Flow-Based Modeling of Economic Process

Sabah Al-Fedaghi

Abstract—**The circular flow model and its extensions are widely used tools to analyze economic process. Several features of the circular flow model have motivated developing more refined tools at the conceptual level. Especially, in ecological economics there has been a need for a better model to incorporate environmental considerations. This paper proposes a new approach to modeling the flow of economic process. The main concept in this proposal is a flow model (FM) that has been developed in the computer science area and applied in modeling several phenomena. FM-based conceptualization of economic process improves several aspects of the circular flow model and provides a descriptive mechanism to incorporate environmental factors.**

Index Terms—**economic process, ecology, flow, environment, models**

I. INTRODUCTION

The construction of a conceptual model is essentially a description of the phenomenon's essential activities and their pattern of flow. The model serves as a standard to be contrasted with any system under study in order to explore different characteristics such as variation and completeness of different constituents of the system. The most useful type of model is the one that reflects general features that ap-pear in different fields of study. This paper is an interdisciplinary effort that shows that conceptual modeling is multi-faceted, and tools that are developed in one discipline can find counter usefulness in other disciplines.

This paper deals with how to enhance the modeling of economic process through integrating current economic conceptual modeling techniques with a flow model (FM) that has been developed in the computer-science area and applied in modeling several phenomena. The methodology followed in pursuing such a goal is as follows:

- First, we scrutinize the very known circular flow model and its extensions in order to explore weaknesses that have motivated researchers to search for a better description of the economic process.

- Second, we redesign the basic circular flow model based on the new FM to demonstrate advantages of FM in over-coming the structural weaknesses of the circular flow model.

- Finally, we select several proposed enhancements of the circular flow model, and redesign them using FM to show the credibility of our claim that FM improves the modeling methodology of economic process.

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It is important to notice that the material in this paper is about modeling. It does not deal with economic analysis or economic research, rather it proposes to economists an improvement in their modeling tools. Thus, the specific economic characterization of models used in the discussion are immaterial since they are introduced as samples of cur-rent methodologies in this area.

The methodology in this paper is imposed by the existence of many known proposals of economic modeling; hence, only few current models are discussed. The aim is not to enrich the analysis of economic systems, but to suggest supplementing the conceptual modeling methodology in the field.

Section 2 reviews the macroeconomic circular flow model. It also discusses known motivations for developing more refined tools for modeling economic process at the conceptual level. The section also introduces new aspects that are considered structural weaknesses of that model, such as modeling agents (e.g., households and firms) as black boxes. This is motivated by the structure of FM, which views such agents in terms of their five internal constituent stages: receiving, processing, creation, releasing, and transportation. The section also reviews the issue of incorporating environmental factors in the economic process. It presents two sample proposals to enhance the basic circular flow model with environmental aspects.

Section 3 reviews the flow model. In section 4 the FM-based economic process is discussed. It is applied to modeling ecological system in section 5.

II. MACROECONOMIC MODEL

The circular flow diagram in Figure 1 represents a widely used model of economic process [13]. Goods and services made by firms (producers) are provided to households (consumers), who in turn receive money for their labor. The model depicts a self-sustaining, circular flow between producers and consumers.

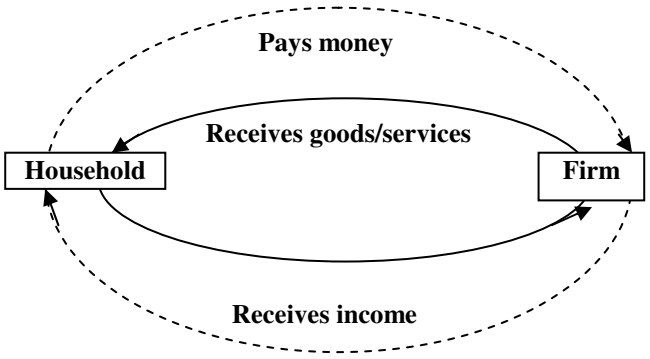

Fig. 1. The basic macroeconomic model.

Several features of the circular low model have motivated the development of more refined tools for modeling economic process at the conceptual level. We divide the bases of these features into structural and environmental considerations.

A. *Structural considerations*

From the structural point of view, the circular flow diagram can be criticized as follows:

- It completely ignores the internal complexity of different spheres (entities) such as "firms," and "households" as structures. In Figure 1, "household" stands for an entity that pays money, receives goods and services, provides labor, and receives income. As we can see, paying money is a consequence of receiving income. This is the flow of money. The vertex reflects a model of a black box with in-put to output. Looking at other substances of flow, we wonder whether receiving goods and services, is likewise linked to providing labor. It does not seem likely, since the substances of the flow are different (goods and services vs. labor, which is actions/activity). So, is there flow here? The lack of ability to view what is happing in the interiority of the vertex "household" makes tying or connecting the flows conceptually difficult. The same argument can be applied to the vertex "firms."

