A System Dynamics Model of Cyclical Office Oversupply

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Abstract. **This article explores office market system dynamics through a simple simulation model. Model lag and adjustment parameters similar to real office markets generate explosive cycles. Simulations show that deviations from equilibrium can be reduced by changing the information structure of the system. System dynamics, principle/agent conflicts, a prisoners' dilemma game, faulty information (*poor forecasting, market research and valuation techniques*), regulatory institutions, and differing equilibria in office space and financial markets all contribute to allocative inefficiency. Thinking of office markets as a "managed feedback control system" may be a useful representation of the oversupply problem. Leverage points for system improvement may be a municipal "queue" to address agency and prisoner's dilemma problems, improved forecasting techniques and more reliance on forecasting.**

Ubiquitous Cycles

Office market cycles are surprisingly widespread. Hendershott and Kane (1992) estimate economic losses from the oversupply in the United States in the 1980s at US$130 billion, chiefly present value of lost rents from excess vacant space. London, Stockholm, Singapore, Tokyo, Johannesburg, Toronto and many other cities have experienced oversupply. Property oversupply certainly contributed to the worldwide Great Depression of the 1930s. Barras (1994) maintains that investment property oversupply occurs in every other macroeconomic cycle—about once every ten years.[1] Shilton (1998) found office employment converging towards a seven year cycle, coincident with macroeconomic activity.

In Australia, 1993 central business district (CBD) office vacancy rates peaked at 32% in Perth, 27% in Melbourne and 22% in Sydney (BOMA, 1993). Sykes (1996) estimates aggregate write-offs and provisionings by Australian lenders during 1991–94 at AUS$28 billion, much of this due to nonperforming real estate. Writing off $28 billion would require reducing assets by AUS$280 billion to maintain bank capital adequacy ratios at 10%. Comparing these figures to the Australian GDP of less than AUS$500 billion, office oversupply must have been a major cause of the severe early 1990s Australian recession.[2]

Office markets may be even more volatile than in the past due to international institutional capital flows and advances in information technology. Hong Kong,

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Bangkok, Jakarta, Kuala Lumpur, Shanghai, Seoul and other Asian centers currently face office space oversupply. Solvency problems stemming from nonperforming commercial property contribute to a spreading financial crisis in the Asian tiger economies and Japan.

Imbalances of supply and demand introduce allocative and production inefficiencies. Too little supply constrains economic growth by imposing high costs on tenants and making it more difficult to add office workers. Too much new supply leads to land and construction cost inflation, followed by excess vacancy, price collapses and negative net present values. Nonperforming properties contribute to financial intermediary liquidity and balance sheet crises, marketwide price drops and recessions. Too much or too little office investment misallocates capital, increases risk and reduces social returns to capital. Diversity of locations, times, economic systems and political regimes where oversupply has occurred suggests a fundamental causal mechanism in the office market process itself.

Explanations for Office Oversupply Cycles

Qualitative interviews with industry informants and literature research led to a list of office oversupply explanations summarized as:

1. *Greed or fee-driven deals.* The finance literature refers to ''asymmetric information'' or ''principal/agent conflict'' (Cole and Eisenbeis, 1996). Graaskamp (1988) remarked that every expense item in a project budget is a profit center for somebody. Land assembly profits, construction profits, lending institution staff bonuses, consulting fees, project management fees and securitization fees reward decision makers even where projects eventually fail. As one agent put it, ''A lot of people don't get paid unless a deal happens.'' However, more deals means that it is less likely that all projects can perform as projected.
2. *Flood of capital seeking investment opportunities and financial deregulation*. Discussing office oversupply in Japan, the United Kingdom and Europe, Downs (1993) stated that office supply is capital market driven. Fisher (1992) recommended integration of research on property and financial markets. In both the U.S. and Australia, financial deregulation in the 1980s led to sudden increases in capital supply, some controlled by inexpert or corrupt lenders. Asian markets experienced foreign capital inflows and plentiful local capital in recent years. Financial journalist Trevor Sykes (1996) describes a process whereby first interest rate spreads, then underwriting standards and finally loan documentation deteriorated as lenders' competed in 1980s' Australian markets, which offered too few legitimate opportunities. Some informants spoke of a ''herd instinct'' among risk averse fund managers. Brueggeman (1993) points out that lenders need time after a bust to repair their balance sheets. This lag delays new projects, drives rents higher and sets the stage for a new cycle.
3. *Strategic behavior—the prisoners' dilemma game*. Each developer could say, ''If my project goes ahead and others' projects do not, rents will be

high and my project profitable. If we all build, market rents will fall and we will all lose money.'' Research on four major Perth projects (Kummerow, 1997) concluded that it was impossible to know during the early stages which projects would go to completion, nor which would be completed first given uncertain delays at each stage during a seven to eight year development process. In this prisoner's dilemma game, absent cooperation or regulation, individually rational behavior leads to a collectively irrational outcome.

4. *Land use regulatory process delays and other government policies*. Land use regulations, tax treatment of real estate, financial regulation (or lack of it) or other policies may promote too much or too little development. Changing tax treatment such as the 1982 or 1986 tax acts in the U.S. encourages or discourages new supply. Regulatory lags and delays inherent in building approval processes extend forecasting horizons, making mistakes more likely.
5. *Faulty data and poor forecasts of supply, demand, rents and values.* Valuation firms have been sued for damages where building finance approvals relied on faulty value-on-completion estimates. Born and Pyhrr (1994) show that conventional valuation methods using naive trend extrapolation misprice investment property. This mispricing exacerbates the tendency to start too many projects during a boom and delay starting projects during a bust. Several authors have proposed econometric models that might improve upon naive forecasts (DiPasquale and Wheaton, 1996; and Hendershott, 1997). Roulac, Lynford and Castle (1990) argued for more intensive, project specific data gathering and analysis. Development budgets typically spend too little on such research relative to investment capital at risk.
6. *System dynamics*. Markets often respond to current prices, forgetting about lags and cycles. This ensures a backlog due to supply lags. Deliveries (office completions) must at some point exceed current demand growth for supply to ''catch up.'' Overshooting of supply is likely, especially if demand growth subsequently falls off due to macroeconomic cycles.[3]

Anecdotal evidence indicates that every cycle is different.[4] Shilton (1998), by estimating ARIMA models, documented diverse cyclical patterns in various U.S. cities. Financial deregulation may have contributed greatly to the 1980s oversupply, but not be as important in the 1990s. The current cycle features securitization, global capital markets, office technology and corporate downsizing. All of the issues listed above probably contribute to cycles at times and various causes interact.

System Dynamics Modeling

In the late 1950s, Jay Forrester at MIT used control theory concepts developed for electrical engineering to simulate Harvard Business School case studies (Forrester, 1991). Since then, system dynamics (SD) models have been used to simulate a droplet of rocket fuel, species extinctions, predator/prey systems, inventory control, transportation systems, manufacturing processes, military battles, disease contagion, urban growth and development, Earth's carrying capacity for humans, etc. SD models offer two advantages: (1) it is relatively easy to incorporate qualitative mental and written information as well as quantitative data; and (2) simulations can be used where data is inadequate to support statistical methods or where change in processes makes historical data misleading. SD models are often written in difference equations, stepping forwards in discrete time increments.

