

Introducing Systems Thinking and System Dynamics Models in Economics Education

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Extended abstract

System dynamics, pioneered by Professor Jay Forrester at MIT in the late 1950s (Forrester, 1958; Forrester, 1961; Forrester, 1995), has evolved into a research discipline with its own academic society, a peer-reviewed journal, degree-granting educational programs (Bosch and Cavana, 2018; Davidsen *et al.*, 2014; Pavlov *et al.*, 2014; Wakeland, 2014), and a collection of well-regarded textbooks (e.g. Coyle, 1996; Dangerfield, 2020; Ford, 2010; Maani and Cavana, 2007; Morecroft, 2007; Pruyt, 2013; Randers, 1980; Richardson and Pugh, 1981; Roberts *et al.*, 1983; Sterman, 2000; Warren, 2008; Wolstenholme, 1990). System dynamics has been widely applied across various fields of research and instruction including management (e.g., Coyle, 1981; Evans, 1988; Georgantzas and Katsamakos, 2010; Ginsberg and Morecroft, 1997; Senge, 1990), engineering (e.g., Gupta, 1982; Hovmand and O'sullivan, 2008; Wolstenholme, 1983), natural sciences (e.g., Bossel, 2007; Hassan *et al.*, 2014), sustainability (e.g., Benabderrazik *et al.*, 2022; Meadows *et al.*, 1972; Meadows *et al.*, 2004; Saeed, 1998; Saysel and Hekimoğlu, 2013; Sterman *et al.*, 2012), and public policy (e.g., Andersen *et al.*, 2007; Cavana *et al.*, 2019; Clancy *et al.*, 2021; Ghaffarzadegan *et al.*, 2011; Homer, 2012; Hovmand, 2014). While there also exists a substantial body of literature that applies system dynamics to economics (e.g. Cavana *et al.*, 2021; Fiddaman, 2002; Forrester, 1973; Harvey, 2002; Low, 1980; Mass, 1975; Meadows, 1970; Pavlov *et al.*, 2005; Radzicki, 2020; Saeed, 2020; Scricciu *et al.*, 2021; Sterman, 1986; Uehara *et al.*, 2016; Wheat, 2009; Yamaguchi and Yamaguchi, 2021), system dynamics is not part of the standard economics curriculum. This raises questions regarding the discrepancy between the versatility of system dynamics and its underrepresentation in economics education. Despite the recognition of 'feedback systems' by economists dating back to the 18th-century (see Mayr, 1971 and Richardson, 1991), the integration of system dynamics into economics teaching has been hindered by a lack of awareness among economists about its principles and educational affordances.

This article asserts that system dynamics can be successfully integrated with economics instruction, often complementing rather than replacing traditional pedagogy. Causal diagrams and system dynamics simulations can enrich traditional comparative statics analysis by allowing students to explore the transitional paths between successive equilibrium points within an economic system. While very few economists are familiar with system dynamics, they already employ practices that are foundational to system dynamics such as project-based learning (e.g., Ghosh, 2013) and numerical simulations (e.g., Gorry and Gilbert, 2015). We are confident that as economists continue searching for innovative pedagogical approaches that enhance the accessibility and relevance of economics material (e.g. Allgood *et al.*, 2015; Asarta *et al.*, 2017; De Muijnck *et al.*, 2021; Frank, 2002), systems thinking and system dynamics models

will enter the mainstream economics education thus fostering a deeper understanding of complex economic systems by students and better preparing them for real-world challenges.

This article contributes to the literature on the pedagogies of system dynamics (e.g. Bosch and Cavana, 2018; Richardson, 2014; Schaffernicht and Groesser, 2016) and economics (e.g. Allgood *et al.*, 2015; Asarta *et al.*, 2017; De Muijnck *et al.*, 2021; Frank, 2002). The article examines the traditional undergraduate economics curriculum and pedagogy with the emphasis on the use of graphs, numerical simulations, and project-based teaching. We also explain the barriers to introducing new instructional methods in economics. Then we discuss the state of the art in teaching economics with system dynamics by drawing on published literature and the authors' experiences. We also develop a framework that suggests practical instructional strategies for introducing systems thinking and system dynamics models into the economics classroom. We conclude by enumerating the shortcomings of this study that can be addressed in future work.

