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PROBLEMS IN THE MODELING OF URBAN DEVELOPMENT:  
A REVIEW ARTICLE ON URBAN DYNAMICS, by Jay W. Forrester

by

Jerome Rothenberg  
Massachusetts Institute of Technology

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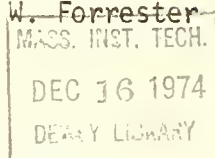
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# ERRATA SHEET

for

## PROBLEMS IN THE MODELING OF URBAN DEVELOPMENT:

A REVEREND ARTICLE ON URBAN DYNAMICS, by Jay W. Forrester

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1. Page 2. Should read: on the wider consensus. (2nd line from bottom.)
2. Page 7, Line 20. Should read: and frequently at substantial variance....
3. Page 5, Line 10. Should read: way to the next.  
Page 5, Line 17. Should read: of view of availability....
4. Page 6, Line 6. Should be on, not in the mix of housing.  
Page 6, Line 8. Should be: tend, not tends.
5. Page 8, Line 1. Should read: on both kinds of flows, not in both kinds of flows.  
Page 8. leave off last word (of).
6. Page 9, Line 3. Sentence left out. Should read: ...Forrester's model simply does not exist for the metropolitan area as a whole. A firm may well be attracted to the metropolitan area in large....  
Page 9, 6th line from bottom. Should read: of influences on the tax, not in the tax.  
Page 10. Line 1. Should read: impacts, not impact.
7. Page 14. Line 5. Should read: form, not from.  
Page 14. 4th line from bottom. Should read: is in fact, not are in fact.  
Page 14. 3rd line from bottom. Should read: is explainable, not are explainable.
8. Page 15. Line 6. No comma after Besides.
9. Page 16. Line 5. No comma after composition.  
Page 16. 3rd line from bottom. Should be: alone, not along.
10. Page 19. Line 13. Should read: And even such short-distance, not  
But even such short-distance.  
Page 19. Footnote, 2nd line from bottom: Should be: Role, not Rose.
11. Page 20. 3rd line from bottom. Should be: tend, not tends.
12. Page 21. Line 11. Should be: are, not is.  
Page 21. Line 16. Should read: and points out, not and it points out.  
Page 21. 2nd line from bottom. No comma after maker.

14. Page 22. Line 5. Colon after processes, not a comma.  
Page 22. Line 14. Should be: If, not Of.
15. Page 24. Last line on page. Should be a period after unpublished.
16. Page 25. Line 1. Should read: within even a modest cluster.
17. Page 26. Line 1. Should be: journeyings, not journeying.
18. Page 27. Line 14 and 15. Should read: the former are more attracted.
19. Page 28. Line 6. Should be: is, not of.  
Page 28. Line 12. Should be: that, not than.  
Page 28. Line 16. Should read: Typically here, a household...
20. Page 31. Line 4. Should read: dealt with, not dealt in.
21. Page 32. Line 7. Should be: undisturbed, not undistrubed.  
Page 32. Line 14. Should be in, not is.
22. Page 36. Line 14. Should be: because, not becouse.

PROBLEMS IN THE MODELING OF URBAN DEVELOPMENT:  
A REVIEW ARTICLE ON URBAN DYNAMICS, by Jay W. Forrester

Jerome Rothenberg\*  
Massachusetts Institute of Technology

I. Introduction

Many students of urban affairs -- economists, sociologists, systems analysts, and others -- have become convinced that the urgent and often agonizing problems that afflict urban areas can be only misleadingly understood unless the complex web of interdependencies constituting such areas are explicitly considered. To do so requires constructing a model in which the relevant problem issues are embedded in a broad set of interrelationships, some of which belong to the same subsection and some of which connect this subsection to others of the larger system. Such an enterprise involves many difficult issues -- e.g., the degree of subsection articulation, the variables to be included, the level of aggregation, the specification of the relations, and the empirical quantification of parameters. No model of this scope so

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\*I want especially to thank Franklin M. Fisher for providing a potent combination of impetus and substantive suggestion. I am grateful also to Robert M. Solow for reading the manuscript and making useful comments. As usual, of course, the author takes responsibility for the end product.

far constructed has been deemed highly satisfactory, because both the analytic and empirical challenges are most formidable. Against this background, progress may be served if we learn as much as possible from the more notable endeavors in the field. Their particular configurations, their successes and failures, may help illuminate the problems and suggest answers. It is to this end that we here examine and evaluate in some detail the rich model formulated by Jay Forrester.

Jay Forrester's Urban Dynamics<sup>1</sup> is an ambitious and provocative attempt to understand the working of a modern urban area so that public policy, so often and so apparently substantially off the mark, may become less blinded by superficial appearances and strike to the core of the urban malaise. It is indeed almost an act of faith for Forrester that large, complex systems give rise to counter-intuitive consequences. Their internal repercussions and adjustments crank out surprises. This is one of the vary reasons that failure to understand them profoundly is so dangerous. And Forrester sets out to rectify the lack of definitive systems analysis of urban areas for the sake of understanding itself, but even more to clarify the urgent issues of public policy thrown up by "the urban crisis." An appreciation of some of the current issues in the large-scale modeling of urban development can be gained by examining this extremely broad undertaking. Thus, while we shall subject the Forrester model to rather close evaluation, we shall be selecting issues that bear in the wider concensus of successful understanding of urban development phenomena.

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<sup>1</sup>Cambridge, Mass.: The M.I.T. Press, 1969.