- There is no apparent logical link between the flow of money and the flow of goods and services. Why do house-holds provides labor? Because they receive money for their labor. However, such a relationship is not explicitly ex-pressed in the graph. If someone does not know English, he or she would not reach this conclusion. Similar arguments can be applied to relationships on the graph.

We claim that the structural representation of the circular flow model is ambiguous. The FM capitalizes on these two features: internal structures of entities and explicit separate flows for different "things that flow" to introduce a uniform descriptions for the transformations involved in economic process. These feature will become clearer when the FM is reviewed in section 3.

B. *Environmental Considerations*

The circular flow model has been criticized in the field of ecological economics. One objection is to its focus on the flow of substances such as money and goods and services, rather than the throughput of natural resources. Also, the physical flow of matter-energy is not circular.

> This diagram has its uses in analysing exchange, but it fails badly as a framework for studying production and consumption. Maintenance and replenishment, in this picture, would seem to be accomplished internally, requiring no dependence on an environment..…
> It is impossible to study the relation of economy to the ecosystem in terms of the circular flow model, because the circular flow is an isolated, self renewing system with no inlets or outlets, no possible points of contact with anything outside itself. Yet in economic theory the circular flow has the spotlight, while the concept of throughput is only dimly visible in the shadows [6].

Many proposals have been introduced to extend the basic model to incorporate economics and environmental resources separately. Some of these proposal follow the circular flow model closely. Figure 2 shows a modified model of economic system [14].

In this model, the natural environment is represented in the model in addition to households and firms. The structural characteristics are similar to the circular flow model of Figure 2. Thus, the structural weaknesses of that model apply here.

The extended versions of the circular flow models seems to exhibit the same weaknesses as the original model. Furthermore, attempts to incorporate the ecological environment obscure the conceptual picture. Consider an-other proposed model shown in Figure 3 to extend the circular flow model to incorporate energy where the "energy sector is separated out to show how it is involved in every single production process in an economy … This process is unidirectional (from "source" to "sink") and irreversible, in comparison to the circular, reversible macroeconomic model" [11][12]. The model "indicates the centrality of the energy concept in describing the thermo-biophysical "engine" that enables the global ecosystem to function, just as it enables the functioning of everything else — economies included — that has life within the global ecosystem" [11].

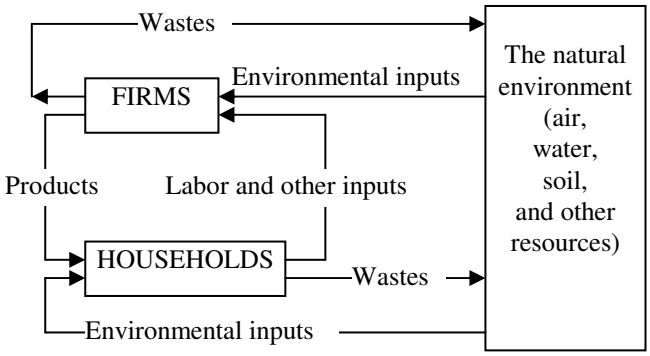

Fig. 2. Modified model of economic system (From Thampapillai, [14]).

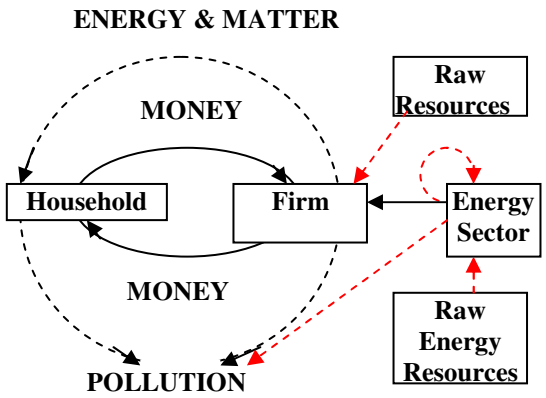

Fig. 3. Peet's thermophysical macroeconomic model [11][12].

Nevertheless, this model conceptually incorporates heterogeneous notions. For example, the arrow from the energy sector to pollution denotes a causality relationship, not flow. Also, raw resources seems to denotes the "things that flow," nevertheless, it is represented as a vertex. Also, there is ambiguity with regard to the reflexive arrow on the energy sector. Of course, clarifications can be given in English to these points; but, in this case, the graphical description looses its merits.

The FM-based economic process is flexible enough to add various dimensions such as ecological issues, and ad-dressing institutional or socio-structural spheres. Because of space limitations, we will not introduce some of these possibilities in this paper.

III. THE FLOW MODEL

The flow model (FM) was first introduced in [5] and has been used since then in several applications such as engineering requirement analysis [1] information communication [3], and database access control [4]. Even though this section reviews the basic model, it includes new illustrations of the model.

