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Globalization, localization and the cost of complexity - a network approach

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Abstract

The process of globalization not only corresponds to a growth in terms of economic scale but is also associated with a profound change in the structural properties of the socio-economic networks towards more connectivity, more interactions, faster changes and greater uncertainties, in sum: more complexity. We apply network metrics to international trade data and show a clear trend towards a rise of complexity in the patterns of global economic exchanges. We suggest that some costs may be associated with this structural evolution such as (i) a suboptimal global efficiency of the economy and diminishing returns on investments (ii) limited accountability and predictability, favouring short-term decisions and (iii) increased risks of large-scale instabilities. We suggest that a sustainable alternative to these rising structural costs may lie in promoting local initiatives, as already demonstrated through numerous successful grassroots initiatives.

1. Introduction

Globalization embodies the ongoing process of growth of international trade and investment, wherein a growing number of countries are linked by increasingly intense exchanges in an open world trading system. Although this process is by no means recent, improvements in telecommunications and transportation and the spread of policies facilitating the exchange of goods, ideas and people across borders appear to bring the world closer. This tends to make physical location less of a factor in determining interaction between nations, firms and individuals. Proponents of globalization claim that the economy benefits from the efficiency gains that flow from superior resource-allocation decisions in more open markets (Bhagwati and Srinivasan, 1999**).** But numerous others voice their concerns at a system of exchanges that leads to uniformization and rising inequalities (Wilterdink, 2000). Although globalization implies that firms and individuals are inter-related in a multilevel network, its analysis is often limited to a mono-dimensional measure based essentially on the notion of scale. However, global growth has deepest implications on the structural characteristics of the socio-economic network. The evolution of these internal properties can be further explored through a quantitative analysis of the interconnections between parts of the system, and in particular its associated complexity.

This paper is organized as follows: In section 2 we suggest to consider the economic network as a Complex Adaptive System. Section 3 quantitatively defines the notion of network complexity through several metrics. These measures are applied in section 4 to international bilateral trade data, and show the evolution of the complexity of the economic network at the global scale in the second part of the 20th century. We discuss in section 5 how the observed this large-scale evolution is related to a complexification of the supply networks. In section 6 we show how complexity leads to several unaccounted economic costs and ultimately augments the risk of global catastrophic failures. We then propose in section 7 that a sustainable alternative to the rising costs of complexity can be found in the establishment of local socio-economic systems, which do not exclude distant interactions but favor small scale, manageable relationships. We provide real-world examples for the local production and distribution of food in section 8.

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2. The economy as a Complex Adaptive System

The economy is composed of a variety of agents (from individuals and corporations to national economies) embedded in the natural environment and connected through a number of social and economic interactions. Such a system can be modelled as a graph where the nodes represent the agents and the edges their inter-relationships. This network description is standard practice in social sciences (Scott, 2000; Freeman, 2004; Newman, Watts and Strogatz, 2002) and is becoming more frequent for the representation of economic systems (Potts, 2000; Foster, 2005). Network analysis comes with a powerful tool kit of quantitative measures that allow a thorough analysis of their inner structure: rather than focusing on a single agent of the economy, a network approach enables to obtain a description of the statistical properties of the inter-connections between agents. Networks can be described through a number of parameters characteristic of their topology, such as the *degree* (number of links per node) and their distribution, the distance between nodes (defined as the number of edges of a shortest path between them), the diameter, etc. (for a recent review, see Costa et al., 2008).

More elaborate descriptions of real-world connected systems may involve the description of the dynamical properties of their associated network, in particular how the agents and their relations evolve (e.g. how nodes and links are created and destroyed, or how nodes respond to a set of input signals) and how information, goods or services transit from agent to agent through non-linear, time-dependent connection patterns. This has led to the notion of Complex Adaptive Systems (CAS, Holland, 1995; Levin, 1998), characterized by their adaptation to change (e.g. locally, at the agent level) and their self-organization (at the network level), and the emergence of - often unpredictable - global behaviors from local interactions. The economy can be described as a CAS where agents (individuals, firms, etc.) related through trade relationships adapt their behavior at each moment as a function of changing environments (Matutinovic, 2005; Foster, 2005).

3. Definition of complexity

Another benefit of representing the socio-economic system as a graph is that we are able to draw in the literature from the existing associated measures of complexity. Complexity is an elusive concept and can lead to an array of definitions, depending on the chosen perspective: simplest measures are traditionally related to the cardinality of the network's subcomponents and relate for example to the number of nodes, the number of links, the connectivity. Other measures explore in more details the inner structure of the graph. These can be based on an estimate of the associated algorithmic complexity (Li and Vitanyi, 1991), on the number of subgraphs (Grone and Merris, 1988), on the graph information content (Standish, 2008), or on the node-node link correlation matrix (e.g. the offdiagonal complexity, Claussen, 2008). A useful comparative discussion on various graph complexity metrics can be found in Kim and Wilhelm (2008). Graph complexity measures have been exploited in various fields, from the characterization of algorithms and software processes (Lew et al., 1988), to organization theory (Fioretti and Visser, 2004) and business methods (Johansson, 2002).

We limit our discussion here to simpler measures of graph complexity that are indicative of an increase in the number of possible interactions between the agents of the economy. We stay in this sense close to Joseph Tainter's intuitive vision: "*Complexity is generally understood to refer to such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole. Augmenting any of these dimensions increases the complexity of a society".* (Tainter, 2006).

