On Component Based Modeling Approach using System Dynamics for The Financial System
(With a Case Study of Keen-Minsky Model)

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The methodology presented will take the modeling to higher level and scale. By using hierarchical component based modeling approach, the model result would be easy to understand and to communicate. We are now able to reconstruct the Keen-Minsky monetary model using system dynamics approach without difficulty. It is because ordinary differential equations and network accounting model can easily be translated into system dynamics form. The resulting model consists of two main blocks, the real sector and the financial sector. The smallest component is exponential growth module in the family of first order system. The price module is created from first order system component. The nonlinear function is encapsulated as a module. The purpose in this modeling is not emphasized on prediction, but more on getting insight by forming an accurate model of the economy's behavior

Keywords: system dynamics, financial system, differential equations, system thinking, financial crisis, component based modeling, accounting model, modeling framework.

Chapter 1: Introduction

Jay Wright Forrester describes three counterintuitive behaviors of social system that are very important in Forrester (1971). The first reason problems are often hard to solve in social systems is that they are frequently far separated from their causes by both time and space. Policies tend to address symptoms rather than causes, so that the result of a policy can be entirely different than was originally intended. This is a result of both system delays (due to stocks) and system interconnectedness (due to feedback loops). In reality, cause-effect relationship may run both directions making it reinforcing feedback loop in the system. Second, it is hard to identify leverage points in the social systems. The social systems seem to have a few high leverage points which are not where most people expect. If a policy intervenes in the low leverage point in the system, then it will not alter behavior of the system. Even though a high leverage point is identified, a policy guided by intuition will alter the system in the wrong direction. Third, social system often presents conflict between short-term and long-term results. A solution that is successful in the short run often erodes success in the long run. Every solution has unintended effect, we has to find it and minimize undermining the solution.

The poem about elephant in the dark by Jalaluddin Rumi, gives a metaphor that different perspectives or paradigms are useless if we have no clue and no preconceived notion about the object in the darkness. We need a light to enables us to see whole at last. To make sense the whole picture is a prerequisite for change of paradigm. We see the world as a series of events that just happened. These events form only the tip of iceberg, we need to learn to look below the surface to see the entire iceberg. Over time we can recognize patterns that relate these events. The patterns are useful for solving problems and we are good at this level. However, we still need to understand the systems underlying the patterns. Light is just a metaphor for a methodology to understand the whole picture as a system.

We believe that the methodology is system thinking that is based on system dynamics. System thinking requires us to construct model of the system before we draw conclusions or make decisions. System dynamics is an interdisciplinary thinking method that uses a powerful metaphor of a bathtub or water tank to model the state of the system in a time point and the change to that state over a time period. System dynamics is also used to study the behavior of complex systems based on the explicit representation of feedback loops. System dynamics also gives visual sense of the whole system picture that could be used to enhance understanding and to communicate effectively. The system dynamics perspective is an inward or endogenous point of view, because it believes that the cause of the system behavior comes from within the system not from external forces or outside the system.

Let us put system dynamics to work with an example of system failure or system problem such as global financial crisis. The following is an excerpt from Mirakhor (2009). The causes of global financial crisis are manifold. The excess liquidity because of episodes of low interest rate caused excessive levels of debt and risk as showed by subprime MBS that lead to housing bubble. The mainstream approach doesn't explicitly model the financial sector so that the crisis wasn't anticipated. It was supported based on the theory from Walras, Arrow-Debreu stating existence of a general equilibrium in a market economy. In the private sector we have Modigliani-Miller theorem about debt-equity indifference where the value of a firm is unaffected by how its capital structure is financed. And in the finance world we have Efficient Market Hypothesis where market prices reflects all needed information and thus the underlying values of real-sector assets. Therefore financial market cannot, by definition, experience bubbles or affect real-sector growth. The alternative explanation is that financial capitalism is inherently unstable. The more debt-based the structure of finance, the more unstable the financial system is. Debt-based leverage amplifies fluctuations as the balance sheets of the leveraged institutions expand and contract as a multiple of asset price increase or decrease. The inherent instability of the financial capitalism was explained by Minsky in his financial instability hypothesis. This endogenous perspective is matched with philosophy of system dynamics.

Scope & Methodology

We will reconstruct Keen-Minsky monetary model using system dynamics. The resulting model should be hierarchical and component based. So we can zoom in or zoom out of the model and the components that have been created can be used for other modeling purposes.

The financial system can be represented using a network accounting model, which reveals the values for all stocks and all flows in one integrated diagram that in an instant gives you an overall picture and forms part of the basis for intelligent and informed decision making (Thomsen, 2003). The accounting model approach of macroeconomic explicitly model financial sector as distinct from the real economy, so allowing for independent growth and contraction effects from finance on the economy. Model outcome or the stability in response to shocks and disturbances in macroeconomics environment and policy is determined by accounting identity not by equilibrium concept (Bezemer, 2010).

Tools

For modeling and simulation tool, we use Simantics system dynamics tool (Lempinen et al, 2011). The tool is based on open source, so that the modeling software becomes more affordable and the distribution of models becomes easier. The tool used the open source OpenModelica environment to simulate the system dynamics models. The models are translated into Modelica language and OpenModelica is used to compile and simulate the Modelica code. The modeler doesn't have to understand the Modelica language. Modelica is an object-oriented, equation based modeling language that has originally been created for modeling and simulating physical systems (Fritzson, 2011). System dynamics models are basically just differential equations that can easily be represented in the Modelica language.

The object-oriented nature of the Modelica language provides a natural solution for the implementation of hierarchical modules. Adopting this type of object oriented approach to system dynamics modeling can significantly speed up the development of large and complex models. The modules clearly and logically separate different functionalities in the model. Reusing the created module is simply a matter of dragging another instance of the module to the diagram and defining the input and output variables.

Simantics System Dynamics runs under Java 6 (not Java 7) and can be downloaded for free from https://www.simantics.org/simantics/download
The documentation and the tutorials can be found in this page
https://www.simantics.org/end_user_wiki/index.php/Simantics_System_Dynamics

Chapter 2: System Thinking and System Dynamics

SYSTEM THINKING

According to Barry Richmond (Richmond, 2004), thinking consists of two processes: the first is constructing the mental model and the second one is simulation the mental model itself. System thinking is part of critical thinking. The adoption of system thinking is hard because of cognitive overload. People need to think with several modes of thinking, or use several thinking tools in parallel.

There are seven thinking tools/mode in system thinking

1. Verbal model, describing the world using the words and narrative story. It is the most flexible also can be ambiguous because of the richness of a language.
2. Conceptual model, a form of visual map that represents concept and relationship between the concepts. The relationship modeled usually static and structural. Examples are data model, class diagram, and causal loop diagram.
3. Spreadsheet model or table/matrix model, usually in form of excel kind of spreadsheet
4. Operational model, which describes the dynamics and behavior of the system. Examples are system dynamics/stock-flow diagram, state diagram, petri net, and workflow.
5. Geometric model, it could be a simple graph describing behavior over time or relations between variables.
6. Mathematical model, takes form of equations, it could be algebraic equations or differential/difference equations.
7. Computer model, a program that will make the model executable by the computers

This entire thinking model can be translated to each other with varying degree of conversion. Let us give example of the thinking tools with virtuous cycle of bank account. (The example was inspired from Don Woodlock's channel http://www.youtube.com/dwoodlock)

Verbal model

We put money in bank account with predetermined interest rate. The savings account generates interest. That interest makes the account bigger. The bigger balance generates more interest, which even accumulates into bigger balance account. This configuration forms positive reinforcing feedback loop

Conceptual model

Conceptual model in the form of casual loop diagram represents interaction between factors qualitatively.

