System Dynamics Problem Definition as an Evolutionary Process Using Ambiguity Concept

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Abstract

Problem definition, as system dynamicists believe, is the most important phase of the system dynamics modeling process. However, its literature is not rich enough so as to match its importance. In this paper, by reviewing the literature, we introduce the idea that the problem definition itself has an iterative and evolutionary nature. Here, we propose an approach to develop and enrich problem definition based on continuous and conscious effort to elicit the hidden ambiguities of the dynamic hypothesis and transform these ambiguities into questions whose answers would precise the definition of the problem and improve the dynamic hypothesis. We show how this approach on one hand can help us build models much more suited to dynamic real world problem and on the other hand help us much more effectively use models to understand and solve these problems. Finally, we propose some guidelines for revealing the ambiguities as basis to the problem definition and dynamic hypothesis in an iterative process.

1. Introduction

The most important step in system dynamics modeling is problem definition (Sterman,2000). Problem definition makes the process of modeling more purposeful and a clear purpose is the most important determinant of success of a modeling process (Sterman, 2000; Richmond, 1997). Most of the text books and course materials on modeling, when talking about problem definition, emphasize on a verbal statement for the dynamic difficulty, selecting the main variables, and drawing the reference modes. There has been, however, some works done to expand the literature on problem definition. Mashayekhi (1992), explained the process of moving from a static picture to a dynamic problem definition. Saeed (2002) developed some techniques for constructing reference modes. And Vennix (2000) proposed some guidelines for better defining problems in Group Model Building.

However, problem definition still has a poor literature relative to its imprtance. In his famous book, Sterman (2000) allocates only five pages, out of more than a thousand, to problem definition. Richmond (1997) devotes less than ten pages to problem definition in his book. There has been no article on problem definition in System Dynamic Review issues published in past ten years. Relative to the other System Dynamics Modeling steps, there have been far less techniques and tools developed for problem definition. Maybe the only work in this regard is the techniques proposed by Saeed (2002) for reference mode construction. In contrast, look at the techniques and tools for conceptualization and model formulation: molecules (Richardson & Hines, 96), Archetypes (Senge, 1990), Generic Infrastructures (Richmond, 1997), Aging Chain and Co-flow Structures (Sterman, 2000), Decision Making Formulation techniques (Sterman, 2000 chapter 13), and Lookup Table formation techniques (Sterman, 2000 chapter 14). This very observation may arise when we compare the literature of problem definition to that of model testing. Pages devoted to model testing in modeling books are far more than those of problem definition. There have been many techniques developed for model testing and validation (Barlas, 1995; Sterman, 2000; Forrester & Senge, 1980 as some examples). The point is, here, not only there are fewer techniques for problem definition than other modeling steps, but also those techniques have not been widely accepted and applied in practice.

The literature and history reviewed above, leads us to a question on a paradox. A question which seems to be overlooked so far:

"In spite its exceptional importance in system dynamics modeling process, why does problem definition have such a poor and small literature relative to other modeling steps?"

To answer this question, one may think of two possible reasons. First, problem definition in modeling for real world problem is quite an iterative job and, in most of practical cases, problem definition is completed based on information gained from the next steps of the modeling project. Although this iterative nature is approved and strongly emphasized in the System Dynamics literature (Forrester, 1994; Richmond, 1997; Sterman, 2000; Martinez & Richardson, 2001), as will be discussed in the next sections of this paper, there is little discussion of *how* this iteration operationally progresses and problem definition has been mostly seen as an isolated and non-iterative process. Since problem definition is the first modeling step and since, at the beginning of a project, there is not enough information and expertise to feed and enrich the problem definition, it should not be surprising that the literature on problem definition is not well developed.

Second, problem definition is the most creative step in System Dynamics Modeling and, hence, is the less amenable to rules. If problem definition is less amenable to methods and rules, less literature may be developed on rules and method to deal with it.

In this paper, we will propose and develop a new concept called "ambiguity" as a part of a SD problem definition process. This concept explains and clarifies the iterative nature of problem definition and, helps us bring more orders to the problem definition process. In section 2, we define the concept “ambiguity” and explain its characteristics. In section 3, we discuss how applying this concept can lead to substantial improvement in the problem definition process. In section 4, we demonstrate that applying this concept will expand the domain of problem definition into the modeling steps through which a model is built and tested. That is, the concept “ambiguity” can help us not only build a model, but also more efficiently understand it and use it. In section 5, we discuss the way this concept contributes to enrich the literature on problem definition. And, finally, in section 6, we summarize the paper and make some conclusions.

2. The Concept of Ambiguity

As noted before, there is a strong emphasis, in the System Dynamics literature, on giving a purpose to the modeling process with the aid of problem definition. Such a purposefulness arises from the importance of making effort to remove a “difficulty” and solve a “problem” (Sterman, 2000) (*i.e.* “concern” (Hines, 2005)) rather than to model a system. For instance, when introducing problem definition and purposefulness, Sterman (2000), says trying to model the economy of a country is a purposeless job as opposed to modeling for understanding what underlies business cycles, which is a problem-oriented and purposeful process.