In FM, the flow of some substance indicates movement of the substance inside and between spheres. The sphere is the environment of the flow that includes five stages. The stages may be named differently. For example, in the in-formation sphere, a stage may be called communication, while in raw-material flow, the same stage is called transportation. The information creation stage may be called manufacturing in the materials flow.

In reviewing FM, we will assume that the substance is information. An information sphere denotes the information environment (e.g., company, department, and per-son).The lifecycle of information is a sequence of states when it moves among stages of its lifecycle.

Information goes through a sequence of states as it moves through stages of its lifecycle, as follows:

1. Information is received (i.e., it arrives at a new sphere like passengers arriving at an airport).
2. Information is processed (i.e., it is subjected to some type of process, e.g., compressed, translated, mined).
3. Information is disclosed/released (i.e., it is designated as released information, ready to move outside the current sphere, like passengers ready to depart from an airport).
4. Information is transferred (disclosed) to another sphere, (e.g., from a customer's sphere to a retailer's sphere).
5. Information is created (i.e., it is generated as a new piece of information using different methods such as data mining).
6. Information is used. Using information indicates exiting the information flow to another type of flow such as actions. We call this point a gateway in the flow.
7. Information is stored. Thus, it remains in a stable state without change until it is brought back to the stream of flow again.
8. Information is destroyed.

The first five states of information form the main stages of the stream of flow, as illustrated in Figure 4.

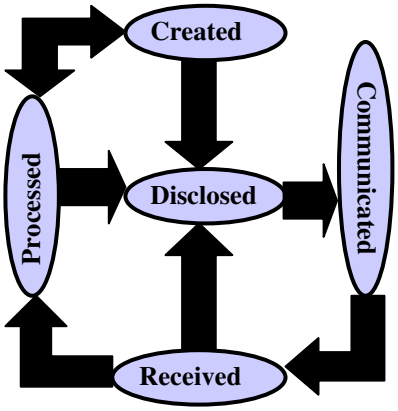

Fig. 4. The basic information flow model

When information is stored, it is in a sub-state because it occurs at different stages: while information is created (stored created information), processed (stored processed information), and received (stored received information). The five-stage scheme can be applied to humans and organizations, and it is reusable because a copy of it is assigned to each agent.

The five information states are the only possible "existence" patterns in the stream of information. To follow the information as it moves along different paths, we can start at any point in the stream. Suppose that information enters the processing stage, where it is subjected to some process. The following are ultimate possibilities:

1. It is stored.
2. It is destroyed.
3. It is disclosed and transferred to another sphere.
4. It is processed in such a way that it generates implied information (e.g., a is the father of b and b is the father of c generates the information that a is the grandfather of c).
5. It is processed in such a way that it generates new in-formation (e.g., comparing certain statistics generates the information that Smith is a risk).
6. It is used to generate some action (e.g., upon decoding or processing the information, the FBI sends its agents to arrest the spy who wrote the encoded message). In the uses sub-stage, information is not a patient. The patient is a term that refers to the thing that receives the action.

The storage and uses/actions (gateways) sub-stages can be found in any of the five stages. However, in the release and transfer stages, information is not usually subject to these sub-stages, so we apply these sub-stages only to the receiving, processing, and creation stages without loss of generality. Figure 5 shows the interiors of these stages.

The "storage" in each stage represents information in a static state. Thus, upon receiving information, it may be stored in its received condition for a later time, when it is activated by being returned to the flow stream. Implicit in Figure 5 is that information may be destroyed and/or duplicated through copying.

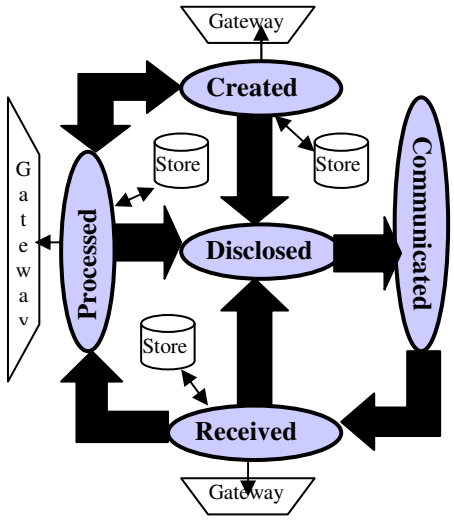

Fig. 5. FM sub-stages.

Figure 5 is a detailed version of Figure 4, showing how the receiving stage leads to the processing stage, which in turn leads to the creation stage. The creation stage may lead back to the processing stage. These three stages may lead directly to the disclosure/release stage, then the transmission stage, which in turn leads to the receiving stage of another sphere.

To illustrate the "gateway" sub-stage, consider a person in Barcelona uses the Internet to ask a person in New York whether it is raining in New York. Figure 6 illustrates the information flow. First, the query flows through links 1, 2, 3, and 4 to the receiving stage of the New Yorker.