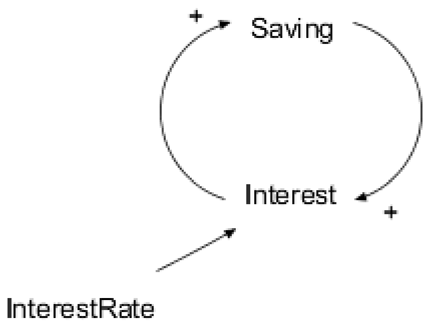

Figure 1. Causal loop diagram of interest-saving model

Causal loop diagrams are inherently weak because they do not distinguish between information flows and conserved (non-information) flows. As a result, they can blur direct causal relationships between flows and stocks. Further, it is impossible, in principle, to determine the behavior of a system solely from the polarity of its feedback loops, because stocks and flows create dynamic behavior, not feedback. Finally, since causal loop diagrams do not reveal a system's parameters, net rates, "hidden loops," or nonlinear relationships, their usefulness as a tool for predicting and understanding dynamic behavior is further weakened. (Radzi, 1997)

Every feedback loop in a system dynamics model must contain at least one stock. Any casual loop diagram can be labeled, quantified and restructured as stock flow diagram (Binder, 2004).

Spreadsheet model

This type of model is commonly used in financial modeling. The advantage of using spreadsheet is its simplicity. The disadvantage is that we can't see the relationship between variables directly.

InterestRate | fx =12%

	A	B	C	D	E	CV	CW	CX
1	Interest Rate	12%	per year					
2								
3	Time in month	0	1	2	3	98	99	100
4	Beginning Savings Balance		100	101	102.01	262.5266	265.1518	267.8033
5	Interest		1	1.01	1.0201	2.625266	2.651518	2.678033
6	Ending Savings Balance	100	101	102.01	103.0301	265.1518	267.8033	270.4814
7								

Figure 2. Spreadsheet table of interest-saving model

Operational model

The causal loop diagram can be converted into a stock flow diagram. System dynamics tool is often used by social scientists. The diagram is easy to understand and communicate because it was using metaphor of water tap and bath tub.

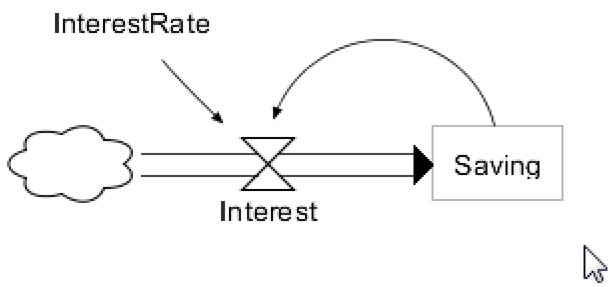

Figure 3. Stock-flow diagram of interest-saving model

Interest represents a change to the saving account, with no withdrawal as an assumption. The savings account accumulates interest over time.

In engineering, the diagram is emphasized more in functional block as shown in figure below:

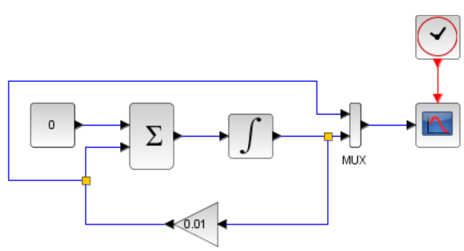

Figure 4. Block diagram of interest-saving model using Scicos

The more verbose type of modeling tools represent variable and function at once, just as shown in the figure below:

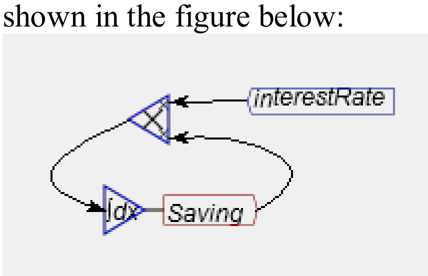

Figure 5. Another block diagram of interest-saving model using Minsky

Geometrical model

The behavior of saving and interest over time can be illustrated geometrically using a graph. We can see that the graph represents an exponential graph. The graph is not just limited to time axis, so it can also be used to represents relationship between variables. Real systems often generate clearly identifiable time patterns and system dynamic models can be built to mimic the patterns.

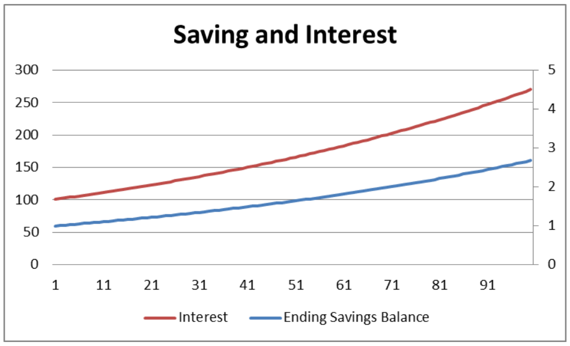

Figure 6. Geometrical model of interest-saving model.

Mathematical model

Mathematical model of the graph in continuous time can be described with an algebraic equation such as:

$$Saving(t) = Saving_0 e^{rt}$$

where $Saving_0$ is the initial value of the saving account. We can also write it differently as a differential equation:

$$\frac{dSaving}{dt} = r * Saving$$

or as a difference equation:

$$Saving(t+1) = Saving(t) + r * Saving(t)$$

Computer model

Equations as shown above can be hidden in a function/module such as:

Saving = calculateBalance(initialBalance, interestRate, time)

Or encapsulated in an object/component

SavingAccount.calculateBalance(initialBalance, interestRate, time)

The module or the component then can be visualized using visual programming style

Figure 7. A module's visualization of an interest-saving model.

SYSTEM DYNAMICS

System dynamics is the study of dynamics of the system as they change and evolved over time. Prof. Jay Forrester develops system dynamics at M.I.T. in 1956. It was first used in engineering control system and feedback methods.

A system is composed of interdependent components that work together to achieve a goal or purpose. Business system has elements of customer, market-share, brand, revenue, R&D, good working environment, etc. These bunches of factors affect each other. We can model these components as stock variables, whose values are measured at a moment/point in time, i.e.: inventories, wealth and debt. Levels of a stock can only be changed by the amount of flows such as goods, services and financial funds which measured over period of time. The amount of inflows and outflows can be determined either from their feedback loops (reinforcing/positive or balancing/negative) and the parameters from external world. The flow is the action or the rate of change and the stock is the outcome.