Although some SD models are complex, the basic principles of system dynamics modeling are simple. System dynamics problems have two things in common. First, a motive to improve a situation by suggesting how people can act upon the system. The perspective is often similar to a corporate executive who has some degree of control, including the possibility of changing system design if the system misbehaves. Second, the ubiquitous presence of feedback loops. Feedbacks are of two kinds:

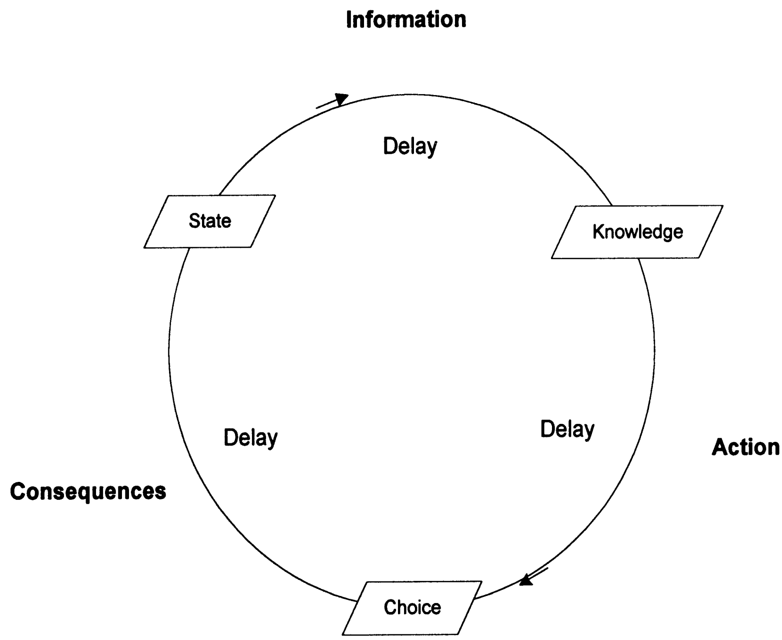
> *Goal seeking or negative feedback*. A discrepancy induces corrective action to return the system to a target state. For example, market equilibrium.
>
> *Self-reinforcing or positive feedback*. Like compound interest or breeding rabbits, growth leads to faster growth, or a decrease accelerates a collapse. For example, a stock market panic (Coyle, 1996:10).

Insights from system dynamic models often have to do with delayed and counterintuitive effects of feedbacks. Delays mean current information may provide misleading signals. Coyle (1996) identifies three types of delays crucial to system dynamics: (1) time to find out; (2) time to decide what to do; and (3) time to remedy discrepancies from desired states. In Exhibit 1, these three delays are labelled information, action and consequence, respectively.

The time it takes before the system reacts to discrepancies from desired states (information flows), and the speed and strength of the responses (physical adjustments) determine the dynamic behavior of the system. In human-designed systems, feedback structures and target state policies are open to re-design by system managers. System models usually include both physical stocks and flows and an information structure to regulate the physical flows.

Paich and Sterman (1993:1449, 1456) cite several studies showing that ''decision making is poor where decisions have delayed, indirect, non-linear, and multiple feedback effects.'' Their results confirmed that, ''In situations of high dynamic complexity, peoples' mental models are grossly simplified compared to reality.'' They presented MIT MBA with students a simple two feedback loop model posing pricing, production and inventory control problems similar to those faced by office market decision-makers. Subjects showed a tendency towards ''conservative demand forecasts which ensure actual capacity will be grossly inadequate during the boom phase, causing high backlogs, long delivery delays and market share erosion'' (Paich and Sterman, 1993:1452). Subjects then failed to cut capacity fast enough in the ensuing

Exhibit 1
Coyle's Representation of System Controlled by Information



Source: Coyle, 1996

bust. In repeated trials, although some learning took place, subjects never succeeded in matching the performance of a simple decision rule.

Validation of SD Models

Forrester and Senge (1980) mention three classes of SD model tests—system structure, system behavior and policy improvement tests.[5] SD model validation is not an "accept" or "reject" statistical significance exercise, but rather a confidence building process resulting from model development and use. De Geus (1992) observes that the future cannot be predicted, so no model can ever be a precise representation. Parsimonious representation means models always leave out part of the story when the system itself is complex.

Renshaw (1991:4), a biologist whose models explore species extinctions, writes:

> "Apparently trivial non-linear models. . . give rise to a surprisingly rich diversity of mathematical behavior ranging from stable equilibrium points, to stable oscillation between several points, through to a completely chaotic regime. . . even aperiodic fluctuations. Where fantasy takes over is in the belief that the mathematically. . . fine structure of deterministic chaotic solutions might be observed in a single set of data. . ."

Users should take care not to confuse the model with the system. Any SD model is a more or less informative parsimonious representation whose results are implicit in the structure chosen. Some investigators prefer the term's "systems thinking" or "system learning." Models play a role as a tool for learning in helping managers to make up their own minds.

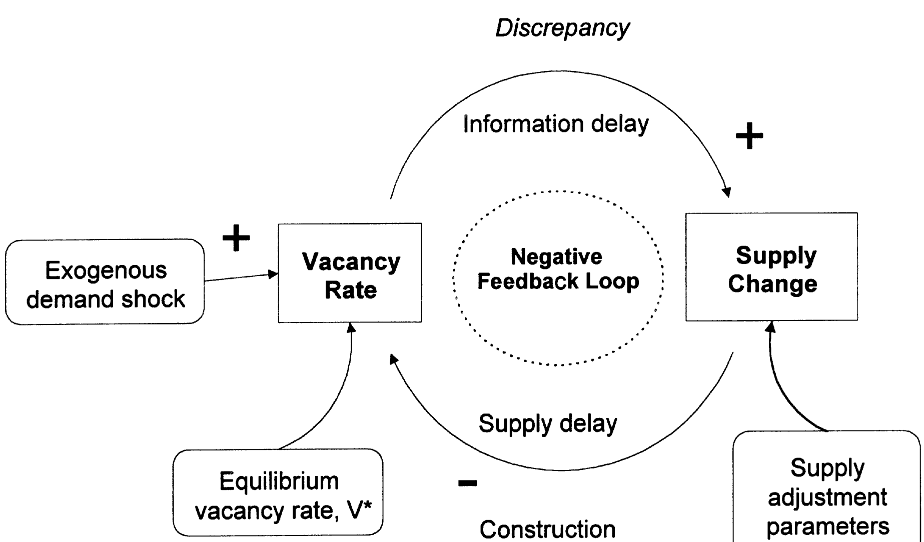
A System Dynamics Model of an Office Market

Coyle (1996:20) advises modelers to "think physics." Physical processes, such as constructing office buildings, may involve unavoidable time delays. In theory, information can be transmitted at the speed of light. In practice, information and decision processes require physical media that may be quite slow—document preparation, verifications and loan committee meetings. Nevertheless, information structures and policies may be easier to modify and improve than physical processes.

