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■ *Research Paper*

Squaring the Circle: In Quest for Sustainability

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Development has been the main strategy in addressing the problem of sustainability since at least the mid-1980s. The results of this strategy have been mixed, if not disappointing. In their objections to this approach, critics frequently invoke constraints imposed by physical reality of which the most important one is entropy production. They question the belief that technological innovations are capable of solving the problem of sustainability. Is development the right response to this problem and is the current course capable of attaining sustainability? The article examines closely and critiques the principal theoretical objection to sustainable development that emphasizes physical constraints, and more specifically entropy production. It also offers a critique of the current approach to sustainable development. The article advocates a systems approach as a way to anchor a broad consensus in the ongoing sustainability debates. Copyright © 2014 John Wiley & Sons, Ltd.

Q7 **Keywords** sustainability; sustainable development; entropy production; complex systems; Gödel's proof~~; and construction of knowledge~~

Sustainability has been one of the most important topics in public discourse over the last several decades (Mebratu, 1998; Rees, 2002; Prugh and Assadourian, 2003; Edwards, 2005). It is a subject of books and articles, a focus of talk shows and discussions in the media, and a major preoccupation of politicians, pundits, and scholars. Conversations about environment often take place around dinner tables in ordinary households. The number of government and nongovernmental organizations that deal with issues of sustainability and environmental protection has grown exponentially in recent decades. Many international organizations at the highest level concentrate their efforts and resources on problems related to sustainability. Hardly a day goes by without one hearing something about climate change or levels of CO^2 in the atmosphere. Sustainability has arguably become the most important social and political issue of our time, right next to the economy and international conflicts.

Definitions of sustainability and its derivatives (such as sustainable development and economic sustainability) abound (cf. Clark, 2007; Jenkins, 2010; Kuhlman and Farrington, 2010). I use the term 'sustainability' in this paper in its most basic sense as the capacity of a system to sustain itself. There are numerous definitions of systems, and a

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thorough coverage of these definitions and their permutations is certainly beyond the scope of this paper. As a working definition for the purposes of this paper, I will use the word 'system' in the following sense with all its imperfections: a system is a set of integrated and interrelated components that perform operations that complement each other and have a common regulatory operation. The system operates in its environment that is reflective of the system but has its own regulatory operation. Systems may evolve and may gradually become components, or subsystems, of a new system, forming a hierarchy of systems and subsystems. Each level of this hierarchy represents a distinct level of organization with its own forms.

A large and constantly growing number of people subscribe to the notion that our civilization in the form that it exists today may be unsustainable. This notion has considerable staying power. Scientists from many different fields marshal massive data and use them in their studies—some more alarmist[1] than others—to demonstrate that our environment is in a state of precipitous decline and, if no major changes are made, will reach a level of degradation that will make our life on this planet very difficult, if not indeed impossible (Gowdy, 2007; Edgerton *et al*., 2008; Hale, 2010; Fan *et al*., 2013; Zickfeld *et al*., 2013).

The global community has not been passive in the face of alarming warnings about this threat to our civilization but mounted a vigorous response. Much has changed since the discussion of sustainability started. In an effort to slow down or even reverse the degradation of our environment, a whole set of policies have been enacted on various levels —from international and national to regional and local, to industries and individual enterprises. Ordinary people are taking very seriously environmental pollution, global warming, or the elevated levels of CO^2 in the atmosphere. They have changed their habits and patterns of behavior. There are new attitudes that have taken shape in the last few decades among broad strata of the global population.

Since at least the early 1980s, sustainable development was the leading trend in global efforts to assure the sustainability of human civilization. Yet despite these efforts, sustainability still remains an elusive goal. There is a growing sense of frustration on the part of many who begin to suspect that sustainability of our civilization may not be an attainable goal; and the problem is not this or that policy or human flaws, it may not be attainable in principle because some immutable laws of nature. Dissipation of energy, or entropy, which naturally occurs in our environment and the universe and which is accelerated by our recklessness, is frequently invoked in this connection.

This article will examine the problem of sustainability. It will pay particular attention to and will offer a critique of the claim that sustainable development is a flawed concept that is totally oblivious to the inexorable force of entropy. Finally, it will outline what I see as a more realistic approach towards the issue of sustainability.

