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CONTENTS

MINSKY'S PLATFORM VERSUS MATLAB AND ANYLOGIC SIMULATION TOOLS FOR REAL TIME IMPLEMENTATION OF NONLINEAR MINSKY'S FINANCIAL DYNAMIC MODEL

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Abstract

In this paper is presented the flowchart paradigm of three demonstrative simulation tools of a nonlinear dynamic system from economics domain, chosen as case study. More precisely, Minsky platform, Forrester AnyLogic diagrams and MATLAB' SIMULINK software packages are more fascinating and educational, hence a good motivation to be investigated. Furthermore, the Minsky software package exhibits real-time simulation features using Godley Tables to generate financial flow equations, the Forrester diagrams are based on the stock-flow concept, and MATLAB' SIMULINK is a friendly user interface between the computer real-time simulation environment and process. The system dynamics visually represent systems of first order differential equations in a multidimensional state-space, and the philosophy behind them consists of system's structure description with the dynamics arisen from it. Also, a system dynamics is described by two key concepts that show underlying structure leading to cyclical and complex behavior, and add complexity to model starting from structural foundations. Both, simulations and visualization extend the mathematical analysis and provide a good insight about Minsky's "financial instability hypothesis" on the foundation of Goodwin's limit stable cycle model. If this assumption is integrated into Goodwin's framework then "converts its stable but cyclical system into a chaotic one, with the possibility of a divergent breakdown-the simulation equivalent of a depression".

Keywords: AnyLogic simulation, Godley Table, Keynesian foundations, MATLAB' SIMULINK simulation, Minsky's model and simulation.

JEL Classification: C63, G01, P43

1. INTRODUCTION

Over time several applications of nonlinear dynamic systems models have been developed in economics field (Magistretti, 2018). The study of their evolution, described through a set of first-order differential equations in the space of states, inspired by the control systems engineering, took full advantage of the remarkable progress of the qualitative theory of differential equations, becoming one of the major objectives of economic research focused on finding a good understanding of phenomena such as economic growth, cycles and market analysis to anticipate and control their behavior (Magistretti, 2018), (Tudoroiu N., Chiru, C., Grigore, M., 2009). Economists increasingly use nonlinear models instead their linearized approximations to capture accurately the entire dynamics of the systems that naturally exhibit a nonlinear behavior. This is the reason why the switch from linearized to nonlinear models is justified, in part, by increased computing power of the PCs and a considerable improvement in simulation tools found on the IT market, but also by a desire to understand economic phenomena unable to be captured by their corresponding linearized models. Unfortunately, majority of simulation tools need to implement the dynamic models are either too computationally complex to be of practical use, or rely on local approximations which fail to adequately capture the nonlinear features of interest. In this research paper the reader is kept informed on the most suitable simulation tools existing on the IT market for an accurate implementation of nonlinear dynamics systems from economics. To prove their effectiveness, a particular well-known nonlinear Minsky's financial model is considered as a case study, computationally simple and easy to be implemented. Additionally, it provides a good insight about Minsky's "financial instability hypothesis" on the foundation of Goodwin's limit stable cycle model. If this assumption is integrated into Goodwin's framework then "converts its stable but cyclical system into a chaotic one, with the possibility of a divergent breakdown-the simulation equivalent of a depression". (Keen, 1995, p.607). Basic insight of Minsky's Financial Instability Hypothesis is that "the capitalism is inherently flawed and prone to booms, crises and depressions" (Keen, 1995, 2011). Such a financial system will be capable of both generating signals that induce an accelerating desire to invest and of financing that accelerating investment. Minsky's thesis emerges from a simple, structural model of capitalism. The analyzed model is introduced in section 2, and three demonstrative simulations tools based on the flowchart paradigm are proposed in section 3. The simulation results of the model implementation are shown in section 4, and a performance analysis accomplishes the section. Section 5 concludes by highlighting the main contributions of the paper and states the future work.