Exhibit 2 represents a simple office supply response model. A single negative feedback loop uses discrepancies from equilibrium vacancy to control supply responses.[6] When vacancy equals the exogenously determined equilibrium vacancy (V^*) supply and demand are in balance, the discrepancy will be zero and no supply adjustment will occur.[7] If there is excess supply, the supply change called for is also zero. This implies that buildings are not demolished or converted to other uses, a simplifying assumption.[8] Once a space shortage occurs in the model, the system adjusts to eliminate the discrepancy, constrained by exogenous supply adjustment parameters.

Clapp (1993), Hendershott (1997) and other authors use the equilibrium vacancy rate concept as the state towards which office markets adjust. In markets, rents (prices),

Exhibit 2
Single Negative Feedback Loop Office Market Model



transmit a signal of the discrepancy to suppliers. Rents respond inversely to vacancy rates so the priceless model is consistent with the stylised facts of office market behavior.[9]

For simplicity, this model allows supply responses to be continuous, rather than coming in ‘‘economic size building’’ increments. Future research will examine this ‘‘building size’’ issue and its effect on cycles. However, excess vacancy in oversupplied markets has often been several times the size of the city’s largest building.[10]

Model supply adjustment is a function of four parameters, which give rise to system behavior:

1. *Oversupply.* The oversupply parameter, *OS*, is the ratio of orders to discrepancy. Orders = $OS*XV$. If *OS*, is 1, developers seek to build exactly the amount of space needed to bring the market back to equilibrium. If *OS* is 2, they order twice the discrepancy. Agency and prisoner’s dilemma market failures justify inclusion of this parameter.[11]
2. *Adjustment time.* In office supply data, one can observe that supply additions do not all appear in one year, but spread across perhaps two to four years. Adjustment time, *A*, represents delays in commencements. When $XV*OS$ amount of space is ordered, $XV/A*OS$ will be commenced in that year. Spreading out of projects is due to planning lags early in the office market development process. For example, if there is a need for 900,000 sq. ft. of new space, and the adjustment parameter is 3, the market will commence 300,000 sq. ft. The remaining 600,000 sq. ft. becomes a backlog. Each year the discrepancy is updated and a third of the new discrepancy (including backlog) commenced.
3. *Supply lag*. Supply lag, *SL*, is the time from order to delivery, defined as construction time minus the demand forecast horizon. Physically, construction may require two to three years for major projects. However, anticipating future discrepancies could result in projects being commenced early in anticipation of future demand, thereby reducing the supply lag to less than the construction time.[12] If *SL* were zero, for example, projects would be completed in the year they are needed, the ideal situation. $SL = 0$ implies forecasting demand at the physical construction lag horizon, *i.e.*, two to three years. When $SL = 0$, early commencement based on forecasts creates ‘‘just in time’’ inventory to meet future demand.
4. *Equilibrium vacancy rate*. Desired holdings of vacant office space vary directly with leasing activity in the market (more transactions implies more inventory needed) and inversely with the costs of holding vacant space.[13]

How well the system functions can be proxied by how close it stays to equilibrium. Taking the discrepancy $XV = S - (D + V*)$ as the system error, statistics such as root mean square error or mean absolute percentage error summarize system allocative efficiency over time. Error statistics could not go to zero except in a static market with no construction or demand changes. Large errors reflect oversupply cycles.

Simulation Results

The ‘‘base run’’ or ‘‘reference mode’’ of the system was set at:

- Equilibrium vacancy 10%.[14]
- Supply lag = 0. The model delivers new supply within the same period in which a discrepancy from the desired vacancy rate occurs.[15]
- Adjustment time 1. The market responds fully to discrepancies, starting all projects within one period.
- Oversupply = 1. The market does not over-react. New supply orders equal new demand.

These parameter settings do not represent the current state of the system. Instead, they represent an ideal situation towards which the system might evolve via system redesign and policy changes. The choice of 1970–2010 as the *x*–axis values in the plots is arbitrary as are supply and demand initial levels. The software used is ITHINK, a system dynamics simulation package with a convenient graphical interface.

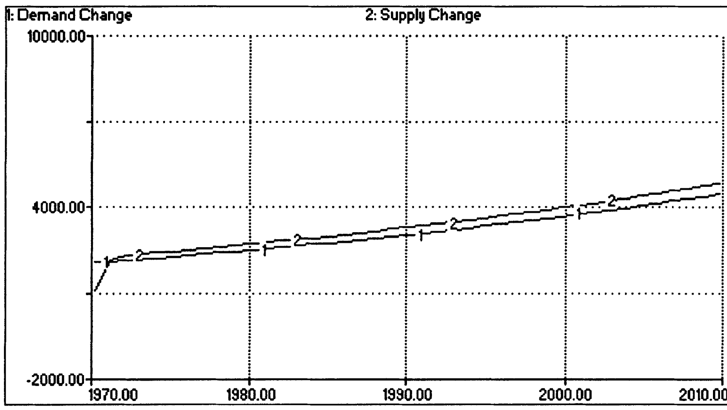
Exhibit 3 shows the effects of increasing the construction lag time in an economy with steady 2% per annum office demand growth. When $SL = 0$, the market stays near equilibrium. Supply growth exactly tracks demand—an efficient market that clears within one time period (Exhibit 3, Panel A).

With the *SL* set to one year, steady growth in demand leads to a decaying cycle (Exhibit 3, Panel B). With the supply lag at two years (Exhibit 4), the cycle explodes—successive cycle’s amplitude increases. Note that in this case, *OS*, the oversupply parameter, is set to 1 meaning orders match discrepancy—oversupply cycles in Exhibit 3, Panel C are not due to too many fee driven deals. The explosive cycles in Panel C come solely from steady economic growth and a two-year supply lag, where new supply orders depend on current vacancy conditions. If we infer that rents reflect vacancy conditions, this means lenders underwrite projects based on current rents. Thus, a ‘‘conservative’’ approach of waiting until rents justify construction, leads to an explosive cycle due to construction lags. A lender policy meant to avoid risk creates risk.