DISCOURSE ON SUSTAINABILITY

The general discourse on sustainability has a long history that goes back several centuries, at least to the age of the Enlightenment if not before (Ayres, 2008). In its present form, it emerged at the end of the 1960s and the beginning of the 1970s. In 1972, for example, the well-known report entitled *Limits to Growth* (Meadows *et al*., 1972) prepared for the Club of Rome[2] raised questions regarding the capacity of the Earth to meet the rapidly growing needs of the global population. That very same year, the United Nations (UN) held its first major conference on sustainability in Stockholm.

Since then, the interest towards environmental problems has grown very steadily throughout the world. Protection of the environment and economic development have become permanent items on the agenda of many national governments and international organizations. The Organization for Economic Cooperation and Development has set up, for example, a special Environmental Directorate,

[1] On the extreme alarmist side, for example, Tom Murphy, a physicist from the University of California in San Diego, offers calculations on his popular blog *Do the Math*, showing that if our energy usage grows by 2.3% a year, in 400 years, the average temperature on the Earth will be above the temperature of boiling. In other words, we will cook ourselves (http://physicsworld.com/cws/article/print/2013/jul/18/web-life, accessed on 18 July 2013).

[2] The Club of Rome is a global think tank that was organized in 1968 and includes current and former Heads of State, UN officials, prominent scientists, and public figures.

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and the UN has launched its own full-scale environmental programme (United Nations Environment Programme) (Ayres, 2008). Many developed countries, including the USA, created special government agencies for environmental protection (Ayres, 2008). The last two decades witnessed inauguration of the professional journals dealing exclusively with issues of economics and environment: *Journal of Environmental Economics and Management*, *Environmental and Resource Economics*, *International Journal of Sustainable Development*, *International Journal of Sustainable Development and World Ecology*, *International Review of Environmental & Resource Economics*, and many others.

The report entitled 'Our Common Future' published in 1987 by the World Commission on Environment and Development operating under the auspices of the UN was a milestone that brought the discussion of sustainability to a new level of urgency (Our Common Future, 1987). Following this report, the issue of sustainability, as one author put it, 'rose to the prominence of mantra—or a shibboleth' (Daly, 1996; as quoted in Mebratu, 1998, p. 494). Since 1992, when the UN held its first world conference on sustainable development and environmental protection in Rio de Janeiro, such conferences (nicknamed Earth Summits)[3] became major forums that attract many world leaders (cf. Clémençon, 2012; Haines *et al.*, 2012; Karlsson-Vinkhuyzen, 2012; Report to the Secretary-General of the UN, 2012).

Despite the growing interest towards the issue of sustainability, the results of the nearly three decades of intense discussions and concerted efforts by national governments, international agencies, public organizations, and an army of committed activists and academics have been, by a widespread admission, less than satisfactory (*The Guardian*, 2012). The problem of sustainability proved to be so tough that one author compared it with squaring the circle, suggesting that this problem may very well prove to be unsolvable (Robinson, 2004).

Many participants of the environmental movement and observers who comment on environmental problems have expressed their disappointment with the pace of change in dealing with the environmental degradation. Responses to the recent UN Conference Rio + 20 are eloquent in characterizing this forum as a failure. The nongovernmental organization community found the final document entitled 'The Future We Want' adopted by the conference to be deeply disappointing and 'out of touch' (Clémençon, 2012; UNCD, 2012). Kumi Naidoo, Executive Director of Greenpeace International, called the conference a 'failure of epic proportion' and its final statement 'the longest suicide note in history' (Clémençon, 2012; *The Guardian*, 2012). Even if these assessments may be to some extent biased and exaggerated, they still point to a very disturbing state of affairs. There is a very substantial body of research that illustrates the continued environmental degradation and climate change and provides eloquent support for such assessments (Edgerton *et al.*, 2008; Ellis, 2013; Moraes *et al.*, 2013). This lack of progress naturally raises questions as to the viability of our current approaches to sustainability; moreover, it creates serious doubts in the minds of many as to whether achieving sustainability is even a realistic goal (Robinson, 2004).