References

Allgood S, Walstad WB and Siegfried JJ. 2015. Research on Teaching Economics to Undergraduates. *Journal of Economic Literature* **53**: 285-325

Andersen DF, Vennix JAM, Richardson GP and Rouwette EAJA. 2007. Group Model Building: Problem Structuring, Policy Simulation and Decision Support. *Journal of the Operational Research Society* **58** (5): 691-694. <https://doi.org/10.1057/palgrave.jors.2602339>.

Asarta CJ, Jennings AS and Grimes PW. 2017. Economic Education Retrospective: 25 Years of Contributions from the American Economist. *The American Economist* **62** (1): 102-117. <https://www-jstor-org.ezpv7-web-p-u01.wpi.edu/stable/26754404>.

Benabderrazik K, Kopainsky B, Monastyrnaya E, Thompson W, Tazi L, Joerin J and Six J. 2022. Climate Resilience and the Human-Water Dynamics. The Case of Tomato Production in Morocco. *Science of The Total Environment*: 157597

Bosch O and Cavana RY, Eds. 2018. *Systems Education for a Sustainable Planet*. MDPI: Basel, Switzerland.

Bossel H. 2007. *System Zoo 1: Simulation Models*. Books on Demand: Norderstedt, Germany.

Cavana RY, Dangerfield BC, Pavlov OV, Radzicki MJ and Wheat ID, Eds. 2021. *Feedback Economics: Economic Modeling with System Dynamics*. Springer: New York.

Cavana RY, Forgie VE, van den Belt M, Cody JR, Romera AJ, Wang K and Browne CA. 2019. A "Power and Influence" Political Archetype: The Dynamics of Public Support. *System Dynamics Review* **35** (1): 70-103. <https://doi.org/10.1002/sdr.1618>.

Clancy T, Addison B, Pavlov OV and Saeed K. 2021. Contingencies of Violent Radicalization: The Terror Contagion Simulation. *Systems* **9** (4): 90

The 42nd International System Dynamics Conference, Bergen, Norway. August 4-8, 2024

Coyle RG. 1981. Survey of Business Schools Teaching System Dynamics. In: Proceedings of the International System Dynamics Conference. International System Dynamics Society: Rensselaerville, NY, p. 306.

Coyle RG. 1996. *System Dynamics Modelling: A Practical Approach*. Chapman and Hall: London.

Dangerfield BC, Ed. 2020. *System Dynamics: Theory and Applications*. Springer: New York, NY.

Dauidsen P, Kopainsky B, Moxnes E, Pedercini M and Wheat D. 2014. Systems Education at Bergen. *Systems* 2 (2): 159-167. <http://www.mdpi.com/2079-8954/2/2/159>.

de Muijnck S, Tieleman J and Wolf M. 2021. The Didactics of Economics Education. In: de Muijnck S and Tieleman J (eds). *Economy Studies: A Guide to Rethinking Economics Education. A Guide to Rethinking Economics Education*. Amsterdam University Press: Amsterdam, pp. 125-139.

Evans JK. 1988. *Application of System Dynamics as a Strategy for Teaching Management Concepts*. School of Education. Boston, MA, Boston University.

Fiddaman TS. 2002. Exploring Policy Options with a Behavioral Climate–Economy Model. *System Dynamics Review* 18 (2): 243-267. <https://doi.org/10.1002/sdr.241>.

Ford A. 2010. *Modeling the Environment*. Island Press: Washington, D.C.

Forrester JW. 1958. Industrial Dynamics: A Major Breakthrough for Decision Makers. *Harvard Business Review* 26 (4): 37-66

Forrester JW. 1961. *Industrial Dynamics*. Productivity Press: Cambridge MA.

Forrester JW. 1995. The Beginning of System Dynamics. *The McKinsey Quarterly* (4): 4-16

Forrester NB. 1973. *The Life Cycle of Economic Development*. Productivity Press: Cambridge MA.

Frank RH. 2002. The Economic Naturalist: Teaching Introductory Students How to Speak Economics. *The American Economic Review* 92 (2): 459-462

Georgantzas NC and Katsamakos EG. 2010. Performance Effects of Information Systems Integration. *Business Process Management Journal* 16 (5): 822-846. <https://doi.org/10.1108/14637151011076494>.