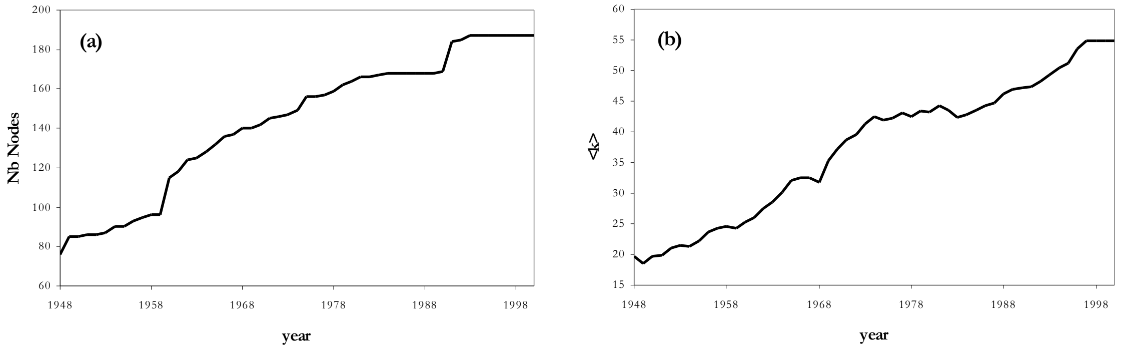
Having modelled the economy as an undirected unweighted network constituted of n nodes and l links, we will consider here the following parameters as indicative of an increased complexity. The scale of the graph, as described by the number of nodes n. The level of interactions between the nodes, measured by the average degree $<k>=l/n$. The link density D (the relative number of edges) defined as $D=(l-n-1)/(n(n-1)/2 - n+1)$. We also estimate the complexity of the network as the number of its different subgraphs. This measure can be roughly approximated by the number of spanning trees N_{ST} contained in the graph (Kim and Wilhem, 2008). Thanks to Kirchhoff's theorem we have $N_{ST} = det(L_{reduced})$, where $L_{reduced}$ is the Laplacian (i.e. the degree matrix – adjacency matrix) of the one-edge-deleted graph. The normalized subgraph complexity is given by: $C_{1,NST} =(N_{ST}-1)/(n^{1.68}-10)$ (Kim and Wilhem, 2008).

Note that we only use here complexity in close relation to size and connectivity of socio-economic networks. The term complexity is taken in its common meaning and characterizes a system composed of many parts in intricate relationships. We do not attempt at a precise definition of network complexity but rather focus on the consequences of an increase in the number of possible inter-relations between the agents of the system.

4. Network analysis of international trade data

The process of globalization can be represented by the intensity and variety of international trade relations among nations. Using data compiling the international bilateral trade relationships between countries over 53 years published in Gleditsch (2002), Bhattacharya et al. (2008) have derived for each year the corresponding trade network, each node representing a country, and the links expressing the import and export between countries. We have re-calculated some of these results in the context of our present study, with a focus on the measures related to the notion of complexity as defined above. These results show a systematic increase of the scale, the average degree and, to a lesser extent of the connectivity (Fig. 1a-c). The evolution of the network complexity measured as $C_{1,NST}$ (Fig. 1d) also grows monotonically from 1948 to 2000.

The trends shown in Figure 1 show unambiguously that the number of countries, the number and variety of interconnections has significantly increased during the second half of the 20th century. This tendency towards more interconnections - a trend that matches the standard definition of complexification and that is measured here through the properties of networks - is corroborated by the recent analysis of the evolution of international trade network in East Asia and Latin America (Kali and Reyes, 2006; Reyes et al., 2007).



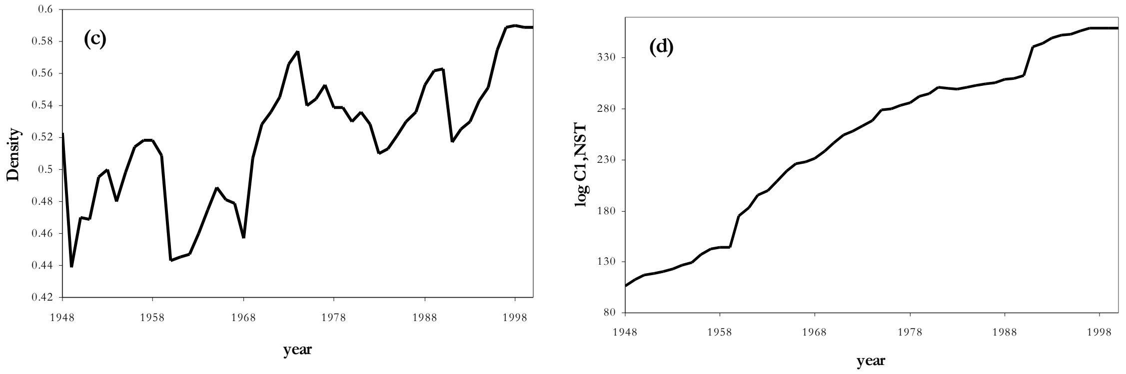


Figure 1: The evolution of the measures of graph complexity of the international trade network. The number of countries involved in the global trade network has increased from 76 in 1948 to 187 in 2000 (Fig. 1a); in the same period the average degree steadily grew from 19.7 in 1948 to 54.8 in 2000 (Fig 1b). The evolution of the link density is shown in figure 1c. The complexity measured as the normalized number of subgraphs $C_{1,NST}$ is shown in figure 1d.