However, “difficulty” is something that is bothering and can be sensed by people who are affected by it. “Difficulty” is something that one tries to remove or gets rid off from. “Difficulty” is not the definition of a problem, but it is the essence of it and does not change all along the modeling process. So, “difficulty” is not a concept that can be changed or affected the *iterative* nature of the modeling process. In addition, each difficulty would lead to a general question that what is the root of difficulty? But such a genera question is not yet a precise “problem definition”. Let us take a look back at the example in last paragraph, which we took from Sterman (2000): he points out that all steps in the modeling process are iterative. However, he does not say whether the question “what does underlie business cycles?” is some sort of an initial question which indicated the “difficulty” and is to be polished and better clarified during modeling or it is the product of an iterative clarification process. The latter, does not seem to be the case. Such a question can be asked easily by everyone who is concerned with the business cycles. So, it seems, this initial and general question is to be polished and turned into more elaborated questions during a modeling process. But, nowhere in the book can one find either a more elaborated version of this question or even a suggested approach for elaboration and clarification. In fact, in many cases a problem is described using a reference mode and a “difficulty” (*i.e.* “concern”) about it. But we can consider the difficulty and the reference mode as the beginning of the “problem definition” which by itself is not sufficient to guide our modeling efforts. The “difficulty” and the “reference mode” and the general question of “what are the causes of the reference mode?” do not change over the modeling process. We need a more precise description of the problem that can help and guide us to start the modeling process.

A description of the problem that can vary over time and its variation can explain the iterative nature of problem definition and modeling process.

In order to fill the gap between the “reference mode” and general question of “underlying causes” on one hand and a more precise description of the problem on the other hand, we introduce a new concept in problem definition called “ambiguity”. We define the concepts of “difficulty” and “ambiguity” as followings:

Difficulty: is some bothering situation that needs to be resolved.

Ambiguity: is a puzzle or a question that its answer may help solve the difficulty.

To shed more light on the difference between the two concepts, let us look at an example. Iran has been facing the difficulty of extraordinarily high volume of energy subsidies so far (as depicted in Figure 1). Economists believe the subsidies should be eliminated and they have done many researches to demonstrate the dramatic consequences of not eliminating the subsidies to prove their claim. But elimination of subsidy has, however, never happened in Iran. So the “difficulty” is, here, “very high expenses of energy subsidies”. But the “ambiguity” is not “we don’t know if the subsidies should be removed.” (Since the economists as well as politicians know the answer”). The ambiguity is, rather, “We don’t know why the subsidies have not been eliminated despite the fact that the most decision makers know the catastrophic consequences of not eliminating them”.

Figure1. Energy Subsidies in Iran (Source: IMF)

“Ambiguity”, if detected right, would guide the whole process of modeling. For example, suppose one is going to develop a model in order to address the difficulty of subsidies based on the former ambiguity stated in the last paragraph (*i.e.* “Should we remove the subsidies?”, which is not a real ambiguity as many people know already the answer). With this not well selected ambiguity, even if everything goes well in the modeling process, the modeler will draw the conclusion “Yes. We should eliminate the subsidy”. This conclusion has been known by many people for many years. This is a natural and obvious consequence of misidentification of ambiguity which has led the difficulty to remain unsolved over these years. Today, “should subsidies be removed?” is not anymore an ambiguous issue.

One should note that unless a difficulty is solved, there are one or more ambiguities about how to solve it. With any unsolved difficulty, there sure is at least one ambiguity based on which one can build up a problem definition. Because if there is nothing ambiguous about how to solve the difficulty, we may claim the difficulty has been solved.

In order to make what we said in the last paragraph clearer, we now consider a possible objection to it. Some may object “In some cases, the solution to the difficulty is quite clear and there is no ambiguity. But no one implements that solution. In fact, some difficulties may remain unsolved due to implementation issues rather than ambiguity”. For example in the energy subsidy example, one may claim “the wise solution to this difficulty is simply and clearly to remove the subsidies. This solution, however, is never implemented by the decision makers”.

But then a new “ambiguity” arises. The ambiguity is “if on one hand, the subsidies create an economical difficulty, and on the other hand, there is a clear solution, then why the decision make makers do not implement it?”

- Do their benefits conflict with that of the society?
- Or have they poor economic backgrounds so they cannot even understand simple and clear solutions?
- Is there a perception of potential social and political consequences associated with the implementation of the solution that prevent decision makers to implement the solution?

The question “which one of the above is the case?” is an important ambiguity itself. Let’s, however, suppose we have hypothesized the answer to this ambiguity. Suppose the answer is “the decision makers’ benefits have conflict with those of the society”.

Then, a new ambiguity arises: “what is the reason for such a conflict?”

- Is the governmental structure so that anyone who is placed in a decision making position, no matter what benefits he has had before getting there, will have his benefits opposed to the benefits of the society?
- Or is there some sort of situation preventing those whose benefits are congruent with the benefit of the whole society from reaching the decision making position?
- Or a combination of the two?

We are not intended to draw a comprehensive problem definition of the Iran subsidy issue. We just wanted to demonstrate the fact that wherever we face an unsolved difficulty, there is an ambiguity, even if there seems the solution is clear but it is not getting implemented.

The above example demonstrates how the concept “ambiguity” explains iterative nature of the problem definition process: if we have answered an ambiguity but we have not still achieved a solution to the difficulty, then there is another ambiguity which should be found and answered. *In other words, “difficulty” determines what we should know and “ambiguity” determines which part of that we don’t know yet*. So, “ambiguity” may change by thinking, reading the relevant literature, and modeling, whereas “difficulty” remains the same.