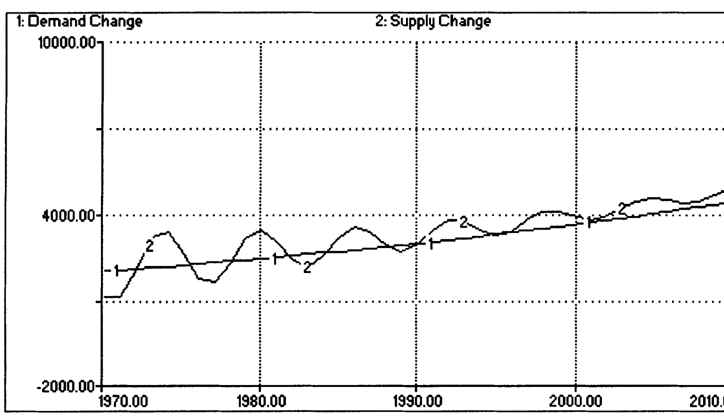
We see from these results that supply lags on the order of two years can generate the seven- to ten-year cycle found in office market data. Additional building commencements continue during the two-year supply lag, resulting in a ten-year peak-to-peak pattern of backlog and overshoot.[16] System behavior depends upon responses to a discrepancy updated and responded to in each period. The recursive difference equations, which drive the results, could generate other patterns, even chaotic or irregular cycles, with other parameter values. The overall outcome or pattern depends on the growth rate and equilibrium vacancy rate, as well as the three supply response

Exhibit 3
Supply and Demand Change—Supply Lag Effect

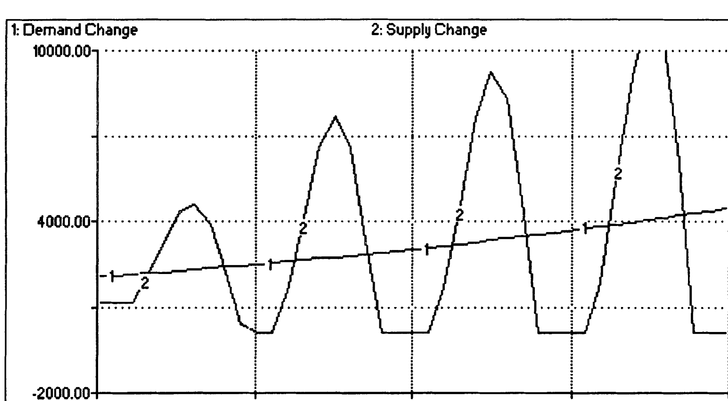
Panel A: Supply lag 0, oversupply 1,adjustment time 1, equilibrium vacancy .10, growth 2%



Panel B: Supply lag 1, oversupply 1, adjustment time 1



Panel C: Supply lag 2, oversupply 1, adjustment time 1



parameters *OS*, *SL* and A. Although the model is relatively simple, the SD software allows the length of the cycles to change, depending on how long it takes to ''catch up'' with each period's backlog. System dynamics recursive updating captures complex dynamics that are more difficult to treat in a static econometric system of equations whose lag order is invariant across time periods.

Spreading out project commencements by setting adjustment times, *A*, to greater than 1, tends to decrease amplitude of cycles (see Exhibit 4, $A = 2$). This quantifies a qualitatively obvious result: Starting too many projects in a single year could lead to oversupply. However, higher adjustment times also increase mean average percentage error (MAPE) because of slower catching up to demand. The analytical solution in the Appendix demonstrates that with $SL = 2$ and $OS = 1$, then the optimum setting for *A* (given $V^* = .10$ and demand growth 2%) is around 1.5 with system behavior becoming less efficient on either side of this setting.

In certain regions, the system is quite sensitive to relatively small changes in parameter values. Reducing the *SL* delay only one quarter, from eighteen months to fifteen months ($SL = 1.5$ to $SL = 1.25$, Exhibit 5), nearly eliminates the cycle. If the real system behaves anything like these model results, major increases in market efficiency can be had by a combination of: (1) reducing planning and construction lags; (2) forecasting demand and building for it, rather than waiting until demand is on hand; and (3) spreading out commencements over time.

No long term cyclical behavior emerged from a single demand spike. Even if supply is constrained in the short run (long adjustment time), a demand shock will eventually be accommodated. System adjustment parameters create cycles, random shocks do not create cycles. For example, Exhibit 6 shows supply responses to a ''boom''

Exhibit 4
Supply and Demand Changes—Adjustment Time Effect

Supply lag 2, oversupply 1, adjustment time 2

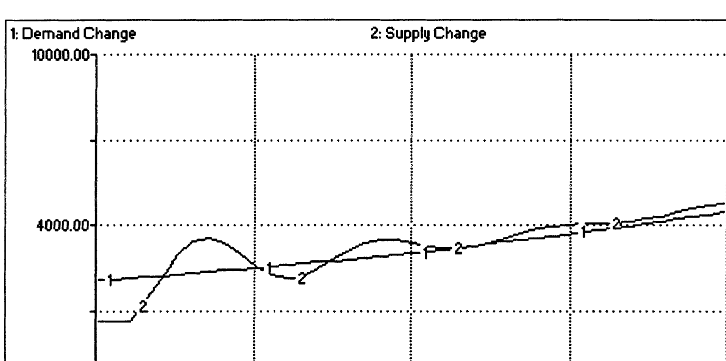
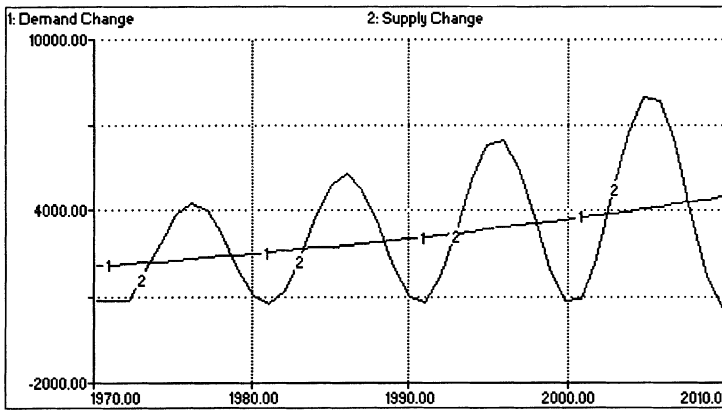
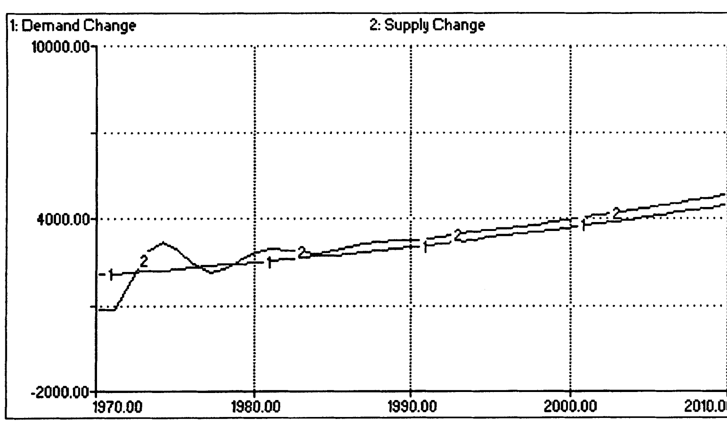