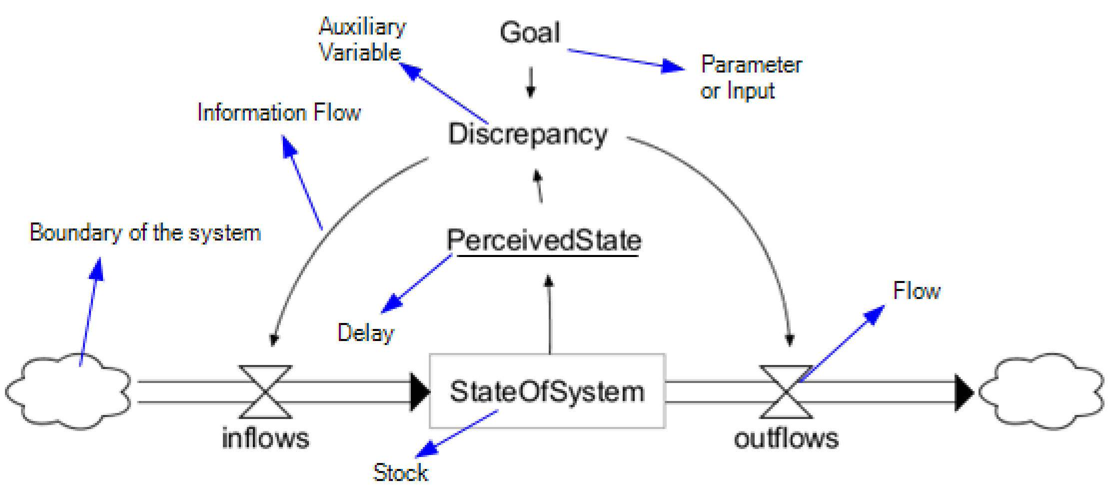

Figure 8. Building block of stock flow diagram

The equation that manages stock is

$$\frac{dS}{dt} = \sum(inflows - outflows)$$

The sum of inflows minus the sum of outflows equals to change of the stock level. By this equation alone we can convert one form to the other form. The principle is simple. The ordinary differential equations can always transfer to stock flow diagram and vice versa. So we can read it as one another, whichever way is more comfortable. But SD diagram can convey 'information flow' nicely, while in the backstage it actually transforms into a full set of differential equations.

System categorization

System can be categorized based on the level of understanding. This is a subjective classification. A system that is considered simple to one person can be considered complex to others, and vice versa. The more familiar with a system the more simple a system becomes. A system ceases to be complex when the rule or the principle that governs the system is fully understood. Nevertheless, let us see two system classifications, the Cynefin framework and cellular automata based classification before we move to classification based on system order size.

The Cynefin framework developed by Dave Snowden is a sense-making model of a system. It has four domains (Snowden, 2010), which are:

1. Simple, ordered system in which the relationship between cause and effect is self-evident, the decision model is to *Sense - Categorize - Respond* and we can apply *best* practice.
2. Complicated, ordered system in which there is relationship between cause and effect but not self-evident and requires analysis or some other form of investigation and/or the application of expert knowledge, the approach is to *Sense - Analyze - Respond* and we can apply several *good* practices.
3. Complex, in which the intermediate interdependence of systems part making the relationship between cause and effect, can only be perceived in retrospect, but not in advance, the approach is to *Probe - Sense - Respond* and we can sense *emergent* practice.
4. Chaotic, in which relationship between cause and effect is not understood, the approach is to *Act - Sense - Respond* and we can do innovation and discover *novel* practice.

Stephen Wolfram classifies system qualitatively into four types (Wolfram, 1984), according to the results of evolving the system from a "disordered" initial state:

1. Simple, leads to stable or homogeneous state.
2. Periodic structures or oscillation.
3. Complex localized structures.
4. Chaotic pattern or random.

In system dynamics, a simple behavior such as linear graph, to infinities, to zero, or reaching a certain level of point, can be explained by zero and first order system. While an oscillation, over or under-damped system can be described by a second order system. Complexity started at third order system where we can still recognize the patterns of behavior. We will have chaotic patterns in a complex system after a while when we lose predictability because of sensitivity dependence on initial value and amplifications of errors/disturbances.

BEHAVIORAL PATTERNS AND GENERIC STRUCTURES

The order of the system is determined by the number of stocks in the system. Behavior of lower order system can be produced by the higher order system, e.g. behavior of zero order system can be produced by first order system or higher and patterns in first order system can be produced by another higher order system.

Hierarchical and component based modeling

When we discuss about the world we talk of it at various level of hierarchy. We think that things are composed by other things. We think about things by using similarity and differences with other things. Examples are hierarchy of plant and animals or organizational structure such as financial accounting structure. Hierarchy is just one way to classifying our view of the world or taxonomy (Lambe, 2007). This hierarchy of ideas or concept doesn't have a definite level and depends on the context.

For the purpose of our modeling we can decompose model into several levels or layers;

1. Very high level model: consists of grouping, typing, and classification for strategic purpose. Examples are sectors, macro and micro economy.
2. High level model: consists of big parties, things, events, and processes for tactical purpose. Examples are aggregates in social classes.
3. Domain model: consists of individual entities and its relationships in a specific problem domain for operational purpose.
4. Component model, serves as reusable components or foundation for building block, works across domain.

Layering can also be based on rate of change, because things change at different rates. Generation change, forest growth, infrastructure replacement has slower rate than price or technological changes. These different rates of changes also cause delay such as information or perception delay. Delay has a lot of impact in feedback loop and can produce oscillations in the system. The idea of pace layering was first recognized in architecture (Brand, 1994).

Building model is faster and easier when we are not doing it from scratch. Molecules are the LEGO from which good system dynamics models are built (Hines, 1996). It is like using object oriented approach in analysis or design patterns in software realm. Each of the molecules will be encapsulated in a module and can be assigned their own inputs, outputs and parameters. In component/object based modeling there are two ways to reuse, the first is composition and the second is inheritance. We use composition approach by encapsulating molecule in a module, and then reuse the module. The inheritance approach uses a different taxonomy of molecules than the composition approach used. The taxonomy is organized based on specialization hierarchy and provides path for model evolution. The inheritance approach constructs simulation models by successively replacing parts of predefined molecules with more specialized molecules (Malone, 2009). The paper gives an example of the approach in supply chain domain.

Chapter 3. Modeling Monetary Keen-Minsky in System Dynamics

MINSKY: STABILITY IS UNSTABLE

Minsky (1986, 1992) considered financial instability to be endogenous to the financial system. The theory is called Financial Instability Hypothesis (FIH) and simply says that stability is inherently unstable. Fundamental characteristic of the system is swings between robustness and fragility and the swings are an integral part of the process that generates business cycle. Therefore the economy is fundamentally cyclical, with each state (boom, crisis, deflation, stagnation, expansion and recovery) containing the elements leading to the next in an identifiable manner. His theory was influenced by Keynes's notion of the fundamental instability of market expectations, and by Schumpeter's creative destruction through disruptive innovation that act as catalyst in creating a new market and destroying old market.

Minsky looked at all participants in the economy – households, companies and financial institutions – in terms of their balance sheets and cash flows. Balance sheet comprises of what the party owns (assets), what the party owes (liabilities) and what is left over (net worth) is the wealth (equities). Balance sheet is a snapshot picture taken at a specific point in time. While cash flows captures the movement of money at a period of time in one balance sheet and from one balance sheet to another balance sheet. Minsky called it a "web of interlocking commitments" – a complex network of interconnected balance sheets and cash flows that is always changing and evolving.

Minsky argued that a key mechanism that pushes an economy towards a crisis is the accumulation of debt by the non-government sector. The borrowers that accumulate insolvent debt can be classified into three distinct categories, according to their balance sheet and ability to make interest and principal payments through their operating cash flow. They are called "hedge", "speculative" and "Ponzi finance". Hedge financing unit can fulfill their entire contractual obligation and usually their equity is bigger than their liability. Speculative finance units can meet their commitments on interest payment but not the principal, so they need to roll over their liabilities. Ponzi units can't pay either interest payment or the principal, so they refinance by selling asset or raising more debt. The necessity is that asset prices must continue to rise. It emerges during a speculative bubble when then margin of safety declines.

