegration Tests

We utilised the Johansen cointegration test to detect any long-term cointegration associations between the price-to-rent time series and macroeconomic attributes. Statistically, the components of a vector C ~CI (i, j) are said to be cointegrated of order i, j if C_t is stationary at the first difference, i.e., I(1), and we can observe a non-zero vector P such that $P'C_t$ follows I(i–j) with $i \geq j > 0$.

Table 1. Descriptions of variables.

Variable	Definition	Inverse Operator	Unit	Data Source
Price-to-rent ratios	Average industrial land price divided by average industrial land rent	No	Ratio	Rating and Valuation Department, Hong Kong
Inflation (I)	The year-on-year growth rate of consumer price index	No	Percentage	Census and Statistics Department, Hong Kong
Employment rate (ER)	The percentage of population aged 15 and over who have been at work for pay or profit during the 7 days before enumeration or have had formal job attachment	No	Percentage	Census and Statistics Department, Hong Kong
GDP growth (GDP)	The year-on-year GDP growth rate	No	Percentage	Census and Statistics Department, Hong Kong
Year-on-year stock market return (HSI)	The year-on-year return on the Hang Seng Index	No	Percentage	Yahoo Finance
RMB/HKD (RMB)	The exchange rate between the Chinese Yuan and Hong Kong Dollar	No	Ratio	Yahoo Finance
US Dollar Index (DXY)	The geometric weighted average of six international currencies (EUR, JPY, GBP, CAD, SEK, and CHF) against the USD	Yes	Percentage	Tradingview
Foreign direct investment (FDI)	The volume of direct foreign investment	No	HKD (M)	Census and Statistics Department, Hong Kong
M3 Money supply growth (ME)	Year-on-year growth of M3 money supply	No	HKD (M)	Hong Kong Monetary Authority
Residential house price (RHP)	Average house prices of Class C [1] residential real estate in the respective districts of Hong Kong Island, Kowloon, and New Territories	No	HKD	Rating and Valuation Department, Hong Kong
Residential price-to-rent (PtR_R)	Price-to-rent ratios of Class C residential real estate in the respective districts of Hong Kong Island, Kowloon, and New Territories	No	Ratio	Rating and Valuation Department, Hong Kong
Industrial value added (VA)	GDP attributable to the secondary (i.e., manufacturing) sector	No	HKD (M)	Census and Statistics Department, Hong Kong
Number of industrial establishments (IE)	Number of industrial establishments in the manufacturing sector	No	Number	Census and Statistics Department, Hong Kong
Industrial workforce (W)	Number of persons engaged in the manufacturing sector	No	Number	Census and Statistics Department, Hong Kong
Operating expense (OE)	Total amount of expenses for purchases of materials, supplies, and industrial work and services	No	HKD (M)	Census and Statistics Department, Hong Kong
Industrial sales (S)	Total sales of goods, industrial work, and services	No	HKD (M)	Census and Statistics Department, Hong Kong
Manufacturing output of Guangdong province (GD), China	Total amount of industrial output of Guangdong province	Yes	RMB (100 M)	Bureau of Statistics, Guangdong Province, China

[1] The Rating and Valuation Department of the Hong Kong Government provides data on average prices and rents measured on a per m^2 basis for five classes of private residential property, which are defined by unit size: Class A (below 39.9 m^2), Class B (40–69.9 m^2), Class C (70–99.9 m^2), Class D (100–159.9 m^2), and Class E (over 160 m^2).

Mathematically, we can detect a cointegration relationship between two time series, X_t and Y_t, by conducting a regression of Y_t on X_t as in Equation (2) below.

$$Y_t = \alpha + \beta X_t + u_t \quad (2)$$

The regression residuals u_t are examined for stationarity by carrying out a unit root test. X_t and Y_t are said to be cointegrated if u_t is a stationary time series. As pointed out by Dickey et al., the above method based on Engle and Granger [42] could be sensitive to the choice of dependent variable, potentially leading to statistical inconsistencies. Hence, a modified modelling approach based on Johansen [43,44] is employed, which considers the following equation:

$$\Delta Y_t = \eta Y_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta Y_{t-i} + BX_t + \varepsilon_t \quad (3)$$

where ΔY_t is the change in Y_t, $\eta = \sum_{i=1}^{k} A_i - I$, and $\Gamma_i = -\sum_{j=1+1}^{k} A_i$. Y_t denotes a k-vector of I(1), which is non-stationary. X_t, on the other hand, represents a d-vector of deterministic variables. η depicts the rank of the coefficient matrix, i.e., the number of cointegrating vectors within the time series. The lag length is determined by the Schwarz Information Criterion. Trace test statistics can be obtained by undertaking the likelihood ratio test on the number of cointegrating vectors between the time series. If the two variables are cointegrated, then they should be integrated to order one.

Granger Causality Test in Error Correction Models (ECMs)

If two time series are cointegrated, their long-term temporal relationship should be determined within the framework of the error correction model (ECM) [45]. The equation of an ECM-based causality equation can be formulated as follows:

$$\Delta Y_t = \lambda + \sum_{i=1}^{u} \alpha_i \Delta Y_{t-i} + \sum_{j=1}^{v} \beta_j \Delta X_{t-j} + \phi z_{t-1} + \varepsilon_t \quad (4)$$

where λ is an intercept term, and z_{t-1} is the error correction (EC) term of the equation with a coefficient of ϕ. The ECM equation contains information about both short- and long-term dynamics between the two time series, with u and v being the number of lags that are large enough to produce an error term that is white noise. It is further noted that all terms are I(0) in Equation (4). $\beta_j s$ measure the short-term influence of Y to changes in X. In other words, $\beta_j s$ signal the short run elasticity of Y with respect to X. On the other hand, the error correction term, z_{t-1}, represents the long-term dynamic between the two variables. Mathematically, z_{t-1} is given by:

$$z_{t-1} = Y_{t-1} - w_0 - w_1 X_{t-1} + w_2 t \quad (5)$$

where w_1 is the coefficient on the lagged independent variable X_{t-1}, which indicates the degree of Y's long-run elasticity with respect to X [46]. The speed of adjustment of short-term disequilibria is captured by the coefficient of the EC term, ϕ. The EC term should have a positive sign if changes in Y are greater than its long-term average value. In other words, ΔY_t should tend to decrease in value so as to follow the path of its long-term equilibrium. On the contrary, the EC term should be negatively signed if ΔY_t is below its average value, which "pushes" Y upward over time. If there is a long-term lead–lag relationship between the variables, the coefficient ϕ should be negative. Put differently, the null hypothesis of long-term non-causality should be rejected if ϕ is negative at the conventional statistically significant level.