Exhibit 5
Model 1: Supply and Demand Changes—Sensitive or Offsetting Cycles

Panel A.: Supply lag 1.5, oversupply 1.5, adjustment time 2



Panel B: Supply lag 1.25, oversupply at 1.5, adjustment time 2

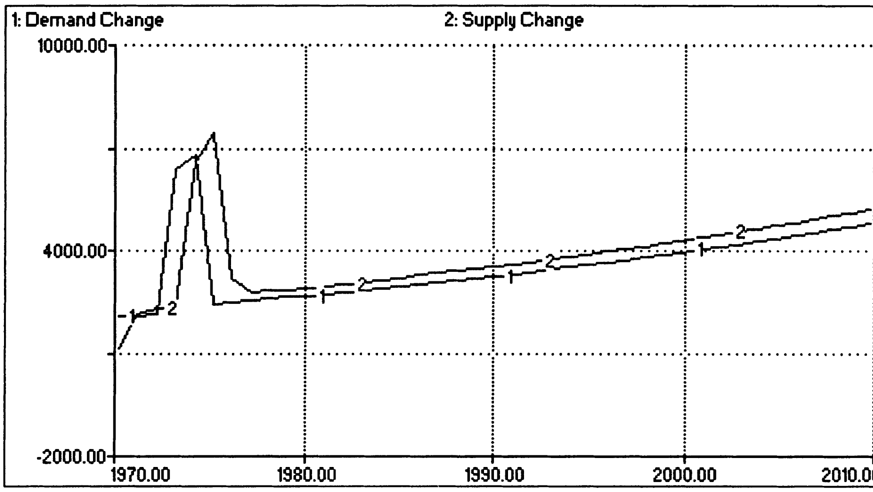


demand shock, two years of 10% annual growth. Panel A shows no cycling because the SD parameters allow for adjustment without a supply lag. Panel B shows cycles due to lags in system dynamic parameters. The shock does produce overshoot followed by cessation of construction, but after that, the lags generate cycles.

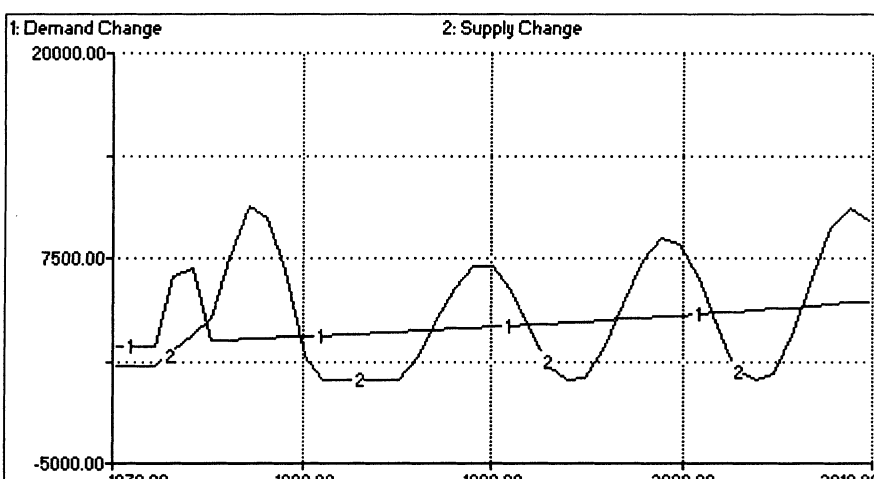
Real systems are confronted with shocks in each period. The demand series in Exhibit 7 is random shocks with mean 0 and standard deviation .03 added to a 2% growth trend.[17] We saw in Exhibit 5, Panel A that with a steady 2% demand growth, parameter settings of $SL = 1.5$, $OS = 1.5$ and $A = 2$ produce exploding cycles. Confronted with random demand shocks plus trend growth, the same system settings again generate cyclical supply response behavior—four supply peaks during this 40-year simulation. Not all patterns of random shocks generate cyclical behavior with these system adjustment parameter settings, but most do. Shocks can cancel out or reinforce the

Exhibit 6
Supply and Demand Changes with Growth Spike

Panel A: Supply lag 0, oversupply 1, adjustment time 1, growth 2% except for 2 year positive shock with growth at 10%



Panel B: Supply lag 1.5, oversupply 1.5, adjustment time 2, growth 2% except for 2 year positive shock with growth at 10%



underlying system dynamics, but the system's adjustment parameters tend to create cycles under most patterns of shocks, given an underlying growth trend. Shocks and changes in system parameters over time probably explain why cycles vary in amplitude and period, but the tendency to cycle comes from the system's lag and feedback structure.

Exhibit 7
Random Demand Shocks—Supply lag 1.5, Oversupply 1.5, Adjustment Time 2

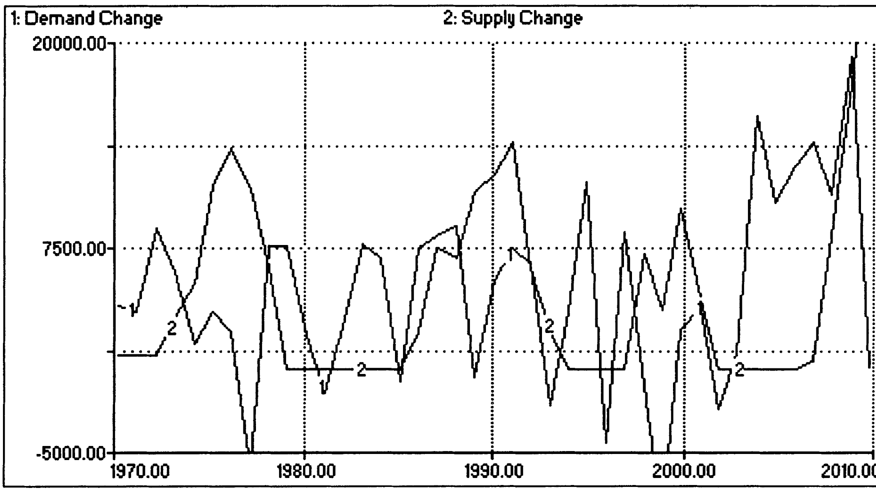
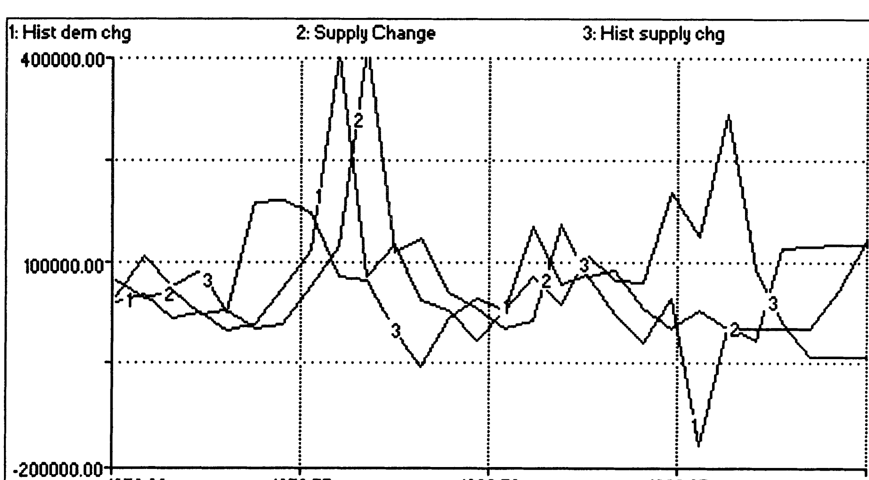