Ghaffarzadegan N, Lyneis J and Richardson GP. 2011. How Small System Dynamics Models Can Help the Public Policy Process. *System Dynamics Review* 27 (1): 22-44

Ghosh IK. 2013. Learning by Doing Models to Teach Undergraduate Economics. *Journal of Economics and Economic Education Research* 14 (1): 105-120. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84891113051&partnerID=40&md5=47d71182522b1553099de673c83d88de>.

The 42nd International System Dynamics Conference, Bergen, Norway. August 4-8, 2024

Ginsberg A and Morecroft J. 1997. Weaving Feedback Systems Thinking into the Case Method: An Application to Corporate Strategy. *Management Learning* **28** (4): 455-473.
<https://doi.org/10.1177/1350507697284005>.

Gorry D and Gilbert J. 2015. Numerical Simulations of Competition in Quantities. *International Review of Economics Education* **18**: 49-61. <https://www.sciencedirect.com/science/article/pii/S1477388015000067>.

Gupta NK. 1982. Electrical Energy Planning through System Dynamics. *Industrial Engineering J.* **9** (2): 59-61

Harvey JT. 2002. Keynes' Chapter 22: A System Dynamics Model. *Journal of Economic Issues* **36** (2): 373-382

Hassan J, Bergaust LL, Wheat ID and Bakken LR. 2014. Low Probability of Initiating Nirs Transcription Explains Observed Gas Kinetics and Growth of Bacteria Switching from Aerobic Respiration to Denitrification. *PLOS Computational Biology* **10** (11): e1003933.
<https://doi.org/10.1371/journal.pcbi.1003933>.

Homer JB. 2012. *Models That Matter: Selected Writings on System Dynamics 1985-2010*. Grapeseed Press: New York.

Hovmand PS. 2014. *Community Based System Dynamics*. Springer: New York, NY.

Hovmand PS and O'Sullivan JA. 2008. Lessons from an Interdisciplinary System Dynamics Course. *System Dynamics Review* **24** (4): 479-488. <https://doi.org/10.1002/sdr.410>.

Low GW. 1980. The Multiplier-Accelerator Model of Business Cycles Interpreted from a System Dynamics Perspective. In: Randers J (ed). *Elements of the System Dynamics Method*. Productivity Press: Cambridge MA, pp. 76-94.

Maani KE and Cavana RY. 2007. *Systems Thinking, System Dynamics: Managing Change and Complexity*. Pearson Education New Zealand: North Shore, N.Z.

Mass NJ. 1975. *Economic Cycles: An Analysis of Underlying Causes*. Productivity Press: Cambridge MA.

Mayr O. 1971. Adam Smith and the Concept of the Feedback System: Economic Thought and Technology in 18th-Century Britain. *Technology and Culture* **12** (1): 1-22

Meadows DH, Meadows DL, Randers J and Behrens III WW. 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books Publishers: New York.

Meadows DH, Randers J and Meadows DL. 2004. *Limits to Growth: The 30-Year Update*. Chelsea Green: Vermont.

Meadows DL. 1970. *Dynamics of Commodity Production Cycles*. Productivity Press: Cambridge MA.

The 42nd International System Dynamics Conference, Bergen, Norway. August 4-8, 2024

Morecroft J. 2007. *Strategic Modelling and Business Dynamics: A Feedback Systems Approach*. John Wiley & Sons: Oxford, UK.

Pavlov OV, Doyle J, Saeed K, Lyneis J and Radzicki MJ. 2014. The Design of Educational Programs in System Dynamics at Worcester Polytechnic Institute (WPI). *Systems* **2** (1): 54-76.
<http://www.mdpi.com/2079-8954/2/1/54>.

Pavlov OV, Radzicki MJ and Saeed K. 2005. Stability in a Superpower-Dominated Global Economic System. *Journal of Economic Issues* **39** (2): 491-501

Pruyt E. 2013. *Small System Dynamics Models for Big Issues: Triple Jump Towards Real-World Dynamic Complexity*. TU Delft Library: Delft, The Netherlands.