Forrester's model of an urban area is by no means the first attempt of its kind. A number of models of metropolitan growth and development, of urban land use, of urban housing markets and transportation systems, exist. Forrester's model, however, is distinctive in a number of respects: (1) it integrates most functional aspects of urban interaction -- household and business populations, employment and unemployment, labor spatial and occupational mobility, public tax and expenditure policy, housing market phenomena, among others; (2) it is explicitly fashioned to consider particular public policies; (3) it is made totally operational, and quantified, to display the consequence profiles of alternative modes of public intervention. These are attractive attributes, and make it incumbent to pay real attention to the endeavor.

After close examination, our judgment is that the book may conceivably serve as a springboard for further investigations into the jungle of complex, multi-faceted urban interaction, but in its present state the model is seriously defective. Its defects are of three types: (1) the methodological presumptions upon which the work is based are weak; (2) the detailed structure of the explanatory relationships is critically misleading; (3) the specific quantification of parameters is at best arbitrary, and frequently a substantial variance from what dependable empirical information does suggest is the truth.

## II. Description of the Model

The Forrester model attempts to show the fate of a city in terms of the size and respective mix of its household and business populations, the

mix and occupancy of its housing stock, the employment-unemployment-skill mobility records of its population, and the local governmental tax rate. There are three types of household -- "managerial-professional," "worker" and "underemployed"\* -- three types of business enterprises -- new, mature and declining -- three types of housing structure -- premium, worker and underemployed -- and three types of business plant -- new, mature and declining.

The fundamental methodological assumption of the whole approach is that a "city," while acted upon by exogenous impulses from outside, can be treated as a system unto itself. External impulses are converted into experiences that depend on the city's peculiar set of interactive processes. On the other hand, the actions of the city do not change the external environment: the adaptive interactions are one-way only. So the city can be taken as a self-maintaining system, but this system does not include the "rest of the world." It is important for Forrester and, because of the one-way nature of interactions, for the nature of his model, that the "city" does not include the suburbs within the same metropolitan area; the suburbs are part of "the rest of the world."

#### A. Firms

The level and character of economic activity occurring within the city at any time is determined in the model by the history of migratory flows into and out of the city. The activity level and input mix for every firm in the city is taken to be determined solely by its age; so

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<sup>1</sup>Characterized presumably as unskilled, and those with casual or part-time marginal jobs, or unemployed.

the aggregate level of activity and land-labor demand depends wholly on how many new firms entered the city in each year past. A firm, once entering, never leaves, but simply traces out a predetermined and uniform life-cycle. In particular, new firms are alleged to be larger - more labor using - than mature and declining firms and to make relatively more use of managerial and professional labor. Declining firms use least labor and a larger percentage of it is the underemployed type. Mature firms lie between these extremes both as to size and composition. Each stage lasts a given number of years, and then inevitably gives away to the next.

#### B. Labor Migration

The outflows that are relevant to the model refer to labor migrations. Establishment of new businesses in the city depends on the attractiveness of this city relative to "the rest of the world." Attractiveness for a business firm is a function of the population mix in the city and the tax rate on property. Population mix enters from the point of view of availability of labor inputs and constitution of a desirable social environment within which to live. It enters indirectly as well through the influence that population mix has on tax rates. A high ratio of unemployed to other population types discourages new business entry both as labor input and as social environment. Moreover, since underemployed families need higher public expenditures, notably welfare, than other types, their presence contributes to high tax rates.

The opposite is true of managerial population. It tends to attract new businesses for the reverse of all these reasons. Besides population mix, which determines the amount of public expenditures, the tax rate is influenced by the size of the tax base. This, in turn depends on the mix of land uses between business and housing on the one hand, and in the mix of housing among premium, worker and underemployed housing. Since assessed valuations decline among these categories respectively, higher portions devoted to underemployed housing use tends to raise the tax rate most, and business use least, with the other in-between.

Households are attracted to and from the city in terms of its attractiveness to them relative to "the rest of the world" (hereafter simply called the "outside"). All three types of household are influenced by job availability, per capita taxes and housing availability, but both direction and magnitude of marginal incentives differ among the household types. For example, while increasing taxes repels managerial and worker types, it attracts the underemployed, allegedly because the size of taxes indicates the size of expenditures and this latter group shares disproportionately in expenditures while contributing less than proportionately to overall taxes. Second, while housing availability has some influence on location decisions for the first two groups, it is assumed to have very heavy influence for the underemployed -- especially with respect to changes in the range of slight or moderate housing market ease or tightness.

### C. Housing

The housing market is treated as one in which premium housing is used only by the managerial-professional class, worker housing is used



only by the worker class, and underemployed housing only by the underemployed class. Units of the first are generated by private sector new construction; units of the second both by private sector new construction and by the filtering down of premium units as they age; units of the third by filtering from worker units and by government sponsored low cost housing programs. There is a normal rate of filtering based upon the aging process, but this can be modified under the influence of excess demand and supply conditions in the different market sectors.

## II. Evaluation: The Predictive Model

The purpose of this evaluation is not so much to praise or criticize a particular intellectual edifice as to throw light on some of the issues that have to be faced in trying to understand comprehensively the working of urban areas.

### A. Strengths

There is no question but that the model is, despite oversimplification, an extremely complex one. Its structure does pay particular attention to the reciprocal relationship between internal processes and migration. It gives dramatic evidence that in a complex model intra-system reverberations can generate surprising, even frustrating, consequences to which public policy must be adjusted. Neglect of systemic interrelations comes at one's peril.

Moreover, the particular character of the model has virtues. The general geographic and occupational mobility formulations, with implicit

market forces highly influential in both kinds of flows -- if not the specific parameter magnitudes -- include important, acknowledged relationships. The housing market, including both new construction and filtering in the different sub-sectors, but operating with distinctive differences, and influenced also by market forces, is articulated in detail (although it does not function as a market in any very meaningful sense. See below). Even the business location relationships, in which labor and land supplies and public sector characteristics, are influential, contains some insights. In addition to particular equations, the basic methodology, centering around connected feedback loops, is flexible enough to permit substitution of a variety of specifications for each relationship, and even the addition of new relationships, or increased detail in different portions of the model. Thus, the overall framework can serve as a springboard for investigation, experimentation and discovery.