In the next sections, we will explain how the concept “ambiguity” can help us define problems in a more dynamic and more effective manner. We will show as two different “difficulties” may lead to two different modeling processes of the same system, two different “ambiguities” may also lead to two different modeling processes of the same system with the same “difficulty”.

3. The Role of Ambiguity in Problem Definition and Model Building Process

3.1. The Role of Ambiguity in Selecting Main Variables

The ambiguities that should be answered play important roles in selecting the variables of a model. Two different “ambiguities” regarding the same “difficulty”, may lead to selection of two totally different sets of key variables for the model. As an example, we investigate two ambiguities for the energy subsidies in Iran.

As the first case, suppose the ambiguity to be “should we remove the subsidies?” If this is the case, the key variables of the model would be as follow:

Current number of cars, average consumption per car, roads capacity, subsidy volume, domestic price of gasoline, international price of gasoline, etc.

As the second case, suppose (just suppose!), by reviewing the literature and interviewing the experts, we have found that the reason that the subsidies have not been removed so far, is that the decision makers have no economic background. Here, the ambiguity is “what is the reason that economic graduates do not reach to high level decision making positions?” If this is the case, we will have the following variables in our model:

Number of economic graduates in the society; number of decision making positions needing economic background; percentage of the position that need economic training that has been occupied by people with such background; the conformity between economic decisions and economic theories, impact of economic conditions on the qualifications of people appointed to economic decision making positions, etc.

With the list of above variables, one should note the following two points:

1. There are variables which are not directly related to the “gasoline subsidy” difficulty.
2. There is no variable which is directly related to the difficulty.

The second point may seem a little weird. But it will no more be weird if it has been correctly hypothesized that people without economic background in decision making position are causing the difficulty. If one can come up with implementable policies that put economic graduates in decision making positions, they themselves think about the “directly related” variables and solve the difficulty of gasoline subsidy.

In this example, we saw two different ambiguities led to two totally different sets of key variables which would lead to two totally different models. So, it should be now clear that detecting the ambiguity will substantially affect the dynamic hypothesis and the modeling process and policy recommendation at the end.

3.2 The Role of Ambiguity in Momentum Policies

The role and importance of momentum policies in problem definition, was first mentioned by Hines (2001). Although Hines points out the importance of momentum policy, he does not go further to explain how one should relate momentum policies to other elements of a problem definition. In this section we will see how the concept “ambiguity” does this job.

Having listed all momentum policies, for each single policy one should then ask himself “With this policy in hand, why is the difficulty still unsolved? What is preventing its implementation? Or what is keeping the difficulty unsolved although the policy is being implemented?” Answers to this “what” and “why” questions, could introduce some variables which will be added to the list of key model variables.

Momentum policies can also help modify or discover the ambiguities that would lead the modeling process. To further explain this point, again, we use the Iranian subsidy example. Suppose the initial list of the key variables is as follows:

Current number of cars, average consumption per car, roads capacity, subsidy volume, domestic price of gasoline, international price of gasoline, etc.

Now, a very straightforward momentum policy is removing the subsidies. Here, if we ask someone, who has a little knowledge of the economy condition in Iran, “Why do you think this policy is not implemented?” he may answer “because if the government does so, it will immediately face intensive social dissatisfaction and protests”. Then a new variable shows up: “social dissatisfaction”, one of most important key variables which should be taken into account when modeling for the difficulty of subsidies in Iran. A model developed without this variable, even if very well-developed, will certainly suggest removing the subsidies as the best way of solving the difficulty: An obviously not helpful and implementable policy in the real world. It is clear that “social dissatisfaction”, in this problem, is much more of importance than such variables as “roads capacity” or “number of cars”.

This variable contributes to a deeper insight to the difficulty. The difficulty government faces is its inability to reduce the subsidies without facing the negative consequences of social dissatisfaction. This way, we may form another ambiguity: “what are the dynamics of social dissatisfaction in response to different possible policies of the government regarding gasoline subsidies and other expenses? And which policy would lead to the least possible negative consequences?” Here, we may draw a new list of key variables:

Government revenues; budget allocated to gasoline subsidy; social dissatisfaction from high gasoline price; social dissatisfaction from low gasoline consumption (or in general: social dissatisfaction from poor transportation system); budget allocated to welfare services; social dissatisfaction from poor welfare services, etc.

Now, we may propose a new ambiguity: “as we saw, in addition to “dissatisfaction from gasoline”, there is “dissatisfaction from welfare services” as a model variable. So, what is the reason that by allocating the subsidy budget to welfare service the government cannot decrease the dissatisfaction of welfare service and overcome the rise in dissatisfaction from gasoline subsidy?”

The answer may be: investment in welfare services has a long delay to increase the quality and quantity of services. So, budget allocated in these activities is not able to diminish dissatisfactions quickly enough. But this is not the case with the gasoline subsidy budget.

Out of this discussion, we may find another variable: “average delay in getting results from government investment in social welfare”

Thus, applying the concept “ambiguity” on momentum policies, may add some key variables to our list. Using the concept of “ambiguity”, as above, may even sometimes cause a complete reconstruction of the list of models constructs and variables. So, the example above demonstrated how the concept ambiguity contributes systematically to using the concept of “momentum policy” in the refining the list of important variables and eventually the problem definition.