Radzicki MJ. 2020. System Dynamics and Its Contribution to Economics and Economic Modeling. In: Dangerfield BC (ed). *System Dynamics: Theory and Applications*. A Volume in the Encyclopedia of Complexity and System Science. Springer: Heidelberg, Germany, pp. 401-415.

Randers J, Ed. 1980. *Elements of the System Dynamics Method*. Productivity Press: Cambridge MA.

Richardson GP. 1991. *Feedback Thought in Social Science and Systems Theory*. University of Pennsylvania Press: Philadelphia.

Richardson GP. 2014. "Model" Teaching. *System Dynamics Review* **30** (1-2): 81-88.
<http://dx.doi.org/10.1002/sdr.1512>.

Richardson GP and Pugh AL, III. 1981. *Introduction to System Dynamics Modeling with Dynamo*. Productivity Press: Cambridge MA.

Roberts NH, Andersen DF, Deal RM, Grant MS and Shaffer WA. 1983. *Introduction to Computer Simulation: A System Dynamics Modeling Approach*. Addison-Wesley: Reading, MA.

Saeed K. 1998. *Towards Sustainable Development: Essays on System Analysis of National Policy*. Ashgate Publishing Company: Brookfield, Vermont.

Saeed K. 2020. Dynamics of Income Distribution in a Market Economy: Possibilities for Poverty Alleviation. In: Dangerfield BC (ed). *System Dynamics: Theory and Applications*. Springer US: New York, NY, pp. 491-522.

Saysel AK and Hekimoğlu M. 2013. Exploring the Options for Carbon Dioxide Mitigation in Turkish Electric Power Industry: System Dynamics Approach. *Energy Policy* **60**: 675-686.
<https://www.sciencedirect.com/science/article/pii/S0301421513003066>.

Schaffernicht MFG and Groesser SN. 2016. A Competence Development Framework for Learning and Teaching System Dynamics. *System Dynamics Review* **32** (1): 52-81

The 42nd International System Dynamics Conference, Bergen, Norway. August 4-8, 2024

Scrieciu SS, Zimmermann N, Chalabi Z and Davies M. 2021. Linking Complexity Economics and Systems Thinking, with Illustrative Discussions of Urban Sustainability. *Cambridge Journal of Economics* **45** (4): 695-722. <https://doi.org/10.1093/cje/beab017>.

Senge PM. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday/Currency: New York.

Sterman JD. 1986. The Economic Long Wave: Theory and Evidence. *System Dynamics Review* **2** (2): 87-125

Sterman JD. 2000. *Business Dynamics*. McGraw-Hill: Boston, MA.

Sterman JD, Fiddaman T, Franck T, Jones A, McCauley S, Rice P, Sawin E and Siegel L. 2012. Climate Interactive: The C-Roads Climate Policy Model. *System Dynamics Review* **28** (3): 295-305. <https://doi.org/10.1002/sdr.1474>.

Uehara T, Nagase Y and Wakeland W. 2016. Integrating Economics and System Dynamics Approaches for Modeling an Ecological-Economic System. *System Dynamics Review* **33** (4): 515-531

Wakeland W. 2014. Four Decades of Systems Science Teaching and Research in the USA at Portland State University. *Systems* **2** (2): 77-88. <http://www.mdpi.com/2079-8954/2/2/77>.

Warren K. 2008. *Strategic Management Dynamics*. Wiley: Chichester.

Wheat ID. 2009. Empowering Students to Compare Ways Economists Think: The Case of the Housing Bubble. *International Journal of Pluralism and Economic Education* **1** (1/2): 65-86

Wolstenholme EF. 1983. The Relevance of System Dynamics to Engineering System Design. *European Journal of Operational Research* **14** (1): 116-126

Wolstenholme EF. 1990. *System Enquiry: A System Dynamics Approach*. Wiley: Chichester, UK.

Yamaguchi K and Yamaguchi Y. 2021. Accounting System Dynamics Modeling of Money Stock as Debts. In: Cavana RY, Dangerfield BC, Pavlov OV, Radzicki MJ and Wheat ID (eds). *Feedback Economics*. Springer: Cham, pp. 69-95.