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FORECASTING OFFICE BUILDING RENTAL GROWTH – USING A DYNAMIC APPROACH

Marcello Tonelli[1], Mervyn Cowley[2] and Terry Boyd[3]

Abstract

Numerous econometric models have been proposed for forecasting property market performance, but limited success has been achieved in finding a reliable and consistent model to predict property market movements over a five to ten year timeframe.

This research focuses on office rental growth forecasts and overviews many of the office rent models that have evolved over the past 20 years. A model by DiPasquale and Wheaton is selected for testing in the Brisbane, Australia office market. The adaptation of this study did not provide explanatory variables that could assist in developing a reliable, predictive model of office rental growth.

In light of this result, the paper suggests a system dynamics framework that includes modified econometric models based on historical data as well as user input guidance for the primary variables. The rent forecast outputs would be assessed having regard to market expectations and probability profiling undertaken for use in simulation exercises. The paper concludes with ideas for ongoing research.

Key Words

Forecasting, Office Rents, System Dynamics, Econometric Modelling, Simulation

[1]Research Associate, School of Construction Management and Property, Queensland University of Technology, Brisbane, Australia or m.tonelli@qut.edu.au

[2] Research Student, School of Construction Management and Property, Queensland University of Technology, Brisbane, Australia or m2.cowley@qut.edu.au

[3] Professor of Property Economics, School of Construction Management and Property, Queensland University of Technology, Brisbane, Australia or t.boyd@qut.edu.au

1.0 Introduction

Earlier approaches in estimating rental growth rates in discounted cash flow valuation exercises were often overly simplistic, generating projections that were far from realistic (Hendershott 1996; Born & Pyhrr 1994). Kummerow (1997) found, during the 1980s, Australian valuers commonly adopted a single, linear and compounding rent growth rate in their assessments. A recent survey of valuers in the city of Brisbane, Australia, found that most valuers use broad cyclical rent forecasts in cash flow studies, but that the conservative nature of recent forecasts in this city appear to lack fortitude in recognising the volatility of the property market. *Figure 1*, below, illustrates this inconsistency with a comparison of the historical volatility of prime office rents spliced onto the median of forecasts from five major valuation firms.

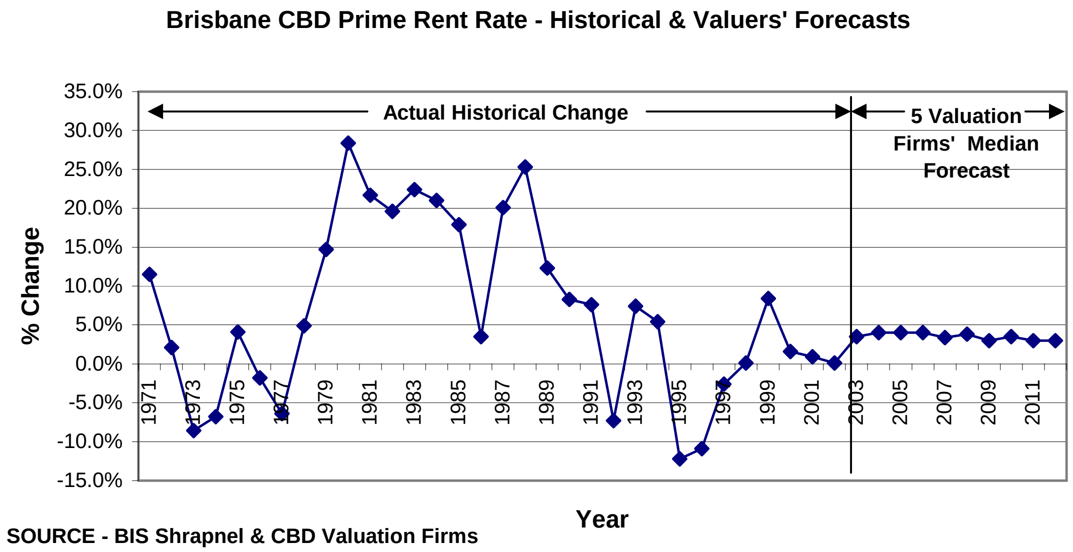


Figure 1 – Historical and Forecast Percentage Change – Brisbane Prime Office Rents

Asset managers are emphasizing the importance of realistic rental growth forecasts and requiring valuers to justify their forecasts. This study examines whether existing or adapted econometric models developed from historical data can be used to predict future rental growth rates.

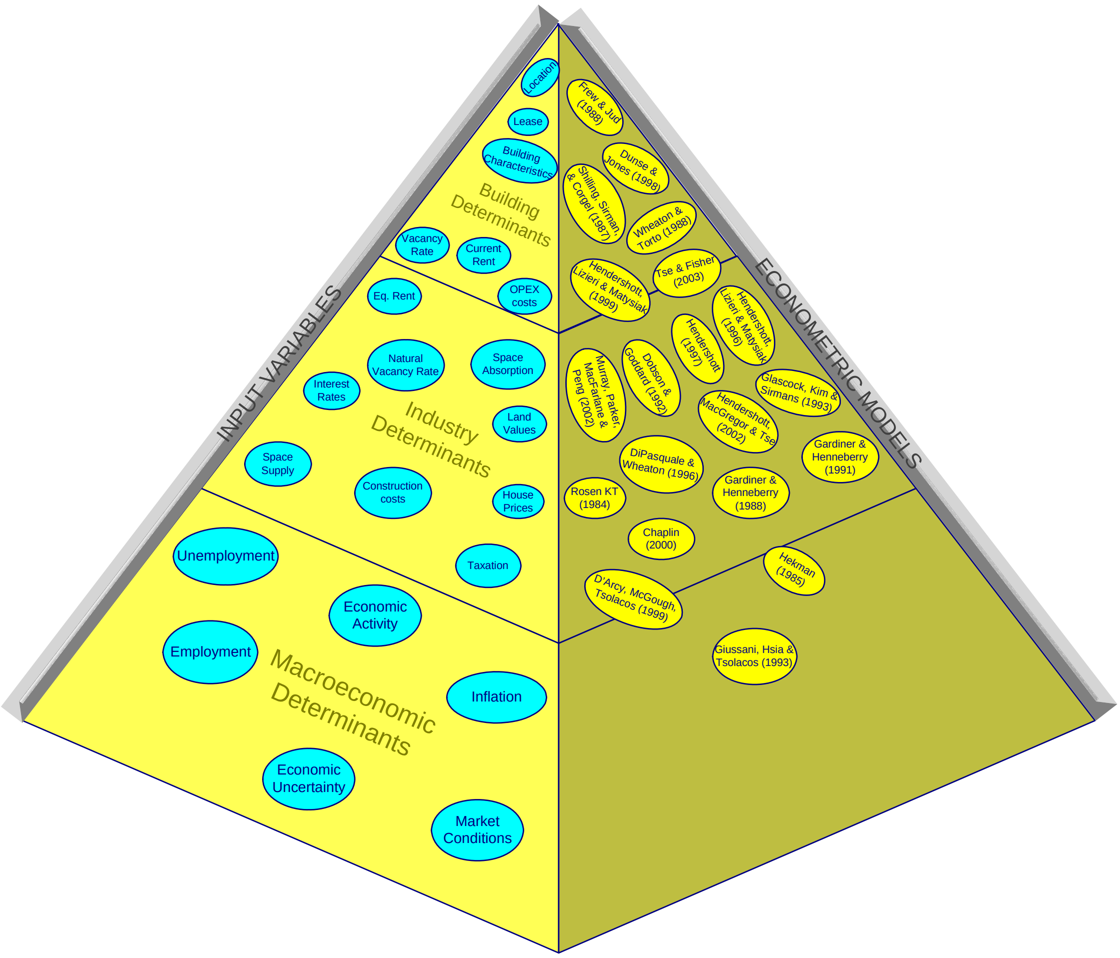
Initially a literature review of property cycle analysis is undertaken and thereafter an econometric model is tested using data from the Brisbane office market. As the results from this study are unhelpful in providing a model for predictive purposes, reference is made to the incorporation of the simulation process and the incorporation of System Dynamics in the forecasting process.