Following the above procedure, problem definition process will confirm with the following quotation of Forrester (1969) that: “the root of a problem is not necessarily close to its symptoms in time and space”. For example, this is a possibility that the root of the subsidy difficulty in Iran is the long delay in social welfare investment to produce results. So the solution may be one of these two: 1) to shorten the delay of investment in welfare services (how to do that, is itself an ambiguity); 2) to change the governmental system in a way that they pay more attention to long-term issues than they do now (the “how” is, again, an ambiguity).

What was discussed in sections 3.1 and 3.2, demonstrates a close relationship between the concept “ambiguity” and the iterative nature of the problem definition process. It also demonstrates how in each iteration, with the aid of "ambiguity" concept, we make the problem definition process much more purposeful compared to the previous iteration.

In the problem definition phase, the iterative process of formulating and answering ambiguities should continue until:

- We reach an ambiguity not answerable without modeling and simulating;
- And we are prepared enough to build a model which can answer this ambiguity (or at least, can help us with the answer).

At the end of this section, we note an important point. The fact that the concept "ambiguity" is not present in the System Dynamics literature does not mean that modeling processes have been done based on no ambiguity so far. But it means problem definitions have usually, and maybe unconsciously, been based on the easiest-to-formulate ambiguity. For example, having a look at model variables in papers and course projects on the Iranian Subsidy issue, one may easily conclude that they have been done unconsciously based on the ambiguity "should the subsidies be removed?"

4. The Role of Ambiguity in Using Dynamic Model to Finding Solutions for Difficulties

4.1 The Role of Ambiguity in Model Analysis

Thinking operationally, one can say "in a modeling-based problem solving process, there are two main phases: first, building a model which well represents the problem; and second, finding the solution to the problem with the aid of model simulation and simulation analysis". When we look at modeling this way, we can conclude what we discussed in section 3 was all about applications of the concept "ambiguity" in the first phase. Now, we face the question of whether or not this concept plays a role in the second phase. This is the question we are to answer in this section.

We should emphasize that the "ambiguity" concept contributes to refining problem definition even to the last stage of modeling process. Suppose we have a model constructed and we are now at the beginning of our job of analyzing the model to solve our problem. At such stage the following items exist and already developed:

- An ambiguity whose answer is to be reached by analyzing the model (and answering it, means solving the difficulty).
- A dynamic hypothesis which we have developed, as an initial answer to the ambiguity.
- A model whose simulation results are to be analyzed to move us from current dynamic hypothesis to a compelling dynamic theory solving the difficulty.

At this stage an iterative process for finding a solution to the difficulty would start. Each iteration consists of two steps:

1. By analyzing the model simulation results, we try to modify and complete the dynamic hypothesis so it can answer the ambiguity we have specified.
2. Then we check whether or not based on the hypothesis we got out of step 1 we can formulate a solution for the difficulty. If so, we are done with the whole modeling process. Otherwise, we should try to understand why the hypothesis cannot explain and regenerate the difficulty. The output is a new ambiguity based on which we should return to step 1.

There is a major difference between enriching problem definition with a model in hand and problem definition prior to developing a model. When a model is present, finding ambiguities is a much harder and more creative job. Here, revealing hidden shortcomings of the dynamic hypothesis and transforming them into ambiguity-statements is as hard as answering the ambiguities. Also, one should note that we have a tool, named model, to answer ambiguities. But, for revealing the hidden shortcomings of the hypotheses based on the analysis of model simulation, the model itself would not be helpful as the simulation is an output of the model and any ambiguity in the behavior is the result of short comings in the model and dynamic hypothesis used to make the model. In this stage, the ambiguity should be raised by the analyst. For example a model simulation might show some exponential growth without limits, and then the analyst may ask what should limit the growth that does not exist in the model. Such question would lead to the extension of the dynamic hypothesis and the definition of the problem.

In this stage, ambiguities should be formulated based on two rules:

1. Ambiguities in this stage are related to the shortcomings of the dynamic hypothesis formulated to explain the behavior of interest and answer the ambiguity in the previous iteration. In each iteration, *we should formulate an ambiguity which we were not able to notice in the previous iteration.*
2. In this stage we should focus on ambiguities of the dynamic hypothesis that should be answered to deliver a solution for the difficulty that the modeling process is addressing. We do not have to pay attention to the ambiguities that are not related to the solution of the difficulty. Because even a theory which completely solves the difficulty is a model and we know “all models are wrong”.

The ambiguity we formulate in relation to the behavior of the model should intelligently elicit the hidden shortcomings of the dynamic hypothesis. As the dynamic hypothesis becomes more and more compelling, the ambiguity gets finer and finer. In fact *the process of modeling may be interpreted as the process of reaching to a more compelling dynamic hypothesis and better model as the ambiguities getting finer.* It is during this process that the boundary of the model is modified and the constructs and variables in the models are changed to reach a better understanding of the causes of the difficulty and the structure that creates the reference mode.

Having in mind these two rules in ambiguity formulation will have a substantial effect in the direction of modeling process (of which a sample we will see in section 4.2). By using rule 1, we transfer the knowledge and expertise, gained through the progress of the modeling process, into ambiguity statements. By using rule 2, we formulate ambiguity statements in a way that their answers direct us to the solution of the difficulty. The two rules, together, will direct the knowledge and expertise gained from modeling to the solution of the difficulty. This is the very attribute we expect from problem definition: “purposefulness”. From this standpoint, problem definition will direct the modeling process, not only at the beginning by proposing a general question, but also all along the process of modeling by raising new questions or new “ambiguities”. In fact, purposefulness is a continuum rather than a 0-1 quantity. Usually the initial general question such as “what underlies the business cycles?” is in the lower bound of such continuum.