Given that the coefficients of the lagged variables ΔX_{t-j} measure the short-term interaction between the time series, the Wald X^2 test can be employed to determine the short-term Granger causality by checking the coefficient restriction on the lagged first difference terms. If the coefficients are statistically different from zero, the null hypothesis of short-term non-causality should be falsified. By examining the data on the DIRE of Hong Kong using the cointegration and causality techniques, the study aims to explore whether the pricing of the property market is causally linked with the macroeconomic attributes in a Granger fashion in the long run.

4. Results and Discussion

4.1. Results of the ADF Test

We design the specification of each of the ADF equations based on an initial graphical analysis proposed by [47]: If a time series graphically shows a time trend, stochastic or deterministic, a linear trend and an intercept term should be encapsulated into the equation to minimise omitted variable biases. The summary of the results of the ADF tests is reported in Table 2 (see Appendix A for full results). The three price-to-rent ratio time series for the residential markets of Hong Kong, as well as those for the employment rate and stock market performance, are found to be stationary at level, implying that they tend not to exhibit statistical properties that depend on the sample period of investigation. The rest of the time series under investigation are non-stationary at level, but stationary at first difference. Accordingly, we apply differencing on the time series and transform the two sets of variables to I(0) and I(I) based on their stationarity [41].

Table 2. Summary of the results of the ADF tests.

Time Series	Stationarity
PtR_R(HK), PtR_R(K), PtR_R(NT), ER and HSI	Stationary at level
PtR(HK), PtR(K), PtR(NT), I, RMB, FDI, ME, DXY, GDP, VA, IE, W, OE, IS, RHP(HK), RHP(K), RHP(NT) and GD	Stationary at first difference

Note: The tests are conducted based on the 5% significance level. Full results are available upon request.

4.2. Results of the Cointegration and Granger Causality Tests

The results of the cointegration tests on the time series are depicted in Table 3. We perform the tests on the price-to-rent ratio time series for the three districts of Hong Kong with respect to each of the macroeconomic attributes. Trace statistics and eigenvalues are utilised to detect whether a cointegration relationship exists between a given pair of time series. It is evident that most pairs of time series are cointegrated in the long term at the 5% statistical significance level, implying that they tend to move in tandem over time. The only two pairs of time series that are not cointegrated are PtR(NT) vs. DXY and PtR(NT) vs. VA. Procedurally, the findings of the cointegration analysis determine the methodological approach that should be adopted to examine the lead–lag relationship between a pair of time series: if they are found to be non-cointegrated, the corresponding causality equation should be constructed within an ordinary vector autoregressive regression framework. Otherwise, the causality should be examined by adopting an error correction model approach. Table 4 presents the results of the Granger causality tests, detailing the chi-square statistics of the Wald test and the t-statistics of the error correction term in Equation (4). The R^2; adjacent R^2, The Akaike information criterion (AIC), Schwarz criterion (SC), Durbin–Watson (DW) value, F-statistic, and the coefficient on the EC term of each pair of the Granger models are also reported in the table.

Emanating from Table 4 are a number of noteworthy and interesting findings in relation to the causal dynamics between the DIRE and the macroeconomic factors. First, the general economic indicators, including inflation, employment, and stock market, appear to Granger-cause the DIRE market in the long run, but not the other way around. The time lags between the variables are typically two to three quarters. It is further noticeable that GDP growth displays a bidirectional causal linkage with the price-to-rent variables across the three districts. In other words, the growth of national income is both a cause and a consequence of the price-to-rent ratio, in a Granger sense.

Table 3. Results of cointegration tests.