The cycle starts when the economy is doing well but firms and banks are conservative. Most projects succeed and firms can easily pay their debt then reevaluate their investment strategy. In prosperous times, when corporate cash flow rises beyond what is needed to pay off debt, a speculative euphoria develops. The debt to equity ratios of the firm rises and Ponzi finance starts to develop. Soon thereafter debts exceed what borrowers can pay off from their incoming revenues. Firm taking more risk than it should. Ponzi units have to sell assets. Liquidity dries out as asset market is flooded. Euphoria becomes a panic which in turn produces a financial crisis. As a result of such speculative borrowing bubbles, banks and lenders tighten credit availability, even to companies that can afford loans, and the economy subsequently contracts. Minsky stated that if hedge financing dominates, then the economy could be in equilibrium-seeking state. On the contrary, the greater weight of speculative and Ponzi finance the greater the likelihood that economy is in unstable state.

MONETARY MODEL OF KEEN-MINSKY

Steve Keen built model of Minsky's FIH (1995) which displayed qualitative characteristics that matched the real macroeconomic and income-distributional outcomes of a period of economic volatility followed by a period of moderation, leading to a rise on instability once more and a serious economic crisis. He also built a strictly monetary macroeconomic model which can generate the monetary as well as the real phenomena manifested by both the Great Recession and the Great Moderation. The content of this chapter mainly extracted from his papers (Keen 1995, 2007a, 2007b, 2010a, 2010b, 2011a, 2011b) unless stated otherwise.

Accounting System Dynamics

Accounting views a business entity as economic values that reside in a set of financial statements such as income statement, balance sheet, and cash flow statement. The balance sheet records state values of assets, liabilities, and equities at a point in time. Over time, these values may change or move around from one state to another state. The balance sheet can be seen as collection of stocks. The inflows and outflows of the stocks over a period of time are represented by income and cash flow statement (Yamaguchi 2003. Thomsen, 2003).

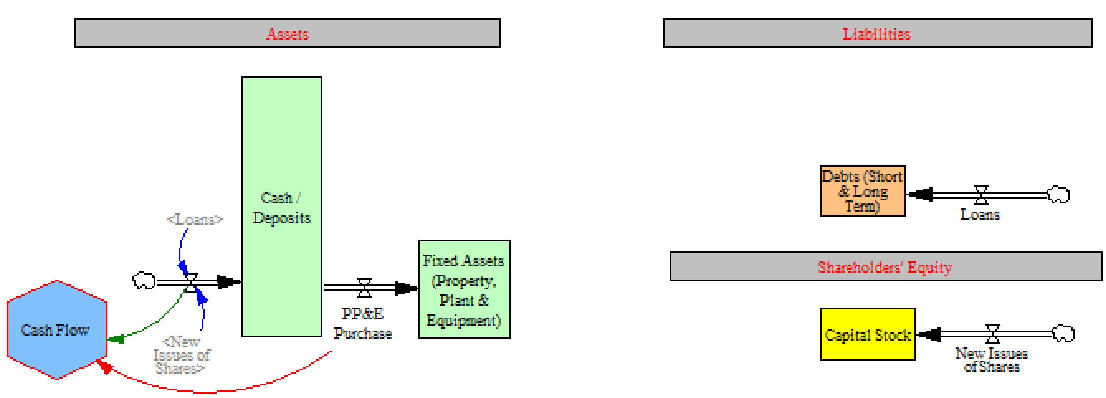

Figure 9. Illustration of balance sheet as collection of stocks (Yamaguchi, 2012)

Thomsen also gives analogy for business as a living entity with a circulation of value, rather than as a collection of lists of numbers in various accounts (Thomsen, 2003). Business is more than just the circulation of value. However, the circulatory system forms the base of the model. The more clearly we understand the business as a living entity the better we will be able to keep it healthy. The five groups of parties are: shareholders/investor, debtor, government, suppliers, and customers interact by means of goods (inventories and long-term assets) and cash. The interaction can be represented by table of stock and flow as shown below.

	Cash	Equity	Customer	Supplier	LongTermAsset	DeferredTaxes	LongTermDebt	Inventory
AddValueProfit		-						+
AdjustValueDefTax		-				+		
SellStock	+	-						
AdjustValueCash	+	-						
AdjustValueLTA		-			+			
BuyStock	-	+						
DistributeDividend	-	+						
RefundsUnlend	-		+					
RepayLTD	-						+	
DistributeTax	-					+		
Pay	-			+				
PayForLTA	-			+				
Lending	-		+					
RepayShortTermDebt	-			+				
DistributeInterest	-						+	
BorrowSTD	+			-				
BorrowFromLTD	+						-	
Unpay	+			-				
ReceiveCash	+			-				
Receive	+		-					
Unsell			-					+
SellGoodsServices			+					-
SellLTA				+	-			
UseLTA					-			+
BuyLTA				-	+			
ConstructLTA					+			-
BuyResearchDevelopment				-				+
BuyGoodsServices				-				+
UnbuyGood				+				-
AddValueTax						-		+
AddValueInterest							-	+

Figure 10. Table representation of a network accounting model

The table above can be converted into a network model where the system is closed. The model can reveal the values for all states and all flows in one integrated flow diagram. It will give an overall situation awareness and forms part of the basis for informed decision making (Thomsen, 2003).