## B. Weaknesses

But the model as presented in Forrester's book has some serious defects. We present some of these briefly.

### 1. The City as Self-Contained System

The insistence upon treating "the city" as a self-contained system is central to the present formulation, and it results in grave difficulties.

a. City-suburb relations. Probably most serious are the misrepresentations of city-suburban relationships in the exclusion of the rest of

of the metropolitan area from the urban system. The metropolitan area does operate as a single system. Business firms attracted to any part of the metropolitan area take their labor forces from the whole area, have close continuing relations across jurisdictional lines in the area. Households residing in one jurisdiction, work in a second jurisdiction, shop in a third, travel daily through a fourth, and partake of public services produced in a fifth. The crucial fixity of land supply in Forrester's model simply does not exist for the metropolitan area in — large measure because of its labor supply, but locate in a suburb because of central city crowding. Such a firm will take advantage of the city's labor force (as well as other features, to be noted below), and will thus generate incomes for city residents just like a city firm, yet be excluded from Forrester's model. Such a firm -- and indeed most real-world firms in the metropolitan area -- will have some, but not total dependence on either city or suburb. The relationships will be badly misrepresented by the Forrester model. Migrations of households as well as businesses generally involve decisions to locate in the metropolitan area, with more specific location within it being subject to intra-metropolitan relations. They will not inevitably carry the kind of influences <sup>in</sup> the tax base that the model fixes, because just as their activities are divided over the metropolitan area, so their public service impact and their total tax liability will be split among the jurisdictions in complicated ways.

It appears that, except for job availability, the postulated influences on labor location refer not to interregional or inter-urban decisions

but only to intra-metropolitan decisions. As such, the impact of these, via migration, on the "welfare" of the city are very different than what is specified in the model.

b. The concept of relative city-rest of the world attractiveness for location. This is a partial equilibrium analysis at best. Events in this part of the larger system are expected to take place while the outside remains unchanged. But, especially as we shall see with regard to policy evaluations -- or even in characterizations of "good" and "bad" consequences, "healthy" and "unhealthy," "balanced" and "unbalanced" situations -- the "constancy" of the outside is seriously compromised. First, the household location decision involves whether it will locate in this city or elsewhere. Either decision makes a difference both to the decision maker and to the outside. He does not disappear from the larger system when he disappears from the Forrester system. Questions about allocational efficiency, well-being of people, must consider what happens to people regardless of their location. This will become of paramount importance when we discuss public policy questions.

An even more striking display of this principle shows with regard to business location. The business location decision is spoken of in the model as creation of new businesses, almost with the presumption that its creation depends on it choosing to reside in the city. But no net business activity is created in the system; the determinants of new business establishment in the Forrester model are too narrow for that. All that is involved is whether a certain business establishment will locate here or

elsewhere. Thus, insofar as the health of a given city is declared to depend on its attracting new business, then, without a much deeper analysis, we must infer that such health is invariably purchased at the cost of illness elsewhere. Neither predictions nor diagnoses can be generalized to the whole of the larger national system when universally employed beggar-my-neighbor actions are treated uncomplicatedly as net income-enhancing policies.

c. General growth vs. specific growth. The partial equilibrium nature of the model breeds some important technical problems in interpreting both flows and levels. Flows are motivated by the relative attractiveness of city and outside. But the outside does not stand still. It experiences growth: in population, in capital stock, in technological change. Except for the former, the other two aspects do not explicitly appear in the model; they are asserted to be taken into account implicitly. The model deals with relative attractiveness in terms only of the attractive forces held to be endogenous. It is asserted to be invariant with respect to exogenous technological changes and other exogenous grounds for a rising national per capita income. So magnitudes must be interpreted as relative, not absolute, magnitudes.

This has at least three consequences. One of these supposedly relative magnitudes is total population in the three categories. Yet the concept of a "normal" rate of population inflows -- inflows which presumably reflect only the rising national trend and not relative attractiveness which is to be superimposed into it -- is measured as proportional to the size of the existing population in the city. Yet this present population

reflects both neutral national trend and the result of the past special attractiveness of this city relative to the rest of the country. So the present "normal" flow is a function of past special flows. Thus, there is an inevitable mixture of absolute and relative determinants in at least one of the important flows that is purported to be pure. Much the same issue occurs in business creations, where a fuller account of business location incentives would have exposed the dependence of present new inflows in the size (and composition) of past business inflows.

A second consequence concerns the source of the "normal" population growth rate to the city. To associate future "normal" inflows with the average inflows of the past, without a deeper questioning of this source is dangerous. These past flows were part of an imposing movement from non-urban to urban areas - indeed, for the most part from non-metropolitan to metropolitan areas. This was fed both by taste revolution and differentially rising per capita incomes in the urban areas. Indeed, much of the rising-living standard trend is associated with rapid urbanization. But this has been an historically specific process: urbanization is nearly complete. The past rates cannot continue much into the future because there is so little non-urbanized population left. Thus, normal inflows for any model that claims to be predictive cannot project the past relationship between overall population growth and normal city inflow into the future.