Sustainable development is currently the dominant approach towards the problem of sustainability. This approach is particularly popular in the government and business circles (Robinson, 2004). Its proponents subscribe to the notion that continued development is the key to resolving the problem of sustainability (cf. Castro, 2004; López *et al.*, 2007; Vivien, 2008). The Brundtland report is generally agreed to be the most influential document representing this line of thinking (Our Common Future, 1987). Adopted in 1987 by the UN World Commission on Environment and Development, the document calls for accelerated economic development and improvement in social and environmental conditions around the world as the path towards sustainability. The report unambiguously connects the solution of our ecological problems with the continued development of the human system. The Brundtland vision rests on three main pillars: interlinkages, intergenerational equity, and dynamic efficiency (Burnett *et al.*, 2011). In the formulation of the report, sustainable development represents those paths of social, economic, and political progress that 'meet the needs of the present without compromising the

[3] Two additional such conferences entitled Rio + 10 and Rio + 20 were held in Johannesburg in 2002 and in Rio de Janeiro in 2012.

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ability of future generations to meet their own needs' (Our Common Future, paragraph 27).

Critics of sustainable development abound (Heal, 2000; Gunder, 2006; Luke, 2006; Vivien, 2008; Martínez-Alier *et al*., 2010). Their numbers are particularly strong among academics and nongovernmental organizations (Robinson, 2004). They charge that the approach outlined in the Brundtland report does not resolve the fundamental tension between its two principal goals: growth economy and sustainability of natural resources and environment (Kuhlman and Farrington, 2010). The alternative, in their view, lies in recognizing and respecting what they see as constraints imposed on human civilization by the physical conditions of our environment.

The camp of the opponents of sustainable development includes many groups that have very different perspectives, but they do share some things in common. They largely belong to the 'limits to growth' school of thought, and their common denominator is the rejection of growth models. Steady-state economics and de-growth are two very prominent perspectives in this camp (Daly, 1993; Daly, 2005; Vivien, 2008; Levallois, 2010; Martínez-Alier *et al*., 2010; Kallis *et al*., 2012). There are several influential organizations that represent voices of the critics, with the Club of Rome being probably the best known of them.

The role of the opponents of sustainable development has so far been rather limited. Their principal contribution to the debate has been 'to dramatize the issue of environmental constraints by projecting a drastic slowdown and even collapse' if we make no changes in our patterns of consumption and in our use of natural resources and sinks[4] (Bhaskar and Glyn, 1995; Mebratu, 1998, p. 503). Representatives of this school argue that humankind is now very close to the growth limits that Donella Meadows first outlined in 1972 (Meadows *et al*., 1972; Meadows, 1992; Meadows *et al*., 2004). They point out that the consequences of our present course are becoming increasingly visible in the current scarcity of food and oil, the crisis of the global financial systems, and the lack of faith we have in the dominant political and economic systems (Mebratu, 1998; Espinosa, 2011).

The widespread disappointment caused by the continued deterioration of our global environment and the voices of critics have reinvigorated the debate on sustainability. As it expands, the debate raises fundamental theoretical issues that go to the very heart of the currently dominant perspective on sustainability. Does sustainable development have a sound theoretical foundation? Is it a viable goal? Is it the right time to consider other alternatives before it is too late?

THE ENTROPY ARGUMENT AGAINST SUSTAINABLE DEVELOPMENT

Objections to sustainable development pivot on one basic argument: nature and our environment impose fundamental constraints on our development. They assert that there are ultimate limits as to what our environment and its resources can support in terms of size of the population and consumption patterns. Central to this argument is one important fact about the physical reality in which we live. This fact is related to dissipation of energy, or entropy production. In the words of Jeremy Rifkin, 'Evolution means the creation of larger and larger islands of order at the expense of ever greater seas of disorder in the world. There is not a single biologist or physicist who can deny this central truth....' (Rifkin, 1989, as quoted in De Pascale, 2012, p. 295).

Human civilization is a dissipative system. It sustains itself by consuming low-entropy inputs and producing high-entropy outputs in its environment. High entropy can manifest itself in different ways: either as scarcity of resources or unavailability of environmental sinks or some combination of the two. But whatever form it takes, these unacceptable levels of entropy in our environment will make it very hostile to human life or even totally unsuitable for biological organisms.

The principal theoretical underpinning for this line of thinking is the second law of thermodynamics that states that in dissipative systems, entropy can never be less than zero. Entropy can

[4] An environmental sink is an area or part of the environment in which, or a process by which, one or more pollutants is removed from the medium in which it is dispersed.