From this standpoint, iteration in problem definition means something more than noticing a shortcoming in the problem definition during the next modeling steps and correcting that shortcoming. But newer and more compelling problem definition means making progress in the all stages of the modeling process and getting closer to the solution of the difficulty, not just modifying and creating more precise definition of the problem.

The case in section 4.2 should well demonstrate that when we have an operating model, improving and modifying the problem definition is both important and challenging.

4.2 An Example: Problem Definition for Real Estate Bubble

Real Estate bubble is defined as a huge increase in real estate prices followed by a sharp drop. Some samples of this phenomenon are depicted in Figure 2.

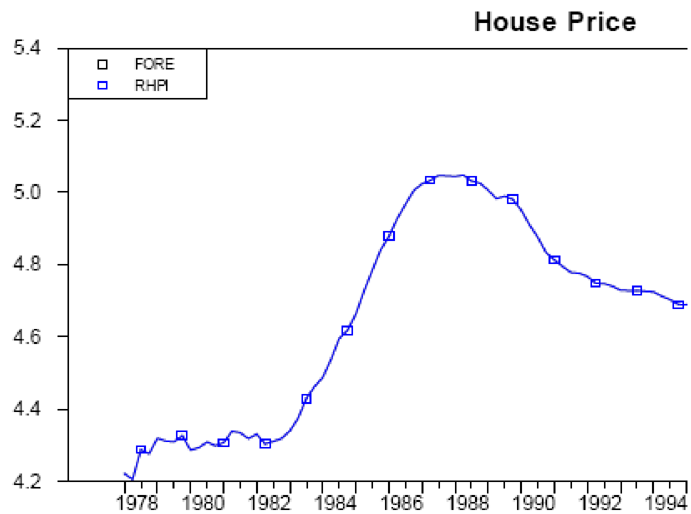

Figure2: Real estate bubble in the U.S. adopted from Wheaton (2007)

This is the reference mode which expresses the difficulty (*i.e.* our modeling objective is to understand it). The relevant literature suggests the following hypothesis for describing bubbles:

When demand in Real Estate market rises, prices increase. The increase in price makes the real estate market more attractive and, hence, brings about more speculative demand which, in turn, further increases the prices, and so on. With this process going on, price increases continuously and rapidly and raises Real Estate construction start rate. When after some construction delay, construction completion rate increases and creates an oversupply along with a shortage of consumption demand, prices drop sharply (Wheaton W. C., 2005; Yazdani, 2000).

This hypothesis knows oversupply as one of the main causes of sharp drop in price after its rapid increase. In the real estate economics literature, the main reason why oversupply happens is postulated to be the time it takes to construct a building (Wheaton, 1999; Kaiser, 1997; Mueller, 2002). With such a delay, an increase in price cannot increase supply immediately, but it increases construction rate. With supply unaffected in short term, prices will still remain high. Therefore, construction start rate may remains high over a period longer than needed to adjust the prices. This means the market will have an over-accumulated stock of "under-construction houses". Due to their large number, these houses will drop the price substantially when they are completed and supplied.

This hypothesis has been widely used to describe the cyclical behavior in real estate markets (Wheaton, 1999; Kaiser, 1997; Mueller, 2002). In the most famous model, Wheaton (1999), describes the cycles of the office rental market based on this hypothesis. In his model there is no speculation.

The above explanation raises an important ambiguity which our hypothesis (Wheaton, 2005; Yazdani, 2000) does not answer:

Ambiguity-statement 1: "Does presence of speculative activities in the real estate market itself inhere mechanisms creating cyclical behavior, independent of supply lag mechanism? Or is it unable of producing cycles and just amplifies the cycles brought about by supply lag?"

It is noteworthy that this ambiguity has not been mentioned in the literature of real estate bubble before as far as we know.

For ambiguity-statement 1 to be answered, a dynamic model was constructed. Since what we are to discuss in this section, will rest on the simulation results of this model, we first illustrate its structure briefly in Figure 3.

This model consists of four major components: 1. Price and its antecedents; 2. Housing chain from construction to depreciation; 3. Consumption supply and demand; 4. Speculative supply and demand.

Price and its determinants

Price behavior is derived by supply-demand mechanisms which are well known in SD and economics literature (*e.g.* Sterman, 2000; Mashayekhi, 2006). Demand is the sum of speculative and consumption demands. Supply is, again, the sum of speculative supply and the supply of housing by constructors.

Housing construction chain

Houses are built by housing constructors. Since it may take some time for a house to be built, we have a stock-variable named "housing under construction" in the model. These houses are completed after some time and are added to the stock-variable "completed vacant houses". These houses may either be sold to consumers (*i.e.* join the stock "occupied houses") or be sold to speculators (*i.e.* join the stock "speculators' houses"). "Speculators' houses" may, in turn, be sold to consumers and add to the stock "occupied houses". For the sake of simplicity, we have disregarded housing transactions amongst speculators themselves.

Transaction flows between the stocks of this chain have all been formulated based on a similar logic. A transaction can take place only when supply and demand are both present. So, transaction flows can be formulated as a fuzzy minimum of supply and demand divided by a "transaction time" variable. It is supposed that constructors will supply all "completed vacant houses" at any price (Wheaton, 1999). However, only a fraction of speculators' houses is supplied. This fraction is a macro-variable reflecting a summation of cost-benefit micro-decisions of all speculators on whether or not to sell their speculative houses. This fraction is a function of how much the real estate market is attractive for investors relative to other investment options. This relative attractiveness, in turn, depends on the trend of housing price.