2.0 Literature Review on Property Cycles

Much research has been devoted to the nature and causes of property market cycles. Born and Pyhrr (1994) conducted practical tests to determine the impacts of accounting for market and economic cycles in property cash flow assessments. McGough and Tsolacos (1995) examined commercial building activity in the UK and its procyclicality with demand side factors, such as GDP and employment growth. Clayton (1996) found, in a Canadian study, real estate returns were a function of general capital market conditions. Kaiser (1997) investigated real estate cycles over a long term extending from the 1800s and argued for the existence of "long cycles" with durations of 50 to 60 years. These "long cycles" were said to be driven by prior periods of above-average inflation. Canter, Gordon and Mosburgh (1997) examined the impact of economic fundamentals on building vacancy rates as a generator of property cycles. The relationship between macroeconomic variables and the property market was said to provide the ability to distinguish between the different stages of real estate cycles when looking at property returns (Grissom and Delisle 1999). Mueller (1999) determined rental growth rates to be statistically different at six different points in the property market cycle. In a defining study, Pyhrr, Roulac and Born (1999) nominated cycles' "*pervasive and dynamic impacts on real estate returns, risks and investment values*". Again, this study raised the key linkages between macroeconomic factors and property supply and demand factors. With a wider view, Dehesh and Pugh (2000), considered the impact of globalisation, economic agglomeration and financial deregulation on real estate cycles.

Many of these and other researchers have recognised the cyclical influences and negative impacts of overbuilding on office vacancy rates and, consequently, on office rents. Barras (1994) considered several cyclical influences, of different periodicity, conspired to produce major, speculative building booms. Barras also considered these occurrences to be self-replicating over time. Gallagher and Wood (1999) noted the property market's tendency to over-react to economic trends, generating excess office construction and this was known to have a negative impact on market performance. The causes of these occurrences were quoted as being: the long-term investment nature of real estate; development lags; space demand uncertainty; high adjustment (acquisition / disposal) costs; and the "*unbridled enthusiasm*" of developers. In this context, Kummerow (1999) spoke of "*allocative and production inefficiencies*" in terms of resources. Sivitanidou and Sivitanides (2000) raised the concept of "*irreversible investment*" in relation to the "*highly cyclical and highly volatile*" office-commercial construction activity in the US.

Past research on property cycles and the supply and demand dynamics of property markets has been paralleled by studies aimed at developing rent, return and space supply forecasting models. Office rent models have been evolving over the past 20 years and the majority of the models explicitly quantify causal relationships between changes in rent levels and property market and macroeconomic determinants. *Figure 2*, below, provides a visual representation of the 20 identified models.



Of interest is a comparison of the relative dominance of the explanatory variables adopted in the 20 models. The following chart provides a representation of the relative level of adoption of the various property, market, economic and financial factors. *Appendix 1* (*Office Rent Models – Determinants*) and *Appendix 2* (*Office Rent Models – Equations / Results*) provide greater detail on the structures of the models.

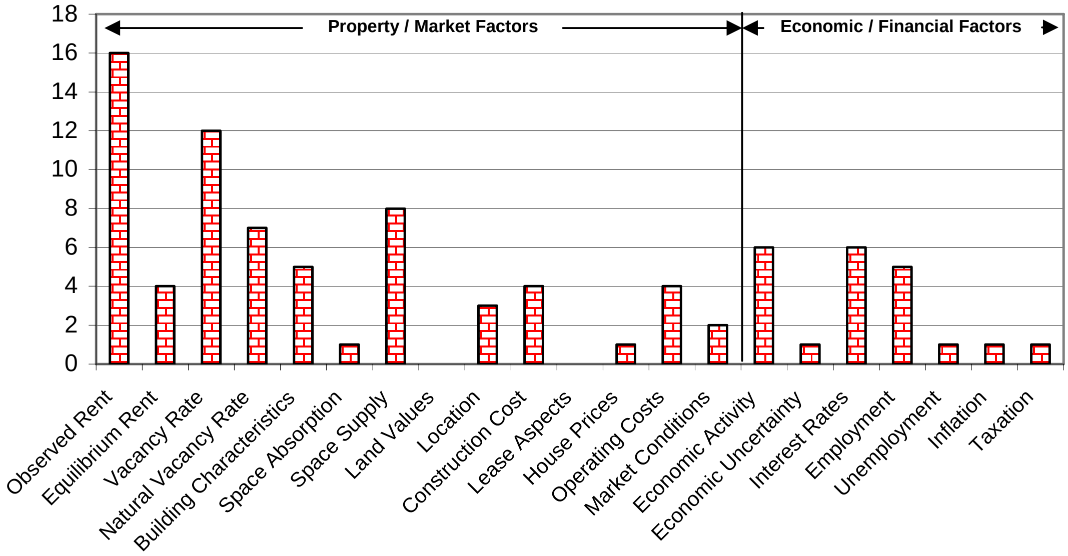


Figure 3 – Explanatory Variables – Frequency of Adoption by Researchers

Aside from historical or observed rents, the dominant property / market determinants adopted for office rents include observed and natural vacancy rates and space supply. The prevalent economic / financial determinants adopted include economic activity, interest rates and employment.

3.0 Dominant Econometric Models

McDonald (2002) surveyed office market econometric models and the study focused on the models developed by Wheaton, Torto and Evans (1997) and Hendershott, Lizieri and Matysiak (1999). Both these models were estimated for the London office market and served as forerunners to the "RICS model" developed in 2000 by the RICS Research Foundation. In commenting on Wheaton Torto and Evans model, McDonald stated that its "*theoretical framework is arguable the best among available models*". A varied version of this model was estimated for the San Francisco office market and was published in 1996 (DiPasquale and Wheaton). The following is a tabulation of the series of equations:

① **TOTAL SPACE – Accounting Identity**	
$S_t = (1 - \delta)S_{t-1} + C_t$	Where: S_t = Total Space in period t C_t = Completions in period t δ = Demolitions / Removals / Space Conversions
② **VACANCY RATE – Accounting Identity**	
$V_t = \frac{(S_t - OC_t)}{S_t}$	Where: V_t = Vacancy Rate in period t S_t = Total Space in period t OC_t = Occupied Space in period t
③ **OCCUPIED SPACE – Accounting Identity**	
$OC_t = OC_{t-1} + AB_t$	Where: OC_t = Occupied Space in period t OC_{t-1} = Occupied Space in previous period AB_t = Net Space Absorption in period t Notes: US data indicates strong relationship between office employment growth and net space absorption. When these two factors diverge, the amount of space per worker must be changing. Space use varies across occupations and should vary with the level of office rents. When vacancies are high and rents are low, space per worker expands and vice versa.
④ **NET ABSORPTION MODEL EQUATION 1 – Regression**	
$OC^*_t = \alpha_0 + E_t\,[\alpha_1 + \alpha_2 \frac{(E_t - E_{t-1})}{E_t} - \alpha_3 R_t]$	Where: OC^*_t is the amount of space all firms in the market would, in principle, demand if there were no lease, moving or adjustment costs to obtaining such space E_t is the number of Office Workers at time t R_t is the Current Rent for space $\frac{E_t - E_{t-1}}{E_t}$ is current or expected growth rate of firms α_1 determines the baseline amount of space per worker α2 + α3 determines how much space use increases with greater employment growth […] term within brackets represents amount of office space demanded per worker Notes: OC_t does not equal OC^*_t because firms cannot adjust their space consumption in response to changes in demand (ie. employment growth or rent movements)