2. THE PSEUDO-GOODWIN CYCLES IN A WAGE-LED MINSKY MODEL

Given the evidence on the strong wealth effects, is interesting to investigate what type of "*a finance-driven economy* "cycles are generated as response to a wage-led demand regime. The answer is given in (Stockhammer and Michell, 2014, pp.14-15) by introducing "*a highly stylized wage-led Minsky's model"* that is extended "*to include a reserve army distribution function*" with a great capability feature to analyze the cyclical behavior. The dynamics of the new model is "*driven entirely by the interaction between financial fragility and demand"*, such that the "*financial fragility increases with output"*, i.e., "*it simply posits that higher fragility leads to lower growth of demand*" (Stockhammer & Michell, 2014, p.8, p.10). Therefore, higher demand leads to lower unemployment, and positive effects on the wage share are expected. As well, the demand is wage-led. Compared to Goodwin original model (Keen, 1995), Stockhammer described only by two equations (2015), the simplest extension version **"***wage-led Minsky model"* is described by the following three dynamic equations (Stockhammer & Michell, 2014, p.7, p.10, p.12):

$$\frac{dF}{dt} = F(-1 + pY)$$
$$\frac{dY}{dt} = Y(1 - F + sW) \qquad (1)$$
$$\frac{dW}{dt} = W(-c + rY - W)$$

First equation represents the financial fragility *F*, positively related to the demand output *Y*. The second equation is the demand equation with a negative impact of fragility *F* and a positive one of the wage share *W*. The last equation is "*a reserve-army distribution function*" that depends positively on output *Y* and negatively on wage share *W* (Stockhammer & Michell, 2014, p.15), (Nikolaidi & Stockhammer, 2017). It is worth to notice that the new extended model version is labelled "*pseudo-Goodwin cycles*", i.e. counter-clockwise oscillations in output and wage share space (*Y, W*), which are not generated by the Goodwin' mechanism (Stockhammer & Michell, 2014), since it is not in operation any time when "*a wage-led demand regi*me" is assumed. The "*pseudo-Goodwin cycle*" is generated only as a side effect as "a *reserve-army distribution function*" is dragged along by fluctuations in output *Y* that are driven by financial factors, as is stated in (Stockhammer & Michell, 2014, p.15).

3. SIMULATION TOOLS USED TO IMPLEMENT THE NONLINEAR DYNAMIC SYSTEMS FROM ECONOMICS

In this section is introduced briefly three simulations tools the most suitable to implement accurately the nonlinear dynamic systems from economics and finance fields.

3.1. REAL-TIME MINSKY'S SIMULATION ENVIRONMENT

Minsky's simulation environment is in fact a true macroeconomic modeling software platform. It is a free open-source computer program, an essential tool for a new approach to economics field, to build and simulate engineering dynamic systems, monetary economic models, models without equilibrium and with a financial sector. It is similar to Vensim, Mathcad, Mathematica, Mathlab and other mathematical modeling/ simulation tools, but adapted and optimized for accounting-based, flow-of-funds analysis. Also it is a new flowchart paradigm with real-time features, similar to AnyLogic Forrester diagrams, the second one valuable simulation tool that will be introduced in next subsection. In the most recent Minsky's simulation platform it is easy to build linear and nonlinear dynamic models in general, and in particular, to build monetary models of the economy. Still, work needs to be done to refine the user interface, such that to enable it to represent an economy as a number of industrial sectors, each of which buys inputs from and sells output to the others. Moreover, in short time will be added the ability to model international trade and financial flows between different national economies, encouraged by the fact that the designers have already done proof-of-concept modeling of multi-sectorial monetary models in Mathcad and Mathematica. Simultaneously will be, also, added the capability to import economic data and to derive system parameters from data using nonlinear parameter estimation techniques. The readers interested to apply this simulation tool can download the program for free via the SourceForge site. In figure 1 and figure 2 are shown the Minsky's platform editor with some components.

There are a number of types of components in Minsky:

1. Mathematical operators such as plus (+), minus (-)
2. Constants or parameters (named also constants) whose values are set by the user
3. Variables whose values are calculated by the program during a simulation and depend on the values of constants and other variables.
4. Godley Tables  , shown in figure 1 and figure 2 on the platform editor that defines both financial accounts and the flows between them. Similar to the Forrester AnyLogic diagrams, based on the stock and flow modeling concept, the columns of a Godley table are the stocks, which are computed by integrating over a linear combination of flow variables.