		Y = Price-to-Rent Ratio of Industrial Real Estate					
		Hong Kong Island		**Kowloon**		**New Territories**	
	X	None Trace Stat. (Prob) Eigenvalue (Prob)	At most 1 Trace Stat. (Prob) Eigenvalue (Prob)	None Trace Stat. (Prob) Eigenvalue (Prob)	At most 1 Trace Stat. (Prob) Eigenvalue (Prob)	None Trace Stat. (Prob) Eigenvalue (Prob)	At most 1 Trace Stat. (Prob) Eigenvalue (Prob)
Group 1	I	33.33664 (0.00) *** 0.491059 (0.00) ***	9.021425 (0.00) *** 0.221663 (0.00) ***	26.63423 (0.00) *** 0.402259 (0.03) **	8.108709 (0.00) *** 0.201677 (0.00) ***	44.26229 (0.00) *** 0.561689 (0.00) ***	14.56851 (0.00) *** 0.332810 (0.00) ***
	ER	45.18061 (0.00) *** 0.564146 (0.00) ***	14.45404 (0.00) *** 0.323383 (0.00) ***	38.93924 (0.00) *** 0.480966 (0.00) ***	14.67519 (0.00) *** 0.327415 (0.00) ***	32.14486 (0.00) *** 0.409107 (0.02) **	12.67842 (0.00) *** 0.290121 (0.00) ***
	GDP	43.89405 (0.00) *** 0.563733 (0.00) ***	13.20252 (0.00) *** 0.300105 (0.00) ***	37.07822 (0.00) *** 0.473791 (0.00) ***	13.32214 (0.00) *** 0.302364 (0.00) ***	29.48732 (0.00) *** 0.361579 (0.00) ***	12.88332 (0.05) ** 0.294041 (0.00) ***
	HSI	42.77438 (0.00) *** 0.587911 (0.01) ***	9.973314 (0.0016) *** 0.236276 (0.0016) ***	34.32131 (0.00) *** 0.484660 (0.00) ***	9.792978 (0.00) *** 0.232545 (0.00) ***	24.12839 (0.00) *** 0.337069 (0.09) *	8.918264 (0.00) *** 0.214185 (0.00) ***
Group 2	RMB	51.00004 (0.00) *** 20.11395 (0.00) ***	0.566021 (0.00) *** 0.419358 (0.00) ***	39.50740 (0.00) *** 0.505264 (0.00) ***	13.46932 (0.00) *** 0.305134 (0.00) ***	35.73811 (0.00) *** 0.457544 (0.00) ***	13.10710 (0.00) *** 0.298298 (0.00) ***
	1/DXY	44.46733 (0.00) *** 0.563370 (0.00) ***	13.80661 (0.00) *** 0.311439 (0.00) ***	36.93921 (0.00) *** 0.467219 (0.00) ***	13.64235 (0.00) *** 0.308375 (0.00) ***	29.17684 (0.00) *** 0.339327 (0.00) ***	13.84045 (0.09)* 0.312069 (0.00) ***
	FDI	44.28514 (0.00) *** 0.569169 (0.00) ***	13.12970 (0.00) *** 0.298726 (0.00) ***	34.51324 (0.00) *** 0.446863 (0.00) ***	12.60369 (0.00) *** 0.288685 (0.00) ***	30.38143 (0.00) *** 0.407928 (0.02) **	10.98872 (0.00) *** 0.256950 (0.00) ***
	M3	45.98939 (0.00) *** 15.25011 (0.00) ***	0.564296 (0.00) *** 0.337785 (0.00) ***	33.33011 (0.00) *** 0.417475 (0.00) ***	13.33592 (0.00) *** 0.302624 (0.00) ***	30.78925 (0.00) *** 0.415742 (0.02)**	10.90501 (0.00) *** 0.255267 (0.00) ***
Group 3	RHP	38.70646 (0.00) *** 0.555853 (0.00) ***	8.677265 (0.00) *** 0.209050 (0.00) ***	40.04824 (0.00) *** 0.535338 (0.00) ***	11.68977 (0.00) *** 0.270897 (0.00) ***	31.59580 (0.00) *** 0.419772 (0.02) **	11.45546 (0.00) *** 0.266265 (0.00) ***
	PtR_R	65.04982 (0.00) *** 0.711587 (0.00) ***	19.034549 (0.00) *** 0.402346 (0.00) ***	37.28334 (0.00) *** 0.504795 (0.00) ***	11.08849 (0.00) *** 0.258951 (0.00) ***	48.69358 (0.00) *** 0.606138 (0.00) ***	14.21862 (0.00) *** 0.319064 (0.00) ***

Table 3. *Cont.*

		Y = Price-to-Rent Ratio of Industrial Real Estate					
		Hong Kong Island		**Kowloon**		**New Territories**	
Group 4	VA	47.06448 (0.00) *** 0.579933 (0.00) ***	15.84018 (0.00) *** 0.355967 (0.00) ***	38.28487 (0.00) *** 0.453507 (0.00) ***	16.53248 (0.00) *** 0.368234 (0.00) ***	30.53394 (0.00) *** 0.359872 (0.07) *	14.47482 (0.00) *** 0.331072 (0.00) ***
	IE	45.03834 (0.00) *** 0.558500 (0.00) ***	15.60557 (0.00) *** 0.351756 (0.00) ***	38.46194 (0.00) *** 0.473172 (0.00) ***	15.39018 (0.00) *** 0.347866 (0.00) ***	33.03596 (0.00) *** 0.424461 (0.02) **	13.14782 (0.00) *** 0.305954 (0.00) ***
	W	51.88273 (0.00) *** 0.645208 (0.00) ***	14.57871 (0.00) *** 0.332999 (0.00) ***	40.70381 (0.00) *** 0.484332 (0.00) ***	16.86130 (0.00) *** 0.373978 (0.00) ***	42.19879 (0.00) *** 0.522432 (0.00) ***	15.59302 (0.00) *** 0.351530 (0.00) ***
	OE	48.60125 (0.00) *** 0.627156 (0.00) ***	13.08383 (0.00) *** 0.304719 (0.00) ***	39.70403 (0.00) *** 0.502303 (0.00) ***	14.58450 (0.00) *** 0.333107 (0.00) ***	32.11027 (0.00) *** 0.393540 (0.04) **	14.10606 (0.00) *** 0.324184 (0.00) ***
	S	49.24067 (0.00) *** 0.633734 (0.00) ***	13.08244 (0.00) *** 0.304693 (0.00) ***	40.09045 (0.00) *** 0.504138 (0.00) ***	14.83795 (0.00) *** 0.337785 (0.00) ***	32.34709 (0.00) *** 0.395053 (0.04) **	14.25298 (0.00) *** 0.326937 (0.00) ***
Group 5	Inverse GD	51.26316 (0.00) *** 0.613456 (0.00) ***	16.09428 (0.00) *** 0.352723 (0.00) ***	39.80090 (0.00) *** 0.445102 (0.00) ***	18.00900 (0.00) *** 0.385367 (0.00) ***	95.57611 (0.00) *** 0.886784 (0.00) ***	14.97301 (0.00) *** 0.332807 (0.00) ***

Note: *** denotes 1% statistical sig.; ** 5% sig.; * 10% sig. Full results are available upon request.

Table 4. Results of Granger causality tests.

