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Multi-agent systems as a tool for analyzing path-dependent macrodynamics☆

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ABSTRACT

This paper discusses the concept of path dependence in macrodynamics, and identifies practical difficulties associated with building path-dependent macrodynamic models of the sort that Keynesians and Schumpeterians regard as necessary for the successful study of long-term growth and development. It is suggested that multi-agent systems (MAS) analysis can help address these difficulties, and therefore provides a useful tool for advancing path-dependent macrodynamic analysis. A concrete example is provided in the form of a simple but illustrative MAS model of path-dependent aggregate fluctuations.

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1. Introduction

Closed form, equilibrium theorizing dominates modern economic analysis. Using the language introduced by Kaldor (1934), traditional equilibrium analysis of this form produces outcomes that are *determinate*—that is, both defined and reached independently of the path taken towards them. Thinking of the economy as an evolving, open system in which decision makers confront fundamental uncertainty is confined to branches of economic analysis that draw inspiration from sources such as Schumpeter and Keynes. Analysis of this form is inclined to emphasize the importance of the traverse and the historically contingent or path dependent nature of economic outcomes[1]. But how should such analysis be conducted? The principal

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[1] "The traverse defines the movement of the economy outside equilibrium" (Halevi et al., 2013, p.175). Broadly speaking, traverse analysis is concerned with whether or not equilibrium states can be reached and, if so, whether and how an equilibrium state is influenced by the path taken towards it.

objective of this paper is to demonstrate that multi-agent systems (MAS) models are a useful tool for advancing the analysis of path-dependent macrodynamics and hence macroeconomic analysis along Schumpeterian and/or Keynesian lines.

The remainder of the paper is organized as follows. In the next section, the concept of path dependence is explored. A general definition of path dependence is furnished, specific concepts of path dependence are discussed, and a typology of dynamical systems is suggested. Consideration is also given to what features of an economic system can (or should) be properly considered path dependent. Section three examines the relationship between path dependence and MAS modeling in general while in section four, a specific example of a MAS model of path-dependent aggregate fluctuations (due to Gouri Suresh and Setterfield, 2015) is discussed. Finally, section five offers some conclusions.

2. Exploring the concept of path dependence

2.1. Towards a general definition

Exploring path dependence demands that we first establish what the term means. It is therefore useful to begin with the following general definition:

> A dynamical system displays path dependence if earlier states of the system affect later ones, including (but not limited to) anything that can be construed as a "long run" or "final" outcome of the system

It is self-evident from the above definition that in a path-dependent system, "history matters." What may be less self-evident – and therefore more worthy of emphasis – is that this historical contingency is a *permanent* rather than transitory feature of the system: "long run" or "final" outcomes are among the properties of a path dependent system that are influenced by its earlier state(s). This is not to say that all history matters, or that any given event that does matter will always manifestly affect observed system outcomes. As will become clear below, there are concepts of path dependency that allow for selective history dependence and so-called memory wiping, without history per se ever becoming irrelevant. But consider an ordinary AR1 process, which always captures the influence of history on current outcomes over *some* interval of time. This influence is, however, often revealed to be transitory, the process eventually "settling down" to an outcome that bears no influence of the adjustment path taken towards it[2]. Such a process does not display path dependence according to the definition of the term adopted here[3].

As defined above, path dependence constitutes an "organizing concept" around which dynamical models of the economy can be built. Methodologically, then, it is comparable to the concept of equilibrium. It is important to note that path-dependent macrodynamic models generally contrast with equilibrium theorizing, because the latter is typically based on a path-independent "traditional equilibrium" organizing concept that is defined in terms of exogenous data and displays asymptotic stability (i.e., it is a position to which the system will automatically return following any arbitrary displacement). But there is no necessary inconsistency between the concept of equilibrium per se and that of path dependence. On the contrary, it is possible (although not necessary) that a state of rest – i.e., an equilibrium of some sort – will be the "long run" or "final" outcome of a path-dependent system (Lang and Setterfield, 2006–2007—see also Arthur, 2006, 2013)[4].

2.2. Specific concepts of path dependence

Consistent with the general definition of path dependence provided above are numerous specific concepts of this phenomena. These differ in the precise ways in which they account for historical contingency, but need not be considered mutually exclusive.

Most famously associated with the work of Kaldor (1970, 1972, 1981, 1985), but also found in the earlier work of Myrdal (1957), Young (1928), and Veblen (1919), *cumulative causation* is usually associated with the dynamics of wealth accumulation and growth. In this context, cumulative causation describes self-reinforcing growth dynamics that give rise to self-perpetuating virtuous or vicious circles of rapid or slow growth (respectively). The origins of cumulative causation are often traced to Smith's dictum that "the division of labor depends on the extent of the market" [and, per Young (1928), vice versa]. In other words, the expansion of product demand induces an expansion of productive capacity, while the expansion of productive capacity induces an expansion of product demand. In its modern Kaldorian variants, the Verdoorn law (linking the rate of growth of productivity to the rate of growth of real output) is understood to account for the first of these linkages (running from "demand to supply"), while the second (running from "supply to demand") is understood to be incomplete in the sense that, in keeping with Keynes' principle of effective demand, an expansion of productive capacity will not induce an equivalent expansion in the demand for output. This creates a role for autonomous demand in determining the fate of a system subject to cumulative causation and thereby, and in traditional Keynesian fashion, privileges the demand side as the "driver" of macroeconomic outcomes.

The interactions characteristic of cumulative causation need not give rise to path dependence. Indeed, in the canonical Kaldorian model of cumulative causation (Dixon and Thirlwall, 1975), they resolve into a conventional, a historical equilibrium outcome (see also Blecker, 2013,

[2] Of course this need not be the case. If an AR1 system has a unit root, for example, the influence of past events on current system outcomes will be indelible. But AR1 systems are not, in general, characterized by unit roots.

[3] In the parlance of unit/zero root characterizations of hysteresis, it may be said to display *persistence*—i.e., its future outcomes will be enduringly but not permanently affected by any given outcome established in the present period. See Setterfield (2009, pp.53-55) for further discussion.

[4] Indeed, authors such as Hahn (1991, p.73) argue that "equilibrium economics in which neither initial conditions nor processes play a part ... is neither credible nor indeed honest. This suggests that what Lang and Setterfield (2006–2007) identify as "path-dependent equilibriaäre the only equilibria that merit attention.

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