Exhibit 8 uses historical space absorption figures as the model's exogenous demand input. Historical Sydney CBD office demand change (net absorption) shows a spike in 1978, positive take-up in the mid–1980s, negative demand in the early 1990s and demand recovery beginning in 1992.[18] Series 3 plots actual supply changes during the period. Note how poorly supply matched demand during the early 1990s when

Exhibit 8
Historical Sydney Supply (3), Demand (1) and Model-Generated Supply Response (2) with Supply Lag 0, Oversupply 1 and Adjustment Time 1



massive new supply hit the market during a recession just as demand fell. Series 2 shows the supply changes generated by the model at its ''efficient market'' settings in response to the historical demand figures. These ''track'' demand with a short lag except for the constraint that supply change does not go below zero.

When lags are included (graph omitted here), the model parameters can be set to do as badly as the real system in matching supply and demand, generating pronounced cycles in response to the historical demand pattern. The model can be set to mimic a real office market by adjusting the parameters to give some indication of lags in the real system. The model can also be set to perform worse than the real system. With longer lags, the model's response to the historical demand data becomes a huge supply peak, which shuts off production for the duration of the simulation.

Model Validity

The strongest argument for whatever validity the simulation model may have is that the adjustment equations seem similar to what occurs in real world markets. We know that when demand appears, projects do not all begin immediately, justifying the adjustment parameter, *A*. There are undoubtedly physical construction lags and attempts to forecast future conditions leading to supply lags, *SL*. Certainly, oversupply tendencies (*OS*) are a reasonable hypothesis given experience and what we know about agency and prisoner's dilemma problems.

It is a plausible hypothesis that the model's behavior may resemble office market systems in some respects. Given system complexity and openness, no model could provide certainty about system behavior. International comparative studies and policy experiments could test modeling results.

Are Office Markets Managed Systems?

Office markets are not usually thought of as ''managed systems.'' Any individual does not manage them as a corporation is managed. However, office markets *are* designed and managed collectively. Aggregate decisions by multiple individuals and institutions determine system outcomes. Each decision maker can not ''get it right'' unless the market as a whole behaves as expected. Uncoordinated management, poor communication, lack of information and naive decision policies lead to unsatisfactory outcomes.

Changes in system design imply institutional changes. Institutional changes come about through what Bromley (1989) calls ''institutional transactions.'' These involve collective decision processes with many individuals contributing to question framing, research, conflict and negotiation. In Senge's (1990:342–357) language, we need to look for ''leverage points'' for redesigning the system structures, which shape individual actions. He states, ''Today the primary threats to our collective survival are slow, gradual developments arising from processes that are complex both in detail and dynamics. The spread of nuclear arms is not an event, nor is the ''greenhouse effect,'' the depletion of the ozone layer, malnutrition and underdevelopment in the third world, the economic cycles that determine our quality of life, and most of the other large scale problems in our world.''

Office oversupply emerges as the collective result of many individual decisions over a period of years. Improvements in information at the individual decision maker level can not prevent problems and might even make things worse by reducing adjustment time and bunching project commencements. Collective or public choice must be a part of office system problem solving. Coyle (1996:34) comments, ''To bring about change to a system...is essentially a *political* act, not a scientific one.''

Is it Feasible to Improve System Design and Policies?

It is not easy to implement changes in complex systems with diverse stakeholders. There are tradeoffs and possible unintended consequences of system changes. Nevertheless, there are a number of ideas for further research and pilot studies to change system adjustment parameters.

Supply Lag. Although design and construction innovations may decrease construction time, building smaller projects is probably the most effective way to reduce physical process delays. Completing planning approvals earlier is controllable by developer decisions to submit plans earlier, and by more expeditious public sector reviews. Singapore may have reduced office cycle amplitude in recent years by cutting adjustment times through government sponsored land assembly and fast planning approvals. Singapore accomplishes office project planning reviews in nine months that take at least two years in Australia.[19] Presenting projects for review earlier in the cycle could create an inventory of pre-approved projects, while still allowing time for public comment. Governments should encourage early stages of office development to create inventories of projects ''ready to go.''

Starting construction projects earlier in anticipation of future demand reduces supply lag. The tradeoff is that forecasting errors increase with the forecast horizon and mistakes are costly. However, even if future demand change were a random walk, it would probably be best to forecast demand as the mean of the past series and begin earlier. This would set the supply lag to zero and lead to just-in-time delivery. Forecasting must also be used to shut off commencements once enough projects to meet demand are in the pipeline. Lenders need to learn to take account of lags, backing projects when current rents are low and stopping further commencements when current rents are highest. Tenants also can play a constructive role by agreeing to earlier pre-commitments to lease new space.

Sydney projects under construction in 1998 commenced earlier than in the last cycle, indicating the market may be more forecasting oriented than in the past. Outcomes are still uncertain but tendencies towards oversupply are visible. Therefore, rents may not go up as much as expected after all. Forecasts are conditional on strategic behavior.

Oversupply. Improving contracts and reward structures could promote alignment of interests between investors and agents. A property industry paid fees proportional to the number of projects constructed, rather than for investment outcomes faces incentives to build more projects regardless of demand. The trend towards entity finance (through REITs, etc.) replacing individual project finance may help create longer-term perspectives. Agents may evolve into property advisory services seeking long-term relationships with institutional investors, rather than fees from single transactions. Securitization of real estate finance is a significant system ''information structure'' change. Markets quickly adjust share prices to reflect market perceptions of impending oversupply. This can quickly shut off the flow of capital into new projects. On the other hand, securitization offers lucrative new sources of fees divorced from investor outcomes.

Adjustment Time. In a prisoner's dilemma game it is hard to see how decisions independent of other decisions can be correct or even evaluated. Each player's rational choice leads to irrational collective outcomes. In oversupplied office markets, outcomes for all investors are linked through system-wide price adjustments. Olson (1971) argued that for better outcomes, cooperation is necessary, enforced by institutions. Otherwise, each player will want to be a free rider who benefits from the restraints imposed on others.

Perhaps coordination can be achieved through a change in the information rules of the ''game,'' where the players all know what the other ''prisoners'' are doing. However, given the momentum of major projects, it seems doubtful that information alone can stop too many projects from commencing. If collectively irrational behavior persists or is worsened by better information, a municipal queue or other institutional enforcement mechanism to prevent over-entry might be considered. A queuing system could smooth commencements by increasing system adjustment time and rewarding early entry. A limited entry policy should seek to avoid both undersupply and oversupply.[20] Institutional details must be carefully designed to avoid unintended effects. A simple rule relating allowable commencements to demand/supply conditions, with limited planner discretion, would probably be most effective.