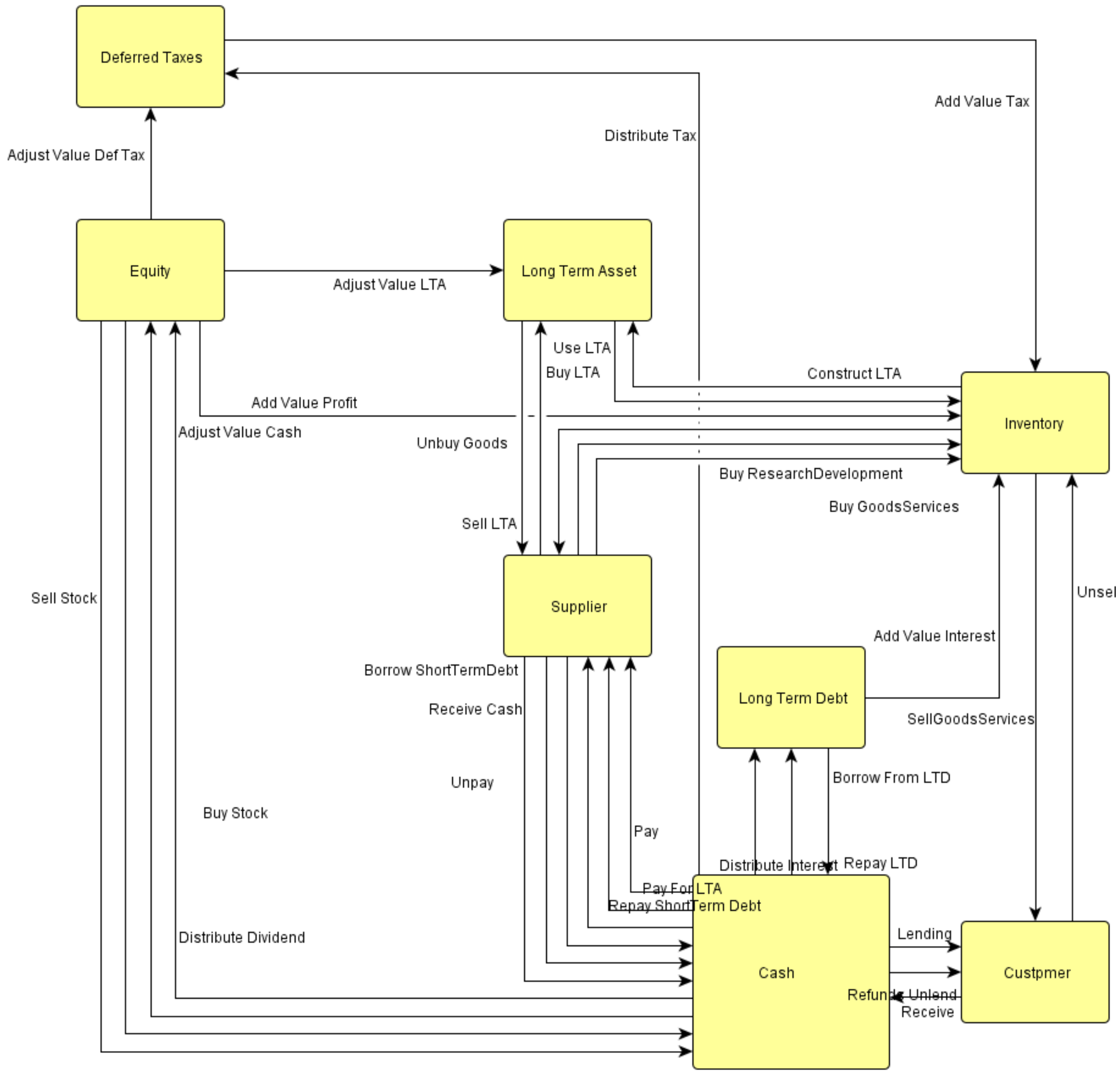

Figure 11. Circuit representation of network accounting model

Yamaguchi (2012) also made a closed loop representation of accounting model for general macroeconomic system. The system consists of five sectors, producer (firm), consumer (household), banks, government, and central bank that are continuously interacting with one another. The sector block can be seen as a module or a component. And the implementation of the sector is based on system dynamics although he did not use component based approach.

Simple endogenous money model

The Keen's framework is called monetary circuit theory (MCT) or monetary accounting matrix (MAM) which has characteristics of:

1. Treats the monetary economy explicitly.
2. Makes no assumptions about the nature of equilibrium.
3. Models behavior at the aggregate level of social classes.
4. Presumes rational behavior of people in the social classes to act according to their best interest given information available.
5. Models the endogenous creation of money by the banking sector in in a pure credit economy
6. Gives credit and debt the pivotal roles in economic theory.

The framework differs with social accounting matrix (SAM) or stock-flow consistent (SFC) approach in the following ways:

1. Time is modeled continuously using differential equations because aggregate economics processes are better captured by continuous time equations and there is no danger of misspecifying a stock as a flow.
2. The model system states are bank transactions accounts, which includes the endogenous creation of money
3. Wage, profit and rentier incomes are not aggregated because the behavior of different social classes is different.
4. The columns do not sum to zero, but instead return the differential equations of the system states. When endogenous money growth is introduced, the rows sum is positive. There is no "n^{th} equation rule" as in the SFC framework.

The core of the framework is a tabular layout of financial relations between the economic entities. The table is called "the Godley Table" to honor Wynne Godley. Each column in the table represents an aggregate bank account for a specific sector of the economy. Each row in the table represents financial transactions between those accounts or a particular economic activity. The model is explicitly monetary. The symbolic sum of the operations in each column generates rate of change for that account in terms of differential equations.

The first main block is Goodwin's model, which provides basic cycle in macro real sector. The second main block is the financial explicit monetary sector where we have a set of sectoral accounts and their interactions in pure credit economy. These blocks will be treated as component and each will be encapsulated in a module. Both of the building blocks will be combined to form the full monetary Keen-Minsky model.

The sub real physical model consists of five blocks of exponential growth module, which are Productivity, Population, Wages, EmploymentRate, and Capital. Inputs are depicted with italic font, while outputs are depicted with boldface. The relationship between the block is shown on figure below:

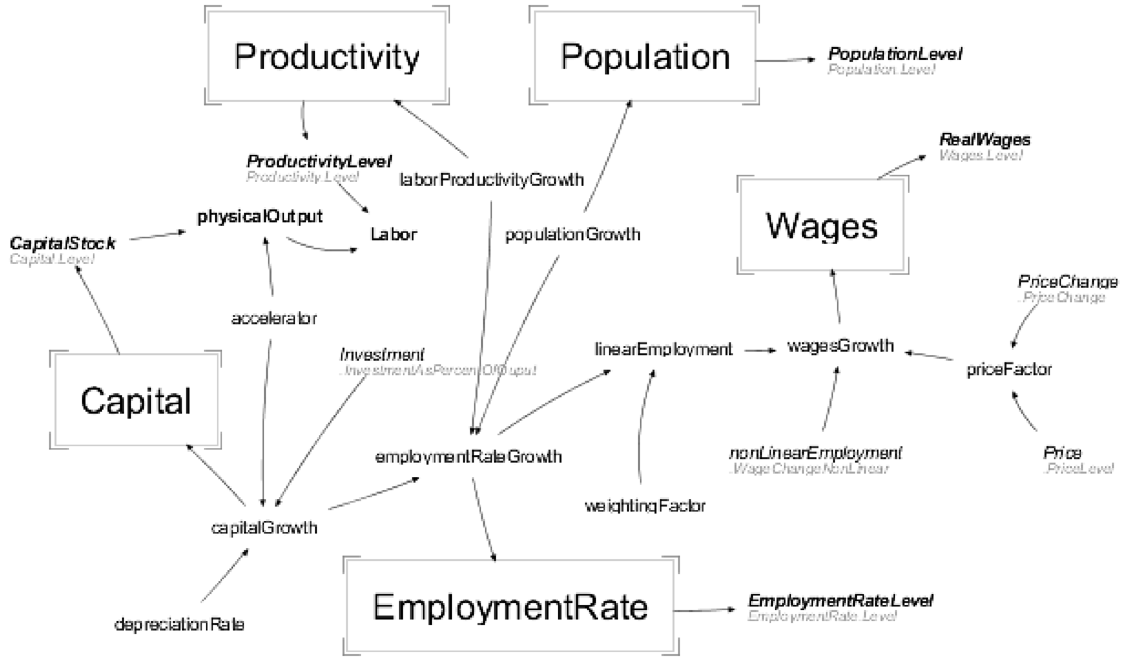

Figure 12. The real sector module for Keen-Minsky model

The relations describing the diagram are

1. Growth of money wages now depends on three factors: level on unemployment through nonlinear Phillips curve, growth of employment rate, and the rate of change of retail prices which operates through cost of living adjustments in wage rates: $\frac{d}{dt}W = W \cdot (P_h(\lambda) + \omega \cdot \frac{1}{\lambda}\frac{d}{dt}\lambda + \frac{1}{P}\frac{d}{dt}P)$ where $\omega < 1$ is a weighting factor
2. Growth of employment rate depends on real growth rate g, rate of technical change α, and rate of population growth β: $\frac{d}{dt}\lambda = \lambda \cdot \left(\mathrm{g} - (\alpha + \beta)\right)$
3. Real growth rate g is determined by rate of investment and depreciation: g$=\frac{Inv(\pi_r)}{v} - \delta$
4. Real capital stock K_R is determined by real growth rate g: $\frac{d}{dt}K_R = \mathrm{g} \cdot K_R$
5. Population N is determined by population growth β: $\frac{dN}{dt} = \beta \cdot N$
6. Real output per annum Y_R is determined by real capital stock K_R and accelerator v : $Y_R = \frac{K_R}{v}$
7. Employment or labor L depends on real output Y_R and labor productivity a : $L = \frac{Y_R}{a}$
8. Labor productivity a is determined by labor productivity growth α : $\frac{da}{dt} = \alpha \cdot a$