The New Yorker's reception of the query triggers an action, such as physical movement to look outside to check the weather. The gateway in his or her information system transforms the information flow to an action flow (point 5). After checking whether it is raining, he or she triggers an-other information flow through creating a response in his or her creation stage (point 6). The response flows though links 7, 8, 9, and 10. The information flow crosses from one information sphere to another at points 3 and 9.

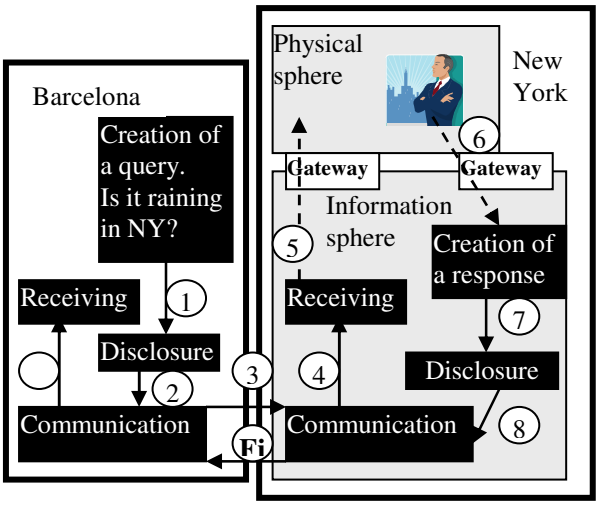

Fig. 6. Illustration of flow of information through gateway.

IV. FM-BASED MODEL OF ECONOMIC PROCESS

In the circular flow model, the agents (e.g., households, firms, environment) are treated as black boxes without internal structure. The black box description focuses only on input and output, and does not present information about the origin of the exchanged resource, its type (e.g., created, processed, etc.), and the roles of the agents such as producers, possessors, or its transporters. Information related to internal processes can contribute to eliminating some weaknesses of the circular flow diagram. For example, the size of storage inside different stages of an environmental sphere may be used as an indicator of exhaustible materials (e.g., oil). Also, the interaction between the processing and creation stages may reflect the production of a renewable resource.

In FM, agents are represented as spheres with the five generic stages as previously described. This would provide a means to track the flow in the interior of the sphere with-out introducing a great deal of complexity. This technique would open the black boxes for economists to examine the connection among different flows coming in and out of the sphere. It is analogous to providing internal city maps in addition to a map of highways reaching the city when studying national roads. This feature is important, especially if these highways are not directly connected with each other.

Additionally in FM, any certain flow refers to the flow of a single thing such as money, materials, and services. The flows of different things or substances do not connect with each other, rather they trigger each other. Such a triggering process directs or diverts the stream of flow to an-other type of flow such as from information flow to actions flow. The triggering mechanism is as a domino effect that propagates the movement to another piece.

Figure 7 shows a general view of FM-based economic process. The two 5-stage schema represent the households and firms spheres. FM requires that the "things that flow" in these two 5-stage schemas be of the same type: money, information, materials, services, etc. This is denoted by the solid arrows between the stages. The flow of one type may trigger a flow of different type. This is de-noted by dotted arrow at the top.

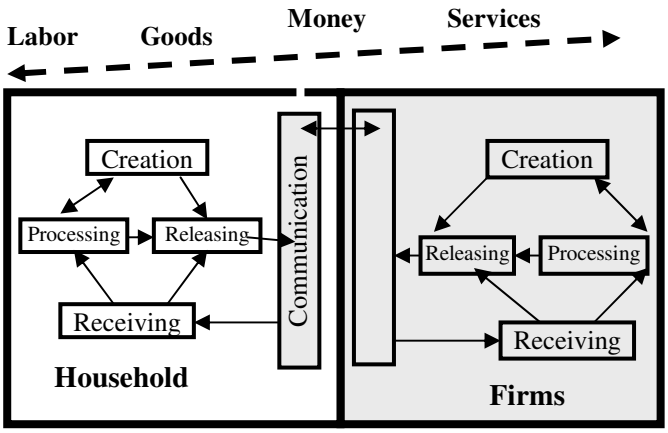

Fig. 7. Basic FM model.

In Figure 7, if the household sphere includes streams of flow of labor, goods, money, services, then there are four different flows of household, and each represents the flow of these elements. Similarly for firms, each type of flow has its own sphere of the 5-stage schema. If the same type of flow crosses a communication stages, it is indicated by solid arrow. If the stream of flow crosses from a sphere to another (e.g., information flow to materials flow) then this is indicated by dotted flow. This last crossing does not go through the communication stages.

Example: To illustrate the features of the FM-based modeling, suppose that a customer (household) sends information to a producer (firm), which processes information and triggers its inventory to send product to the customer. We assume that the producer has two internal sub-spheres: the inventory and the delivery departments. Accordingly, we have four spheres:

- Customer with an (a) information sphere: to facilitate communication with the firm such as requesting product catalog and ordering forms, and (b) physical sphere: to facilitate the actual receiving of purchased product.
- Producer with an (a) information sphere, (b) inventory sphere, and (c) delivery sphere.