5. Globalization and the complexification of the economy

The above analyses of the global trade in terms of network tend to point toward a steady increase of the variety of possible trade patterns, indicative of more complex systems of dependencies between countries. This global tendency is also reflected at lower levels of the economy. Indeed, if globalization entails an increase of the scale of the economy, it is also associated with the access to new markets, meaning that more products and services are exchanged, and as distance becomes less of a factor in determining interaction between agents of the economy, more connections are established between parts of the system. This may appear – at the user level – as a simplifying mechanism (as direct connections are created easier exchanges are made possible) but this is without accounting with the structural growth of the complexity of the economic network. Tucket et al. (2003) note that, as the scale of the economy grows, the number of possible trade options increase, leading to more complex decision-making processes and thereby imposing higher demands on organizations to operate (Williams, Maulla and Ellis, 2002). Furthermore, in a Complex Adaptive System perspective, signals (information, events, resources, etc.) transmitted nonlinearly through a larger network, lead to unpredictable large-scale consequences. Examples in the financial sphere abound (Kaminsky and Reinhart, 2000). The effects of these distant interconnections can be quite subtle and hard to link together, as in the case of 1998 earthquake in Taipei that disrupted the world's supply of computer chips and shut down the production lines of several PC manufacturers in the US (Tucket et al., 2003), or in the case of the 1997 East Asian financial crisis that affected the irrigation of farmland in the Rio Grande Basin through the presence of Intel's water intensive manufacturing plants near Albuquerque (Tainter, 2006). These secondary unforeseen consequences are another indication of the strongly interconnected nature of today's world economy.

Globalization not only increases the number of possibilities for the agents, but also sets up greater interdependencies at various scales of the economic network. A particularly relevant example in this respect is provided by the structure of modern international supply chains involving many foreign partners: events in the various countries participating in the chain can now directly influence the organization's functioning. This has been emphasized by a recent trend to outsource activities that were previously conducted within the organization (Peck et al., 2003). As a matter of fact, as Kumar and Stecke (2008) remark: "*Outsourcing, globalization, and decentralization are* *interlinked supply chain practices. By outsourcing, organizations motivate decentralization, while globalization provides options for the outsourced operation to be sourced globally. Outsourcing increases the number of external disruption points for a supply chain. For example, overseas shipments may pass through as many as 11 middle-men (Monahan et al., 2003), which greatly increases the risk of disruption. Outsourcing makes it harder for a company to foresee a brewing glitch in the supply chain (Murphy, 1999)".* Such a multi-level chain of consequences is characteristic of a strongly connected complex network and is getting more and more out of hand as the complexity of the interdependence patterns in the system grows.

This complexity is further augmented as today's large scale product structures are composed of a huge number of parts and subassemblies and therefore directly involve complex processes within the manufacturing. The planning, coordination of this web of suppliers, assemblers and distributors requires a huge effort (Guercini and Runfola, 2004) in particular in the case of Just In Time (JIT) supply chains (Martha and Subbakrishna, 2002). For example, electronic products such as computers use thousands of components. These components may come from hundreds of suppliers, from all over the world. A small disturbance in any one of these suppliers may significantly delay or even prevent the final product from reaching customers. This unpredictability is inherent to the nature of complex nonlinear systems and is strongly dependent on the topology of the economic network; a more complex set of inter-relations leading to a more unpredictable system. Examples of such systematic increase in complexity can be found at many different levels of the economic scale and in many different fields, from modern health care systems (Plsek and Greenalgh, 2008) to business environments (Rycroft, 2007) and R&D Networks (Roediger-Schluga and Barber, 2006). But few may be as emblematic and far reaching as the production and distribution of food: In trying to make sense of the food we eat, each of us face the complexity of global agri-food systems that link together diverse people, places and processes through product flows and multiple intermediaries. This theme will be further developed below.

6. The costs of complexity

Increasing the connectivity of the network structure may not be systematically counter-productive. As a matter of fact, at low connectivity levels, increasing the average degree of the nodes (i.e., the number of connections per node) may lead to positive returns: the addition of new links in the socio-economic network provides shortcuts between previously unrelated nodes and offers new chances for direct interactions. However this connectivity gain eventually comes at a price: As the number of links per node grows, it becomes indeed more difficult (i.e. computationally costly) to navigate the maze of connections; the benefit (a shorter average path between nodes) becoming dominated by the difficulty of exploring a growing number of links to find a path between two given nodes. In this sense, the cost of complexity grows faster than its associated benefits. On a study of over 130 biotech firms, Rycroft (2007) revealed that an increased level of partnerships (e.g. higher connectivity) was not linearly related to an increase in efficiency (measured as product development time): At low levels of connectivity new products were introduced faster, but as the level of networking increased, the temporal benefits tend to decline. At high levels of connectivity the cost of an additional cooperation outweighs the benefits and the product development time is actually increased. Similar conclusions are obtained in the field of supply networks (Choi et al., 2001). In the field of evolutionary biology, Kauffman (1993) modelled the evolution of organisms as adaptive walks on fitness landscapes (similar to hill climbing optimization, higher positions being the most favorable), where the topography of the landscape is determined by the interdependence between the organism genes. Kauffman revealed a non-monotonic relationship between the degree of interdependence and the height of the peak found during the search process, with a maximum at intermediate connectivities. The same model was used to conceptualize the innovation process as a search over a technology landscape and indicated that high degrees of interdependence (or in network language, high level of connections) lead to a sub-optimal outcome (Fleming and Sorenson, 2001; Rivkin, 2001). Tainter (1988) proposed that in any system of problem-solving, the initial returns on investment are high (simple and inexpensive solutions are chosen first), but as the highest return solutions are exhausted only more costly approaches remain. The marginal return is therefore expected to be maximum at intermediate levels of complexity.

