Steps to industrial ecosystems.
New models for interfirm interaction

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Introduction

The following document explores some critical points connected with the possible adoption of ecosystem models for industrial production. It is necessitated by the desire to underscore some fundamental questions possibly arised by policies trying to introduce or implementing forms of systemic interaction for firms. Such questions are essentially directed to a better knowledge about the system-thinking approach industrial ecosystems imply and the systemic boundary conditions the manufacturers are asked to operate. This paper simply focuses on some priorities to be addressed.

A perspective and a focus: premises on methodology

The study of the implications deriving from ecosystem models for industrial interactions necessitates a clear perception either of the perspective from which the phenomena are observed (or anticipated) and of the focus (i.e. the specific manufacturing sector) where theoretical observations may become operative.The methodology that was at the base of this analysis[1] *tacitly implied a progressive shifting from a broad perspective to a close-up observation. Such a methodology of progressive reduction of the area of analysis - moving from a broad scenario to a myopic vision - has a twofold explanation:*
(i) from a theoretical point of view, the choice of a systemic approach to industrial phenomena requires a coherent systemic methodology: the possibility of an holistic vision is thus recognized in a parallel vision including the whole scenario and some specific elements.
(ii) from an operative point of view, implications for specific sectors of industry can be derived only from the wider horizon of intersectorial experiences.

Work hypothesis

One of the essential elements of this analysis goes with in the hypothesis that any product is potentially expected to have a recognizable ecosystem which is determined by the network made of raw material suppliers, component manufacturers, systems of delivery, maintenance and collection, waste handlers, recyclers and consumers. Within this articulate spatial and temporal web of human production and consumption activities, materials and product components may be traced through several different industrial ecosystems and each company may play a role in different ecosystems. Implicit object of study is thus is the possible definition of conceptual frames for industrial ecosystems, trying to identify their essential, specific components (i.e. industrial agents) and processes (i.e. product and material onward, backward and circulating flows).

Limits

However, instead of thinking about the ecosystem of a product, a change of perspective could lead to the recognition that an industrial ecosystem may be bounded by geography, so that the system to be considered could be isolated in a special area. Shifting to a global perspective, it could even be possible to perceive the world industrial system as made up of the whole network of interrelated industrial subsystems. Finally, as industrial activities contribute in transforming materials and energy flows not only in industrial systems but in natural systems providing raw materials and serving as sink for wastes either for producers and consumers, the set of relations would still be far from complete if

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[1] Elements of this analysis are derived from the research financed by the European Union "*Expres. Extended Producer Responsibility for Complex products:a research analysis of the socio-economic and technical implications of devising and implementing a policy on this principle*", carried on within a research unit based at Politecnico di Milano, under the coordination of University College Cork (Ireland) and with Lund Universitet (Sweden).

natural processes were not included. In fact, an ecosystem approach to the analysis of an industrial sector should be utilized to include the interaction between industrial and natural processes.
Such a complex, intricate set of interactions obviously goes far beyond the scope of this analysis, which will more modestly focus on some theoretical implications of looking at industrial relations from a systemic point of view.

An industrial ecosystem for products

Accepting an ecosystem as a model for an industrial system is to accept that unit processes and industries are interacting systems and not isolated components. Such an assumption is appropriate to represent the conceptual context of an analysis concerning ecosystem models, one of their primary, more important effect being precisely that of requiring systemic interactions.

Ecosystem models provides the basis for thinking about the ways different waste-producing processes, actors and industries could be connected in an operating framework whose goal is to control products and materials lost in intermediate processes and minimize the final volume and impact of end-of-life goods.

Although several industries and industrial systems are already noted for using the waste of one process as feedstock for another (steel scrap recycling is considered as old as steel industry itself), the new implications provided by a broader, system-based approach to industrial activities point out two fundamental aspects:

(i) the need for a better understanding of current industrial ecosystems and the consequences of changing production and consumption processes under the pressure of environmental constraints;

(ii) the impact of fiscal and regulatory policies in favouring the structure and processes of industrial ecosystems.