Supply and demand

Consumption demand is a fraction of the number of "families who are not owner". This fraction is a decreasing function of housing price. The number of "families who are not owner" is determined by subtracting "occupied houses" from "total number of families".

Constructors' supply, as we said, equals "completed vacant houses". These houses are accumulations of "completion rate" minus "sales rate". "Under construction houses" is accumulation of "construction start rate" minus "completion rate". "Construction start rate" is an increasing function of housing price.

Speculative supply and demand

Speculative demand is a function of price. Price affects speculative demand in two ways:

1. When the price grows with a rapid rate, the "relative attractiveness of the real estate market" for investors increases. As a result, a larger fraction of total liquidity of speculators flows to the real estate market to invest in houses. That is, the demand increases. Therefore, the growth rate of price positively affects speculative demand for real estate.
2. However, as price rises, lower number of houses can be bought by a given amount of liquidity for investment. So the absolute price level negatively affects speculative demand for real estate. Of course if we assume that the total liquidity is unlimited for the housing market, then this effect can be ignored.

Speculative supply is also a function of two determinants. The first is "speculators' houses". The second is "the relative attractiveness of the real estate market" for speculators. The more the attractiveness is, the smaller fraction of these houses speculator are willing to supply.

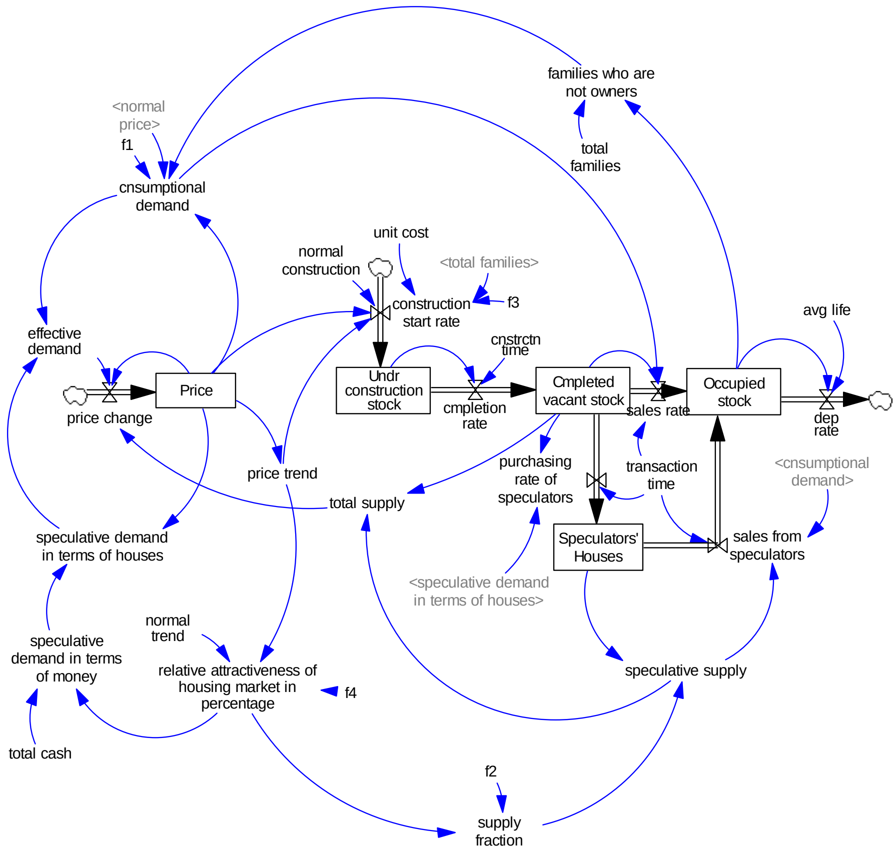

Figure3: Model structure

Now, with the aid of this model, we answer the first ambiguity. We perform an experiment on the model by examining four different combinations of supply lag and speculation conditions. The result follows:

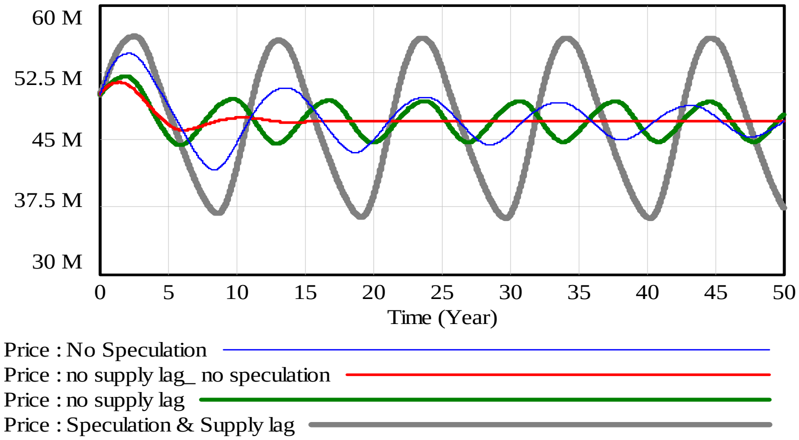

Figure 4: Model behavior

As is clear from Figure 4, speculative activities embody a mechanism which may produce cyclical behavior even in the absence of supply lag. Now, one should ask "what is this mechanism?"