⑤ NET ABSORPTION MODEL EQUATION 2 – Adjustment	
$OC_t - OC_{t-1} = AB_t = \tau_1[OC^*_t - OC_{t-1}]$	Where: OC_t = Occupied Space in period t OC_{t-1} = Occupied Space in previous period AB_t = Net Space Absorption in period t τ_1 is the portion of office space occupiers that change the amount of space they occupy, from what prevailed in the market previously, to what is now desired
⑥ NET ABSORPTION MODEL EQUATION 3 – Combination of ④ and ⑤	
$AB_t = \tau_1[\alpha_0 + E_t[\alpha_1 + \alpha_2 \frac{(E_t - E_{t-1})}{E_t} - \alpha_3 R_t]] - \tau_1 OC_{t-1}$	Symbols as for Equations ④ and ⑤
⑦ RENTAL ADJUSTMENT MODEL EQUATIONS – Regression	
$R^* = \mu_0 - \mu_1 V_{t-1} + \mu_2 \frac{AB_{t-1}}{S_{t-1}}$ $R_t - R_{t-1} = \mu_3(R^* - R_{t-1})$ $= \mu_3(\mu_0 - \mu_1 V_{t-1} + \mu_2 \frac{AB_{t-1}}{S_{t-1}}) - \mu_3 R_{t-1}$	Where: R^* is the equilibrium rent that eventually emerges in the market – determined as a linear function of absorption and vacancy rates V_{t-1} = Vacancy Rate (%) in previous period AB_{t-1} = Net Space Absorption (%) in previous period S_{t-1} = Total Space in previous period R_{t-1} = Rent for Space in previous period Notes: Given a stock of space and the level of office employment, these combined equations depict how rents eventually adjust to equate office demand to a given stock of office space.
⑧ OFFICE SPACE SUPPLY EQUATION – Regression	
$C^*_t = \beta_0 + \beta_1 S_{t-8} + \beta_2 S_{t-8} V_{t-8} + \beta_3 AB_{t-8}$ $C_t - C_{t-1} = \tau_2 (C^*_t - C_{t-1})$ $C_t = \tau_2 (\beta_0 + \beta_1 S_{t-8} + \beta_2 S_{t-8} V_{t-8} + \beta_3 AB_{t-8}) + (1 - \tau_2) C_{t-1}$	Where: C^*_t = level of desired Completions S_{t-8} = Total Space 8x6 months previous V_{t-8} = Vacancy Rate 8x6 months previous C_{t-1} = Completions in previous period τ_2 = adjustment rate to account for the gradual response by construction - actual completions at time t are assumed to move proportionally (at rate τ_2) to the difference between desired completions and those just undertaken Notes: Reasonable to assume the desired rate of new completions (% of stock) depends on the developers' estimate of the level of rents at the time of project delivery. Hence, the absolute level of new completions will depend on estimated future rents together with the current stock of space.

Table 1 – DiPasquale and Wheaton Office Market Econometric Model – Derived from DiPasquale and Wheaton (1996 : 293-309)

A diagrammatic representation of the workings of this model has been produced below:

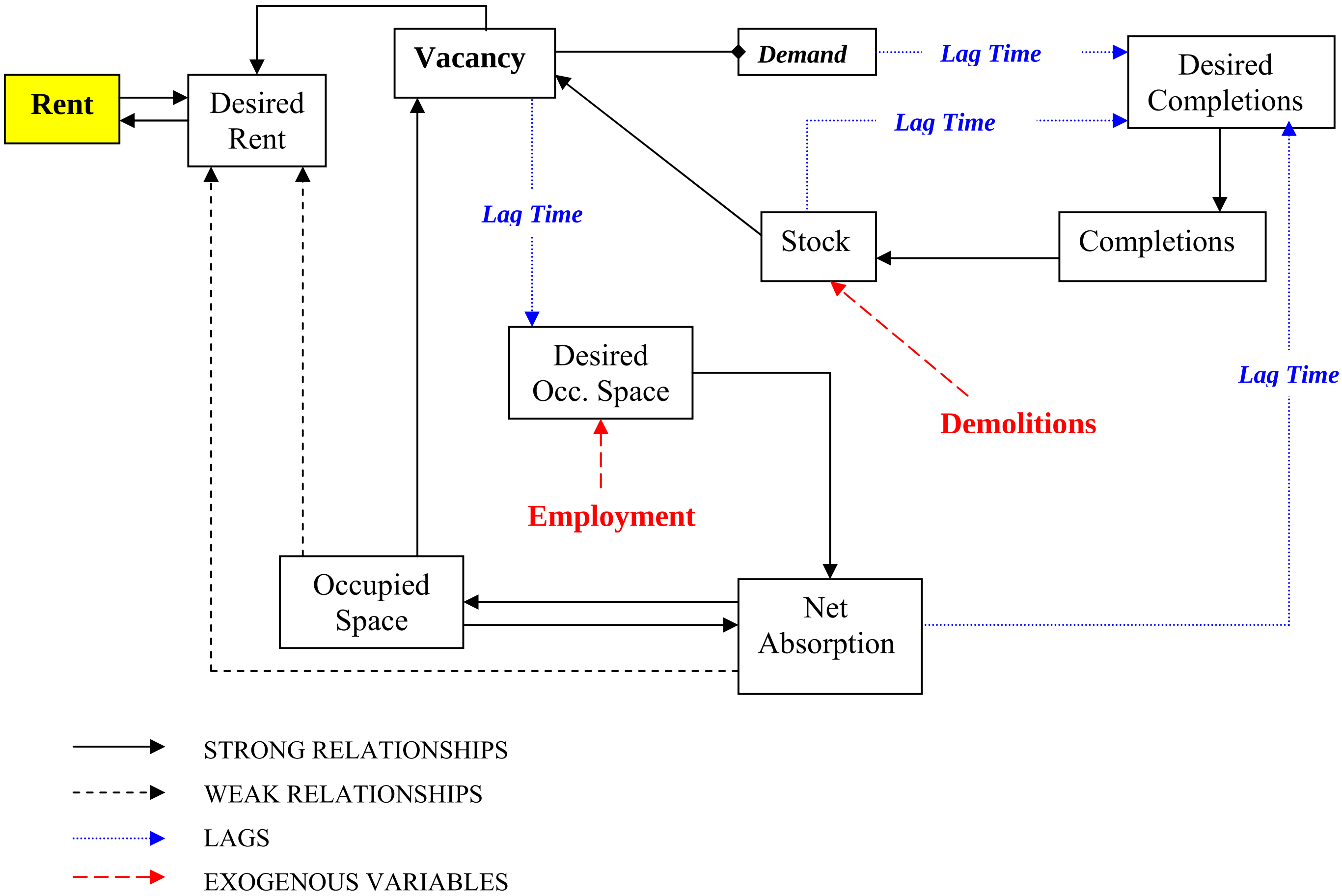


Figure 4 – Conceptual Map – DiPasquale and Wheaton Office Market Model (1996)

The publication of full econometric models is relatively rare. The DiPasquale / Wheaton – Wheaton / Torto / Evans models incorporate the majority of the explanatory variables found to be dominant in the many models that have evolved over time. This together with McDonald's (2002) support for the framework and the relative transparency of how the models were applied to the San Francisco and London markets assisted in selecting the framework for testing and forecasting with data for Brisbane, Australia.