	Y = Price-to-Rent	**Hong Kong Island**			**Kowloon**			**New Territories**		
	X	Short-term chi-sq (Prob)	Long-term t-statistic (Prob)	R^2, Adj R^2 AIC; SC DW; F EC Lag based on SIC	Short-term chi-sq (Prob)	Long-term t-statistic (Prob)	R^2; Adj R^2 AIC; SC DW; F EC Lag based on SIC	Short-term chi-sq (Prob)	Long-term t-statistic (Prob)	R^2; Adj R^2 AIC; SC DW; F EC Lag based on SIC
Group 1	I									
	X→Y	1.958261 (0.3756)	−4.937419 (0.0000) ***	0.739127; 0.683225 5.660394; 5.971464 1.933729; 13.22197 −2.133166 Lag = 2	6.664995 (0.0357) **	−3.941771 (0.0005) ***	0.503569; 0.397191 4.779536; 5.090606 2.064788; 4.733765 −0.967190 Lag = 2	9.719646 (0.0078) ***	−2.042917 (0.0506) **	0.482433; 0.371525 4.765590; 5.076660 2.172811; 4.349871 −0.338907 Lag = 2
	Y→X	1.632070 (0.6521)	4.031771 (0.0005) ***	0.592373; 0.461932 0.524383; 0.928420 2.022130; 4.541320 0.000102 Lag = 3	2.054872 (0.5611)	4.291386 (0.0002) ***	0.680403; 0.578131 0.281092; 0.685129 2.010390; 6.652928 0.061624 Lag = 3	20.56348 (0.0045) ***	−3.064139 (0.0091) ***	0.822174; 0.603312 0.203525; 0.997537 2.224203; 3.756579 −0.124806 Lag = 7

Table 4. *Cont.*

	Y = Price-to-Rent	Hong Kong Island			Kowloon			New Territories		
Group 1	ER									
	X→Y	1.985117 (0.3706)	−4.612383 (0.0001) ***	0.707950; 0.647526 5.734648; 6.042554 1.977709; 11.71635 −2.034770 Lag = 2	3.574402 (0.1674)	−4.701829 (0.0001) ***	0.541435; 0.446559 4.668355; 4.976262 1.916656; 5.706784 −1.610318 Lag = 2	12.99918 (0.0430) **	−2.766420 (0.0132) **	0.811747; 0.656716 4.346942; 5.034005 1.932279; 5.236011 −2.138274 Lag = 6
	Y→X	23.15500 (0.0003) ***	1.958936 (0.0642) *	0.639065; 0.422504 −3.281432; −2.691898 2.207866; 2.950969 0.007809 Lag = 2	2.666108 (0.4460)	3.768261 (0.0009) ***	0.820853; 0.765731 −3.686986; −3.287039 2.060798; 14.89154 0.008717 Lag = 3	1.069561 (0.5858)	3.861961 (0.0006) ***	0.840052; 0.806959 −3.760328; −3.452421 2.086704; 25.38473 0.001029 Lag = 2
	GDP									
	X→Y	3.413240 (0.1815)	−4.797933 (0.0000) ***	0.731594; 0.676061 5.650226; 5.958132 1.986572; 13.17418 −1.997423 Lag = 2	6.523643 (0.0383) **	−4.751474 (0.0001) ***	0.592315; 0.507966 4.550747; 4.858654 1.951795; 7.022226 −1.431508 Lag = 2	18.89957 (0.0003) ***	−2.863480 (0.0082) ***	0.594807; 0.470133 4.635098; 5.035045 2.210271; 4.770878 −0.747543 Lag = 3
	Y→X	11.77424 (0.0082) ***	−3.213163 (0.0035) ***	0.479295; 0.319078 3.923093; 4.323040 1.957848; 2.991535 −0.389145 Lag = 3	8.278265 (0.0406) **	−3.677872 (0.0011) ***	0.502512; 0.349439 3.877480; 4.277426 1.879596; 3.282827 −0.512787 Lag = 3	10.31308 (0.0161) **	−4.332135 (0.0002) ***	0.580910; 0.451959 3.705996; 4.105943 1.828528; 4.504890 −0.710709 Lag = 3
	HSI									
	X→Y	2.554783 (0.2788)	−5.642554 (0.0000) ***	0.769634; 0.721972 5.497393; 5.805299 1.957942; 16.14777 −2.374291 Lag = 2	5.441938 (0.0658) *	−5.572355 (0.0000) ***	0.630735; 0.554335 4.451768; 4.759674 1.833642; 8.255722 −1.743983 Lag = 2	7.561901 (0.0228) **	−2.962609 (0.0060) ***	0.543689; 0.449279 4.614976; 4.922882 1.947396; 5.758848 −0.841496 Lag = 2
	Y→X	14.78769 (0.0634) *	0.671763 (0.5145)	0.807270; 0.534237 −1.681588; −0.840869 1.504834; 2.956668 0.030857 Lag = 8	17.34044 (0.0153) **	3.685796 (0.0022) ***	0.769862; 0.539723 −1.704402; −0.964279 1.916224; 3.345210 0.035582 Lag = 7	4.086430 (0.2523)	−4.200321 (0.0003) ***	0.468145; 0.304498 −1.305758; −0.905811 1.927231; 2.860693 −0.044620 Lag = 3