An additional cost of increasing network connectivity - and an intrinsic hurdle of complex socio-economic systems - lies in the practical impossibility, as complexity grows, to safely evaluate the consequences of one's actions. To better understand this point in a CAS perspective, let us suppose that the systems evolves in a discrete time and that at each time step, information is processed by individual agents and exchanged through the network of connections. As time passes, the domain of influence of an initial (localized) perturbation (e.g. a change of the state of a node or the decision to pass some information to certain neighbors) spreads through the network and reaches a growing number of nodes. After N time steps the size of the domain of influence can be expressed as the number of possible interactions pathways (subgraphs) between the subset of nodes distant by at most N edges from the source node. How fast the domain of influence grows depends on the structural properties of the network, and in particular of its degree distribution. Let us further assume that each agent has a limited capacity C to follow the diffusion of the information on the network (C can be, for example, the maximum number of subgraphs than can be recorded at any time). Qualitatively, for a small number of agents NA_1 and average degree k_1, the number of subgraphs grows moderately at each time step and it is possible to record the various alternative interaction routes on a relatively long time span $T_R(NA_1,k_1)$. However, as the number of nodes NA_2 and degree k_2 increases, the number of affected nodes and the number of possible interactions pathways between them grows accordingly, and the maximum capacity C is reached in a smaller number of steps. The corresponding $T_R(NA_2, k_2)$ will therefore be shorter than $T_R(NA_1,k_1)$ and so will be the time span on which it will be possible to foresee the probable consequences of a change in the system (Fig. 2). The evolution of the structural properties of the interaction network towards more connectivity and more nodes therefore forces short-term views for finite capacity actors of the economy. A possible consequence will be to trade longer evaluation of future impact (or past actions) in a low complexity system, with short-term evaluation in a large scale, highly connected economy. A shift towards short-term decision-making process that has a dramatic impact on environmental systems, which timescales are usually orders of magnitude longer. The practical impossibility to track the consequences of one's actions in a complex system is even worsened as the system is constantly changing, unbeknownst to the agents. The system responds indeed to (i) endogenous changes due to the effects of past decisions (Beck 1994; Faucheux and Froger, 1995) and (ii) the introduction of new options pathways.

As medium to long-term states of the system become lost in the mist of combinatorial uncertainties, positive short-term decisions may not reflect their subsequent evolution and can eventually prove counter-productive. This is exemplified in the so-called *Rebound Effect* (Polimeni and Polimeni, 2006; Sorrell and Dimitropoulos, 2008) which can be attributed to a lack of forecasting capacity in a complex system. The occurrence of such paradoxical situations will undoubtedly become more frequent as the complexity of the system grows.

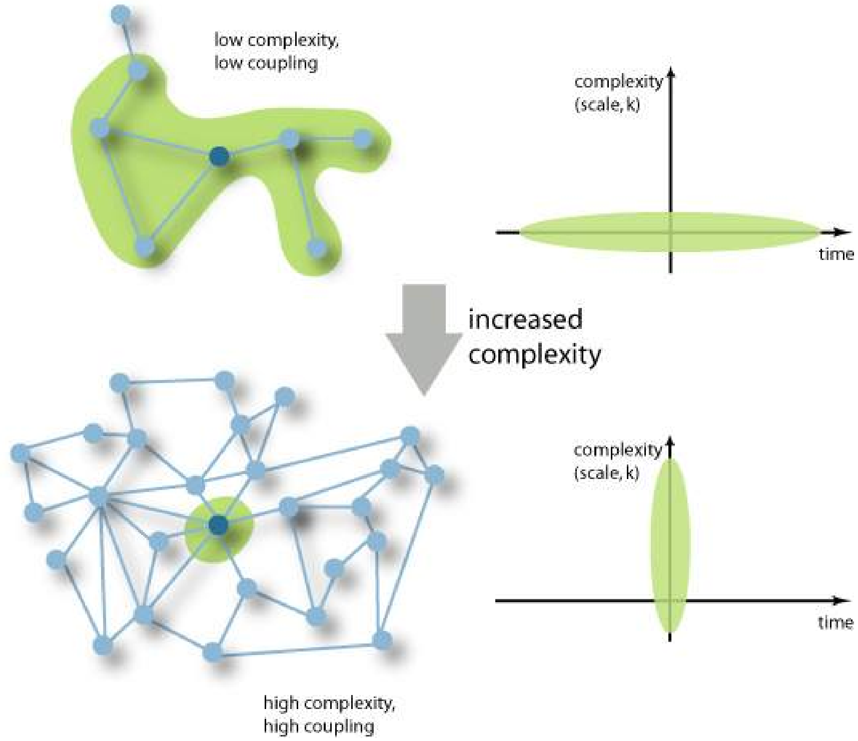


Figure 2: An illustration of the impact of network complexity on the forecasting interval. At low complexity, low coupling network, it is possible to follow the propagation of a perturbation on a significant portion of the network (or equivalently, for a long time span, as illustrated on the right-hand graph). As scale, connectivity (k) and coupling increases, it becomes more and more difficult to follow the perturbation, or equivalently it is only possible to forecast the evolution of the system on a short timescale.