To start a course toward environmentally preferable industrial systems, it will be necessary to take into consideration the current state of present industrial ecosystems. Three possible stages in the evolution of industrial ecosystems are usually considered[2]:

type A: industrial ecosystems characterized by linear, one way flows of products where the production, use and disposal of goods occur in absence of reuse or recovery of materials or components.

type B: industrial ecosystems where some internal cycling of products and relative materials occurs, even if there is still need for virgin material input and wastes are disposed outside the economic system.

type C: hypothetical industrial systems characterized by complete or nearly complete internal cycling of products and relative materials.

Present industrial ecosystems for products should be characterized by a mix of type A and B; pure type C models - the no waste ecosystems - are beyond any reasonable capability allowed by present technology.

Considering such a premise, the question is not of course to focus on unattainable goals but to pursue the objective of a progressive shifting from type A system to type B ones, trying to close the cycle as much as possible.

While ecosystem models have been largely applied to energy and materials flows within industrial systems, applications for products - durables for instance - are still far from being analysed.

Even if the studies on industrial metabolism have reached relevant levels of elaboration, they still tend to be directed to homogeneous flows of materials and

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[2] Deanna J. Richards, Braden R. Allenby, Robert A. Frosch, *The Greening of Industrial Ecosystems: Overview and Perspective*, in Allenby, Braden R. and Richards, Deanna J. (editors), *The Greening of I ndustrial Ecosystems*, National Academy Press, Washington, 1994, pp. 1-19.

energy, whose circulation can be reasonably controlled in defined boundary conditions.
A strong difficulty in trying to define a product ecosystems lays in boundary definition: in fact products, durables in particular, imply a complex network of raw material suppliers, component manufacturers, systems of delivery, maintenance and collection, waste handlers, recyclers and consumers.
This network representing a product ecosystem could also be part of other products ecosystems; the single product, on its turn, is often made up of many materials, each one referring to different material flows belonging to different industrial systems.
Within this articulate spatial and temporal web of production and consumption phases, where each company may play a role in different ecosystems, product flows and industrial relations tend to be not controllable once a product has ended its useful life and could potentially be involved in take-back and recycling systems.

The external environment of products

The flow of products and materials, the use of energy, the development of services in an industrial system do not occur in a vacuum. Each economic activity is influenced by a complex mix of business practices, technological options, scientific understanding, regulations, economic forces, public perceptions and demands.
Each of these elements is in turn not isolated: regulations reflect public values and try to address societal concern, public demand shapes the market and economic forces, economic forces drive technological options and viceversa.
Such a complex context is not strictly part of an industrial ecosystem: more appropriately it could be considered as the *external environment* or the *climate* of the industrial ecosystem itself, where *external environment* stands as "*the legal structures that fundamentally define economic activity*"[3].
This environment could be essentially described not only as the complex including the physical conditions producers operate within (meaning natural resources and limits) but the framework of economic, regulatory, cultural and technological constraints as well.
This notion of environment stands as a flexible concept, where a manufacturing system and its context can not operate apart from each other, each of them being at the same time subject and object of the other's evolution, according to a reciprocal process of successful or failing adaptation.
Should a rough profile of the external environment of product manufacturing be traced, it would include at least:
(i) as a social demand, the recognition that the unidirectional industrial processes - beginning with the extraction of raw materials and ending with waste disposal - are beyond any environmentally carrying capacity and no longer tolerable. The progress towards an ecocycle society rests on the principle that products are to be used, recycled, re-used and managed trying to close as much as possible the circuit of materials flows and components;
(ii) as an industrial trend, for industry, assimilation to an ecocycle society implies the setting of systemic programme of environmental responsibility. A number of companies are already working along this lines, being their pilot experiences a model for other manufactuirng sectors (experiences in the automobile sector are prominent).