The third consequence concerns the dependence of this urbanizing flow on per capita income increases occurring disproportionately in urban areas. For one thing, since new relative attractiveness inflows depend

on existing population stocks, and thus on past "normal" inflows, it means that critical flow magnitudes in the model are not invariant to the absolute improvement trends upon which the relative attractiveness impacts are supposedly already superimposed. For another, the total flows are a reflection of absolute per capita income changes. Yet these background well-being changes are not allowed to appear in any of the outcome characteristics of the equilibrating process. The "stagnant" equilibrium stage for the city is treated as a "poor" situation. Yet if it represents a situation that reflects the background rising trend of per capita income, it is something more akin to the average growth factor in the country as a whole. As such it may be closer to the highest average supportable rate of growth in the nation. The relative growth syndrome may well represent a growth situation that can only be supported in part of the overall economy at the expense of relatively declining sectors elsewhere. If so, the so-called "stagnation" situation is not stagnation at all, but average growth. Its use as an example of unhealthy progress -- which forms the basis of Forrester's whole public policy concern -- must be radically revised.

The problem posed here is not merely that a diagnosis of illness must comprehend the meaning of health, it is also that a way must be found to show consistently how the trend process influences the "trend-disturbance" process where important inter-penetration between the two is present. The Forrester model fails to do this, and as a result misinterprets the meaning of the overall situation.

d. Endogenous vs. exogenous disturbances. The above issues skirt a general defect whose details will be examined more closely below. It is that by drawing the system boundaries as narrowly as they have been drawn, the forces for change which can be considered to be endogenous comprise a very narrow family. Those which have been excluded as exogenous from a most imposing set. Indeed they constitute by far the most important determinants of the fate and development of particular urban areas. Changes in them have impacts on the urban system of a magnitude and frequency so great as to overwhelm the endogenous variations. It is as though one concentrated on the development of hives in a person about to be hanged for murder.

Forrester's methodological defense is that, while he admits that outside forces influence the city, these "are not the primary cause of aging and stagnation in cities. If slum areas can be generated without such external changes, then internal interactions must be more essential." (p.18). This defense is a non-sequitur. Just because internal interactions could account for some observed phenomena does not mean they do. The issue is whether in fact it is the external rather than the internal forces which are most influential. What portion of the real observed variations in urban circumstances are in fact explainable by the kind of processes treated as endogenous and what part are explainable by exogenous processes? This is an empirical question, not one of principle, but it is nowhere faced.



The policy issues stemming from this are formidable. Policies that would "benefit" the city by addressing themselves to the endogenous forces may conflict with those that would benefit the city by addressing themselves to the exogenous forces. If the latter forces preponderate, then the former policies are not only irrelevant, they are mischievous.

Besides, this question of relative importance, the question arises of what observations are relevant in evaluating different policies. If endogenous forces are paramount in the system, then, aside from the question to be raised below about the evaluative comparability of events in different years, it is quite appropriate to draw out the consequence of different policies -- or of different initial conditions -- until the inherent temporal regularities have had a chance to reveal themselves. But if the endogenous variations are typically overwhelmed both in amplitude and frequency by exogenous impulses, then the convergence behavior of the endogenous system becomes irrelevant both to understanding the system and evaluating different policies. Short-run transitions may be what is most relevant.

These methodological doubts about the model are far-reaching. We shall attempt to justify their tenor in discussing the determinants of business activity in the next section.

## 2. The Determination of the Level of Economic Activity

The Forrester model excludes the forces that appear to be the dominant determinants of the origin, growth and development of cities, and of

the level of economic activity in them at any time. Moreover, those forces which he does include are not dependably related to these observable phenomena, or they are misspecified in the model.

a. Exclusions and Inclusions

1. Exclusions. The long-term size and activity composition, of a city and its shorter run operating levels appear to depend upon: a) special locational features; b) economies of scale in production; c) vertical economies of inter-process production complexes; d) agglomerative economies in an area making for different degrees of variable scale and input and output specialization; e) technological changes; f) multiplier-accelerator effects of local spending; g) changes in national and international demand for outputs exported from the city; h) temporary bottlenecks due to differences in lagged responses by different types of decision makers. None of these is included in the model.

2. Inclusions. The basic mechanisms present in the model are the life-cycle pattern for businesses and the migration processes for businesses and households. The life-cycle business hypothesis is highly vulnerable, both as to the dependability of an age-activity level relationship and to the attribution of relative magnitudes to different parameters. The first of these is more basic. There is just no evidence that business firms in the aggregate (i.e. across industrial categories) have either their size or their level of activity significantly predictable on the basis of age alone. The excluded explanatory variables explain most of what can be predicted. Moreover, identification of growth or size

or level of activity of a firm with age of the structure it occupies is misleading; a new firm can occupy old structures, old firms can occupy new structures; and size is certainly not predictable from age of building. Nor can one even say dependably that different growth stages inevitably follow one another. Changes in technology, in external demand, in important locational factors like transportation systems, can lead to irregular successions of fast and slow growths; and both of these are not significantly related to existing absolute size. Finally, age of firm is not closely related to input mix at all. In short, the model's heavy reliance in principle on the life-cycle hypothesis for determining business levels is a very serious defect.

Moreover, the model's attributions of relative magnitudes to parameters of the life-cycle relationship compounds the damage wrought. One example will suffice. New firms are cited as being larger than mature firms! Unless some time trend in enterprise size is being adduced -- so that relative size does not refer to the same firm over time but simply to cross section comparisons of aggregates of firms of different age -- the attribution is clearly wrong. New firms grow to larger mature size. Indeed, new firms have the highest failure rate of all; not only are they smaller, they are also, as a class, less secure, than mature firms. Moreover while the successful new firms may grow at a faster rate than mature firms as a whole, the absolute amount of growth may well be smaller.

If intended in a time-trend cross-section sense (which the text belies), this age-size relation does not appear to be supported by any known trend.

The explanation advanced for business location decisions is deficient also, although not nearly so bad as the age-size-activity relationship just discussed. Firms are postulated as being attracted in terms of labor supplies and tax rates. To some extent this is true. But the presence of sources of materials supply, or output markets, or special transportation facilities, are probably more important for most firms. Thus, the predictive power of the included locational factors is likely to be small, not so much because of their inclusion but because of the important exclusions.

b. Misspecifications of Migration Attractiveness.