4.0 Brisbane Central Business District Data

Brisbane is the capital of the Australian State of Queensland and is the third largest Australian central business district in terms of office floor area with a total net lettable area of approximately

1.65M square metres. Some of the city's fundamental office market variables and their change over the last 31 years are mapped in the charts below:

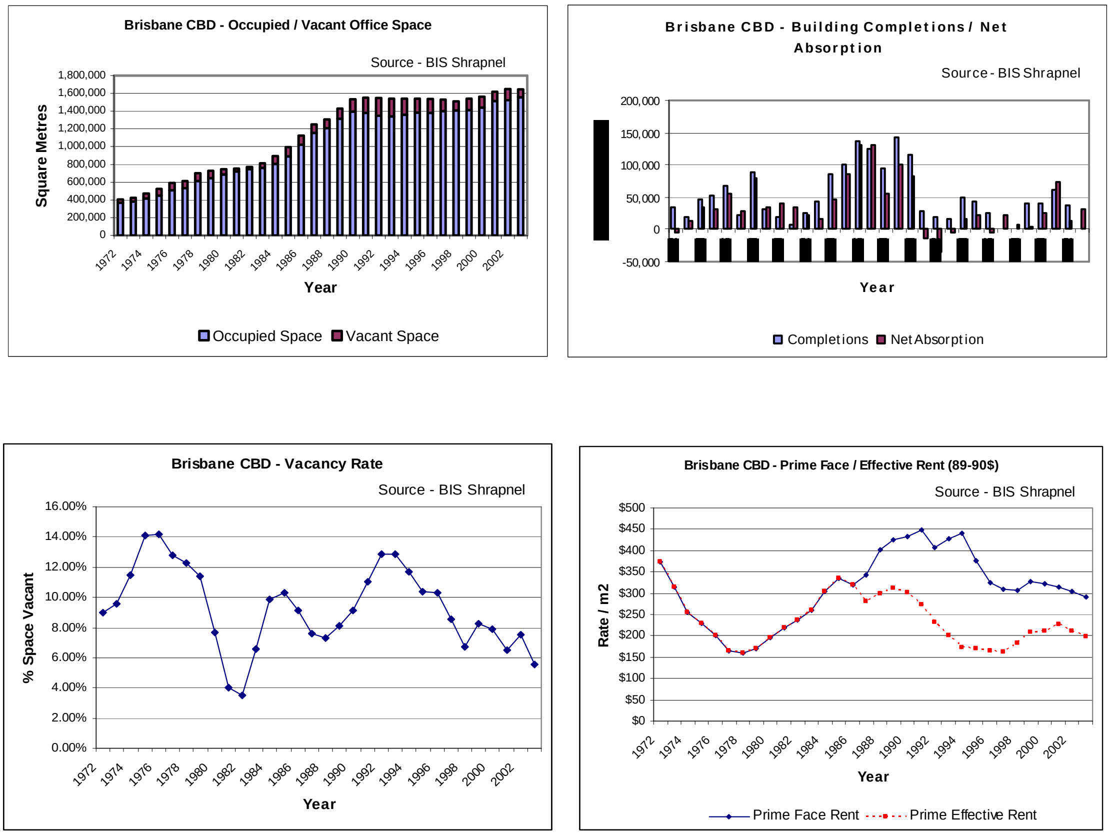


Figure 4 – Brisbane CBD Market Variables – Historical Change

A frequent lament of property researchers is the quality and extent of available property market data (for example: Jones 1995; Mitchell and McNamara 1997; Tsolacos and McGough 1999; Mueller 2002; MacFarlane, Murray, Parker and Peng 2002). In this instance, due to the lack of longer term CBD employment data, the scope of the study has been limited to annual data extending from 1980 to 2003. Some summary statistics for the data utilized for model testing are tabulated below:

Variable	Period	Mean	Std Dev	Minimum	Maximum
Vacancy (%)	1980-2003	8.5%	2.4%	3.5%	12.9%
Occupied Space (Δm^2)	1980-2003	37,450m²	43,636m²	-33,600m²	132,100m²
Net Absorption (Δm^2)	1980-2003	37,433m²	43,646m²	-33,600m²	132,000m²
Employment (Δ)	1981-2003	1,450	1,689	-1,300	4,100
Withdrawals (m²)	1980-2003	14,825m²	13,698m²	0m²	48,300m²
Completions (m²)	1980-2003	52,979m²	43,992m²	0m²	142,300m²

Work Space Ratio (Δm^2)	1981-2003	$0.2m^2$	$0.8m^2$	$-1.0m^2$	$2.3m^2$
Gross Effective Rent ($/$m^2$)	1980-2003	$195	$39	$152	$264

Table 2 – Data Summary Statistics

5.0 Results of Brisbane Study

A summary of some of the results from applying the DiPasquale and Wheaton model to the Brisbane data is set out below. Some adjustments to the lag periods have been adopted to better reflect the workings of the Brisbane market.

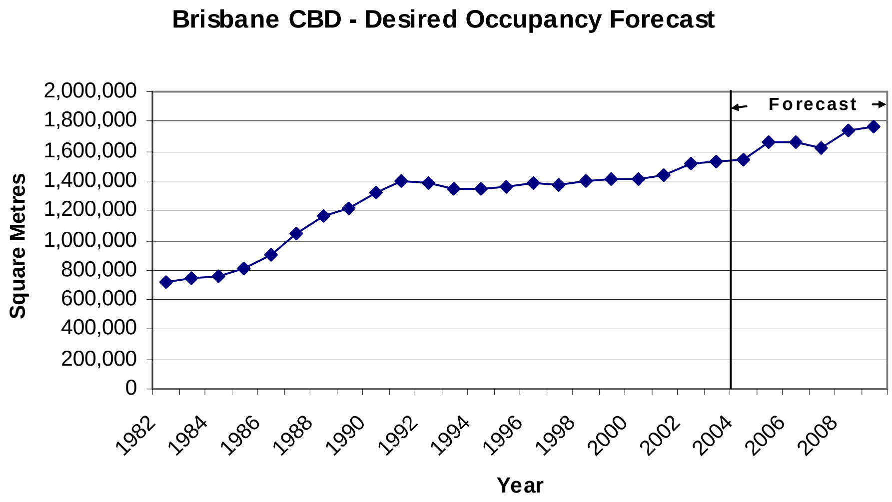
Equation 4 – Net Absorption Model – Desired Occupancy

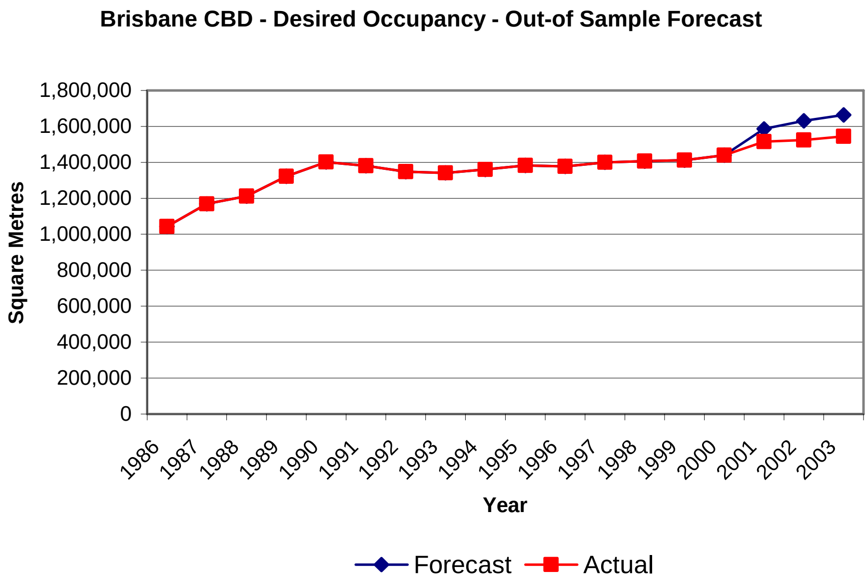
$OC^*_t = \alpha_0 + \alpha_1 E_{t-2} + \alpha_2(E_t - E_{t-2}) + \alpha_3 E_{t-2} * V_{t-2}$

Descriptor	Coefficient	t-statistic
Intercept	57,345.49	(0.323)
α_1	3.60	(4.250)
α_2	13.24	(1.254)
α_3	16.61	(2.101)
Adjusted R^2 = 0.74	Durbin-Watson = 0.29	

DiPasquale and Wheaton substituted lagged vacancy (four years) in their estimated equation for San Francisco as a proxy for rent. This was due to a data availability issue. However, the same substitution, with a lag of two years, had the effect of marginally improving the fit of the equation for Brisbane. Unfortunately the results indicated that the only significant variable in the equation was employment lagged by two years. In addition, the Durbin-Watson statistic indicates positive autocorrelation in the residuals signaling the explanatory power of the equation is weak and needs enhancement in the Brisbane context.