Table 4. *Cont.*

	Y = Price-to-Rent	Hong Kong Island			Kowloon			New Territories		
Group 2	RMB									
	X→Y	42.70838 (0.0000) ***	−5.056897 (0.0001) ***	0.903347; 0.845354 5.110120; 5.699653 1.974470; 15.57707 −3.761158 Lag = 5	1.105385 (0.5754)	−4.250169 (0.0002) ***	0.606239; 0.524771 4.515997; 4.823904 1.897391; 7.441443 −1.183168 Lag = 2	37.82489 (0.0000) ***	−3.776939 (0.0010) ***	0.774242; 0.676087 4.211121; 4.704944 4.379529; 1.948474 −1.309565 Lag = 4
	Y→X	35.37248 (0.0000) ***	3.099452 (0.0065) ***	0.829431; 0.688962 −4.685261; −3.998198 1.847607; 5.904733 0.026114 Lag = 6	15.67224 (0.0004) ***	3.746013 (0.0008) ***	0.536986; 0.441190 −4.336964; −4.029058 2.041578; 5.605523 0.012468 Lag = 2	6.505884 (0.0387) **	4.159254 (0.0003) ***	0.548309; 0.454856 −4.361723; −4.053816 1.931055; 5.867199 0.009320 Lag = 2
	M3									
	X→Y	1.086964 (0.5807)	−5.056468 (0.0000) ***	0.735879; 0.681233 5.634130; 5.942037 1.952700; 13.46637 −2.238344 Lag = 2	17.90539 (0.0001) ***	−4.973773 (0.0000) ***	0.613794; 0.533889 4.496623; 4.804530 2.029943; 7.681579 −1.406375 Lag = 2	10.38446 (0.0156) **	−3.868645 (0.0007) ***	0.585580; 0.458066 4.657617; 5.057563 2.039515; 4.592277 −1.340024 Lag = 3
	Y→X	2.142361 (0.3426)	0.197897 (0.8445)	0.302903; 0.158676 24.22203; 24.52994 2.221385; 2.100185 952.4243 Lag = 2	0.656998 (0.7200)	−1.475277 (0.1509)	0.338300; 0.201396 24.16992; 24.47782 2.112508; 2.471084 −7803.518 Lag = 2	3.568198 (0.1679)	−1.705136 (0.0989) *	0.343396; 0.207547 24.16219; 24.47009 2.099994; 2.527773 −8115.359 Lag = 2
	Inverse DXY									
	X→Y	2.078931 (0.3536)	−4.874538 (0.0000) ***	0.725904; 0.669195 5.671200; 5.979107 2.083470; 12.80042 −2.065161 Lag = 2	4.330951 (0.1147)	−4.534927 (0.0001) ***	0.555297; 0.463290 4.637659; 4.945565 1.842611; 6.035346 −1.386748 Lag = 2	0.123896 (0.9399)	NA	0.067120; −0.0317451 4.649881; 4.867573 1.909190; 0.054042
	Y→X	3.126074 (0.2095)	1.210780 (0.2358)	0.389267; 0.262908 −12.31526; −12.00736 2.055909; 3.080652 6.37×10^{-5} Lag = 2	7.542668 (0.0230) **	1.948857 (0.0610) *	0.458534; 0.346507 −12.43564; −12.12774 1.797401; 4.093056 6.00×10^{-5} Lag = 2	2.727393 (0.2557)	NA	0.082326; −0.032384 −12.72465; −12.50696 2.094587; 0.717690

Table 4. *Cont.*

	Y = Price-to-Rent	Hong Kong Island			Kowloon			New Territories		
Group 2	FDI									
	X→Y	19.61473 (0.0001) ***	−6.131878 (0.0000) ***	0.781301; 0.736053 5.445418; 5.753324 1.836672; 17.26710 −2.22298 Lag = 2	3.528794 (0.1713)	−4.775521 (0.0000) ***	0.580850; 0.494130 4.578481; 4.886387 1.897027; 6.697946 −1.583678 Lag = 2	2.479107 (0.2895)	−2.820380 (0.0086) ***	0.461262; 0.349799 4.781030; 5.088936 1.923781; 4.138250 −0.890324 Lag = 2
	Y→X	3.560104 (0.1686)	−1.933148 (0.0630) *	0.503902; 0.401261 26.59458; 26.90248 2.216759; 4.909359 −27276.01 Lag = 2	0.957831 (0.6195)	0.412721 (0.6828)	0.448994; 0.334993 26.69955; 27.00745 2.187116; 3.938505 8706.255 Lag = 2	1.277016 (0.5281)	1.931720 (0.0632) *	0.503010; 0.400184 26.59637; 26.90428 2.151742; 4.891873 33290.95 Lag = 2
Group 3	RHP									
	X→Y	9.867830 (0.0072) ***	−6.369505 (0.0000) ***	0.813884; 0.775377 5.284093; 5.592000 1.975044; 21.13615 −2.607543 Lag = 2	11.17467 (0.0037) ***	−6.425298 (0.0000) ***	0.674943; 0.607690 4.324252; 4.632159 1.697076; 10.03586 −1.963624 Lag = 2	9.339842 (0.0094) ***	−3.521734 (0.0014) ***	0.605306; 0.523645 4.469911; 4.777817 1.920124; 7.412441 −1.211647 Lag = 2
	Y→X	1.728108 (0.4214)	1.540901 (0.1342)	0.187383; 0.019256 21.08895; 21.39686 2.078472; 1.114531 44.22952 Lag = 2	0.668911 (0.7157)	0.489285 (0.6283)	0.181072; 0.011638 20.82714; 21.13504 2.081673; 1.068691 573.1691 Lag = 2	1.422560 (0.4910)	1.138375 (0.2643)	0.319341; 0.178515 19.36244; 19.67035 1.772581; 2.267628 671.0844 Lag = 2
	PTR_R									
	X→Y	3.723506 (0.1554)	−6.472288 (0.0000) ***	0.811471; 0.772465 5.296975; 5.604881 2.187910; 20.80376 −2.253099 Lag = 2	2.822869 (0.2438)	−4.968101 (0.0000) ***	0.577532; 0.490125 4.586366; 4.894273 1.820342; 6.607370 −1.708182 Lag = 2	3.727361 (0.2924)	−3.778072 (0.0008) ***	0.634194; 0.521638 4.532838; 4.932785 2.328615; 5.634494 −1.095677 Lag = 3
	Y→X	1.383438 (0.5007)	1.431040 (0.1631)	0.204225; 0.039582 4.455241; 4.763148 2.069618; 1.240412 0.850319 Lag = 2	0.218645 (0.8964)	0.420556 (0.6772)	0.186884; 0.018653 5.215656; 5.523562 2.109472; 1.110877 0.1980069 Lag = 2	1.056220 (0.5897)	1.294459 (0.2057)	0.233955; 0.075463 3.367587; 3.675493 2.208741; 1.476133 0.222972 Lag = 2