The above analysis relates to following the probable future consequences of a change, but it also stands with respect to back tracking the present situation to its root causes. In complex networks there are so many possible pathways that causal relations are not immediately apparent, and the (past) time span within which one can relate cause and effects is reduced. In this sense, the accountability of each agent decreases as the system's complexity grows. To come back to the previous example of supply chains, it becomes increasingly difficult to attribute the responsibility of a faulty outcome to a particular intermediary as the complexity of the supply network grows (Choi et al., 2001).

We cannot meaningfully define policies or stir strategies before the causal chain of relationships has been clearly identified. In a complex network of interactions this causality link is blurred within the combinatorial explosion of possible dependency paths. Much effort is required to explore and weigh these options in order to identify and address the probable cause. This often corresponds to a situation where the problem under scrutiny has reached a catastrophic stage before it is widely recognized (e.g. the destruction of the ozone layer by CFCs, or the current situation with climate change). To quote Voss and Kemp (2005): "*In highly developed societies, most problems are the unintended result of past choices*".

As complexity of the economic network increases, it becomes as difficult to estimate the medium to long-term effects of our current decisions as to measure the impact of our past actions. We are left confined in an ever smaller temporal domain within which the causal chain of events can be followed and responsible decision taken.

In a largely connected, large scale system, not only do unintended outcomes become more frequent, but their consequences become more volatile and risk affecting a larger number of agents. In other words, large-scale catastrophic events become more probable. Results from network analysis, and in particular from the field of theoretical ecology, help justify this statement. According to the May-Wigner stability theorem (May, 1973), increasing the complexity of a random network inevitably leads to its destabilization. Although this approach, based on the study of the local asymptotic stability of simple random Lotka-Volterra networks (i.e. limited to small perturbations from an assumed equilibrium), had raised some critics[1], it has been recently shown to remain quantitatively valid for more realistic network topologies (Sinha, 2004), where no initial equilibrium is assumed (Chen and Cohen, 2001; Sinha and Sinha, 2004). The evolution of the network's *long-term global stability* has also been shown to follow May-Wigner's criterion (Sinha, 2004). This indicates that the complexity-stability relationship holds in a large variety of situations and that, as the connectivity of the socio-economic system increases, the chance that small perturbations disrupt the entire system becomes highly probable (Perrow, 1984; Sovacool, 2008; Fisk and Kerhervé, 2006).

7. Managing complexity ?

We have advanced above that the observed increase in scale and connectivity of the common economic networks induces greater uncertainties and risks of large-scale instabilities. The question then arises of how to manage complexity and its consequences. Two sets of strategies can be considered: adaptation and mitigation. Adaptation deals in this context with our capacity to cope with the consequences of a growth of complexity (i.e. to (at least) maintain a certain level of efficiency as the size and connectivity of the economic network increases). The results in Rivkin (2000) seem to indicate that it may not be possible to keep controlling the system globally as complexity grows: above a certain level of connectivity, the problem of optimizing the system (e.g. finding the best strategy amongst all possible routes) becomes NP-complete (computationally too costly to be manageable). Moreover our standard problem-solving methodologies at the core of the adaptation strategy are actually sources of complexity and, as stated earlier, due to increased difficulty to forecast the probable medium-term consequences, may actually be the cause of future problems. Furthermore, by letting complexity grow, one faces the risks of lowering the system's resilience in the sense of increased catastrophic failures and global spill over effects beyond our control. In this view, adaptation to the consequences of a rise in complexity (such as greater volatility, greater uncertainties, larger maintenance costs) without internalizing the notion of complexity might prove counter-productive. Mitigation on the other hand, tends to address the problem at its roots, by tackling the causes before they develop and not by limiting the response to the symptoms. In the context of this study, this means reducing the level of complexity of the system. A possibility to limit the complexity and the large scale dependence induced by the global economy – with the drawbacks we have underlined above – is to reduce the *size* of the network of inter-relations between agents of the economy. This can be achieved by a localization of the economy. Reducing the distance between producer and consumer (thereby keeping the supply-chain at a manageable scale) allows indeed to keep a better understanding of the consequences of one's actions, both socially and on the surrounding environment to which the individual is attached. Some initiatives are already going in this direction.

8. Local alternatives to complexity

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[1] (i) a local asymptotic analysis is indeed only valid for small neighborhoods around the equilibrium, (ii) it depends on the choice of interaction coefficients which vary considerably in real networks, and (iii) it excludes complex dynamical behaviors such as periodic and chaotic solutions, which may be consistent with community persistence.

8.1 Localization

Localization of the production-consumption patterns is a concept nowadays often present in the popular media. In a way, the notion of *local* has become ‘‘beautiful,’’ as was *small* in the 1970s and 1980s (Schumacher, 1973), *organic* in the 1990s or -at least in the US- *wilderness* early in the last century (Dupuis and Goodmann, 2005). But beyond the gimmick and the fashion, local economies do offer examples of sustainable alternatives to global networks, dependent on ever more complex economic systems. These solutions emphasize, as much as possible, local production for local consumption and strike a healthier balance between trade, local production and local ownership using local labor and materials within ecologically stable democratic models (Mander, 2007). Localization is often seen as a process, which shifts emphasis from the politics of space to a politics of the place in place (Sachs, 1992).