Using the equation to cast forward a five year forecast generates a plausible result, but the true test of an out-of-sample forecast (three years) confirms further refinement is required. The graphs, below, show the results:





The calculation of the Theil's U-statistic (6.95) for the out-of-sample forecast infers a naïve forecast would eclipse the forecast derived from the equation.

Applying the equation for equilibrium rent from DiPasquale and Wheaton, resulted in the following output:

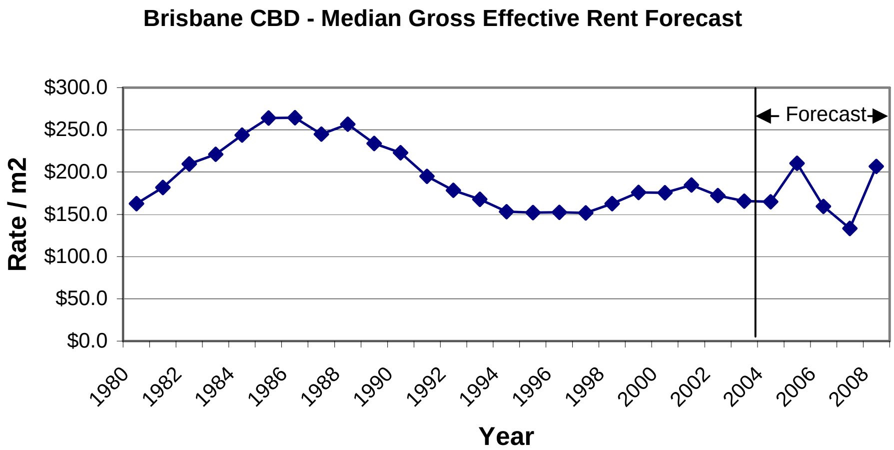
Equation 7 – Equilibrium Rent

$$R^* = \mu_0 - \mu_1 V_{t-1} + \mu_2 \frac{AB_{t-1}}{S_{t-1}}$$

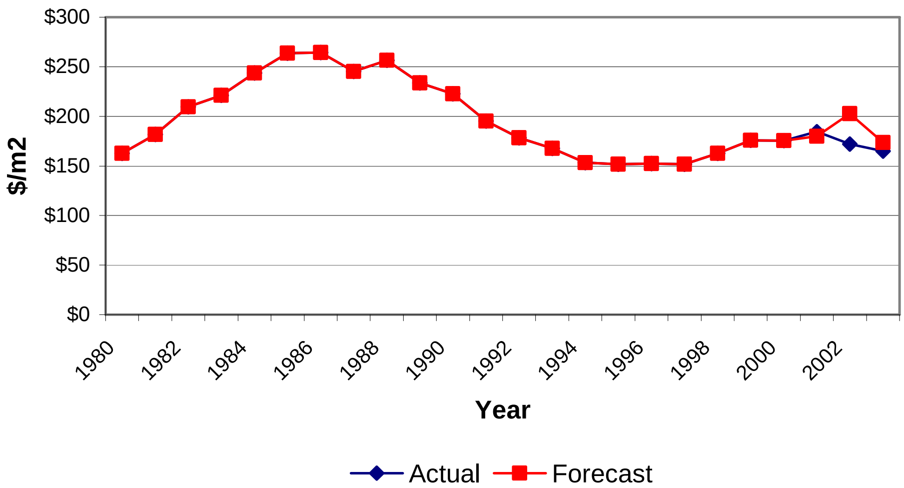
Descriptor	Coefficient	t-statistic
Intercept	160.27	(7.116)
μ_1	103.26	(0.436)
μ_2	825.28	(5.220)
Adjusted R^2 = 0.53	Durbin-Watson = 1.18	

Surprisingly, the vacancy rate variable did not register as significant in this case while the lagged absorption / stock ratio was found to influence the level of equilibrium rent. A case for further refinement of the equation's structure is supported by a degree of positive autocorrelation remaining in the residuals.

Using the stock, new supply, absorption and vacancy forecasts derived from the model, a five year forecast of the equilibrium rent was generated. Applying the results to the DiPasquale and Wheaton rent equation [$R_t = \mu_3(R^* - R_{t-1}) + R_{t-1}$ where μ_3 is an adjustment parameter quantifying speed of movement towards equilibrium rent] a five year median gross effective rent forecast is generated. The results were found to be quite erratic and the out-of-sample forecast Thiele' U-statistic confirmed a naïve forecast would produce a far superior result.



Brisbane CBD - Mean Rent - Out-of Sample Forecast



The results of this analysis are disappointing although no reasonable fit was anticipated. While much further work is required to estimate a model that exhibits a sound fit to the Brisbane market, this research will extend beyond the application of econometric models into a potentially complementary area of system dynamics.

6.0 System Dynamics

System dynamics theories offer the opportunity to model the complex interrelationships of the real estate environment and to observe their dynamic behaviour over time, with particular respect to how these interrelationships impact the investment prospects facing the building company or even the private investor. Strangely enough, simulation modelling in general seems to be a relatively new concept in the real estate industry.

Other industry sectors have proven that the use of well-calibrated structural models, such as system dynamics simulators, can do a reasonable job of forecasting in situations where regression and trend forecasts have proven their individual weaknesses (Sterman, 1988; Sterman, 2000; Lyneis, 2000), but the use of such theories in real estate markets has been very sporadic. Forrester (1969), founder of system dynamics, developed Urban Dynamics, a complex model counting 150 equations for the prediction of urban growth and decline, used to understand America's urban crisis. Vennix (1996) offers a case study to illustrate the dynamics of the housing market from the perspective of housing associations. Kim and Lannon (1991) examined Minneapolis' real estate activity arguing that delays, self-ordering dynamics, speculation and short-term individual gain are the factors that need to be addressed. Kummorow (1997, 1999) developed a series of dynamic models, integrating econometric and simulation principles with forecasting methods, to study and forecast supply and demand cycles for the areas of Sydney and Perth. Aptek Associates LLC also developed a series of corporate real estate simulation tools that can be used to do more accurate planning and forecasting (Klammt, 2001). Bakken, & Sterman (1993) designed a real estate flight simulator, in which the user takes command of a firm in the volatile market of office buildings and pilots it from start-up to success.

The adaptation of a statistical model to a system dynamics framework has several advantages. First of all, spreadsheet analyses are static in nature, no matter how complex the macros are, and do not take into account the changing dynamics of the market environment. Conversely, a system dynamics model does not simply determine future rates under current market conditions, but it also considers changes that occur overtime from the interaction of different variables. Secondly, allowing parameters such as employment growth and demolition rate to be varied exogenously by the user adds credibility to the simulation model, because it gives the user a better understanding of the industry structure and makes the user participate to the decision making process. On the other hand, we must also be very careful with the type and amount of freedom granted to the user. Assumptions should not deviate from reasonable ranges set in consistency with historical patterns to prevent the model from coming up with illogical values. Additionally, only a limited number of parameters should be given the possibility of having arbitrary values: the main inputs such as supply and demand should always be kept endogenous to the system.