Figure 8 shows the resultant flow model and demonstrates several FM features. Each agent sphere may be decomposed into several sub-spheres (e.g., produces has several departments). The internal flows inside different spheres are not shown. This type of representation will be applied for different agents in the economic process. Households, firms, environment, or any sub-sphere of these agents are treated uniformly as a 5-stage sphere.

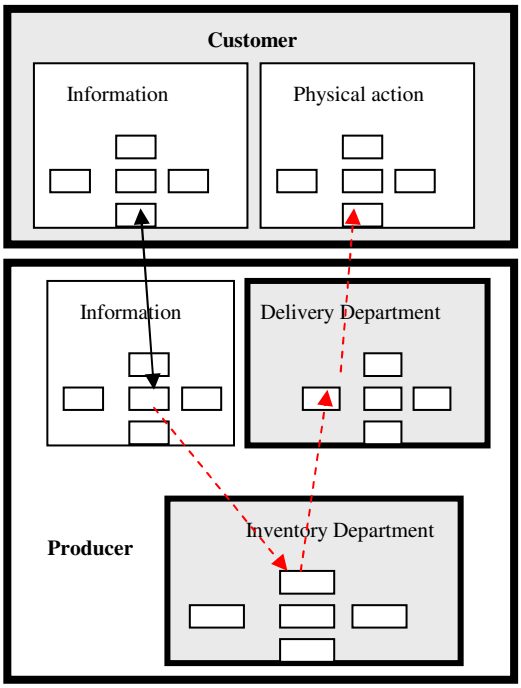

Fig. 8. Information flow between the customer and producer (solid lines) triggers inventory to initiate product flow (dotted lines) that physically moves to the delivery department then to the customer who receives the physical product.

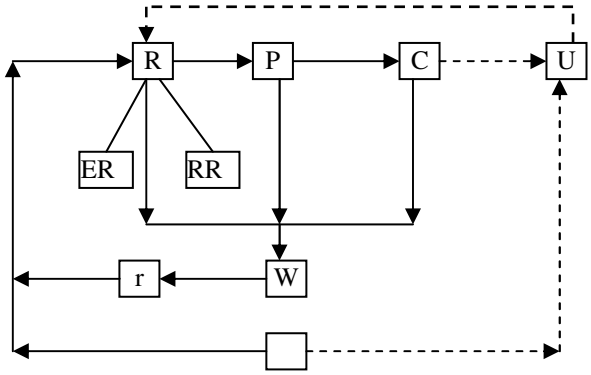

Fig. 9. Exhaustible and renewable resources (Partial view from NOAA Coastal Services Center, [10]).

V. APPLICATION TO ECOLOGICAL SYSTEMS

According to the Web site of National Oceanic and Atmospheric Administration (NOAA, [10]):

> The relationship between the economy and environment does not represent an open, linear process, but is rather illustrative of a closed, circular system. Within the environment and economic flow diagram, raw materials (R) are used as inputs into the production process (P) that creates the goods consumed by households (C). The end result of production and consumption is the creation of utility (U) or satisfaction [10].

Consequently, an enhanced view of ecological process is introduced as shown in Figure 9. The resource ® is expanded to encompass two forms of natural resources: exhaustible (ER) and renewable resources (RR). The figure includes the generation of waste products (W).

The box R represents the share of total waste that is recycled and thus put back into the production process. The environment has a limited capacity to absorb waste and convert it into biologically benign material. This absorption capacity is known as assimilation (A) [10].

To contrast FM-based modeling with this type of mod-els, we developed an FM version of involved spheres in Figure 10. The details of the parameters assigned in the model is not important since our purpose is to contrast the modeling styles. From NOAA's description [10], we roughly recognize the following spheres based on the type of "things that flow":

1- Row materials:
- Environment sphere where raw materials originate
- Manufacturing sphere where raw materials are received and processed

2- Products (artifacts produced from raw materials):
- Production sphere where finished products are exported
- Consumption sphere where products are consumed

3- Recycling:
- Recycling sphere 1 of raw materials produced as by-product of manufacturing
- Recycling sphere 2 of products of consumption.

Notice that the process of identifying different spheres is guided by the type of materials that flow. For example, since the flow of raw materials is different from the flow of products, two recycling spheres are declared. Consequently, we end up with six spheres in Figure 10. Unused internal arrows have been removed to simplify the figure.

Examining Figure 10 starts with the environment sphere. There are two sources of raw materials:

- Renewable resources indicated by point 1 in the circle. Some processes in the environment sphere create raw materials.
- Exhaustible resources that have been stored in the environment indicated by point 2.

These two sources of raw materials are included in the same figure to illustrate different descriptive possibilities in FM.

