Structural dominance in large and stochastic models

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Abstract

The last decade and a half has seen a significant effort to develop and automate methods for identifying structural dominance in system dynamics models. To date, however, the interpretation and testing of these methods has been with small (less than 5 stocks), deterministic models that show smooth behavioral transitions. While the analysis of simple and stable models is an obvious first step to provide proof of concept, the methods have become stable enough to be tested in a wider range of models. In this paper we report the findings from expanding the domain of application these methods in two important dimensions: increasing model size and incorporating stochastic variance in some of the model variables. Exploring the effectiveness of these methods in these two dimensions will increase their applicability into more realistic model analysis situations.

Introduction

The link between system structure and dynamic behavior is one of the defining elements of dynamic modeling. In a sense, a simulation model can be viewed as an explicit and consistent theory of the behavior it exhibits. Although this point of view has certain merits, not least the fact that it lifts the discussion from outcomes to causes of these outcomes and from events to underlying structure (Forrester, 1961; Sterman, 2000), we are concerned here with a more compact explanation of the system's behavior. In fact, most dynamics modeling projects report their results in terms of simpler explanations of the observed results, typically in terms of dominant feedback loops and, occasionally, external driving forces to the system that produce the salient features of the behavior.

For simple systems with relatively few variables it is usually easy to use intuition and trial and error simulation experiments to explain the dynamic behavior as resulting from particular feedback loops. In larger systems, this method becomes increasingly difficult and the risk of incorrect explanations rises accordingly. There is a need, therefore, for analytical methods that provide some consistency and rigor to this process.

Eigenvalue elasticity analysis (EEA) is a set of methods to assess the effect of structure on behavior in dynamics models. It works by considering observed model behavior as a combination of characteristic behavior modes and by assessing the relative importance of particular elements of system structure in influencing these behavior modes. Elements of the model structure that have a large influence on particular behaviors can provide important clues to the modeler to identify areas for further testing and study, and for policy analysis. The method represents a high degree of mathematical rigor compared to the traditional experimental simulation methods normally used in the field. The method uses linear systems theory to 1) decompose the observed behavior into its constituent *behavior modes*, such as oscillation, growth, and exponential adjustment, and 2) outline how particular behavior modes and its appearance in a given system variable depends upon particular parameters and structural elements (links and loops) in the system. In this manner, the method provides a very precise account of the relationship between structure and behavior.

The last decade and a half has seen a significant effort to develop and automate methods for identifying structural dominance in system dynamics models (see Duggan and Oliva, 2013 for an overview of this literature). To date, however, the interpretation and testing of these methods has been with small (less than 5 stocks), deterministic models that show smooth behavioral transitions (e.g., Gonçalves, 2009; Güneralp, 2006; Kampmann and Oliva, 2006; Mojtahedzadeh, 2011; Mojtahedzadeh, Andersen, and Richardson, 2004; Saleh *et al*., 2010). While the analysis of simple and stable models is an obvious first step to provide proof of concept, the methods have become stable enough to be tested in a wider range of models. In this paper we report the findings from expanding the domain of application these methods in two important dimensions: increasing model size and incorporating stochastic variance in some of the model variables. While we only show results of the analysis of *one* large and stochastic model, the results are promising. We find that the methods work as predicted with large stochastic models, that they generate insights that are consistent with the existing explanations for the behavior of the tested model, and that they do so in an efficient way.

Please contact the author for the latest version of this work.

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