Auxiliary variable that does not depend on other variables become the parameters in the module real sector as shown in figure below:

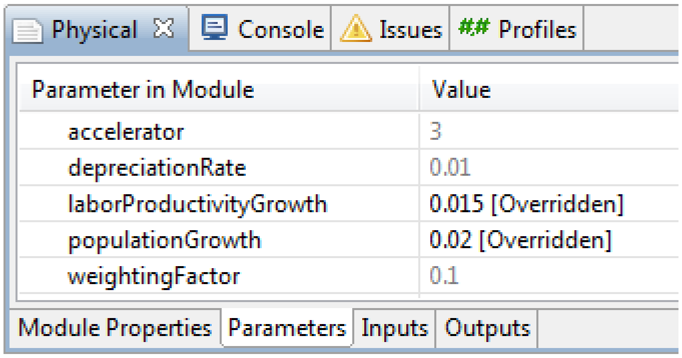

Figure 13. Parameters in physical sector module

In the financial sub model, the Godley's table is shown in the figure below:

Flow/Stock	**Bank Reserve B_R**	**Firm Loan F_L**	**Firm Deposit F_D**	**Worker Deposit W_D**	**Bank Deposit B_D**
Lend money	-Money lending		+Money lending		
Record loan		+Money lending			
Compound debt			+Debt compounded		
Charge interest			-Interest charge		+Interest charge
Record charging		-Interest charge			
Pay firm interest			+Firm interest		-Firm interest
Pay wage			-Wage payment	+Wage payment	
Pay worker interest				+Worker interest	-Worker interest
Worker's purchase			+Worker consumption	-Worker consumption	
Banker's purchase			+Bank consumption		-Bank consumption
Repay loan	+Loan repayment		-Loan repayment		
Record repayment		-Loan repayment			
Investment finance				+Investment	
Record investment			+Investment		

Figure 14. Godley's table for Keen-Minsky model

The substitution, description and parameter values for model simulation are given in figure below:

Flow	**Expression**	**Description**	**Parameter values for simulation**
Money lending	$\frac{B_R}{\tau_R(\pi_r)}$	lending of the existing money stock not in circulation is a function of the rate of profit	$F_L(0) = 100$ $F_D(0) = 70$

<table>
<tr><td>Debt compounding</td><td>$r_L \cdot F_L$</td><td>debt is compounded at the rate of loan interest</td><td rowspan="9">$W_D(0) = 13$
$B_R(0) = 12$
$B_D(0) = 5$
$r_L = 5\%$ p.a
$r_D = 1\%$ p.a
$1/\tau_B = 1$ p.a
$1/\tau_W = 26$ p.a
$v = 3$
$\omega = 0.1$
$\delta = 0.01$
$\beta = 0.02$
$\alpha = 0.015$
$\lambda(0) = 1$
$W(0) = 1$
$K(0) = 900$
$N(0) = 300$
$\tau_P = 1$
$P(0) = 1$
$\sigma = 0.2$
$P_h(\lambda) = GenExp(\lambda, 0.95, 0.5, -0.01)$
$Inv(\pi_r) = GenExp(\pi_r, 0.05, 0.05, 1.75, 0)$
$\tau_R(\pi_r) = GenExp(\pi_r, 0.03, 10, 100, 3)$
$\tau_L(\pi_r) = GenExp(\pi_r, 0.03, 2, -50, 0.5)$</td></tr>
<tr><td>Interest Charge</td><td>$r_L \cdot F_L$</td><td>rate of interest on loans times debt level</td></tr>
<tr><td>Firm Interest</td><td>$r_D \cdot F_D$</td><td>rate of interest on deposits times firm deposit level</td></tr>
<tr><td>Worker Interest</td><td>$r_D \cdot W_D$</td><td>rate of interest on deposits times worker deposit level</td></tr>
<tr><td>Wage Payment</td><td>$W \cdot L$</td><td>money wage times employment level</td></tr>
<tr><td>Bankers Consumption</td><td>$\frac{B_R}{\tau_B}$</td><td>bank consumption with a time constant</td></tr>
<tr><td>Workers Consumption</td><td>$\frac{W_D}{\tau_W}$</td><td>worker consumption with a time constant</td></tr>
<tr><td>Loan repayment</td><td>$\frac{F_L}{\tau_L(\pi_r)}$</td><td>rate of loan repayment is a nonlinear function of the rate of profit</td></tr>
<tr><td>Investment</td><td>$Inv(\pi_r) \cdot Y$</td><td>investment share of output is a nonlinear function of the rate of profit</td></tr>
</table>

Figure 15. Parameter and initial values for Keen-Minsky model

The differential equations of the systems are

$$\frac{d}{dt}B_R = \frac{F_L}{\tau_L(\pi_r)} - \frac{B_R}{\tau_R(\pi_r)}$$
$$\frac{d}{dt}B_D = r_L \cdot F_L - r_D \cdot (F_D + W_D) - \frac{B_R}{\tau_B}$$
$$\frac{d}{dt}F_L = \frac{B_R}{\tau_R(\pi_r)} - \frac{F_L}{\tau_L(\pi_r)} + Inv(\pi_r) \cdot Y$$
$$\frac{d}{dt}F_D = (r_D F_D - r_L F_L) - W \cdot L + \left(\frac{B_R}{\tau_R(\pi_r)} - \frac{F_L}{\tau_L(\pi_r)}\right) + Inv(\pi_r) \cdot Y + (\frac{B_R}{\tau_B} + \frac{W_D}{\tau_W})$$
$$\frac{d}{dt}W_D = r_D \cdot W_D + W \cdot L - \frac{W_D}{\tau_W}$$

We can convert the accounting table or the differential equations into system dynamics diagram as shown in figure below and encapsulate it in a module.