Capital markets' concerns about risk may be the key to political implementation of system design innovations. Better forecasting and attention to the agency and prisoners' dilemma problems could save investors billions in lost rents and depressed capital values. More stable and efficient markets would improve risk-adjusted returns to investors and lower costs to tenants. Designing institutions that produce more efficient system outcomes would give investors and communities a competitive advantage in attracting lower cost capital for office investments.

Conclusion

System dynamics models allow testing innovations in system structure or decision policies. One avenue for future research is to continue developing SD models for real estate applications. A second is to test system re-design ideas through implementation experiments or comparative studies. Humility is appropriate in modeling economic systems—all models oversimplify, the real test is to try out ideas in practice. Implementation is not a trivial research problem—the devil is in the institutional details. I mentioned Singapore's success in avoiding the oversupply now visible in most other Asian cities, but Singapore did experience oversupply in the 1980s.

The prisoner's dilemma game theoretically provides an explanation for market failure through faulty information. Not knowing which competitive projects will go to completion, creates a ''circular reference'' where the feasibility of each project is contingent on other projects. Municipalities should experiment with simple objective, hard to corrupt, and self-correcting rules to create more orderly markets. A queuing system might reduce risks at all stages of development and building operation. No single innovation is likely to eliminate office cycles and it is quite conceivable that the unintended effect of new institutions or information technology could be to make cycles worse.

Solutions to the allocative inefficiency or market failures evident in office markets can be thought about at two levels. First, individual projects must be properly developed and underwritten. Property heterogeneity means there are no shortcuts for careful examination of the feasibility and market for each building in order to price risk and find optimal design, marketing and financing solutions. This article argues, however, that even if one is brilliant and does a perfect job on a project, there may be emergent dynamics in the market as a whole that nevertheless destroy the bottom line. Outcomes are a function of system dynamics at the aggregate market level. Increasing allocative efficiency (risk adjusted rates of return) requires changes in system design and policies. At the market or national level, reducing risks requires collective choice and institutional innovations.

Appendix

Analytical Solution of a System Dynamics Model of Cyclical Office Oversupply under Simplifying Assumptions

The model in this article is a system of nonlinear difference equations whose order depends upon the supply lag, *SL*. If we assume constant values for the parameters oversupply, *OS*, and adjustment time, *A*, and omit the nonlinearity caused by the nondestruction of buildings, a linear system of difference equations is generated, which can be solved analytically. The solution enables us to find optimum system parameter settings that, if achieved in practice, could reduce the volatility of commercial real estate cycles.

One complication is the fact that the supply lag is a system parameter. There will thus be a different model for every different postulated supply lag. In this analysis, we work with a two-year supply lag, a plausible assumption. In general, reducing time lags increases the stability of a dynamic model, so reducing *SL* is a desirable policy aim. This Appendix takes the supply lag as given, and focuses upon the interaction of the oversupply parameter *OS* with the adjustment time, *A*. This ratio reflects the ''gain'' in the system—the degree to which the system dynamics amplify any initial discrepancy, given a particular fixed *SL* assumption.

The discrepancy in period t (XV_t) is a function of demand (D_t) and supply (S_t) in period t and the equilibrium level of vacancies (E_v):

$$XV_t = D_t - S_t \times (1 - E_v). \tag{1}$$

Demand in period t is exogenous. Here we assume demand grows exponentially at the rate of δ percent per annum:

$$D_t = (1 + \delta) \times D_{t-1}. \tag{2}$$

Supply in period t (S_t) is the sum of supply in period $t - 1$ and completions in $t - 1$ (C_{t-1}).

$$S_t = S_{t-1} + C_{t-1}. \tag{3}$$

SL is the time between the discrepancy (negative excess vacancy) and completions, the "delivery" of office space. *OS* is multiplied times the excess vacancy to determine the desired "orders" of new supply, reflecting inflation by principle/agent conflict or strategic behavior irrationalities. This inflated supply order quantity is then divided by the parameter *A* to determine how many projects will actually commence, given a particular level of excess vacancy *XV* (Equation (1)).

$$C_t = \begin{matrix} 0 & \text{if } XV_{t-SL} < 0 \\ XV_{t-SL} \times \dfrac{OS}{A} & \text{if } XV_{t-SL} \geq 0. \end{matrix} \tag{4}$$

The simulation model can thus be expressed as a pair of coupled fourth order difference equations:

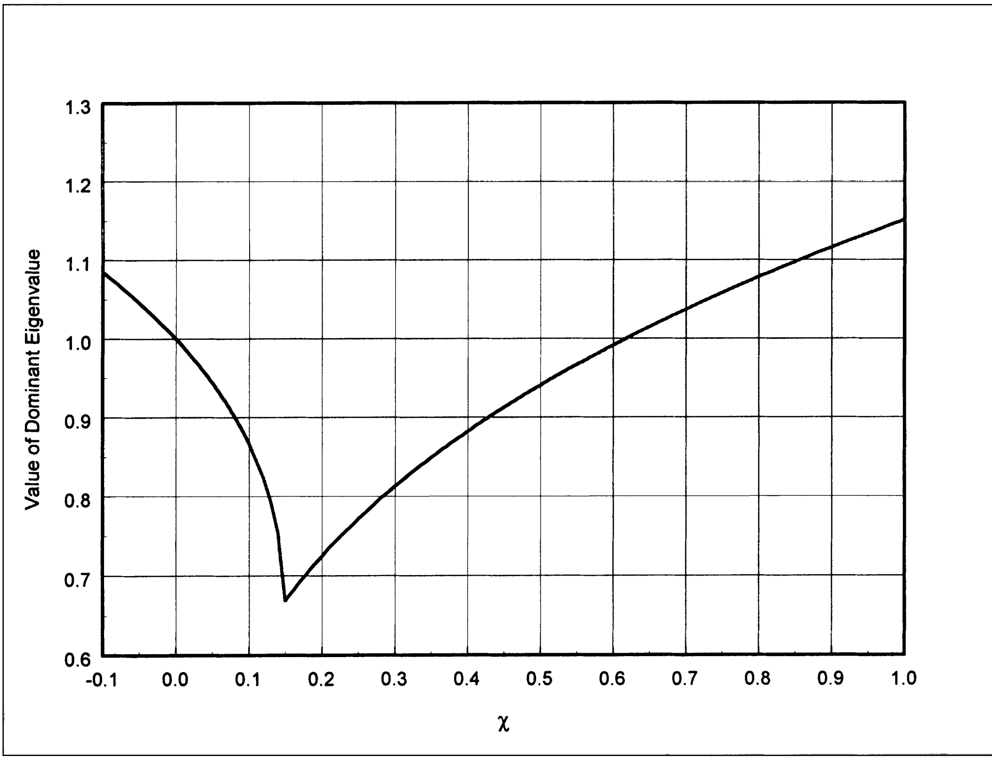
$$\begin{bmatrix} S_{t+4} \\ D_{t+4} \end{bmatrix} := \begin{bmatrix} S_{t+3} + \left| \begin{matrix} 0 \text{ if } [(1 + \delta) \cdot D_t - S_{t+1} \cdot (1 - E_v)] < 0 \\ [(1 + \delta) \cdot D_t - S_{t+1} \cdot (1 - E_v)] \cdot \dfrac{OS}{A} \text{ otherwise} \end{matrix} \right. \\ (1 + \delta) \cdot D_{t+3} \end{bmatrix} \tag{5}$$