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[3] Braden R. Allenby, *Understanding Industrial Ecology from a Biological Systems Perspective*, "Total Quality Environmental Management", Spring 1994, p. 351.

(iii) as a legislation potential constraint, although limited products are directly affected by regulations concerning recovery or recycling, the adoption - in Germany and in Northern Europe countries - of legislations imposing packaging recycling and re-use may work as a starting engine for similar laws requiring re-use and recycling for any other product.
(iv) as a shifting in environmental policy, environmental polies have progressively moved from a focus on the process to a focus on the product. For policy makers such a shifting implies that the attention moves from the economic elements of traditional regulatory theory to the central elements of the market. This strategical effort to control products forces the manufacturers to face threats to the most significant of their asset, which is the market share[4]. In addition, addressing the product captures the process, while the inverse is not true.

Towards a redefinition of the producer

The idea of systemic interaction among firms implicitly suggests an evolution of the private, for profit producer from strictly profit-seeking behaviour to more socially comprehensive goals[5]. Producers are pivotal economic agents in any modern economy: they reflect and shape the cultures within which they function. Furthermore, to some extent, the producer is defined by law and may be modified by law.
This arises a central question: what form of producer structure would industrial ecosystem require? That is to say: what form of producer could be the most suitable to contribute to the evolution of (partially) closed industrial ecosystems?
As a matter of fact, the behaviour of producers is already changing.
Even apart from environmentally constraints, agents such as manufacturers routinely adjust as the conditions within which they find themselves change.
Thus, a reasonable question is not whether change will occur; it is how deep and global that change would be when facing the radical adjustments an industrial ecosystem would require.
Should industrial ecosystems be generally promoted, this would strenghten the trend driving to a redefinition of the manufacturer itself. In particular, the manufacturer would tend to be larger in scale and scope. Furthermore, producers will include significant public interest components into their goal structure.
The implications of such an evolution are substantial and open a further question: what form of other agents within the existing economic system and what boundary conditions on their behaviour will be most coherent with EPR policies?
To approach this open question, it will be assumed that - in spite of what stated above - manufacturers are to remain narrowly defined and substantial transformations will occur in the external conditions they operate in.

New models of interfirm organization

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[4] John R. Ehrenfeld, "Industrial Ecology: a Strategic Framework for Product Policy and Other Sustainable Practices", prepared for Stockolm Conference, September 1994, draft, p. 9.

[5] It is argued however "that progress towards sustainability can best be achieved by modifying the boundary conditions within which private corporations operate, rather than by trying to change them into organizations which reflects social goals beyond profit seeking" (Braden R. Allenby, *Evolution of the private firm in an environmentally constrained world*, prepared for *Engineering within Ecological Constraints*, National Academy of Engineering Workshop, Washington D.C., April 1994, draft).

Should ecosystem models be adopted, product manufacturing would then turn into a collaborative effort, implying new models of interfirm organization to implement life cycle programmes and responsibilities.
Either if oriented to direct or indirect forms of responsibility towards its products, a manufacturer would be asked to relate in a different way to traditional operators of the industrial chain or to emerging actors depending on take-back systems, dismantling, recycling or reuse operations, discarded products and material circulation, treatment operations, recovered products and material flows, related service organization activities.
Even if not directly carrying out all these operations, a manufacturer would thus be involved in organizing forms of profitable cooperation with other operators.
Voluntary consortiums and voluntary agreements have already emerged as possible forms of this kind of partnerships, witnessing a willingness of companies to start systemic initiatives.
As already mentioned, partnerships could be formed:
. horizontally between companies within the same industrial sector to develop mutual cooperation and noncompetitive goals;
. horizontally on an interfirm base to connect different sectors;
. vertically with the actors of the industrial chain (suppliers, vendors, recyclers, dismantlers) to ensure the global handling of the product in any phase (production, delivery, sale, use, maintenance, reuse, possible recycling, disposal).