Such initiatives are numerous, from people working on reforming, inventing, developing new food systems[2], alternative businesses[3], independent local monetary and banking systems[4], to independent small scale media[5], local adapted technology and farming[6], personal attempts at a simpler life[7], or the development of community initiatives as a response to Peak Oil and Climate Change[8]. Some of these initiatives are embedded in political, social movements such as the De-growth Movement (in France and Italy), the Relocalization Network (in the US) or the Transition Network (in the UK).

These alternatives are the answers to different individuals’ or communities’ concerns regarding various issues such as Peak-Oil, Climate Change, Food Insecurity, etc. Nevertheless they directly or indirectly participate in reducing the size of the network of inter-relation between agents of the economy. They act therefore as a practical means to decreasing the complexity of the economic network.

8.2 The example of local food systems

Lacy heralds that numerous scholars and practitioners are currently trying to redress the imbalances in the global food system through the development of locally based alternatives. (cited in Born and Purcell, 2006). One of these alternatives is the *Community Supported Agriculture* (CSA, or AMAP in France, Teikei in Japan), which refers to a particular relationship between farmers and consumers where the consumer pays a share of the farm’s expenses in return for a share of the harvest. It enables small-scale commercial farmers to have a successful, small-scale closed market. By providing a guaranteed market through prepaid annual sales, consumers essentially help finance farming operations, limiting the number of connections to the complex global market. Typically, CSA farms are small, independent, labor-intensive, family farms. In France, the first CSA started in 2001 and in 2007 the total number of CSA was close to 1000 (Olivades, 2008). In North America 1200 CSA have sprung up since 1985 (Robyn Van En Center). Concerning farmers’ markets, they have increased in the USA from 1755 in 1994 to 4385 in 2006

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[2] Community Supported Agriculture, Box Scheme, Community Garden, Farmer’s market, Urban Gardening, School Gardens, Seeds Saving, Seeds Banks.

[3] Business Alliances for Local Living Economies (BALLE), Community Cooperative, Buy Local Campaigns.

[4] Local Currency, Local Exchange Trading Systems (LETS), Credit Union, Community bank

[5] Local TV, newspaper and radio.

[6] Natural Building, Appropriate technology, Alternative medicine, Permaculture.

[7] Downshifters, Ecovillage, the Voluntary Simplicity, Back to the Land movement, Cultural Creatives.

[8] Transition Town, Post Carbon Cities, Community Powerdown, Oil Depletion Protocol.

(USDA). The UK went from having no farmers' market at all in the mid-1990s, to having more than 270 at the end of the decade (Norberg-Hodge et al., 2002).

Douthwaite (1996) identifies three reasons why such initiatives are spreading rapidly. The first one is that only within local, diverse, small-scale food production can one be reasonably sure about the safety and the content of what one eats (Henrickson and Heffernan, 2002). Friedmann, a keen observer of the globalization of food, underlines this point: ''*only food economies that are bounded, that is, regional, can be regulated because they bypass the corporate principles of distance and durability''* (cited in Dupuis and Goodman, 2005). Local food supply chains are indeed low complexity networks (small scale, low global connectivity). In the case of CSA and farmers' markets, the consumer is in direct, face to face, contact with the producer. Furthermore Hartwick argues that a local food system entails "*a greater realization of connections between consumers, places, and networks*[9] *[which] allows an ethical politics of consumption"* (cited in Dupuis and Goodman, 2005). Indeed, Bill Mc Kibben noted, for example, that shoppers have "*ten times as many conversations at farmers markets as they do at supermarkets"* (McKibben, 2007). A small scale, low complexity network discourages carelessness or deceit, the producer and the consumer being offered a market concentrated within a limited region, within a restrained population. The accountability of a faulty outcome to a particular supplier or consumer in a simplified food supply chain becomes an easier task.

The second reason is that large scale food production for a global market, leaves communities dependent on a socio-economic system related to many parameters beyond any local control (such as food stock market, direct/indirect subsidies, global competition, currency speculation). For example as the Andersonville Chamber of Commerce showed every $100 spent with a local firm leaves $68 in the Chicago economy; $100 spent at a chain store leaves $43 in Chicago (Civic Economics, 2004). The money invested locally[10] stays within the local area and does not fuel an unstable global network. A small scale, relatively low connected economic network reduces the probability of unexpected outcomes. Consequences of local actions are more likely to remain local and will not tend to spread unpredictably over long distances and risk affecting a large number of agents.

The third reason is for the people to look for a more sustainable system. People involved in a local food system are aware of the unsustainability of intensive farming. The more localized a food system, the less the need for global transportation and communication networks, for long supply-chain, for complex technologies, producers and consumers being closer to each other (Norberg-Hodge, 2002). It allows also a diversification of the production adequate with the respect of biodiversity. In a simplified, local, socio-economic system, it becomes easier to estimate the impacts of past actions, and it remains possible to foresee their outcome. As Tainter (2006) notices: "*Being unaware of larger forces that affect them, local societies lose control of their destinies. As local autonomy disappears, dependency and environmental deterioration follow"*. Scaling down economies and decreasing the complexity of socio-economic networks has also the multiple benefits of bringing control, understanding and foreseeability over the use of natural resources. Local economies give the opportunity to see the effects of everyone's actions, a situation practically impossible in modern complex societies.