Bertsche, Crawford and Macadam (1996) assert the existence of a deep body of theoretical literature that praise the power of simulations to change behavior by giving managers the opportunity to experiment, test their assumptions, and learn from their mistakes in a risk-free environment. But the literature has little to say about how the theory can be applied in real corporate situations. In fact, their study also shows that over 60 percent of US corporations have used some sort of simulation and that only a few have succeeded. This statistic shows that simulations can play a useful role in successful transformations, but if they are poorly designed they have no more than an entertainment value. For this reason the econometric structure of the model remains a primary concern and it needs to be designed on the basis of logic, expert opinion, and historical trends.

7.0 Application of System Dynamics

Due to the inadequacy of econometric models this study is considering whether a system dynamics approach can provide a basis for rental growth forecasts. A three steps approach has been identified:

a) Develop a theoretically based model that simulates market activity
b) Choose the input matrix type
c) Apply system dynamics theories to estimate the model

a) The first priority remains the creation of an econometric model that is market tested. Structural equation modeling (SEM) is based on causal relationships, where the change in one variable is assumed to result in a change in another variable. Regression analysis, which has been widely adopted by previous researchers, has the great limitation of allowing only a single relationship between dependent and independent variables at a time. But SEM can estimate many equations at once, and they can be interrelated. Furthermore, SEM has the ability to represent unobserved concepts (latent variables) in these relationships and to account for measurement error in the estimation process. The stages involved in developing a theoretically based model are expressing causal relationships in terms of equations and portray these relationships thorough a path diagram.

The equations that are being considered while writing this paper are:

$$R_t = R_{t-1} + [R_{t-1} * (Eq\_V - V_t)] \qquad (1)$$

where R_{t-1} is the rent from the previous period, V_t is the current vacancy rate, and *Eq_V* is the equilibrium vacancy rate, a fixed value specific to the analysed market used to trigger construction. ‘Completions’ (C_t) is a function of demand and most researchers seem to agree that vacancy rate is the engine that drives cycles. The adoption of a minimum vacancy value is required to make construction feasible (or to start the engine) and *Eq_V* represents this level.

$$C_t = S_{t-3} + S_{t-3} * (Eq\_V - V_{t-3}) \qquad (2)$$

After careful consideration, a supply lag time of 3 years was chosen for the equation. Studies of the Sydney CBD have shown that 3 years is the best fit (Murray, Parker, MacFarlane & Peng, 2002), however not as many studies have been conducted in Brisbane. Cowley (2003) has compared the time taken to develop different buildings in the CBD and its results show that 3 years is probably a good estimate for Brisbane as well. The table shows that in average it takes 1 year for the acquisition process and 2 years to complete the building.

Project	Levels NLA	Date of Site Acquisition	Construction Commenced	Completion Date
Waterfront Place	40 59,179m²	Jul-84	Mar-88	Jun-90
Riverside Centre	40 51,687m²	Apr-84	Apr-84	Oct-86
Central Plaza One	36 40,290m²	Jan-85	N/A	May-88
Mincom Central	13 24,619m²	Mar-94	Dec-98	Nov-00
Hall Chadwick	22 15,661m²	May-98	Apr-00	Oct-01
CUA House	17 18,000m²	Oct-00	Feb-01	May-02

The formula for vacancy in period *t* is:

$$V_t = (S_t - OC_t) / S_t \qquad (3)$$

where OC is the occupied space and is calculated by multiplying employment times space per worker in terms of square metres:

$$OC_t = E_t * SW_t \qquad (4)$$

Total space at time *t* is simply total space from the previous period plus constructions less space withdrawals:

$$S_t = S_{t-1} + C_t - \delta_t \qquad (5)$$

C_t is the symbol for completions, while δ_t includes demolitions, removals, and space conversions. Employment (E_t) and demolition rate (δ_t) are the only two variables that are external to the feedback cycle and therefore the user must select a value for each period *t*. The range values for E_t are set to 80000-105000. Employment has always been incremental, going from 46,500 units in 1980 to 85,000 in 2003. In fact, only three small drops were registered in the period of study (*n=24*): 1,000 in 1983; 700 in 1991; and 100 in 1998. The parameters chosen for δ_t are instead 0 (in the event that there are no demolitions registered in the period *t*) and 50,000. In the last thirty-four years (*n=34*), the highest number of demolitions registered in a single year has been 48,300 (1994), and there has been an average of 10,953 per year.

Space per worker depends upon differentials between current and previous rent:

$$SW_t = SW_{t-1} + [SW_{t-1} * (R_t - R_{t-1})] \quad (6)$$

where SWt-1 is space per worker in the previous period.

b) The second step is to develop a correlation matrix to understand the pattern of the relationships between constructs. The coefficients obtained from the correlation matrix are then used as inputs for the dynamic model, which will run a forecast over a five years period (*n=5*).

The final step involves employing simulation techniques to estimate the model. The formulas of the econometric model are pasted into the structural layer of the I-THINK software. The model will be developed over a three layers structure: formulas; a graphical representation of the interrelationships that exist among the variables; and a very friendly graphical user interface (GUI) that allows the user to run different simulations and to perform "what-if" scenarios and sensitivity analysis of those variables that are exogenous to the model cycles and therefore in the hands of the user's discretion.

8.0 Conclusions

Recent observations of rent forecasts adopted by Brisbane property professionals for cash flow studies resurrect concerns raised by researchers about the use of overly simplistic, near linear forecasts for a variable that has experienced significant historical volatility.

A review of literature on property cycles revealed an increasing amount of research being devoted to the subject through an evolutionary process covering the previous 20 years. The recent formulation and publication of a cycles research framework and classification model (Pyhrr, Born, Manning & Roulac 2003) represents a significant advance in the drive for a standardised approach in categorising research on the subject.

Many studies have recognised a natural progression from the property cycle discipline to the field of property market variable forecasting. The dominant method for evaluating the value / viability of major commercial buildings / developments requires the incorporation of rent forecasts in cash flow analyses. An examination of 20 rent growth models developed since 1984 has provided an indication of the dominant explanatory variables adopted by researchers. The prevalent property / market determinants have included historical rent levels, vacancy rate, natural/equilibrium/structural vacancy rate and space supply. The prevalent economic / financial determinants adopted have included economic activity, interest rates and employment.

The DiPasquale and Wheaton (1996) econometric model was selected for testing with Brisbane city data on the basis that it incorporated many of these dominant explanatory variables. The explanation of the model was generally more comprehensive than normally published. In addition, a recent study (McDonald 2002) comparing the relatively few published commercial property market econometric models indicated the theoretical soundness of this model.

The out-of-sample forecasts produced for Brisbane city using the model produced disappointing results, but this could be due to incompatibilities between the San Francisco and Brisbane markets rendering the model as a poor fit to the later. In addition, the time span of the available Brisbane data did not cover two complete market cycles and the quality of the CBD employment data needs to be further investigated. These aspects may have also contributed to the relatively weak explanatory power of the equations.

Testing and development of rent models for Brisbane will continue with the aim of developing a forecasting module for incorporation with the office building investment evaluation model developed by the Australian Cooperative Research Centre for Construction Innovation.

However, it is anticipated the application of system dynamics will accentuate the forecasting module by truly reflecting the causal relationships and dynamic interaction of market variables to surpass the existing static rent models that purely rely upon multiple regression equations. In addition, the scope to incorporate simulation capabilities in a user friendly package offers significant advantages.