The different nature of products
The nature of each product is specifically different. The differentiation introduced by Allenby [6] provides a preliminary distinction. Among classes of products and materials it proves to be useful to differentiate between two classes of manufactured items:
- low design/high material items (from packaging to bulk chemicals, soaps, detergents ..)
- high design/low material products (i.e. automobiles, electronic equipment, ...)
It is disputable whether all durable products can be defined high design/low material or high design/high material products, but the differentiation is meaningful enough to stress the assumption that these products - when turning into waste or recyclable streams - generally have very different life cycles within the economy.
A synthetical inventory of differences could include:

<u>about product dispersion or dismission:</u>
¤ low design/high material items tend to be used up and dispersed in the environment rather discarded,
¤ high design/low material products are usually discarded (even if their final destination mostly remains undefined);
<u>about materials use:</u>
¤ materials use in low design product stream tends to be rather simple and in many cases (not always however) few materials are incorporated into individual items; at least in theory, recycling is fairly straightforward,

[6] Braden R. Allenby, *Integrating Environment and Technology: Design for Environment*, in Braden R. Allenby and Deanna J. Richards (eds.), *The Greening of Industrial Ecosystems*, National Academy Press, Washington D.C., 1994, p. 138.

¤ structure and materials use of high design products is highly complex and many materials are often present in a single product.
about life cycle:
¤ low design/high material items have (usually) a rather short life,
¤ high design products are usually durable. Furthermore, their physical integrity tends to survive their useful life;
about product and manufacturing process levels of complexity:
¤ associated upstream and downstream product and manufacturing process implications tend to be much more complex for high design products than for low design ones;
about the supplier/customer network:
¤ the supplier/customer network tend to be far more complex for high design products than for low design items;
Such differences have a number of relevant implications possibly affecting the potential structure of related industrial ecosystems:
(i) should the hypothesis of a closed or cyclic industrial system be feasible, circulating streams of high design products potentially involved on take-back systems would be very different from low design items: while low design streams could result into homogeneous material waste streams, complex producs would result into complex waste streams;
(ii) should take back or return system be based on financial incentives (deposit or cautions), the long life cycle of durable products would postpone the deposit return to such an extent to make it socially unacceptable;
(iii) being complex products durable, a technological gap would characterize the return route: complex products to be potentially recovered at present were manufactured years ago, and present ones will be dismissed in some years: how to harmonize this temporary gap would stand as a priority;
(iv) regulatory tools that may be effective in encouraging environmentally appropriate technology for low design items may be disfunctional or inefficient when applied to high design/low material products.

Waste stream managing as a nutrient web
Product waste stream management turns to be a crucial question. If we accept as a working assumption that an economic system should more closely resemble mature biological communities where the importance of activities concerning detritus is notable, more attention has to be paid to waste streams, explicitly conceiving them for reuse at other points of the industrial web.
Consumption and recycling of detritus, and the agents performing that function in the system, are critical to the efficiency of the system as a whole.
"*In contrast* - it is observed[7] - *the equivalent functions in human industrial structures - often handled by recyclers, scrap dealers, secondary smelters, or junk yards - have been slighted or regarded only as problems in many environmenatl policy debate. Manufacturing, with its resourse draws and effluent streams, and new products and techniques, has been the focus. Consider, for example, how much R&D and policy attention, and how many human and financial resources, are committed to manufacturing and consumption, and how few are directed toward reuse and recycling of products and materials. The gap, although perhaps narrowing, is still*

[7] Braden R. Allenby and William E. Cooper, *Understanding Industrial Ecology from a Biological System Perspective*, "Total Qality Environmental Management", Spring 1994, p. 347.

huge. Perhaps, then, the structural and functional importance of the waste reuse and processing component of industrial economies needs to be reevaluated. The current mindset, which tends to view waste collection, management, treatment, and recycling activities as secondary to "real" economic activity might be replaced with one that sees these activities as underpinning the movement toward a sustainable industrial structure".