5. Integrals representing a variable computed by integrating a function forward in time.
6. Groups, which allow components to be grouped into modules that can be used to construct more complex models. All these components appear in figure 1 in a palette similar to the one shown below:

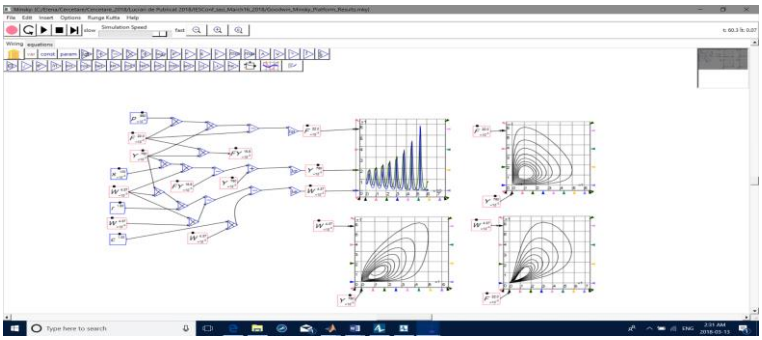

Figure 1 *The snapshot of the Minsky's platform editor with Minsky's economic dynamic mode*

Source: Authors based on the simulation results obtained in. Minsky's platform free downloaded via sourceforge.net site

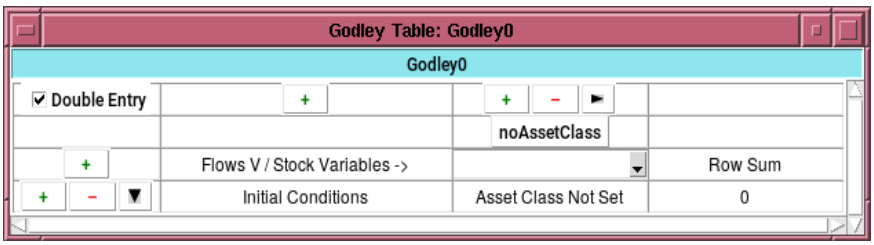

Figure 2 *The Godley Table (Minsky's simulation platform editor)*

Source: Authors based on Minsky's platform software package free downloaded via https://sourceforge.net/projects/minsky/

3.2. REAL-TIME ANYLOGIC SIMULATION ENVIRONMENT

AnyLogic is the only simulation tool that supports three main paradigms in place today: system dynamics, discrete-event, and agent-based modeling. It provides a visual language that simplifies development of agent-based models significantly. For example, Unified Modeling Language (UML) states that charts are used to define agent behaviors, action charts are designed to define algorithms, environment objects are used to help describe the agent environment and collect statistics, and events are used to describe occasional or time-certain occurrences, as

can be seen in (Tudoroiu, 2012). These constructions allow users to describe almost all the behavioral aspects of agents. In addition, users can always write specific Java code to model something more specific or unanticipated. Agent-based models can be also combined effortlessly with discrete-event and system dynamics models. The agents themselves may be included inside system dynamics stock and flow diagrams or flow charts, as is shown in figure 3. In other words, AnyLogic provides a highly friendly environment for multiparadigm modeling, which combines different simulation methods within one model in various ways: hierarchical, series hand-off, or parallel. External libraries and packages can also be added and used in AnyLogic models. In addition, AnyLogic provides a variety of statistical tools, such as dataset, bar chart, time plot, and histogram. These components are usually added into the main class for demonstrating analysis results during the simulation run, as in figure 6 that shows the simulations results of Minsky's economics model. The most current version, AnyLogic 8.3, allows the integration of AnyLogic models with external Java applications. Furthermore, the AnyLogic Web site shows many examples of models that have been developed for several applications, including the study of social, urban, and ecosystem dynamics.

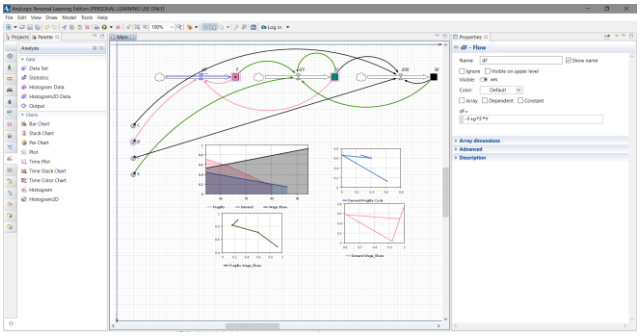

Figure 3 *A snapshot of AnyLogic Editor with Minsky's economics model flowchart*

Source: Authors based on simulation results obtained by implementation in AnyLogic Personal Learning Edition version 8.2.3 free downloaded via https://www.anylogic.com

3.3. REAL-TIME MATLAB' SIMULINK ENVIRONMENT

SIMULINK is used to model, analyze and simulate dynamic systems using block diagrams. It is fully integrated with MATLAB, easy and fast to learn and flexible. It has comprehensive block library useful to simulate linear, non–linear or discrete systems, thus an excellent research tools. Additionally, C codes can be generated from Simulink models for embedded applications and rapid prototyping of control systems. Also, SIMULINK is useful to model, analyze and simulate dynamic systems using block diagrams, as is shown in figure 4. Additionally, SIMULINK provides a graphical user interface for constructing block diagram of a system, and thus is easy to implement the models. To build one model in Simulink, by means of a simple "*Drag and drop' block"* action the block is transferred from the *Simulink library* window to the *Editor* window.