Table 4. *Cont.*

	Y = Price-to-Rent	**Hong Kong Island**			**Kowloon**			**New Territories**		
Group 4	VA									
	X→Y	1.326520 (0.5152)	−5.309510 (0.0000) ***	0.746388; 0.693916 5.593529; 5.901436 1.969655; 14.22464 −2.021836 Lag = 2	2.067229 (0.3557)	−5.024951 (0.0000) ***	0.568995; 0.479821 4.606372; 4.914279 1.884626; 6.380763 −1.672703 Lag = 2	0.561103 (0.7554)	NA	0.020047; −0.102447 4.636363; 4.854055 1.963868; 0.163658
	Y→X	1.975198 (0.5776)	0.372068 (0.7129)	0.715701; 0.628224 9.877112; 10.27706 1.855581; 8.181613 1.994489 Lag = 3	22.44526 (0.0021) ***	3.715394 (0.0023) ***	0.931559; 0.853341 9.154412; 9.940792 2.163976; 11.90972 47.56728 Lag = 7	1.671632 (0.4335)	NA	0.971420; 0.967847 9.973481; 10.19117 2.247396; 271.9114
	IE									
	X→Y	1.916654 (0.3835)	−5.286917 (0.0000) ***	0.745101; 0.692363 5.598590; 5.906497 1.996232; 14.12843 −2.131167 Lag = 2	3.124283 (0.2097)	−5.162852 (0.0000) ***	0.602126; 0.519807 4.526389; 4.834295 1.926339; 7.314551 −1.510751 Lag = 2	1.934065 (0.3802)	−3.923758 (0.0005) ***	0.552655; 0.460101 4.595130; 4.903037 2.035659; 5.971155 −0.855768 Lag = 2
	Y→X	2.011355 (0.3658)	0.702251 (0.4881)	0.795408; 0.753079 8.151648; 8.459554 1.903162; 18.79097 1.434385 Lag = 2	3.970888 (0.1373)	1.557829 (0.1301)	0.806344; 0.766278 8.096713; 8.404620 2.019635; 20.12507 2.658745 Lag = 2	3.311911 (0.1909)	1.287965 (0.2079)	0.812432; 0.773625 8.064771; 8.372678 1.888818; 20.93516 5.286974 Lag = 2
	W									
	X→Y	3.405656 (0.1822) *	−5.378885 (0.0000) ***	0.750835; 0.699283 5.575839; 5.883746 2.187224; 14.56478 −2.372866 Lag = 2	6.066062 (0.0482) **	−5.137415 (0.0000) ***	0.621716; 0.543450 4.475897; 4.783804 1.837567; 7.943667 −1.534625 Lag = 2	5.188325 (0.0747) *	−3.161005 (0.0037) ***	0.552116; 0.459450 4.596335; 4.904241 1.900366; 5.958146 −0.174312 Lag = 2
	Y→X	1.863957 (0.3938)	1.357643 (0.1850)	0.750386; 0.698742 13.13369; 13.44160 2.022517; 14.52992 29.89178 Lag = 2	2.111863 (0.3479)	1.158494 (0.2561)	0.751795; 0.700442 13.12804; 13.43594 2.009519; 14.63982 33.89436 Lag = 2	2.581034 (0.2751)	2.632681 (0.0134) **	0.792251; 0.749269 12.95011; 13.25802 2.064789; 18.43198 98.47509 Lag = 2

Table 4. *Cont.*

	Y = Price-to-Rent	Hong Kong Island			Kowloon			New Territories		
Group 4	OE									
	X→Y	0.474635 (0.7887)	−5.694094 (0.0000) ***	0.763015; 0.713984 5.525719; 5.833625 2.038555; 15.56180 −2.306712 Lag = 2	0.928861 (0.6285)	−5.472595 (0.0000) ***	0.609229; 0.528380 4.508375; 4.816281 1.946536; 7.535369 −1.535889 Lag = 2	14.87873 (0.0050) ***	−6.234057 (0.0000) ***	0.764768; 0.662493 4.252232; 4.746054 1.888514; 7.477583 −3.376131 Lag = 4
	Y→X	31.32345 (0.0001) ***	1.745425 (0.1087)	0.959275; 0.892633 14.30348; 15.19091 1.831260; 14.39452 163.5588 Lag = 8	22.19343 (0.0024) ***	3.367591 (0.0046) ***	0.925420; 0.840186 14.75712; 15.54350 2.086138; 10.85742 1099.633 Lag = 7	20.79339 (0.0077) **	2.851538 (0.0158) **	0.936674; 0.833050 14.74493; 15.63235 2.304097; 9.039124 161.2888 Lag = 8
	S									
	X→Y	0.436888 (0.8038)	−5.696917 (0.0000) ***	0.763285; 0.714309 5.524582; 5.832489 2.044707; 15.58499 −2.317066 Lag = 2	0.948955 (0.6222)	−5.463812 (0.0000) ***	0.608442; 0.527430 4.510386; 4.818292 1.944401; 7.510521 −1.536109 Lag = 2	22.60465 (0.0002) ***	−6.082147 (0.0000) ***	0.757631; 0.652253 4.282121; 4.775943 1.871033; 7.189665 −3.352625 Lag = 4
	Y→X	38.78412 (0.0000) ***	2.158196 (0.0539) *	0.962532; 0.901219 14.25850; 15.14592 1.856848; 15.69889 165.1394 Lag = 8	31.14026 (0.0001) ***	2.960016 (0.0130) **	0.947979; 0.862854 14.58664; 15.47407 2.217405; 11.13635 1083.299 Lag = 8	17.33499 (0.0154) **	3.373241 (0.0045) ***	0.914213; 0.816171 14.93146; 15.71784 2.626648; 9.324673 652.6142 Lag = 7
Group 5	Inverse GD									
	X→Y	1.847946 (0.3969)	−4.079670 (0.0003) ***	0.792944; 0.750105 5.390711; 5.698618 1.966966; 18.50982 −1.867908 Lag = 2	0.931476 (0.6277)	−4.692798 (0.0001) ***	0.544498; 0.450256 4.661653; 4.969559 1.841403; 5.777667 −1.588144 Lag = 2	8.810966 (0.0660) *	−5.214551 (0.0000) ***	0.737014; 0.622672 4.363760; 4.857583 1.879728; 6.445714 −2.286376 Lag = 4
	Y→X	8.347398 (0.0154) **	−0.431743 (0.6691)	0.487439; 0.381392 0.381392; −18.43094 2.090009; 4.596438 -1.14×10^{-6} Lag = 2	1.322985 (0.5161)	−0.615597 (0.5430)	0.336976; 0.199799 −18.48146; −18.17355 2.169379; 2.456497 -1.96×10^{-6} Lag = 2	3.459276 (0.1773)	2.976093 (0.0058) ***	0.484575; 0.377935 −18.73328; −18.42537 1.914375; 4.544041 5.88×10^{-6} Lag = 2

Note: *** denotes 1% statistical sig.; ** 5% sig.; * 10% sig. Full results are available upon request.