From either of these two sources, raw materials flow to the release and transportation stages and then to the manufacturing spheres (point 3). In the manufacturing sphere, the raw materials are received and processed. The result of transforming raw materials into products (artifacts) triggers a flow of products in the production sphere (point 4). Notice that there is a dotted arrow from the manufacturing sphere to the production sphere.

This indicated change in the type of "things that flow." If the material that flows is of the same type, then is should go between the transportation stages of the two spheres. The flow that originated in the creation stage of the production sphere moves to the releasing and transportation stages, hence, crossing over to the consumption sphere (point 5).

The products are then consumed, which is a type of processing.

At this point, consumption produces waste, thus triggering (point 6) the creation of waste in the recycling sphere 1. In this recycling sphere, the waste is processed and transported to the manufacturing sphere (point 7).

It is not clear, or at least it is not explicitly motioned, in the description of the NOAA Coastal Services Center [10], whether there is a possibility of shipping some of the recycled waste back to the environment (not shown in Figure 10).

At point 8, the manufacturing sphere produces raw materials (we assume) waste such as oxygen dioxide, which is processed and is sent back to the manufacturing sphere (point 9). It is possible to modify the flow such that some of the recycled materials are send to the environment.

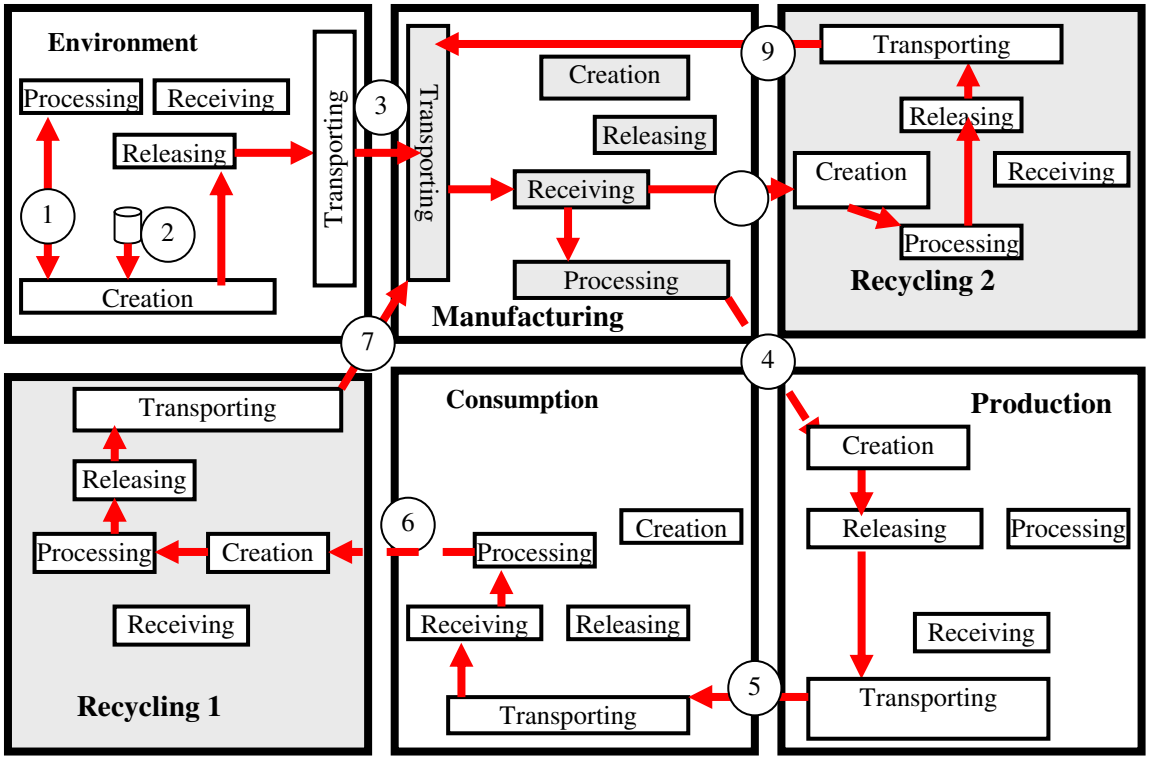

Fig. 10. Ecological FM that corresponds to the general ecological system of figure 9.

Clearly this FM covers all possible flow and transformations of all possible substances from the phase of creation to the phase of terminations. Other elements such as information, services, and money can be incorporated in this grand picture of flow. As indicated in our descriptions of the flow in Figure 10, the model uncovered what seems to be missing continuation of flow.

Also, the final ecological chain described above is only one possible chain of flow. For example, consumers may create some products, production can receive some products from other production spheres, etc. This opens many possibilities to explore different chains of the eco-logical system.

In comparison with the sketchy graph of Figure 9, FM presents a rich picture of the economic process. Because of the repeated application of the 5-stage schema applied uniformly to different spheres with different flow substance, the complexity of FM structure is systematic and suitable to apply variable measurements. Also, FM structure exhibits clear critical points in the system.