Elementary interactions in industrial ecosystems

Should the possibility of industrial ecosystems be feasible their efficiency would depend not only on the availability of appropriate technological solutions but fundamentally on the global efficiency of the system as a whole: meaning an efficient nutrient web including entities acting as producers, scavengers, consumers of different levels.

Thus, the need to set efficient interactions stands as a priority. According to this perspective, linear manufacturing processes are axpected to be progressively substituted by technological solutions which should not be necessarily innovative in principles but capable of efficiently connecting industrial components.

A preliminary step in defining this web of relations could be to recognize the elementary interactions within an industrial system.

If we look at biology we learn that all the different interactions between pairs of species can be essentially classified into competition (a species having an inhibiting effect on the other), commensalism (each species having an accelerating effect on the growth of the other), predation (the predator having an inhibiting effect on the prey and the prey having an accelerating effect on the predator).

Competition is virtually the only category of interaction to be studied beyond the disciplinary borders of biology and developed for example by economics in the theories of perfect competition, imperfect competition or in the competition generated by the schumpeterian entrepreneur introducing innovations in the economic system. However, present forms of competition among producers are very different from the processes studied by orthodox economic theories.

For instance, the competitive advantage tends to be represented by the ability an organization demonstrates in reacting to sudden changes occurring in its environment.

Furthermore, competition may be sided by forms of symbiotical co-operation, commensalism or mutualism allowing advantages to any actor involved.

A definition for new industrial actors and their scope would any way be required. As emerging actors of the industrial chain, decomposers - for example - still stand as indefined entities: they can be recycling companies, authorized or non authorized shredders, pilot disassembling centres, dismantlers, hybrid manufacturers recycling their materials or products.

Such indefinition of respective roles strictly depends on the fact that their scope and scale have not been ufficially recognized.

In spite of a model of hybrid producer - acting as a producing and decomposing entity at the same time - a different approach could recognize decomposers as independent, even if related, entities of the industrial system: in this sense decomposers would stand as independent and self-organized elements of the industrial chain.

Such a vision opens relevant critical points; just to mention some of them:

- manufacturers would be asked to relate in a different way either to

traditional operators of the industrial chain or to emerging decomposers depending on take-back systems, dismantling, recycling, or reuse operations, discarded products and material circulation, treatment operations, recovered products and material flows, related service organization activities;

. new forms of profitable cooperation among the operators would have to be set;

. voluntary consortiums and voluntary agreements could be implemented as possible forms of partnership, driving companies to systemic initiatives;

. respective roles and responsibilities for each operator would have to be set, together with the definition of economic advantages;

. operators for clearing the products and materials at end of life and for their correct treatment should become authorized or recognized entities;

- decomposing entities could take the form of different level consuming entities (different from final consumers).

From closed loop recycling to industrial symbiosis

The possibility of extending the range of interfirm relations opens new possibilities for industrial loops.

Traditionally, closed-cycle policies may be appropriate for fairly simple products where it is economically, logistically and technically rather simple to start closing the loop. Such a possibility usually implies that waste products can be reconverted into the same typology, avoiding loss of performance over many cycles.

On the contrary, end-of-life materials and components derived from durable products - object of quick obsolescence either due to technological innovation or customer preferences - might be more profitably directed to a variety of destinations.

A further practice - coherent with durable products peculiar configuration - suggests that loop-closing takes the form of integrated industrial complexes, i.e. industrial symbiosis. In this case the loop could be closed by routing obsolete products, components, materials and energy from the sources to the other activities using them as feedstock.

Even if most current experiences of industrial symbiosis were mainly designed for efficient energy co-generation and re-use of waste materials flows [8], the possible extension of such a model to products of different nature appear promising, suggesting that waste components and materials derived from one industrial sector could be profitably re-used in other sectors, promoting efficient interfirm circulation of waste products.

[8] For instance the well-known case of Kalundborg ecosystem, in Denmark.

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