The most serious misspecification -- not because of the size of the probable discrepancy but because of the importance of the relationship -- is that for underemployed households. This has two aspects. First is the identification of the normal net inflow with something like the national experience of the recent past. As argued earlier, this confounds a specific historical process of rapid, nearly completed urbanization with a supposedly unchanged and indefinitely projectable set of incentives. The normal inflow rate seems much too high for projections into the concrete future.

The second -- and more important -- aspect is the size and shape of the function sharing the marginal influence that housing availability has on underemployed location decisions. The great international and inter-regional migrations of the unskilled to cities seem to have occurred despite housing conditions, since they generally coincide with extremely tight housing markets for the poor. These migrations seem best explainable, as

most researchers of these phenomena\* have concluded, in terms of the attractions of differential economic opportunities between origins and destinations -- job availability, unemployment rates, racial discrimination, less significantly per capita income differences -- and size of moving costs and adequacy of information flows. Housing availability, and even leniency of welfare programs, do not seem to enter. At best these latter factors -- but especially housing availability -- may be relevant to intra-metropolitan locations but not to longer distance moves. Even this conjecture appears erroneous. Housing availability probably is associated with intra-metropolitan location for higher income classes. But the known exclusionary policies of suburbs vis a vis the poor make it unlikely that housing availability is the prime determinant of intra-metropolitan locational decision. <sup>and</sup> ~~But~~ even such short-distance location decisions if they occur, do not have the impact on the central city that the model postulates, for reasons given earlier. A household locating in the suburb is part of the metropolitan area, and its presence is felt in the central city, but in a complicated way. Thus, its presence may influence business location in the city, almost as if it were a city resident.

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\*Greenwood, M.J., "An Analysis of the Determinants of Geographic Labor Mobility in the United States," Review of Economics and Statistics, May 1969, pp. 189-194.

Lowry, I.S., Migration and Metropolitan Growth: Two Analytical Models, Institute of Government and Public Affairs, U.C.L.A., 1966.

Nelson, P., "Migration, Real Income and Information," Journal of Regional Science, Spring, 1959, pp. 43-74.

Sjaastad, L.A., "Income and Migration in the United States", unpublished Ph.D. dissertation, University of Chicago, 1961.

Renshaw, Vernon, "The <sup>role</sup> Rise of Migration in Labor Market Adjustment," Ph.D. dissertation, Massachusetts Institute of Technology, June, 1970.

Not only is the average size of the marginal effect of housing availability much too high in the Forrester model, the slope of the table function that Forrester uses to adjust the size of this marginal effect to different levels of availability is most peculiar. In the range of availabilities near normal, very small changes in housing market tightness lead to very large changes in the parameter -- as though slight changes in a normal market engender enormous real income effects. At the market extremes, where alone one would expect to observe real market responsiveness in terms of price, and therefore impressive real income differences, market changes have very little effect on the size of the marginal incentive. This certainly seems like perverse specification.

Misspecification of this aspect of underemployment migration is of great importance because its strategic role makes the model extremely sensitive to different values of the parameter in question.

c. Functional form of attractiveness functions.

The attractiveness multipliers which modify normal flow incentives in the Forrester model are generally multiplicative in all explanatory variables. This implies: (1) general interaction among explanatory variables for absolute level changes; (2) log linearity for proportional changes in attractiveness. This functional form in conjunction with table functions of parameter values that tend to offset extreme values of the explanatory variables, tends to eliminate turning points in migration flows. Flows are simply damped in any one direction rather than changing direction. Analysis of the actual kind of impact each explanatory variable

has upon the location decision suggests that many variables enter linearly: they have separable plus or minus effects on the real income of the affected groups, with fixed impact coefficients. Their absolute values are important for the sizes of these income effects. A greater reliance on such linear components in the attractiveness multipliers would impart more variability and change of direction, less obvious convergence, to the dynamic path of the system.

Our criticisms about model specification are, to an important extent, instances of a more underlying general difficulty. Forrester's model does not make explicit a set of market processes. What is omitted is a set of prices, expressions about the impact of prices on goal realization (and thus on behavior), and the patterns of adjustment in the market by the several participants when equilibrium is disrupted. Direct recognition of these market processes helps clarify both the changing direction and intensity of behavioral relationships under different market circumstances, and it points out the kinds of adjustments provoked by such changing circumstances.

While the Forrester model does not delineate an explicit market, some market-type adjustments are implicitly envisioned, as for example the effect that different housing occupancy rates have on new housing construction and housing filtering. But by not introducing prices, for example, the aggregate impact of various forces acting simultaneously upon any type of decision maker, cannot be calculated on a consistent basis, since a single comparable dimension of impact is lacking. In addition, various types of

price-influenced substitutions are slighted, resulting in misleading outcome predictions. These have relevance to functional forms, to the size of parameters, even to variable inclusions -- to the shape, the size and direction of relationships. A number of subsections in the Forrester model postulate relationships which seem suspect as reflectors of implicit market processes, the treatment of land use density, productive input combinations, housing quantity and quality occupied, labor migration, business "formation," and other central variables of the overall system, is weakened by omission of the various types of adaptability that embeddedness in a market system confers.