FM introduces many possibilities to study the sphere's internal processes using the same modeling methodology. Consider the notion of self-recycled, as described by the following:

> Natural systems also generate waste, from leaves that drop from the trees every fall to animals that perish every winter due to starvation or exposure. The important difference between natural and economic systems is that waste generated by natural systems is generally re-cycled [10].

In FM, it is possible to assign the transporting and receiving roles to the same agent as shown in Figure 11. The arrows represent the flow of naturally produced "waste." It is exported from the environment and received by itself. Recycling involves different stages, as shown in Figure 11. For example, the natural "waste" is stored at different stages.

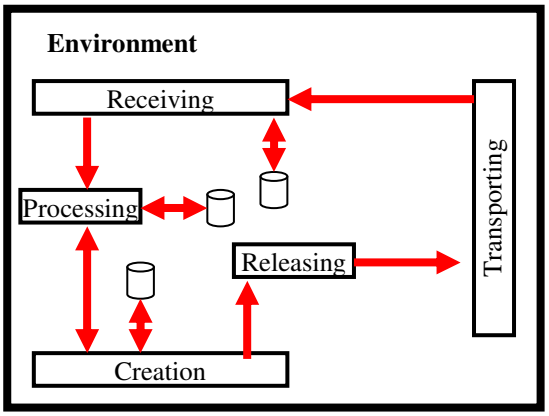

Fig. 11. Flow that reflects self-recycling.

VI. ANALYTICAL TOOLS

Decision-making in environmental policy uses analytical tools including Material Flow Accounting (MFA). In an MFA, the flows of materials are quantified and sometimes modeled [8]. According to Kleijn and Voet [8], "the flow of matter lies at the heart of many environmental problems." Some of the key characteristics of MFA in general are:

- the systems perspective
- all flows are considered from the cradle to the grave
- calculation principles based on law of conservation of mass.

MFA can be utilized to facilitate "the concept of industrial metabolism, where an analogy is drawn between the economy and the environment on a material level. The economy thus is viewed only in terms of its materials flows and stocks. Applications vary from the accounting of total mass flows … to flows of elements" [8].

Luks and Hammer [9] present the input and output flows of an economy that constitute its metabolism in Figure 12.

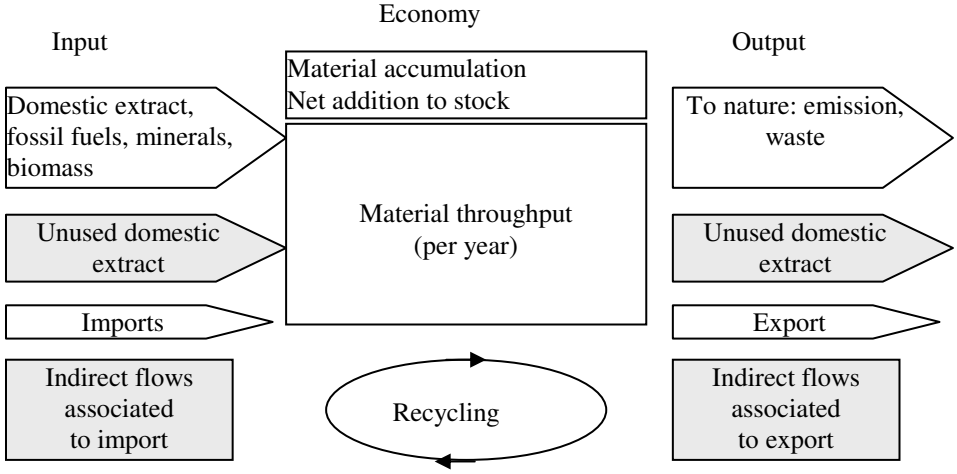

Fig. 12. The input and output flows of an economy that constitute its metabolism (from Luks and Hammer [9], modified after Eurostat [7]).

We claim that the FM is a "better" conceptual modeling methodology to describe such a system. There are several features that makes the modeling technique in Figure 12 less attractive. For example, the notion of "recycling" does not connect to the appropriate parts of the graph. There is no clear connections among the pointed shapes (boxes) on the left and right sides. For example, it is not clear whether the unused domestic extract flows to other component for recycling. Figure 13 shows the corresponding FM representation.

FM-based MFA modeling as illustrated in Figure 13 contains, in Kleijn and Voet's [8] words, a map of "all flows … considered from the cradle to the grave." The top left box represents the "domestic extract" in nature. It is a self-sustaining system where the materials are created then return (point 1) to the system as described in the previous section. Some materials flow to the economy (point 2). Some created materials are unused domestic extract and has its own flow (point 3). Imports flow to the economy (point 4) and also causes indirect flows (point 5) associated in the exporting economy (another economy).