Let us return to the hypothesis proposed at the beginning of this section (Wheaton, 2005; Yazdani, 2000) and formulate the above question more clearly as another "ambiguity".

Ambiguity-statement 2: "The hypothesis (Wheaton, 2005; Yazdani, 2000) postulates that the price drop as the result of lack of consumption demand. But we know with price increasing during bubble, speculative demand is increasing while consumption demand should be decreasing. Is it the case that at the beginning that price starts to increase, increase in speculative demand dominant the reduction of consumption demand and as price continues to grow, further reduction in consumption demand overcomes growth of speculative demand? But if the decreasing trend of consumption demand can drop the price and burst the bubble, why cannot it prevent the growth of the price at the beginning and prevent the bubble?

This is an important ambiguity. In order to understand how price bubbles are produced, one should know why and how dominance shifts from the mechanism producing the growth part to the mechanism producing the drop part. The starting hypothesis (Wheaton, 2005; Yazdani, 2000) has not specified an answer to this question. Thus, to answer this, we run the model, again, without supply lag to obtain the results depicted in Figure 5.

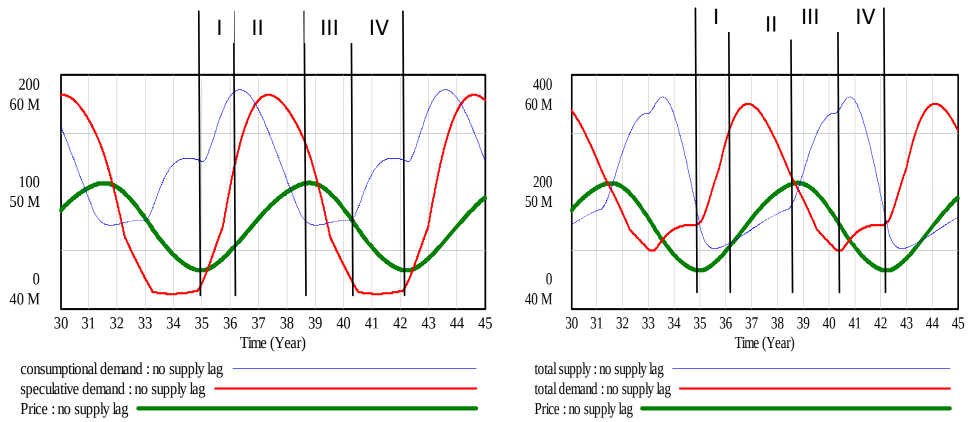

Figure 5: Behavior of price, demand (speculative, consumption and total), and supply in absence of supply lag

Note a surprising behavior (Forrester, 1991) that is produced by the model. During phase I, price and consumption demand are both increasing! The reason is that the "sales rate" is low, due to lack of adequate supply, leading the "number of homeless families" to accumulate. So, although increase of price is lowering the "percentage of homeless families who demand houses", demand is increasing as a whole (this is a dynamic characteristic of durable goods. For a more detailed discussion, refer to Mashayekhi and Ghili (2008)). The key to answer ambiguity-statement 2 lies here. The question, there, was "if the decreasing trend of consumption demand can drop the price and burst the bubble, why cannot it prevent the growth of the price at the beginning?" The answer is "consumption demand is not decreasing at the beginning!" This way, we may formulate the following hypothesis:

1. When price is low, so is supply and consumption demand is more than supply. The positive demand-supply gap increases the price. But, as discussed, consumption demand keeps rising due to supply shortage. Therefore, price keeps on growing. Price growth leads to presence and growth of speculative demand bringing about even more increase in price which, in turn, increases speculative demand, and so on.
2. The speculative-demand-growth-engine increases the price substantially at the end of phase 1. Also, along with price increase during phase 1, supply and, hence, sales rate increase as well. These two factors cause consumption demand to stop rising and then begins falling. This negatively affects growth of price and, then, after a while, stops the growth of speculative demand. Therefore, price growth slows down even more and speculative demand begins to fall consequently (the positive loop of speculative demand works in a direction opposite to that of phase 1). At the end of this phase, supply and demand meet and price growth stops.

3. When price stops growing, the positive loop of speculative supply begins to work in the opposite direction. The speculators sell their speculative houses. This way, price decreases leading speculators to sell even more. As a result, price will drop substantially.
4. After a while, speculative supply decreases as speculators gradually run out of houses while price reaches to a very low level. With price being so low, constructors' supply is low as well. So, the market faces a low level of total supply that strongly limits sales rate. Also, low level of price means a high percentage (fraction) of demand. These two factors, low supply and high consumption demand, provide the necessary condition for the price to start rising and a new cycle begins.

We now know how each of the two mechanisms (*i.e.* supply lag and speculative activities) is able of producing cycles. With ambiguity-statement 1 answered, we know there are two mechanisms (*i.e.* supply lag and speculative activities) each able of describing the boom and bust in the real estate market. A theory for the supply lag mechanism was present in the literature (Wheaton, 1999). We developed a theory for the latter mechanism by proposing and answering ambiguity-statement 2.

But at this point, an important question as "ambiguity-statement 3" may arise: "how do these two mechanisms interact?" In the real world, supply lag and speculative activities are both present and their dynamic consequences may interact. The result from combination of two mechanisms could be more than just the sum of the results from each of them alone.