Second, the four liquidity-related variables, namely, RMB, M3, DXY, and his, are long-term leading indicators for the price-to-rent ratio in a Granger fashion. They tend to lead the DIRE market by two quarters, with an exemption of the exchange rate of RMB/HKD being ahead of the Hong Kong Island and New Territories industrial real estate market by five and four quarters, respectively. Third, it is statistically evident that the residential market and the industrial real estate market are causally correlated with the causal pathway running from the former to the latter across the three regions in Hong Kong. The average house prices, as well as the price-to-rent ratios, Granger-cause the pricing of the DIRE market.

Fourth, the results seem to suggest that the industrial sector specific attributes, including value-added, number of industrial establishments, size of workforce, operation expense, and sales, are prone to leading the DIRE market in terms of property pricing over a long time horizon, with these attributes showing unidirectional Granger causation with the price-to-rent variables. Lastly, Table 4 further reveals that the rate of the industrialisation process in China, proxied by the total amount of manufacturing output in the province of Guangdong, has a statistically significant negative impact on the price-to-rent ratio of the DIRE of Hong Kong. The inverse of GD Granger-causes the three price-to-rent variables in the long run, statistically significant at the 5% level.

5. Discussion

The findings stemming from the above cointegration and causality analyses reveal several empirically important observations pertaining to the market nature and fundamentals of the DIRE of Hong Kong. First and foremost, the DIRE market is highly cointegrated with other segments of the economy in terms of pricing, despite its shrinking economic significance over the past decades. For example, the general price level, employment level, and the year-on-year performance of the Hang Seng Index seem to be moving synchronously with the price-to-rent ratios of the DIRE over time, as the results of the cointegration analysis suggest. More crucially, the DIRE market appears to causally lag behind the general economy by circa two quarters for most economic indicators. From the perspective of price discovery, this could be attributed to the inefficient nature of the DIRE market, which is highly heterogenous and informationally untransparent. In the context of Hong Kong, there is no well-established industrial real estate agency that is specialised in collating and centralising market data and information of the DIRE the same manner we can observe for the residential property sector, which partially explains why the DIRE is not informationally transparent. In addition, the GDP variable showing a bidirectional Granger causal connection with the DIRE may indicate that the industrial sector and the general economy are inextricably linked. A growing economy could naturally, on one hand, result in a swelling demand for industrial goods through the effect of wealth accumulation, which in turn drives the prices of DIRE up. On the other hand, an expansion of the industrial sector could induce more demand for other economic activities such as accounting, legal services, and construction through a feedback loop, which explains the causality from DIRE to GDP. Indeed, recent developments in Hong Kong seem to have proven themselves to be a revelation of the observed bidirectional causal link between the industrial real estate sector and the general economy. A decade of strong and persistent economic growth of the city has induced more government-led high-end industrial property development programmes focusing chiefly on scientific innovation and technological advancements, with hectares of land such as Hong Kong Science Park designated for these specific land uses. The city has also witnessed a rapid expansion in the sectors of computer cloud servicing and data processing and storage, which has simultaneously fuelled demand for special-purpose industrial properties for data centres and warehouses, for instance.

Second, the findings of our Granger causality analysis seem to confirm the Quantity Theory of Money. The four liquidity variables, namely, M3, FDI, RMB, and 1/DXY, all exhibit a unidirectional lead–lag relationship with the price-to-rent variables. When the RMB appreciates against the HKD, or the DXY becomes weaker relative to other international currencies, HKD-denominated assets, including DIRE, would become more financially appealing to non-local buyers, causing the prices of DIRE to escalate. Along a similar line of reasoning, when the money supply (M3) and FDI increase within the economy of Hong Kong, prices of DIRE assets, which are denominated by HKD, would be buoyed by the influx of new liquidity. Consequently, the price-to-rent ratios of DIRE should also increase.

Third, the housing market and the industrial real estate market of Hong Kong are intertwined in terms of cointegration. Further, we observe a Granger causation running from the two housing market variables to the DIRE price-to-rent ratios across the three districts. One possible explanation for such a causal observation is that land supply for residential development is extremely limited in Hong Kong. The scarcity of developable land more often than not drives residential property prices up to an exorbitant level, making the remaining undeveloped land even more scarce and valuable. Therefore, some developers in Hong Kong would turn to converting existing industrial or commercial properties into residential housing units through the rezoning of land and/or lease modifications, resulting in swelling the prices of DIRE. Upon closer examination of the data, the price-to-rent ratios of industrial properties have increased by circa 460% in the New Territories over the sample period, seemingly confirming the persistently strong demand for this category of real estate.

Another important revelation of our empirical results is that we can indeed use certain information that is specific to the industrial/manufacturing sector to predict the movement of the price-to-rent ratios of the DIRE. The five industry variables, namely, value-added, number of industrial establishments, total industrial workforce, operating expenses, and sales, are all causally correlated with the DIRE variables in a Granger fashion. In other words, the growth of the industrial sector, which is, generally or by definition, accompanied by a higher level of output, a more intense formation of establishments, larger numbers of workers, and more capital expenditure for investment and revenue, could lead to an elevation of the price-to-rent ratio, but not the other way around.

Last but not least, the Granger causality analysis on the variable GD unequivocally confirms the commonly held view that the process of industrialisation in mainland China has a long-lasting negative impact upon the pricing of industrial real estate in Hong Kong. The larger the output of the manufacturing sector in Guangdong, the more the prices of DIRE in Hong Kong are depressed relative to rents. As aforementioned, this could be attributable to the great disparity of land and property prices between the two places, resulting in a clear yet sophisticated division of labour in production between the two places, with the mainland specialising in the actual hand-on manufacturing whilst Hong Kong plays a managerial role by providing tertiary-level services along the production line to support the industrial operations in China. Indeed, the average industrial land prices of Guangdong have skyrocketed over the past ten to fifteen years. Take Shenzhen, a neighbour city of Hong Kong, as an example: the average industrial land prices of the special economic zone of China were circa RMB 500 at the beginning of the market cycle in 2008, with prices topped out at circa RMB 4500 in 2019, posting an eight-fold increase (Source: CEIC Data (see https://www.ceicdata.com/en/china/land-price-city-industrial/cn-land-price-industrial-shenzhen, accessed on 1 August 2022), whilst the Hong Kong industrial land market observed a comparatively more modest growth of circa 400% during the same time period.