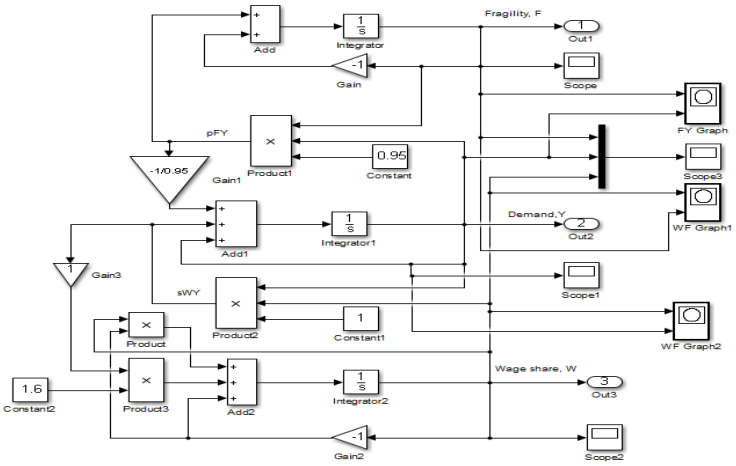

Figure 4 *The SIMULINK Minsky's model*

Source: Authors based on simulation results obtained in MATLAB/SIMULINK version 2017a download via https://www.mathworks.com/downloads/

4. SIMULATION RESULTS OF NONLINEAR DYNAMIC SYSTEMS

In this section are presented the simulation results of Minsky's economics model in all three simulation platforms, as is shown in figure 5, figure 6 and figure 7.

4.1. SIMULATION RESULTS OF NONLINEAR MINSKY'S MODEL IMPLEMENTATION IN REAL-TIME MINSKY'S SIMULATION ENVIRONMENT

The simulation results of Minsky's model implemented on Minsky platform are displayed in figure 5 that reveal the instable evolution of fragility, demand and wage share, as well as the stable or unstable Goodwin's limit cycles.

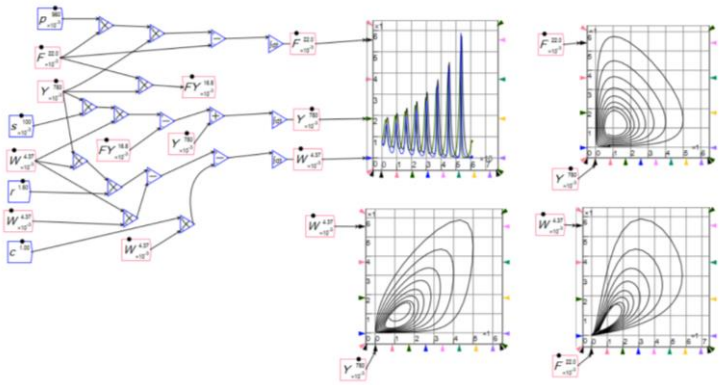

Figure 5 *The nonlinear Minsky's economics model flowchart implemented in real-time Minsky's simulation platform*

Source: Authors based on Minsky's platform software package free downloaded via https://sourceforge.net/projects/minsky/

4.2. SIMULATION RESULTS OF NONLINEAR MINSKY'S MODEL IMPLEMENTATION IN REAL-TIME ANYLOGIC SIMULATION ENVIRONMENT

The simulation results of Minsky's model implemented on AnyLogic platform are shown in figure 6. Similar to the Minsky platform, the simulation results reveal the same instable evolution of fragility, demand and wage share, as well as the Goodwin's cycles. Compared to AnyLogic simulation results it can be seen that the accuracy to represent the Goodwin limit cycles is better on Minsky platform.