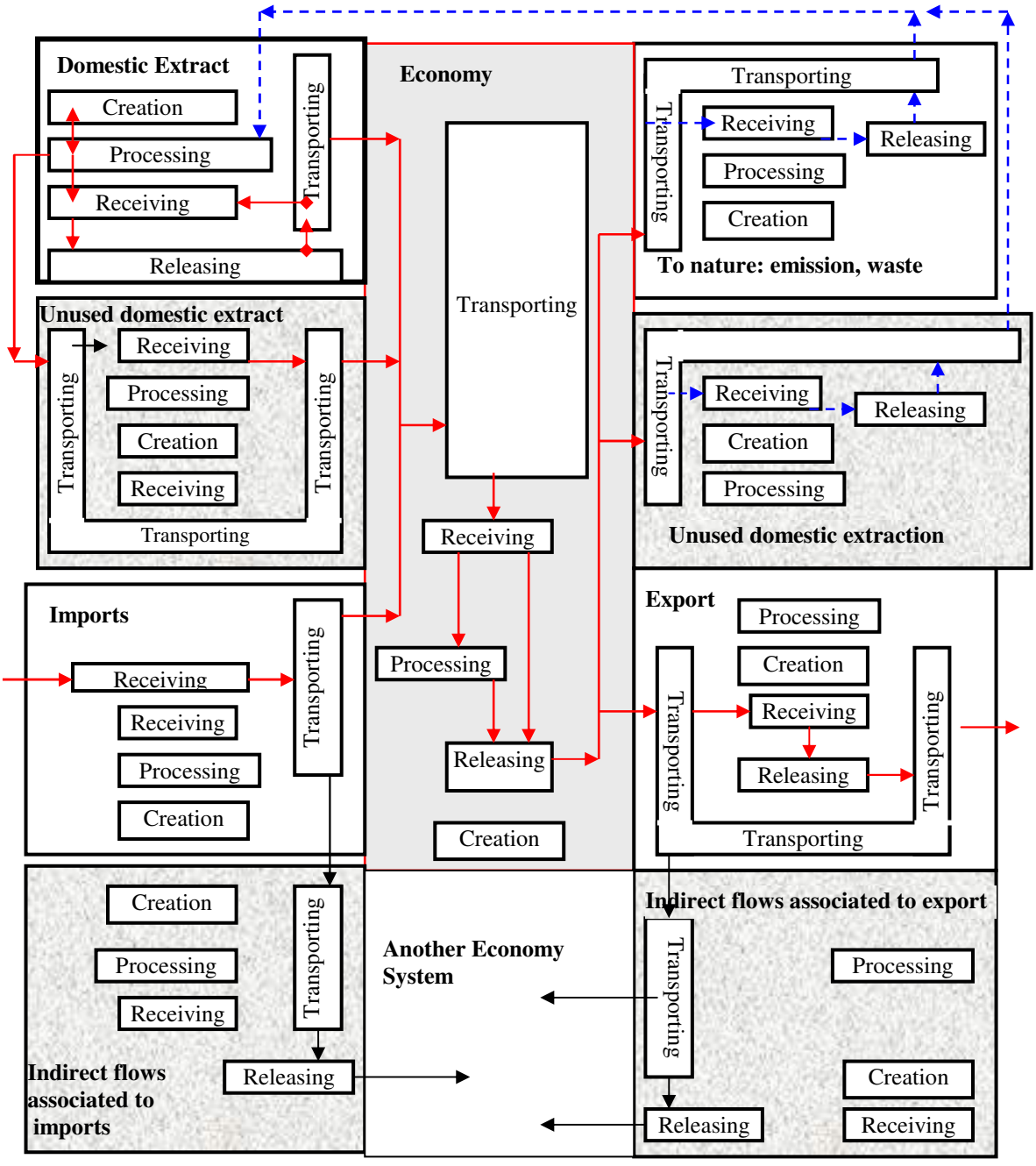

Fig. 13. FM version of Material Flow Accounting.

In the right corner box, nature receives emission and waste, which may be cycled back to the processing stage of the "domestic extract" (point 8). The "unused domestic ex-traction" may also flow back to the processing stage of the "domestic extract" (point 9). Export causes "indirect flows associated to export" that affect another economy system (point 11).

To simplify the graph, the internal connections among stages are removed. The shown chains of flow (among stages) are selected according to our general understanding, because the black box methodology (Figure 12) does not specify the interiors of different spheres.

We can go on in describing different possible flows in Figure 13. Space limitation does not allow further exam-ples, however, it is clear that the economist or researcher can specify in precise manner all possible flows.

VII. Conclusion

This problem that has been dealt with in this paper is how to enhance the conceptual modeling of economic process through integrating current economic modeling techniques with a proposed flow model (FM). The improvement in modeling has been demonstrated though redesigning published economic models. The examples seems to indicate good enrichment in describing the economic process. However, real results can only be provided by applying the technique to actual economic problems. In this context, ecological economics seems to be a very promising field to experiment with the methodology.

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