6. Conclusions

This study has made at least two contributions to the literature of industrial real estate. First, it dissects the pricing of the industrial real estate market using the price-to-rent ratio, which has not yet been thoroughly explored in the existing literature. The affordability/overvaluation of real estate, which is commonly measured by the price-to-rent ratio, is generally examined in the context of residential property, and to a lesser extent, commercial office property. Relatively little is known about the dynamics between price and rent in the field of DIRE. Second, it empirically examines the cointegration and lead–lag relationships between the price-to-rent ratio and a large array of macroeconomic and financial determinants in a holistic and systematic fashion using the property and economic data of the Hong Kong property market. The results reveal that the industrial property market in Hong Kong is generally informationally inefficient, which can, to a large degree, be explained or predicted by sector-level and economy-wide fundamentals using Granger causality techniques. Specifically, macroeconomic attributes such as employment rates, money supply, FDI, inflation, equity market, and industrial sector-specific factors including sales and value-added are observed to Granger-cause the price-to-rent movements of the DIRE. Further, GDP and the pricing of the DIRE are interlinked by bidirectional Granger causal links.

The findings emanating from this study carry significant and potentially far-reaching practical implications for investors and policy makers. For example, our causality analysis suggests that the price-to-rent ratio of DIRE is a lagging indicator of a number of macroeconomic attributes including housing prices and the stock market index, providing valuable insights to traders or investors keen to develop arbitrage investment strategies to exploit the market. In addition, from a policy-making point of view, a more thorough conceptualisation of the determinants of the industrial land market should help policy makers design and formulate policies and regulations that are in the interest of the long-term sustainable development of the industrial sector and its stakeholders. For instance, our analysis demonstrates that the performance of DIRE is closely causally linked to the amount of foreign direct investment. Policy makers intent on revitalising the industrial real estate market in Hong Kong could perhaps consider introducing more pro-FDI policy measures within the DIRE sector through offering tax incentives and/or providing a more level playing field amongst local and foreign-market players. In addition, our findings appear to suggest that the performance of the industrial sector is a leading indicator of the DIRE, signalling that if the government is keen to reinvigorate the traditional industrial land market, an indirect way would be to provide financial support to the industrialists and/or facilitate the development of the manufacturing sector, whose expansion would, in turn, reinforce the growth of the DIRE in the long run in terms of pricing.

Whilst the paper empirically reveals significant lead–lag relationships between the pricing of DIRE and its macroeconomic attributes, shedding new light on issues around appraisals and market forecast of industrial real estate, we believe future research efforts in the area of research could be devoted to exploring the micro-spatial dynamics between a given industrial market and its economic, social, and/or demographic determinants using geo-referenced or spatially granular information. The classification of the three districts in the current study is based on a set of politically-imposed geographical boundaries, not on the actual underlying economic working or fundamentals of the markets. With the use of GIS techniques, the effect of macroeconomic and other factors affecting the DIRE could be identified and measured in a more spatially explicit manner. Lastly, the cointegration and causal relationships examined in this study could be re-evaluated by employing a multivariate modelling approach in future studies when data of a sufficiently long time span are available. Given the relatively small sample size and the associated statistical complications arising from issues such as degree of freedom, a bivariate analytical framework is chosen in this study, which could potentially ignore indirect channels through which cointegration linkages and causal associations amongst the variables could be formed (we thank a reviewer of our article for highlighting the issue concerning the bi-variability of our models) [48,49].

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Full results of ADF tests.

Variable	t-statistic (level) Prob (level) t-statistic (1st diff) Prob (1st diff)	Variable	t-statistics (level) Prob (level) t-statistic (1st diff) Prob (1st diff)	Variable	t-statistic (level) Prob (level) t-statistic (1st diff) Prob (1st diff)
PR(HK)	−2.756358 (0.0740) * −8.830476 (0.0000) ***	1/DXY	−1.189171 (0.6695) −6.773987 (0.0000) ***	PtR_R(NT)	−6.381109 (0.0000) *** −8.379050 (0.0000) ***
PR(K)	−2.776863 (0.0711) * −5.448885 (0.0001) ***	FDI	−2.636348 (0.0682) * −6.559269 (0.0000) ***	VA	−2.731652 (0.0781) * −6.041304 (0.0000) ***
PR(NT)	−2.375346 (0.1551) −5.433777 (0.0001) ***	M3	−0.892727 (0.7800) −4.934122 (0.0003) ***	IE	−1.235322 (0.6490) −6.047171 (0.0000) ***
I	−1.210615 (0.6599) −6.027234 (0.0000) ***	RHP(HK)	−1.035658 (0.7309) −5.990680 (0.0000) ***	W	−1.163165 (0.6802) −6.062103 (0.0000) ***
ER	−3.024789 (0.0415) ** −5.027312 (0.0044) ***	PHP(K)	−1.063254 (0.7202) −1.063254 (0.7202)	OE	−2.793364 (0.0687) * −5.993349 (0.0000) ***
GDP	−1.534898 (0.5057) −7.305895 (0.0000) ***	PHP(NT)	−0.730942 (0.8264) −4.812043 (0.0004) ***	S	−2.786345 (0.0697) * −6.006693 (0.0000) ***
HSI	−3.626772 (0.0100) *** −7.468470 (0.0000) ***	PtR_R(HK)	−7.176993 (0.0000) *** −9.832806 (0.0000) ***	1/GD	−1.986720 (0.2912) −5.963282 (0.0000) ***
RMB	−1.347538 (0.5976) −5.334136 (0.0001) ***	PtR_R(K)	−3.049188 (0.0391) ** −8.880541 (0.0000) ***		

Note: *** denotes 1% statistical sig.; ** 5% sig.; * 10% sig. with lag length determined by SIC.

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