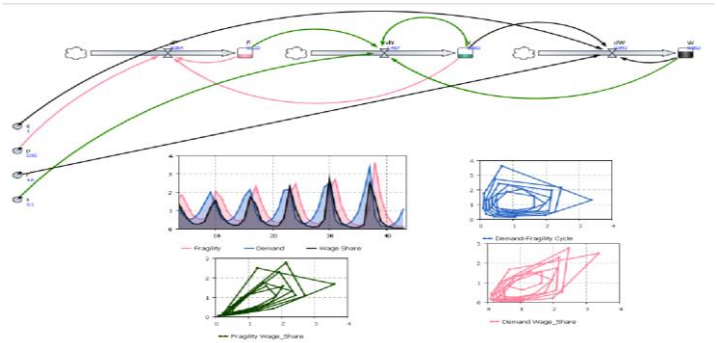

Figure 6*. The Minsky's economics model implemented in AnyLogic simulation platform*

Source: Authors based on simulation results obtained by implementation in AnyLogic Personal Learning Edition version 8.2.3 free downloaded via https://www.anylogic.com

4.3. SIMULATION RESULTS OF NONLINEAR MINSKY'S MODEL IMPLEMENTATION IN MATLAB' SIMULINK SIMULATION PLATFORM

The simulation results of Minsky's model implemented on MATLAB' SIMULINK platform are shown in figure 7. Similar to the Minsky platform, the simulation results reveal the same unstable evolution of fragility, demand and wage share, as well as the Goodwin's cycles. Also, you can notice same accuracy in the representation of the Goodwin limit cycles as on Minsky platform case.

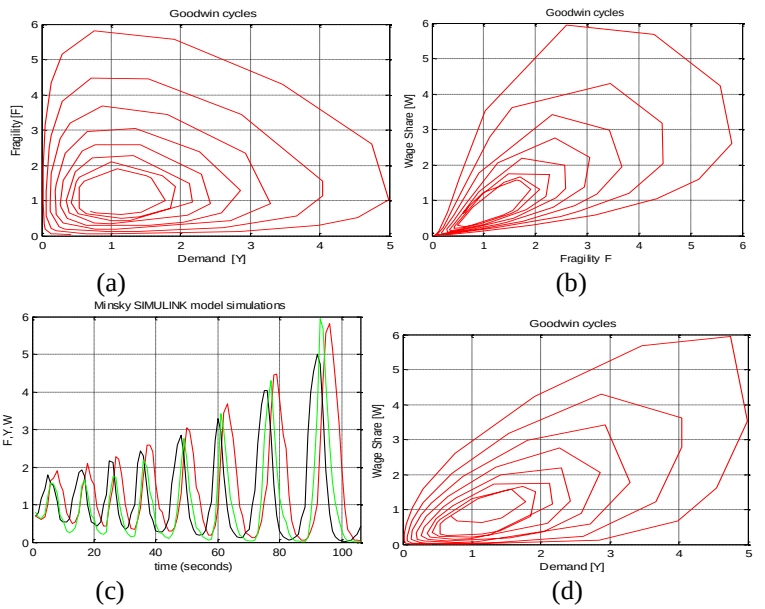

***Figure 7**. Fragility, Demand, Wage share and Goodwin limit cycles in Minsky's model SIMULINK simulations*

Source: Authors based on simulation results obtained in MATLAB/SIMULINK version 2017a download via https://www.mathworks.com/downloads/

Comparing the simulation results on all three platforms, it is easy to notice the best accuracy in model implementation and Goodwin limit cycles simulations for Minsky and MATLAB' SIMULINK platforms. Overall, the simulations in Minsky platform are more accurate, the economics nonlinear model implementation is easier, humbler and the simulations take place in real-time. Closing, the Minsky platform compared to other two platforms is more adequately to simulate the dynamics of the nonlinear models from economics and finance fields.

5. CONCLUSIONS

This research work is focused on the presentation of three demonstrative simulation platforms, such as Minsky, AnyLogic and MATLAB'SIMULINK. All three platforms are based on the flowchart implementation paradigm, suggested by the engineering simulation tools for linear and nonlinear dynamics systems. The Minsky model implementations and extensive simulations on all three platforms disclose that the most suitable simulation platform seems to be the real-time Minsky macroeconomic modeling software platform. This one is recommended by its real-time features, implementation simplicity and accuracy, as well as by the fact that is more adequately to implement and simulate the dynamics of nonlinear systems from economics and finance fields, especially when their models exhibit naturally stable or unstable limit cycles, similar to Goodwin cycles presented in this paper.

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