9. Conclusion

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[9] It is to be noted that here Hartwick refers to living web of interdependencies, and not a network composed of highly connected global economic agents spread all over the world.

[10] Local currencies and LETS are good examples of monetary systems keeping money in a community.

As discussed above, a network analysis of international trade data shows unambiguously a trend towards more complex sets of relations in the global economic network. Some of the costs that may result from an increase in both the degree of connection and the scale of the economy include: (i) a suboptimal global efficiency of the system and diminishing returns on investments, (ii) limited accountability and predictability, favoring short-term decisions and (iii) increased risks of large-scale instabilities. These costs are directly related to the structural properties of the network, and cascade down from the global scale (country to country exchanges) to smaller entities (firms, individuals). We suggest that a sustainable alternative to these rising structural costs may lie in promoting local initiatives, as already demonstrated through numerous grassroots initiatives.

Although by no means fully integrated in the socio-economic debate, the theory of complexity can be an effective tool to all social and political organizations working towards sustainability. Bringing this tool to the public sphere, will undoubtedly help policy makers and citizens alike internalize the costs associated with a global economy largely out of our control, and hopefully choose a more local, manageable and responsible path.

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References

Battini, D., Persona, A. and Allesina, S., 2007. Towards a use of network analysis: quantifying the complexity of Supply Chain Networks. International Journal of Electronic Customer Relationship Management. 1(1), 75-90.
Bhattacharya, K. et al., 2008. The International Trade Network. in Econophysics of Markets and Business Networks, New Economic Windows Serie, Springer. 139-147.
Born, B., Purcell, M., 2006. Avoiding the Local Trap-Scale and Food Systems in Planning Research. Journal of Planning Education and Research. 26, 195-207.
Chen, X., Cohen, J. E., 2001. Global Stability, Local Stability and Permanence in Model Food Webs. Journal of Theoretical Biology. 212(2), 223-235.
Choi, T.Y., Dooley, K.J. and Rungtusanatham, M., 2001. Supply networks and complex adaptive systems: control versus emergence. Journal of Operations Management. 19, 351-366.
Civic Economics, 2004. The Andersonville Study of Retails Economics, Executive Summary.
Costa, L. da F., Rodrigues, F.A., Travieso, G. and Villa Boas, P.R., 2007. Characterization of complex networks: a survey of measurements. Advances in Physics. 56, 167-242.
Claussen, J.C., 2008. Offdiagonal Complexity: A Computationally Quick Network Complexity Measure - Application to Protein Networks and Cell Division. in Mathematical Modeling of Biological Systems, Volume II, Epidemiology, Evolution and Ecology, Immunology, Neural Systems and the Brain, and Innovative Mathematical Methods, Deutsch A. et al. (eds), Birkhauser, Boston, 279-287.
Douthwaite, R., 1996. Short Circuit – Strengthening Local Economies for Security in an Unstable World. Green Books.
Dupuis, M.E., Goodman, D, 2005. Should we go home to eat?: toward a reflective politics of localism. Journal of Rural Studies. 21, 359–371
Faucheux, S., Froger, G., 1995, Decision-Making under environmental uncertainties. Ecological Economics. 15, 29-42.

Fioretti, G., Visser B., 2004. A cognitive interpretation of organizational complexity. E:CO. 16(1-2), 11-23.

Fleming, L., Sorenson O., 2001. Technology as a complex adaptive system: evidence from patent data. Research Policy. 30, 1019-1039.

Foster, J., 2005. From simplistic to complex systems in economics. Cambridge Journal of Economics. 29, No 6, 873-892.

Freeman, L.T., 2004. The Development of Social Network Analysis: A Study in the Sociology of Science. Emprirical Press.

Gleditsch, K.S., 2002. Expanded Trade and GDP Data. Journal of Conflict Resolution. 46, 712-24.

Grone, R. and Merris, R., 1988. A lower bound for the complexity of a simple graph Discrete Mathematics. 69, 97-99.

Guercini, S. and Runfola, A., 2004. Sourcing strategies in clothing retail firms: product complexity versus overseas supply chain. Journal of Customer Behaviour. 3, 305-334.

Hendrickison, M.K., Heffernan, H.D., 2002. Opening Spaces through relocalization: Locating potential Resistance in the Weaknesses in the Global Food System. Sociologia Ruralis, 42 (4).

Holland, J., 1995. Hidden order: how adaptation builds complexity. New-York, Helix Books

Johansson, A., 2002. Entropy and the cost of complexity in industrial production. Exergy. 2, 295-299.

Kaminsky G. and Reinhart C., 2000. On crisis, contagion and confusion. Journal of International Economics. 51(1), 145-168.

Kauffman, S., 1993. The Origins of Order. Oxford University Press; New-York

Kumar, S. and Stecke K.E., 2008. Sources of Supply Chain Disruptions, Factors that Breed Vulnerability, and Mitigating Strategies. Journal of Marketing Channels. 16 (to be published)

Levin, S.A., 1998. Ecosystems and the Biosphere as Complex Adaptive Systems. Ecosystems. 1(5), 431-436.