### 3. Lags in decision making

The model specifies long perception-decision lags in the system. These are potentially very important, but little use is made of them. Of large exogenous impulses are expected to be operative on the system, as suggested above, then policy makers cannot afford the luxury of looking to the consequences of distant system adjustments, since these will never occur. It is near-future outcomes that are most relevant. But near-future outcomes depend critically on the length of response lags in the system. Two issues are important. First, if lags are important, then it matters exactly how long they are. One cannot safely adopt casually-estimated lags. The near-term system consequences will be very sensitive to small changes in lag attribution. Second, the whole relevant dynamic behavior of the system will depend importantly on the different lags for different types of decision makers, and for different decisions. Once again, since serious



issues are at stake, serious empirical estimation must be resorted to in quantifying the lag structure of the model. No such serious attention is evident in the present model.

#### 4. Estimation of Hypothesized Parameters

This last point brings us to the aspect of the Forrester book which has been most subject to criticism. Very simply stated, no parameters in the quantified version of the model were derived by sophisticated empirical procedures. They were given values on the basis of various impressionistic practices, noteworthy among them being consultation with "persons knowledgeable in the field." Not only are all the parameters arbitrary in this sense, some of them seem unreasonable on the basis of empirical studies that do exist but of which Forrester did not avail himself.

Forrester defends his practice in two ways. First, he claims that he is convinced that the basic structure of interrelationships in the model is sound, and this structure is more important than parameter values: "The barrier to progress in social systems is not lack of data...[it] is deficiency in the existing theories of structure...It is far more serious to omit a relationship that is believed to be important than to include it at a low level of accuracy that fits within the plausible range of uncertainty...When structure is properly represented, parameter values are of secondary importance...Parameter values must not be crucial because cities have much the same character and life cycle regardless of the era and the society within which they exist." (pp. 113-4)

Forrester supports this methodological faith with some resort to sensitivity analysis of the model. He subjects it to the effect of

varying each of a number of parameters. For these, he finds that only changes in the parameter relating underemployed housing availability to underemployed inflow attractiveness impart significant changes to the model performance. He concludes that this indicates a substantial insulation of the model from any urgency over precise accuracy of specific parameters.

The first tack is, of course, simply a methodological faith, and does not represent a rational argument which it is possible to answer. The second, concerning sensitivity analysis, is more relevant. To this two points should be noted. First, we have already argued that the one parameter to which Forrester found his model sensitive seems very substantially overstated. Second, it is not at all surprising that the kind of sensitivity analysis conducted failed to show model vulnerability to parameter accuracy. The model spells out a number of adaptive, non-linear processes which are likely to offset changes in any one parameter at a time -- various tradeoffs, compensations from one sector to another. Thus, the real test of sensitivity is to examine the effect of changes in several parameters at once. Since all the parameters are arbitrary, all are suspect. It is not at all inappropriate to make substitutions in whole clusters of parameters at a time. The model is very likely to display extreme sensitivity to such a relevant examination.

That this suspicion may be valid is borne out by the fact that at least one pair of other researchers have shown\* that reasonable substitution

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\*Morris and Horton, "Urban Dynamics", by J.W. Forrester: A Review," unpublished

within even a models cluster (3 or 4 parameters) can have radical effects on the performance of the model.

The upshot of these strictures about parameter estimation is that the model as presently quantified cannot safely be used to make policy recommendations. It may have its uses as an exploratory device, but to expect that it solidly supports any policy recommendations is tantamount to expecting to suspend a bridge on thin air.

### III. Evaluation: The Policy Evaluations

Serious as are the deficiencies of the model for explanation -- prediction purposes, it is the treatment of policy questions that is weakest in the book. Most of the shortcomings of the model in its predictive context carry over to the policy application, but in addition some very grave defects relating to normative analysis creep in.

#### A. Invariance of Policy Outcomes to Parameter Accuracy

This is simply to carry over to the normative context the implications of the special kind of quantification performed on the model's parameters. In order to demonstrate the impact of different public policies and parameter quantifications, Forrester produces 250 year computer runs to illustrate alternative quantification "equilibrium" profiles and 50 year runs to illustrate policy "intervention" profiles. But both, whether the former for avowedly politive explanatory purposes or the latter for policy evaluative purposes, depend on the sizes of the different parameters. Policy evaluations are no less immune from clusters of errors inhering

in parameter values than are the undisturbed dynamic journeying of the system. It is not true that the model's structure itself is so commanding as to impose a distinctive, intrinsic stamp to policy outcomes regardless of the model's specific quantification.

Since we have argued that some important quantitative errors do seem to be evident even without searching empirical confrontation, and that no strong confidence should be felt for most of the rest of the quantitative assignments, the proper attitude toward the policy demonstrations should clearly be one of non-commitment. Specific policy comparisons should be viewed as illustrative at best of how the model works -- not as valid evidence upon which to build policy recommendations. Early in the book Forrester seems to express the same disclaimer. But the tone of the book progressively changes to one in which the reader is seriously advised to accept specific policy conclusions. This is a grave methodological error.

#### B. The Normative Criterion

In making public policy evaluations it is necessary to specify the criterion on the basis of which different outcomes will be compared in normative judgment. No explicit welfare criterion of this sort appears in Forrester's book. Readers have differed from one another as to what it might be -- more precisely, what criterion is implied, or at least is consistent with, the applied judgments in the book. Our belief, derived from examining the various kinds of normative statement made in the book, is that the most important -- although not the only -- "welfare" criterion

employed is the city tax rate ("per capita taxes"). When it rises the situation "worsens," when it falls the situation "improves." The tax rate seems to form the content of notions like "The situation of the city."

This is a most curious criterion. Since it is a per capita amount of payment for public goods it is in itself neither good nor bad. Moreover, even as used in Forrester's model, there are important differences in the attitudes of different parts of the population toward it. As a reflection of public services rendered, the underemployed respond more favorably in the model than do the rest of the household and business populations, because the former are assumed to consume these services disproportionately relative to the rest. Similarly, as a financial burden it is disliked less by the underemployed than by everyone else. Indeed, in expressing the influence of the tax rate on net migration, the former are more attracted the higher the tax rate is, other households and business are more repelled. Thus, the associated evaluations of "unbalanced" population and business-household mixes, and the "health of the city," together with the city tax rate suggest a welfare criterion that is either not directly relevant to people at all but only to an abstraction called "the city," or is a hidden criterion about people, but possessing some highly special inter-group judgments about relative social worth.