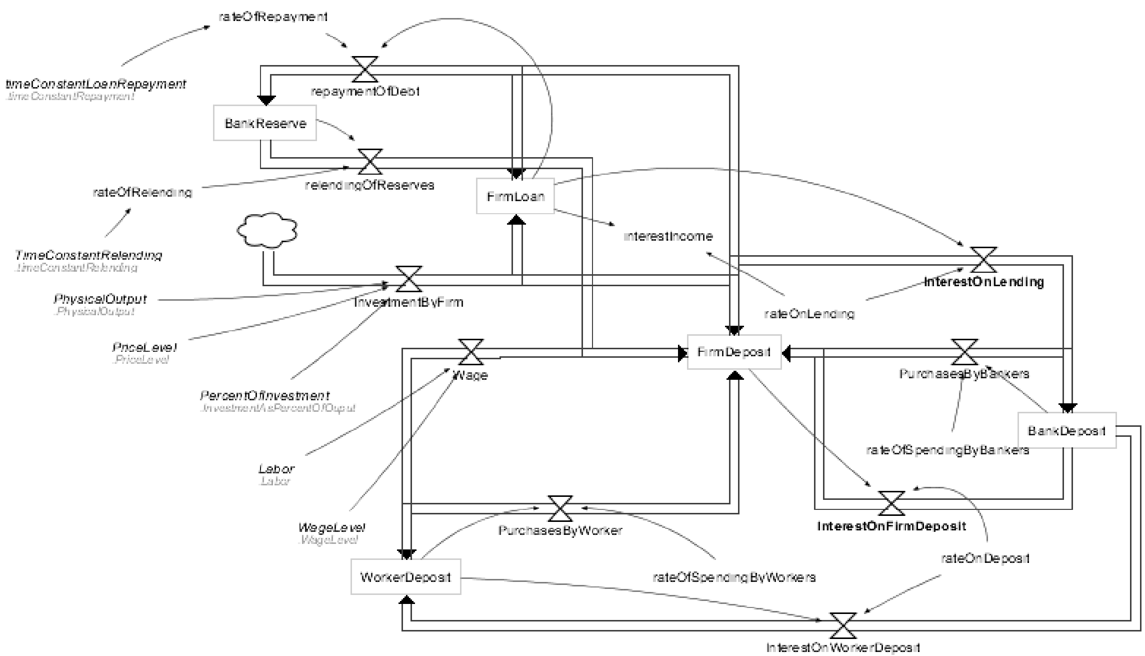

Figure 16. Financial sector sub module of Keen-Minsky model

Mapping of inputs and outputs in the financial sector with the main model is shown in figure below:

Financial | Console | Issues | Profiles

Input in Module	Refers to output
Labor	Labor
PercentOfInvestment	InvestmentAsPercentOfOuput
PhysicalOutput	PhysicalOutput
PriceLevel	PriceLevel
TimeConstantRelending	timeConstantRelending
WageLevel	WageLevel
timeConstantLoanRepayment	timeConstantRepayment

Module Properties | Parameters | Inputs | Outputs

Financial | Console | Issues | Profiles

Output in module	Referes to input
InterestOnFirmDeposit	InterestOnFirmDeposit
InterestOnLending	InterestOnLending

Module Properties | Parameters | Inputs | Outputs

Figure 17. Inputs and outputs of financial sector sub module

Use of a nonlinear function

To generate a monetary Minsky model, Keen uses nonlinear functions for key monetary relationships. The rate at which existing money is circulated, the rate of loan repayment, and the rate of investment are all made nonlinear function of the rate of profit. The investment function returns the proportion of nominal output devoted to producing investment goods. Firms invest more than profits during booms (high rate of profits) to finance "euphoric" expectations and invest less than profits during slumps (low rate of profits). The rate of relending and rate of repayment are expressed as time constants. In a nonlinear Phillips curve, wages rise rapidly at high levels of employment and fall slowly at lower level.

This nonlinear function captures the behavior of agents under future uncertainty. When a system modeler looks for relationships in an actual system that prevent its stocks from going negative or growing infinitely large, he or she is usually looking for the system's nonlinearities. Nonlinear relationships usually define a system's limits (Radzi, 1997)

The same generalized exponential function is used for nonlinear Phillips curve, investment function, time constant for relending, and time constant for repayment, which is:

$$GenExp = (x, x_{val}, y_{val}, s, \min) = (y_{val} - \min) \cdot e^{\frac{s}{y_{val} - \min}(x - x_{val})} + \min$$

The implementation can be done with function feature, but this exponential type function is at minimum a kind of first order system, so it is modeled explicitly as a module. By using the module, the user of the module can change the parameters from user interface. Implementation using module in Simantics system dynamics tool is illustrated in figure below, where *x* becomes input variable, GenExp as an output, and the rest variables become parameters:

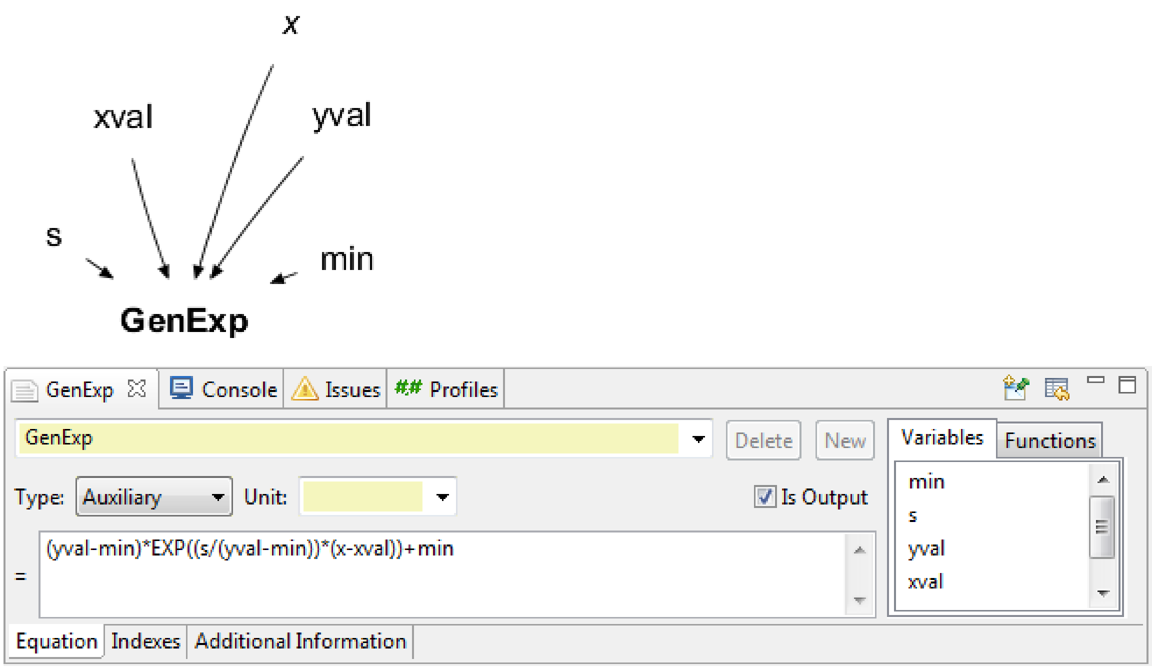

Figure 18. Generalized exponential function implemented in a module

Price module and profit rate

The financial system is coupled to the physical production model via mechanism of prices. Price converge to a markup over the monetary wage cost of production, where the markup factor $(1-\sigma)$ is equivalent to the equilibrium workers' share of real output

$$\frac{d}{dt}P = -\frac{1}{\tau_P}(P - \frac{1}{1-\sigma}\frac{W}{a})$$

Implementation of price module can easily use the first order system that converges to a desired goal using only EquilibriumPrice as the input. Since no other parts use the module, we can safely extend the first order system to accommodate full price equation. The inputs are WageLevel and ProductivityLevel. The outputs are changePrice and Price. And the parameters are markupCoefficient and timeConstantPrice. The module implementation is shown in figure below:

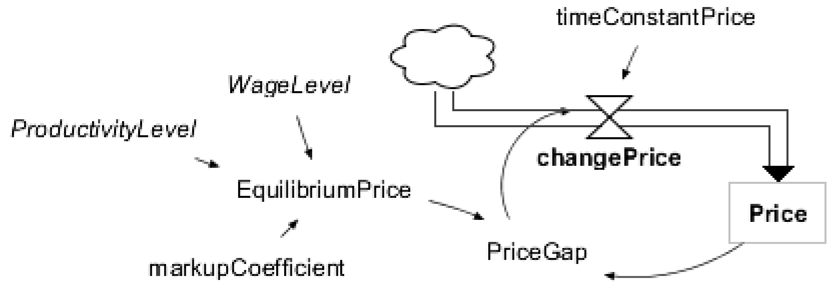

Figure 19. Price module inherited from first order system (not by composition)