APPENDIX 1 - OFFICE RENT MODELS – DETERMINANTS

		DETERMINANTS																				
		Property / Market Factors														Economic / Financial Factors						
Researcher(s)	Year	Current Rent	Equilibrium Rent	Vacancy Rate	Natural Vacancy Rate	Building Characteristics	Space Absorption	Space Supply	Land Values	Location	Construction Cost	Lease Aspects	House Prices	Operating Costs	Market Conditions	Economic Activity	Economic Uncertainty	Interest Rates	Employment	Unemployment	Inflation	Taxation
Rosen KT	1984	■		■	■			■			■							■			■	■
Hekman JS	1985			■							■					■		■	■	■		
Shilling J, Sirman C & Corgel J	1987	■		■	■									■								
Wheaton WC & Torto RG	1988	■		■	■																	
Frew J & Jud GD	1988	■		■		■				■												
Gardiner C & Henneberry J	1989							■								■						
Gardiner C & Henneberry J	1991	■														■						
Dobson SM & Goddard JA	1992	■											■	■				■				
Glascock JL, Kim M & Sirmans CF	1993					■				■					■							
Giussani B & Tsolacos S	1993							■							■	■	■		■			
Hendershott PH, Lizieri CM & Matysiak GA	1996	■	■	■	■	■					■			■				■				

		Property / Market Factors														**Economic / Financial Factors**						
Researcher(s)	Year	Current Rent	Equilibrium Rent	Vacancy Rate	Natural Vacancy Rate	Building Characteristics	Space Absorption	Space Supply	Land Values	Location	Construction Cost	Lease Aspects	House Prices	Operating Costs	Market Conditions	Economic Activity	Economic Uncertainty	Interest Rates	Employment	Unemployment	Inflation	Taxation
DiPasquale D & Wheaton WC	1996	■	■	■			■	■											■			
Hendershott PH	1997	■	■	■	■																	
Dunse N & Jones C	1998	■				■				■								■				
D'Arcy E, McGough T & Tsolacos S	1999	■						■								■			■			
Hendershott PH, Lizieri CM & Matysiak GA	1999	■	■	■	■	■					■			■								
Chaplin R	2000	■						■								■						
Murray J, Parker D, MacFarlane J & Peng V	2002	■		■				■										■				
Hendershott PH, MacGregor BD & Tse RYC	2002	■		■				■											■			
Tse RYC & Fischer D	2003	■		■	■																	

APPENDIX 2 – OFFICE RENT MODELS – EQUATIONS / RESULTS

Researcher(s)	Year	Equations (Researchers' Notation)	Key		Data	Results (Rent)
Rosen KT	1984	$R_t = f(V^*_t - V_t, P^*_t)$ where $V^*_t = f(i_t, R^e_t)$ and $\Delta SQFT_t = f(V_t, R^e_t, CC_t, i, TAX)$	R_t = change in net rents V^*_t = optimal vacancy rate V_t = actual vacancy rate P^* = change in price level R^e_t = expected rent levels	i_t = interest rate $SQFT_t$ = occupied space CC_t = construction cost TAX = tax laws affecting real estate	San Francisco Office Rents – 1961-1981	Adjusted $R^2 = 0.55$. Said to confirm an inverse relationship between rent change and deviations between the actual and "optimal" vacancy rate and a direct relationship with the cost of living
Hekman JS	1985	$R_t = \alpha_0 + \alpha_1 Vt + \alpha_2 Y_t + \alpha_3 E_t + \alpha_4 U_t + \varepsilon_{1t}$ $Q_t = \beta_0 + \beta_1 R^*_t + \beta_2 G_t + \beta_3 C_t + \beta_4 I_t + \varepsilon_{2t}$	R_t = real rent per sq. ft V_t = vacancy rate (A Grade) Y_t = Gross National Product E_t = total employment (local) G_t = office employment ratio	U_t = unemployment rate (local) C_t = construction cost per sq. ft I_t = interest rate ratio	14 US cities – 1979-1983	$R^2 = 0.40$ with lags. Overreactions of supply to market signals, such as high rents, perceived to create periods of sustained low or high vacancy rates and rents.
Shilling J, Sirman C & Corgel J	1987	$R = b_0 + b_1 E - b_2 V$ where $b_0 = b_2 V^n$	R = change in rents E = change in operating expenses V = observed vacancy rate V^n = normal vacancy level		17 US cities – 1960-1975	R^2 ranging from 0.66 to 0.98 for cities. Vacancies said to play an important role in responding to demand fluctuations and in setting short-run prices (significant at 90% for 11 of 17 cities).
Wheaton WC & Torto RG	1988	$R(t)/R(t-1) - 1 = a[b + ct - V(t)]$	R(t) = real rent (average effective) V(t) = vacancy rate b + ct = "structural" vacancy rate	a = speed of adjustment parameter	National US rent and vacancy data (spliced) – 1968-1986	$R^2 = 0.78$. Excess vacancy said to have strong relationship with rents. Indicated "structural" vacancy rate had risen over time. Provided seven forecast for office rent.
Frew J & Jud GD	1988	$R_t = f(V_t, D_t, A_t, F_t, C_t, H_t)$	R_t = marginal rental rate V_t = vacancy rate D_t = distance from CBD A_t = building age	F_t = number of floors C_t = % common area H_t = location adjacent major thoroughfare / highway (dummy)	Survey of 66 buildings in Greensboro, USA	Adjusted R^2 ranging from 0.49 to 0.58 depending on data format. All variables, except "common area %" and "distance from CBD" found to be significant.
Gardiner C & Henneberry J	1989	$RR_t = a + b.GDPR_t + c.GDPR_{t-2} + d.FSR_t$	RR_t = rent level GDP = Gross Domestic Product	FSR = ratio of regional floor space to total national floorspace	Eight UK regions – office rent index – 1977-1984	R^2 ranging from 0.397 to 0.975 for the eight regions. Model had difficulty in forecasting rents for a declining region.
Gardiner C & Henneberry J	1991	$R_t = \alpha(1 - \lambda_1)(1 - \lambda_2) + (\lambda_1 + \lambda_2)R_{t-1} - \lambda_1\lambda_2 R_{t-2} + \beta(1 - \lambda_1)(1 - \lambda_2)D_t + (u_t - \lambda_2 u_{t-1})$	R_t = rent bid λ_1 = "adaptive expectation" parameter (0-1) D_t = demand for floorspace	λ_2 = "partial adjustment" parameter (0-1)	Eight UK regions – office rent index – 1977-1984	R^2 ranging from 0.51 to 0.98 for combined "habit persistence" model. Model said to improve forecasts for declining regions.