Lew, K.S., Dillon, T.S. and Forward, K.E., 1988. Software complexity and its impact on software reliability. IEEE Trans. on Software Engineering. 14(11), 1645-1655.

Li, W. and Vitanyi, P.M.B., 1991. Combinatorics and Kolmogorov complexity. in Proceedings of the sixth annual IEEE conf. on structure in complexity theory, Springer Verlag.

Mander, J., (editor) 2007. Manifesto on Global Economic Transitions. International Forum on Globalization.

Martha, J. and Subbakrishna, S., 2002. Targeting a Just-In-Case Supply Chain for the Inevitable Next
Disaster. Supply Chain Management Review, 18-24.

Matutinovic, I., 2005. Microeconomic foundation of business cycles. Journal of Economic Issues. 39(4), 867-897.

May, R. M., 1973. Stability and Complexity in Model Ecosystems. Princeton Univ. Press, Princeton, NJ.

McKibben, B., 2007. Deep Economy. New York, Henry Holt.

Monahan, S., Laudicina, P. and Attis, D., 2003. Supply Chains in a Vulnerable, Volatile World. Executive Agenda. 6(3), 5-16.

Murphy, T. 1999 JIT When ASAP Isn't Good Enough Wards Auto World. 35(5), 67-73.

Newman M. E. J., Watts D. J. and Strogatz S. H., 2002. Random graph models of social networks. Proc. Natl. Acad. Sci. USA. 99, 2566–2572.

Norberg-Hodge, H, Merrifield, T, Gorelick, S, 2002. Bringing the Food Economy Home-Local alternatives to global agribusiness. Zed Books.

Olivades, http://www.olivades.com/Creamap/Presentation.html, retrieved July 5th 2008

Peck, H., Abley, J., Christopher, M., Haywood, M., Saw, R., Rutherford, C., and Strathern, M., 2003. Creating Resilient Supply Chains: A Practical Guide. Centre for Logistics and Supply Chain Management, Cranfield School of Management, Cranfield, UK

Perrow, C., 1984. Normal Accidents, Yale Univ. Press
Plsek, P.E. and Greenalgh, T., 2001. Complexity science: The challenge of complexity in health care. British Medical Journal. 323, 625-628.
Polimeni, J.M. and Polimeni, R.I., 2006. Jevon's paradox and the myth of technological liberation. Ecological Complexity. 3, 344-353.
Potts, J., 2000. The new evolutionary microeconomics – complexity, competence and adaptive behavior. Edward Elgar Publishing.
Reyes, J., Schiavo, S. and Fagiolo, G., 2007. Using complex network Analysis to assess the evolution of international economic integration: the cases of East Asia and Latin America. Lab. of Economics and Management Working paper Series (2007/25), Sant'Anna School of Advanced Studies, Pisa, Italy.
Rivkin, J.W., 2000. Imitations of Complex Strategies Management Science, Vol. 46, No 6, 824-844.
Robyn Van En Center, Community Supported Agriculture, at Wilson College, http://www.wilson.edu/wilson/asp/content.asp?id=804; retrieved July 5th 2008
Roediger-Schluga, T. and Barber, J., 2006. The structure of R&D collaboration networks in the European Framework Programmes. United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology, No. 036.
Rycroft, R.W., 2007. Does cooperation absorb complexity? Innovation, networks and the speed and spread of complex technological innovation. Technological Forecasting and Social Change. 74, 565-578.
Sachs, W., (editor), 1992. The Development Dictionary – A Guide to Knowledge as Power. Zed Books.
Schumacher, E.F., 1973. Small Is Beautiful: Economics as if People Mattered. Harper Perennial.
Scott, J.P., 2000. Social Network Analysis: A Handbook. Sage Publications Ltd.
Sinha, S., 2005. Complexity vs Stability in Small-World Networks. Physica A: Statistical Mechanics and its Applications. 346(1-2), 147-153.
Sinha, S. and Sinha, S., 2005. Evidence of universality for the May-Wigner stability theorem for random networks with local dynamics. Phys. Rev. E: Stat. Nonlin. Soft Matter Physics. 71(1), p. 020902.
Sorenson, O., Rivkin, J.W. and Fleming, L., 2006. Complexity, networks and knowledge flow Research Policy, 35, 994-1017.
Sorrell, S. and Dimitropoulos, J., 2008. The rebound effect: microeconomic definitions, limitations and extensions Ecological Economics. 65, 636-649.
Sovacool, B.K., 2008. The cost of failure: A preliminary assessment of major energy accidents, 1907-2007 Energy Policy. 36, 1802-1820.
Standish, R.K., 2008. Concept and Definition of Complexity in Intelligent Complex Adaptive Systems, Yang, A. and Shan, Y. (eds), IGI Global: Hershey, PA, 105-124.
Tainter, J., 1988. The collapse of complex societies Cambridge University Press
Tainter, J., 2006. Globalization Then and Now: Increasing Scale Reduces Local Sustainability. USDA Forest Service Proceedings RMRS-P-42CD. 565-572.
USDA, Website http://www.ams.usda.gov/farmersmarkets/ retrieved July 5th, 2008.
Williams, T., Maulla, R. and Ellis, B., 2002. Demand chain management theory: constraints and development from global aerospace supply webs Journal of Operations Management. 20, Issue 6, 691-706.