The behavior of this model matches that of the simulation system shown in the previous system. Its linear form is:

$$\begin{bmatrix} S_{t+4} \\ D_{t+4} \end{bmatrix} := \begin{bmatrix} S_{t+3} + [(1 + \delta) \cdot D_t - S_{t+1} \cdot (-[])] \cdot \dfrac{OS}{A} \\ (1 + \delta) \cdot D_{t+3} \end{bmatrix}. \tag{6}$$

This is more volatile than the article's model because of the artifact of "negative construction" when supply exceeds demand. Demolitions do occur at times, so which

Exhibit 9
Magnitude of Dominant Eigenvalue of Model Against Value of χ



assumption is better is an empirical question. The eigenvalues of the model indicate whether the system is stable or unstable. In a difference equation, if any eigenvalue exceeds one then the model will be unstable. The eigenvalues of this model are zero, $(1 + \delta)$ which is the rate of growth of demand, and the roots of the cubic Equation (7).

$$\lambda^3 - \lambda^2 + (1 - E_v) \times \frac{OS}{A} = 0. \tag{7}$$

While these roots have a complicated form, their magnitude can be plotted as a function of the constant in the equation. Making the substitution of χ for the constant in the equation $(1 - E_v) \times OS/A$, we can generate the plot shown in Exhibit 9 of the magnitude of the dominant eigenvalue against different values of the constant.

The plot indicates that the system is unstable for a value of χ greater than approximately 0.6. Given a value for equilibrium vacancies (E_v) of 10%, this means that the system is unstable if the ratio of OS is divided by A, exceeds two-thirds. A condition for allocative efficiency would be that in the long run $\Delta S = \Delta D$, so supply and demand remain in balance. Hence, the "rational" setting for *OS* is 1.0. It therefore seems that a worthwhile policy objective would be to reduce the *OS*/*A* ratio to two-thirds by increasing *A* to 1.5. This means that only two thirds of required projects should be begun in any year.

This conclusion is valid as an approximation in a system in which the supply lag is two periods. A different conclusion could apply for different supply lags (as the numerical simulations in the paper indicate). However, as a general rule, shifting *OS* towards 1.0 and increasing *A* to smooth commencements over time would result in greater system stability. Parameter *A* should not be set too high or system discrepancies will take too long to eliminate and MAPE due to cyclical behavior will again increase. With the supply lag reduced to zero through forecasting and (earlier project commencements as recommended), it is not necessary to increase *A* to smooth responses.

Endnotes

[1] Barras (1994), Leitner (1994) and Wheaton, Torto and Evans (1995) list additional examples of office market cycles.

[2] Minsky (1992) espouses this asset value deflation/debt crisis theory of macroeconomic cycles. Because debt is usually denominated in nominal dollars, asset price deflation and non-performing assets can lead to balance sheet and liquidity problems.

[3] Similar dynamics—demand shock, order increase, backlog, catch up and oversupply—occur in many inventory control problems. Senge (1990) presents a "beer game" inventory control model in which inventory adjustments and delivery backlogs tend to magnify a small demand shock into a boom and bust cycle.

[4] Additional possible causes of office demand changes include demographics like baby boomers entering the workforce, employment structure changes, corporate cultures, office technology and workspace design.

[5] Barlas (1996), Coyle (1996) and Homer (1996) describe methods for validation of SD models. Formal statistical hypothesis testing is normally impossible with SD models. Instead an arbitrary structure meant to represent the system is proposed and tested, essentially, by means of forecast errors relative to historical system data. Non-sample information plays a crucial role. Often, especially in physical systems, the modeler "knows" that certain relationships hold in the system. An example, in the present case is our knowledge that it normally takes two to three years to construct a major office building.

[6] Prices are omitted from the model for simplicity and to focus attention on the underlying dynamics. Mohammed Quaddus, Curtin University, Graduate School of Business suggested the idea of a priceless physical processes model.

[7] In the real world, irrational supply may be ordered, even when there is a space surplus.

[8] Mohammed Quaddus, Curtin University, Graduate School of Business suggested the idea of a priceless physical processes model.

[9] For example, in Perth, Australia, admittedly an extreme case, excess vacancy was approximately five times the size of the largest building.

[10] Rosen (1984) used vacancy rate as a proxy for rents.

[11] Alternatively, the herd instincts of fund managers. Short-term thinking prevails, regardless of long term damage to agency businesses from cyclical oversupply and loss of credibility.

[12] Shilton (1995) found supply lags in different American cities of from zero to four years.

[13] The literature includes models to estimate equilibrium vacancy rates. Voith and Crone (1988) and Pollakowski, Wachter and Lynford (1992) found equilibrium vacancy rates vary between cities and over time. I simplify by leaving V^* an exogenous constant.

[14] Sydney 1970–1996 average vacancy was 9.2%. Coefficients from regressions of rent change on vacancy rates for five Australian cities indicated 8%–11% equilibrium vacancy rates, but this model is underspecified so the coefficients may be biased.

[15] If macroeconomic and office market cycles were eliminated, then future demand growth would become a random walk. The best forecast would be the mean of the past net absorption (a drift term in the demand series). Mueller (1997) reviews methods offered by Torto-Wheaton, a Boston forecasting firm.

[16] Similar cobweb cycles are observable in inventory control and predator prey systems. For example, the three years required to produce beef animals leads to an eleven-year cattle cycle.

[17] Mean and standard deviation figures are consistent with 1970–1995 Sydney office data.

[18] These data include measurement errors. Early data confuse gross and net demand. Data sources include Knight Frank, Jones Lang Wooten and the Australian Property Council.

[19] Singapore assembles land quickly through the powerful Urban Redevelopment Authority agency. Reviews are expedited because there is only one level of government (as opposed to significant state and municipal reviews in Australia), and a top down, more authoritarian planning philosophy.

[20] *Mathematical Bioeconomics* (Clark, 1990) develops the economic rationale for limited entry fisheries regulation. It is well established by theory and experience that absent regulation, too much capital enters an unregulated fishery. The fixed productivity of fisheries may be analogous to exogenously derived demand in office markets.

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