This criterion, or criterion-segment, is inconsistent with all the traditional normative criteria in economics. Besides this fact, it has anomalous properties, especially when account is taken of the rest of the economic system. First, the attraction of a business or household

of any type to the city necessarily makes that unit better off, since the locational choice means that the unit would improve its situation here rather than elsewhere. But it is logically possible for this to set off a train of reverberations in which a large number of people would be better off, with no one worse off, yet the city condition criteria register a worsening. A dramatic example of where city per capita income level is the criterion. Then poor people might be attracted to the city and more well-to-do families be induced to leave it on terms which make them better off too. Nonetheless, these population movements lead to a worsening of per capita income in the city, so the situation would be declared an impairment of welfare.

The problem is both that an improper indicator is being used to register welfare changes, and that only the situation in the city is being consulted, with no question raised about what happens outside. The last is especially important. In this model the only linkages the city has with the rest of the world occur through migration decisions (new business "creation" is really only a location decision) -- strictly redistributive processes. Typically, a household migration that benefits the city will hurt the outside, and vice versa. We say "typically" instead of "invariably" because while inflow of underemployed seems generally deplored, and inflow of managerial-professionals generally applauded, worker class movements may be one or the other, depending on circumstances.

But business migration is unambiguous. In this model it is always preferable "for the city" to have more rather than less business in the

city. Yet each such accession of new business inevitably makes other areas worse off for the very reason that its gain makes this city better off. Nothing in the model really deals with the productivity of the economic system or of individual resources within it. Even the categories of new, mature, and declining businesses refer only to inputs, not to outputs or productivity. And "creation" of new enterprises means only that they choose to locate in the city, not that their very existence is at stake.\* So this most approved action is purely a transfer -- what the city gains, the outside loses.

This last point incidentally indicates that Forrester's most strongly recommended public policy -- subsidized attraction of new business -- is self-contradictory if generalized to the larger system. For while one city can gain by a differential attractiveness, not all parts of the system logically can: general adoption of the policy means that all communities compete against one another for the given total of business activity.

Thus, even use of an indicator that does potentially bear real welfare significance, a ratio of labor force to jobs, is not able to carry such significance unambiguously. Will a decrease here in what may be taken as a proxy for unemployment simply worsen unemployment elsewhere?

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\*Indeed, even the grounds for locational attraction refer only to financial advantages -- tax differentials, labor input prices -- not to efficient use of resources.

There is a genuine efficiency issue involved in this kind of question. It is possible for the mix of labor skill supplies - job skill requirements to differ substantially in different communities. In such a situation is it better to bring people to jobs or jobs to people? The answer to this requires considering some complicated costs and benefits, including costs of moving. But none of these considerations is, or can be raised, in the model as presently constituted.

Thus, the very structure of relationships in the model, which in effect concern inputs alone and not outputs (except housing) or input-output relationships, makes the partial equilibrium focus especially vulnerable where normative analysis is concerned. It cannot be assumed that occurrences in the city have no effect on the outside. There is a dependable, almost Newtonian, rule: every gain to the city has an equal, and opposite, loss elsewhere. When one adds to this a blurry at best, preverse at worst, choice of welfare criterion to register these gains and losses, the result is a normative instrument with little persuasiveness for public policy evaluation.

c. Stagnation vs. Growth.

In terms of the model (as opposed to the alleged real world counterparts), the whole ground of Forrester's examination of alternative public policies is that the 250 year equilibria represent unsatisfactory situations. Sometimes, this is stated in terms of there being an unhealthy balance among the components of the city: the mix among population types, the balance between housing units and business plants. More frequently, it is simply characterized as "stagnation." It is the stagnation that must be



countered by policy interventions. Yet if we take seriously earlier allegations by Forrester about the model, his later diagnostic characterization of stagnation may be ill-conceived.

We earlier stated that Forrester claimed that the model dealt in relative attractiveness vis-a-vis the outside, even though he recognized that the outside did not remain unchanged. The model must therefore automatically change in conformity with outside trends that are general and not location-specific. Population trends are demonstrably built-in by means of an indigenous birth rate and a normal rate of population inflow. But changes in the capital stock, in technology, in productivity, do not appear to have a reflection in any of the state variables or flows of the city system. Yet they must, if the integrity of the migration flows -- the heart of the model -- is to be preserved. They must show changes in average living standards, probably in number of jobs per plant, growing input densities per business establishment -- and thus, per acre of land. None of these is explicitly included in the model. But suppose that their effects on living standards are includable in a special indicator that we can conceive adding to the model. Consider also the purely redistributive (relocational) nature of "creation" of new business in the model. Then, the long-run equilibrium can be interpreted as the only long-run sustainable passage through time for the average of cities: there is a balance of attractive and repulsive forces maintaining the birth, maturation and aging process on an unchanging plateau. But this plateau is superimposed on a national growth

process. Rather than being stagnation it is the only generally sustainable rate of growth for a system of urban communities. It is therefore not a "bad" but a "good": it is the warranted serene ascension of well-being in an affluent society!

Thus, if one takes seriously the consistency requirements of the model as a whole (especially in the implied crucial but submerged relationship between city and outside), one is led to perceive the undisturbed system -- despite all of its blandishment of the underemployed, and with it, their unwholesome numerous presence in the community -- as performing well, not badly. In this context urgent search for policy remedies is utterly superfluous.