The profit rate is defines in fully monetary terms

$$\pi_r = \frac{P \cdot Y_R - W.L - (r_L \cdot F_L - r_D \cdot F_D)}{P \cdot K_R}$$

The profit rate depends on PriceLevel from price module. It needs Labor, WageLevel, PhysicalOutput, and Capital from physical sector, while InterestOnFirmDeposit and InterestOnLending are supplied from financial sector. The final model is shown in figure below:

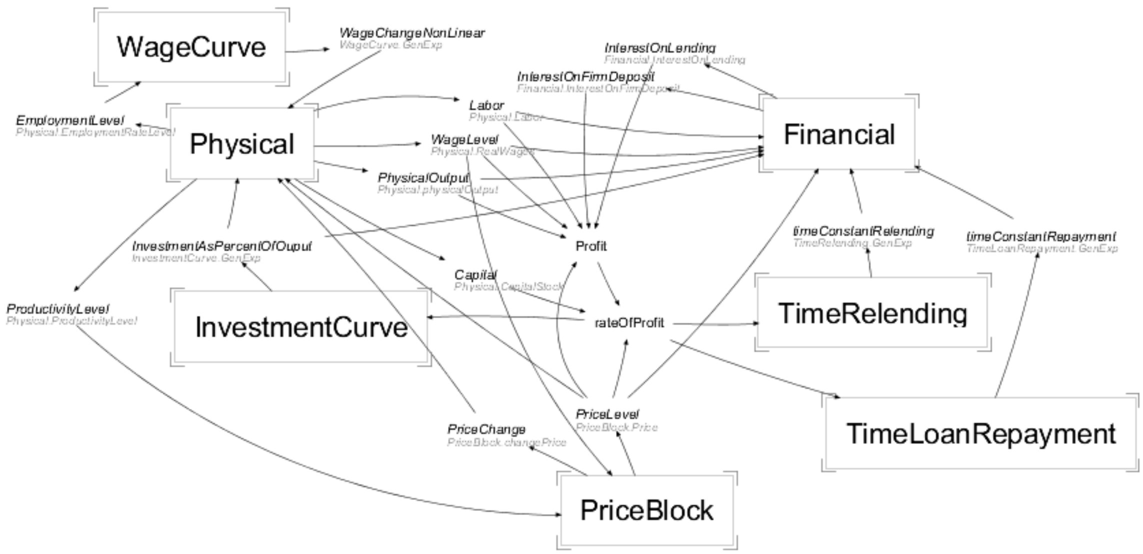

Figure 20. The modular diagram of monetary Keen-Minsky model

The Keen-Minsky model is now fully reproduced with system dynamics approach. Some of the graph output of model simulation is shown in the figure below:

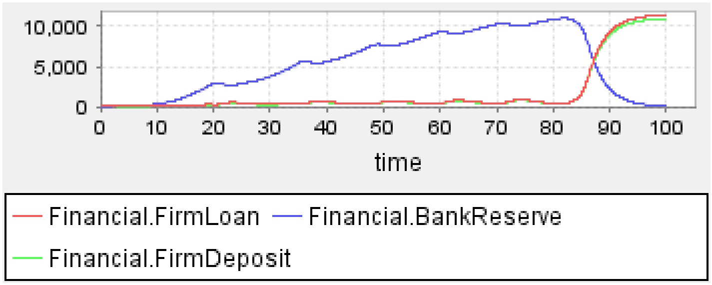

Figure 21. Some behavior instability patterns that produced from Keen-Minsky model

Chapter 4. Conclusions and Extensions

CONCLUSIONS

We are now able to reconstruct the Keen-Minsky monetary model using system dynamics approach without difficulty. It is because ordinary differential equations and network accounting model can easily be translated into system dynamics form. The resulting model consists of two main blocks, the real sector and the financial sector. The smallest component is exponential growth module in the family of first order system. The price module is created from first order system component. The nonlinear function is encapsulated as a module.

In other disciplines like physics, technical or engineering it is relative easy to find standard component for modeling. For example: resistor, capacitor, and inductor in electric or linkage, motor, turbine, and process tank in other engineering fields. In contrast to this, the social sciences especially finance and economics which are quantitatively based, it is very hard to find this kind of component model. The physical components are acausative type model utilizing concept of effort and flow variables.

The benefits of component based modeling are abundant. It can decrease the modeling cost and time by using standard component. It is also relaxing the requirement skill for beginner in modeling.

EXTENSIONS

We can try out different theory or strategy in simulation model and see their impact on the overall system. We can extend the model by combining it with the work of Yamaguchi, Godley & Lavoie, and other derivatives works from the 'accounting approach'. Obviously, the model can be developed more by including entities such as government and central bank. We can expand entities such as households into several classes, the real sector firms into several sectors, and adding more types of financial institutions. Each sector will be a component by itself containing their assets, liabilities, and equities. The transaction between the sectors will be represented by more granular transactions. There is also possibility to add element of distributions in population such as demographic by age and region, not to mention distribution of income and wealth. The multidimensional array feature can be used for this modeling purpose.

Forrester said that social systems belong to the class called multi-loop nonlinear feedback systems (Forrester, 1971). The world and business system is more complex than just like a simple short time linear cause effect. The real world complex systems are not in equilibrium and are continually changing. Many modelers spend a lot of resources trying to develop models to predict the future state of a system. If the system is complex then the development is just wasting money and time. There are two reasons for this. First, there is no such thing as long run predictability for complex system. We can only forecast for very short term. Just like the weather, we can predict accurately only in one week period. Second, even though it were possible to predict the future state of complex system, it is better to structure a system using leverages point so that it behaves well and withstand uncertain external shocks in the future.

Leverage point is the place to intervene in the system for creating positive long term sustainability effect (Meadows, 1999). One of the leverage points in the economics and financial system is interest rate. In the words of Yamaguchi:

The introduction of interest always plays in favor of commercial banks and the central bank in terms of the equity distribution. The commercial banks can exploit non-financial sector's equity, no matter how positive interest payments please depositors in the non-financial sector. In other words, non-financial sector's equity will be completely exploited by bankers unless economic growth is attained with debts as investment. By the power of exponential growth of interest rates, this financial system of distorted equity distribution does not work consistently. Perpetual business cycles could collapse, and its resetting eventually needs be enforced by financial and economic crises. This is the essence of the introduction of interest to the monetary economy. Banking services with interest is an obstacle to the sustainability of the economic activities. (Yamaguchi, 2012)

We can try to design alternative system that provides profitable lending and investment without explicit earning on interest in three basic ways (Jobst, 2012):

1. Synthetic loans (debt-based) through a sale–repurchase agreement or back-to-back sale of borrower- or third party-held assets;
2. Lease contracts (asset-based) through operating lease or financing lease
3. Profit-sharing contracts (equity-based) of future assets

We can also put the alternative financial institutions such as Islamic bank (Mirakhor et. al., 2012) alongside with the conventional bank inside the model. We can then compare a system based on principles risk-sharing and equity participation with a system based on interest rate and debt by simulating the evolution in the long run to see which system is more stable and sustainable to shock and macroeconomic disturbance.

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