Therefore, we have not yet answered completely the question of "how bubbles are produced?" Ambiguity-statement 3 points to a missing piece of this puzzle. However, this paper is not intended to provide a full answer to this question. So, we close this section here leaving ambiguity 3 unanswered.

In sections 4.1 and 4.2, we introduced a method of implementing problem definition when we have a model in hand. In this method, we try to discover the hidden shortcomings of the dynamic hypothesis we have for understanding the reference modes and solving the difficulty and we try to transform them into proper ambiguity statements. This method has the following advantages:

- Although "purposefulness" is not a clearly defined concept, one can intuitively compare the process described in Section 4.2 with a process whose purpose is set just once, at the beginning, with a question of "what does produce this reference mode?" Section 4.2 showed that by asking questions and raising ambiguity in the hypothesis and description of the behavior we continuously get more and more purposeful along the process by sharpening our questions and refining our purpose.
- Ambiguities embedded in dynamic hypotheses are usually hidden and discovering them requires thinking skills and devoting time and energy. Discovering these ambiguities, even without answering them, create value by raising sharp and relevant questions. For

example, in Section 4.2, if we had finished with the answer to ambiguity statement 2, we would clearly have created less value-added for the reader compared to finishing with ambiguity statement 3.

- Using this approach, we reach questions whose answers are of importance in solving the difficulty but they are not mentioned in the relevant literature. So, by answering them we take some important steps for solving the difficulty which have not been taken before.
- Such a viewpoint to problem definition, not only, as in Section 4.2, helps us get more compelling dynamic hypotheses out of models, but also helps us build better models.

However, ambiguities and shortcomings are not always visible and discovering them requires *conscious effort*. In the real world, questions whose answers are of importance for solving difficulties are embedded in Messy Problematic Situations (Ackoff, 1994) and eliciting them needs *conscious effort.*

There have been many models of real estate bubbles so far (Malpezzi & Wachter (2002) and Wright (1997) for example). In these researches, models have been simulated with and without speculation to show presence of speculation amplifies the oscillations. None of them, however, has kept speculation present and run the model with and without the other cycle-producing mechanisms to check if speculation itself has a cycle-producing mechanism or just can amplify an already existing cyclical behavior (ambiguity statement 1, section 4.2). With a model in hand, such an experiment is easy to perform and it worth to perform even if the question does not seem to be of great importance. However, answering such question may reveal some important points using the model and experimenting on the model (Homer & Oliva, 2001).

5. Some Guidelines to Use Ambiguity to Enrich Problem Definition

Based on the concept of "ambiguity" some guidelines can be proposed to help the problem definition in system dynamics modeling. Based on what was discussed in this paper, the following guidelines are presented:

1. Based on the process of formulating ambiguity-statement 1, the first guideline emerges. Suppose we have hypothesis *A* for behavior *a*. We may ask "Is all of *A* necessary for describing behavior *a*? Or may only a part of *A* be sufficient?" Now suppose we have found a part of *A* –call it *A1-* to be sufficient (*i.e.* a model built based on just *A1*, not the whole *A*, will well explain behavior *a*). One may now ask "so what is the role of the remaining part of *A* (*i.e. A*-*A1*)? Does it just amplify the behavior produced by *A1*? Or is it able to separately produce behavior *a* as well? Or the remaining part of A is not necessary and does not add any value to explain the behavior *a?*"

2. Consider ambiguity statement 2. This ambiguity has been stated based on an important characteristic of Dynamic Hypothesis. A good dynamic hypothesis not only should specify

which mechanism is dominant (*i.e.* has the most influential role in determining the behavior) in each time, but also it should illustrate why and how dominance is shifted through different mechanisms.

3. Consider ambiguity statement 3. If a dynamic hypothesis, which is to describe a specific behavior, explains two or more mechanisms and introduces the behavior as the product a summation of those mechanisms, there still is something missing. It should explain how those mechanisms *interact* to produce that behavior. In the real world, what produces a behavior consists of a set of mechanisms and, of course, *their interrelationship.* So, a cluster of ambiguity statements may correspond to overlooking the interrelations among mechanisms in dynamic hypotheses.

6. Summary and Conclusion

Problem definition plays a crucial role in good system dynamics modeling practice. In spite of its importance, the literature in problem definition is far less than its importance implies. In the present literature, although the modeling is described as an iterative process, such iteration has not been discussed with respect to the problem definition and not enough attention has been paid to the iterative nature of the problem definition.

This paper introduced the concept of "ambiguity" to facilitate and apply an iterative approach to problem definition. In this approach, the definition of the problem is enriched as through different iterations the problem becomes more precise and the modeling process becomes more purposeful.

Using some examples, we discussed operationally how applying concept of "ambiguity" can have considerable effect on the list of key variables of the model, and the way we make use of momentum policies to enrich the definition of a problem. And, hence, the final model will be strongly influenced by the concept "ambiguity".

We demonstrated that the concept "ambiguity" may expand the domain of problem definition to the model development and simulation stages where we have a model in hand (this is another aspect of the iterative nature of problem definition). The main point was that *for solving problem in the real world, we should not content ourselves with answering the questions we start with. But as important and as complex is the elicitation of questions which are of importance in solving the difficulties but have not been questioned yet. So, in our scientific works, we should continuously and consciously try to discover and propose* *important questions which have not been asked so far.* We applied this approach using a case study of real estate bubble.

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