Forrester sees in the outcomes of his model lineaments of problems he claims to recognize as counterparts of real world problems. This recognition, indeed, constitutes for him success for the model is passing the test of verisimilitude. Yet our analysis suggests that when examined closely the "problems" of the model are not the real world problems; and may not even be problems at all.

The real world city certainly is beset with problems. But these are not to be generated from the model, because most of them are integrally connected with the special, intimate relationship that exists between central cities and their suburbs in metropolitan areas. And these, of course, are excluded by the fundamental premise of the self-maintaining city system with homogeneous relationships with all parts of the outside world. The real world city experiences problems like some of the following:

1. Specialized spatial concentrations of different activities within metropolitan area, with the associated problems of accessibility, changes over time in intra-metropolitan locational forces.

2. Relative mobilities and immobilities of different resources with the metropolitan area: jurisdictional specialized zoning and exclusiveness. Urban poverty and income-racial segregation. Inequality of public services.

3. Political fragmentation, making for deliberate and inadvertent localized separation of public service needs and fiscal capacities without adequate metropolitan-wide coordination. Externalities across jurisdictional lines: divorce of public service use and fiscal responsibility.

4. The central importance of the urban transportation system for a) functional linkages among activities -- the basic rationale for the existence of cities; b) influence on the spatial distribution of economic activities and the size and shape of the urban area; c) problems of congestion and pollution.

5. The differential impact on urban areas of impulses from outside -- technological changes, wars, changes in the composition of national demand, among others.

From among these one can piece together the plight of true cities in the present day. But none of these can be derived from the Forrester model, and no merely minor tinkering with it can rectify the omission. It is embedded in the basic structure of the model.

#### D. Temporal Comparability.

After expounding a number of broad, rather fundamental weaknesses in the Forrester model, it may seem uncharitable and picky to end with a technical point of seeming triviality. Technical though it may be, it is not trivial, but indicates an issue of some importance in studying the behavior of systems over time. Briefly, the problem is that Forrester's approach provides no useful way to compare the significance of events that occur at different times. There is an almost cavalier disregard of when particular things happen. Forrester compares "outcomes" simply by waiting until confusing cross-variations calm down and present orderly profiles. It hardly matters when that will be to the substance of the evaluations of outcome. Thus, a comparison of outcomes 250 years distant is not essentially different than a comparison 50 years distant. And more particularly, policies can be compared simply by looking at their respective consequences at some arbitrary time in the future, rather than over the whole time interval until that arbitrary future time. We have already argued that the 250 year equilibria are not much relevant for comparison because, given the frequency and importance of exogenous impulses impinging on the system, no long endogenous adjustment periods are likely to be permitted to occur. Near future changes in the system are likely to be the only endogenous ones uncontaminated by exogenous shocks. Now we argue that within even that relatively short period the time shape of events is important.

The technical issue is simply that events at different times must be made comparable to one another in terms of welfare significance by transforming each into a present value form -- or more generally, into a valuation common to any single point of time. So the whole history of outcomes from any policy becomes relevant to its comparison with other policies. A policy in which all good things are postponed into the distant future is less desirable than one in which the same good things are available sooner.

Intertemporal comparability is traditionally achieved by discounting the events of each time period by a discount rate which expresses the tradeoff terms by which the population would be just willing to interchange the outcome of the year in question with that of a base year (usually the present). In comparing two different policies, the discounting process would be applied to the outcomes of every year from inception to the time when discounting itself had rendered different outcomes normatively indifferent (the economic horizon). Both time sequences would thereby be collapsed to comparable one period capitalized values.

The especial relevance of such a thoroughgoing procedure for rendering time sequences comparable is that near-future outcomes would have disproportionate weight over distant-future outcomes in the policy comparisons. Since the so-called counterintuitive consequences generated by the model are almost always those that result finally after long internal adjustment processes, these would obtain much smaller significance

weights than the more conventionally intuitive early impact effect of the policies. Others, the consistent evaluations of overall sequences, would be likely to produce comparative judgments much less counter-intuitive than Forrester now purveys.

#### IV. Conclusion.

This paper has been long. It has also, we trust, been self-explanatory. Little should be required in conclusion. Forrester's model is indeed an ambitious, bold and imaginative construction of urban relationships in a complete system. Its internal adjustment processes help to remind one of the dangers of neglecting overall system aspects of policies designed to reach particular ends.

We have argued, however, that the specific relationships selected are in important respects the wrong ones to include, both because some excluded relationships are of much greater empirical salience and because some of those included do not reliably exist in an empirical sense. We have argued that some of the valid relations used are wrongly specified, with errors that can make a real difference to the overall working of the model. We have argued that the predictive power of the model, granting its theoretical defects, is further compromised by the absence of a detailed, objective, empirical search for the most appropriate quantification of the relationships. Besides these, we have argued that the attempt to make use of the model for policy recommendations is flawed by an imprecise and/or highly questionable criterion of evaluation. The fundamental dubiousness of treating a city as a self-maintaining system

isolable from its suburbs and even from other parts of the socio-economic system seriously undermines the endeavor to make meaningful normative judgments about events in the city alone. Finally, the normative treatment of generated time sequences as though only arbitrary end points matter would be cause for concern even if the instrument that generated them were an object of much greater confidence than the present one.

Yet despite all this, Forrester's book has received wide and respectful attention. Deservedly so for its emphasis on the complexity of the urban system and the need to evaluate the system consequences of particular policies. In attempting to provide a tool which can be readily used for such evaluation by means of computer simulation, Forrester has attempted a project well worth doing. For those who believe that there is a real city with real problems outside the computer laboratory, it is questionable whether he has succeeded. Yet the scope and ambitiousness of his attempt can teach us much about the issues involved in trying to understand and predict urban processes.







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