Researcher(s)	Year	Equations (Researchers' Notation)	Key		Data	Results (Rent)
Dobson SM & Goddard JA	1992	$logR_t = a + b.logR_{t-1} + c.logR_{t-2} + d.logI_t + e.logH_t + \varepsilon_t$ (+ regional dummies)	R_t = rent index (inflation adjusted) I_t = real interest rate (spread) H_t = house price index (local)		Four UK regions – 1972-1987	Adjusted $R^2 = 0.94$. Interest rates and house prices said to have positive effects on office rents.
Glascock JL, Kim M & Sirmans CF	1993	$y_t = X_t\beta + v_t y + W\delta + \xi t J_T + u_t$	y_t = average real rent X_t = constant and variable that vary over time periods and individual buildings	v_t = location characteristics w_t = market condition variables	Baton Rouge, USA – six sub-markets – 1984-1989	Used random effects and heteroscedastic autoregressive models. Suggested rent process different across time and building classes. Assumption of parameter constancy is not supported.
Giussani B & Tsolacos S	1993	$\Delta_1 RERV = \alpha_0 + \alpha_1 A_4(\Delta_1 GDP) + \alpha_2[(\Delta_1 BFI_{t-5} + \Delta_1 BFI_{t-6})/2] + \alpha_3 \Delta_1 PROF_{t-2} + \alpha_4[(\Delta_1 NO_{t-26} + \Delta 1NO_{t-27})/2] - \alpha_5 UNCER$	RERV = estimated rental value GDP = real Gross Domestic Product BFI = employment (banking, finance and insurance)	PROF = market conditions index (tender price – building cost) NO = office buildings new orders UNCER = uncertainty	UK quarterly rent index – 1971-1991	Adjusted $R^2 = 0.67$. Indicated most significant variable to be uncertainty (4th quarter standard deviation of change in GDP), followed by GDP and employment.
Hendershott PH, Lizieri CM & Matysiak GA	1996	$\%dR = \alpha + \lambda v + \beta (R^* - R)$ where $R^* = (r + dep + oper)RC$ and $\alpha = -\lambda v^*$ $Completions = \alpha + \beta(Gap_{t-1} + Gap_{t-2})$	%dR = % change in real effective rents v = actual vacancy rate R* = equilibrium rent r = real interest rate v* = equilibrium vacancy	dep = depreciation rate oper = operating expense ratio RC = replacement cost Gap = R* - R	City of London prime office face rents – 1977-1995	Adjusted $R^2 = 0.58$. Real effective rents considered to be mean reverting, responding to gaps between actual and equilibrium rents and actual and natural vacancy rates.
DiPasquale D & Wheaton WC	1996	$R_t - R_{t-1} = \mu_3(R^* - R_{t-1}) = \mu_3(\mu_0 - \mu_1 V_{t-1} + \mu_2 AB_{t-1}/S_{t-1}) - \mu_3 R_{t-1}$ Where: $AB_t = \tau_1[\alpha_0 + E_t[\alpha_1 + \alpha_2 \frac{(E_t - E_{t-1})}{E_t} - \alpha_3 R_t]] - \tau_1 OC_{t-1}$	R_t = current rent R* = equilibrium rent V_{t-1} = vacancy rate previous period S_{t-1} = total stock previous period	AB_{t-1} = net space absorption previous period E_t = number of office workers at time t τ_1 = occupier space change adjuster	San Francisco office rent index – 1980-1992	$R^2 = 0.73$. Equation developed as part of econometric model. Given a stock of space and a level of office employment, the equation was said to depict how rents adjust to equate office demand to a given stock of space.
Hendershott PH	1997	$(g_t - g_{t-1}) / g_{t-1} = \lambda_1 (v^* - v_{t-1}) + \lambda_2 (g^*_t - g_{t-1})$	g_t = actual real effective rent rate g^*_t = equilibrium real effective rent rate λ_1 & λ_2 = positive adjustment coefficients	v_t = actual vacancy rate v* = natural vacancy rate (assumed to be constant over time)	Sydney annual rent data – 1970-1992	$R^2 = 0.68$. Percentage change in effective rents was related to the gaps between actual and equilibrium rents and actual and natural vacancy rates.
Dunce N & Jones C	1998	$R(z_k) = \beta_0 + \sum_{i=1}^{n} \beta_i z_{ik} + \varepsilon_i$	$R(z_k)$ = rent for space in kth building z_i = individual characteristics of space (25 variables	including area, age, location, physical building aspects)	Glasgow – 477 asking rents – 1994-1995	Adjusted $R^2 = 0.61$. Studied aimed at identifying and quantifying the contribution of different explanatory attributes to office rents. The results were said to emphasise the importance of age and location as the principal rent determinants.

Researcher(s)	Year	Equations (Researchers' Notation)	Key		Data	Results (Rent)
D'Arcy E, McGough T & Tsolacos S	1999	$\Delta rent_t = \alpha_0 + \Sigma\alpha_{1i}\Delta gdp_{t-i} + \Sigma\alpha_{2i}\Delta sse_{t-i} + \Sigma\alpha_{3i} ofnc_{t-i} + e_t$	Rent = real rent gdp = Gross Domestic Product sse = service sector employment	ofnc = volume of new office completions (first differences and natural logs)	Dublin prime rack (effective) rents – 1971-1997	Adjusted $R^2 = 0.49$. Service sector employment found not to be significant. Key determinants of office rents said to be GDP (lagged one year) and new space (lagged three years).
Hendershott PH, Lizieri CM & Matysiak GA	1999	$\Delta R\% = \alpha + \lambda v + \beta (R^* - R)$ where $R^* = (r + dep + oper)$ and $\alpha = -\lambda v^*$ $Completions = \alpha + \beta(Gap_{t-1} + Gap_{t-2}) + \gamma\, DUM$	$\Delta R\%$ = change in real effective rents v = actual vacancy rate R* = equilibrium rent r = real interest rate v* = equilibrium vacancy	dep = depreciation rate oper = operating expense ratio RC = replacement cost Gap = R* - R	City of London – real new prime effective rents – 1975-1996	Adjusted $R^2 = 0.69$. Real effective rents said to respond to gaps between actual and equilibrium rent levels and actual and natural vacancy rates. Construction and absorption said to feed back onto rents through their effects on the vacancy rate.
Chaplin R	2000	$DLROHP = CONST + \alpha.DLROHP(-1) + \beta.DLRBFQ1 + \gamma.DLRONOQ1(-1) + \delta.DLRONOQ1(-2) + error$	DLR = first difference and natural logs used OHP = office rent index BF = output of business and finance sector	ONO = office building new orders	Great Britain – office rent index	Adjusted $R^2 = 0.51$ (average). 15 model permutations tested. "Naïve competitors" often beat the best fitting models and these were unable to predict the correct timing of market changes.
MacFarlane J, Murray J, Parker D, & Peng V	2002	$\ln(R_{t-2}^{e,t}/R_{t-2}) = \beta_0 + \beta_1\Delta Y_{t-2} + \beta_2\Delta VAC_{t-2} + r_t$ $R_t = \beta_0 + \beta_1 VAC_{t-1} + \rho\, e_{t-1} + r_t$ $COMP_t = \beta_1 DEP_{t-1} + \beta_2 DEP_{t-2} + \beta_3 DEP_{t-3} + \beta_4 VAC_{t-3} + \beta_5\Delta VAC_{t-3} + \beta_6 RERENT_{t-3} + \beta_7\Delta RERENT_{t-3} + r_t$	$R^{e,t}$ = expected real effective rent R = real effective rent Y = 10 year bond rate VAC = vacancy COMP = Completions DEP = withdrawals / demolitions	RERENT = real effective rents	Sydney rent data – 1977-2000	Adjusted $R^2 = 0.49$ (expected change in rents). Adjusted $R^2 = 0.90$ (rent estimation). Equations are variations of the RICS (2000) econometric model equations for London. Vacancy rates found to have strong influence on Sydney rents. Bond yields said to be insignificant.
Hendershott PH, MacGregor BD & Tse RYC	2002	$\Delta\ln R_t = \alpha_0 + \alpha_1\Delta\ln E_t + \alpha_2\Delta\ln(1 - v_t) + \alpha_3\Delta SU_t + \alpha_4\{\ln R_{t-1} - \beta'_0 - \gamma'_1\ln E_{t-1} - \gamma'_2\ln[(1 - v_{t-1})SU_{t-1}\}$	R = real effective rent E = employment V = vacancy rate SU = space supply		Sydney and London market data – 1977-1996	Adjusted $R^2 = 0.70$ to 0.80 for long-run error correction model. Vacancy and rent equilibrium variables were said to be highly significant in determining rent adjustments. Introduced time-varying equilibrium rent as explanatory variable.
Tse RYC & Fischer D	2003	$g_t = \alpha v_{nt} - \alpha v_t + \varepsilon v$ Where $v_{nt} = v^* + \epsilon_v$	g = rent growth rate v_n = natural vacancy rate v = vacancy rate v* constant parameter ϵ_v = time-varying constant		Hong Kong (1975-1997), Sydney (1970-1996), Perth (1992-1994 monthly) & London (1975-1996)	Adjusted R^2 ranging from 0.36 to 0.611 for the four cities. Introduced time-varying vacancy rate. Static vacancy rates were said to exaggerate cyclical swings in rental growth rates. The "stationary component" of vacancy rates was said to vary across cities.

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