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only grow. If we continue to increase our dissipative capacities in disregard of the law of entropy, critics claim, we will soon destroy the environment that sustains our civilization.

The connection between the second law of thermodynamics and economic development emerged at the beginning of the 1970s when Nicholas Georgescu-Roegen published his now famous book *The Entropy Law and the Economic Process* (Georgescu-Roegen, 1971). Since then, many new studies on the subject have appeared that both support and reject the validity of the connection between entropy production, economics, and sustainability (Young, 1994; Addiscott, 1995; Kåberger and Månsson, 2001; Floyd, 2007; Annila and Salthe, 2009; De Pascale, 2012). It is beyond the scope of this paper to get into a detailed discussion of this rich literature. Rather, I would like to dwell in some detail on an exchange that contains one of the most rigorous analytical expositions of the entropy argument against sustainable development.

In 1997, George F. McMahon and Janusz R. Mrozek published a critical response to an article by Jeffrey T. Young in which Young, like many other sustainable developmentalists, had voiced his disagreement with the limits to growth school of thought (Young, 1991, 1994; McMahon and Mrozek, 1997). Young argued that scientific and technological innovations were capable of offsetting the most deleterious entropic effects on the environment and of ensuring unimpeded development of our economy and civilization.

In their response, McMahon and Mrozek mount one of the most rigorous critiques of the very axiomatic foundation and logic of sustainable development. They claim that the proponents of sustainable development base their assertions about the future on faulty premises and logic. They further charge that there is no way to provide a logical proof that science and technology are capable of constraining the law of entropy.

Science and technology, McMahon and Mrozek maintain, are based on mathematics and are bounded by the limits of formal decidability. According to the proof provided by Austrian mathematician and logician Kurt Gödel, such systems can never establish their own consistency; in other words, they cannot prove that they do not contain contradictions. In fact, Gödel proves that they will always have contradictions. And since science and technology are based on formal mathematics, there will always be problems that science and technology will not be able to solve. For this reason, any assertion that scientific and technological innovations can constrain future problems is an example of wishful thinking that lacks analytical rigour and cannot demonstrate the truth of its proposition. Therefore, policies based on such thinking essentially pursue an illusion, not something that can be attained.

The law of entropy, McMahon and Mrozek argue, is not an ordinary empirical law. Rather, it is an axiomatic principle that we use for organizing our knowledge about the universe. One cannot prove that human ingenuity can reverse the effects of entropy because, they contend, one would have to disprove entropy from within the axiomatic system that posits entropy as its organizing principle. In other words, one has to prove something contrary to our formal theory of the universe using this very same formal system. Only on the basis of a different system that would not use entropy as its organizing principle can one produce such proof. And Young does not provide such system. Moreover, even if Young had a different system, McMahon and Mrozek argue, there would be no way of proving that one system is better than the other.

Thus, in their view, the argument for sustainable development fails because it cannot demonstrate that there are conditions under which the entropy law can be constrained. As they categorically state: 'Thus no thought experiment nor any sequence of formal statements can decide the truth or falsity of entropy' (McMahon and Mrozek, 1997, p. 510). Because any constraint on entropy is indemonstrable, the idea that we can attain sustainability through continued development has no justification, and therefore, other alternatives—such as limiting growth and consumption or even de-growing our economy—might offer more realistic paths towards sustainability (McMahon and Mrozek, 1997).

In contrast to many other arguments against sustainable development that are usually heavily laden with ideology, the argument made by

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McMahon and Mrozek appears to be impartial. It is devoid of sweeping condemnations and strident polemics. On first glance, it may appear modest in its scope. But its strength actually lies in this modesty. McMahon and Mrozek make two important points: (1) they prove quite convincingly that proponents of sustainable development have not demonstrated the truth of their proposition; and (2) they also claim that this truth is in principle indemonstrable, and as such, should be held in doubt. The rigour of their arguments is formidable and may be one reason why the article has remained largely unchallenged since the time it has been written. The issue that McMahon and Mrozek raise goes to the very heart of sustainable development—its very axiological foundation—and puts it in serious doubt. For this reason, their argument merits serious attention.

The principal claim that McMahon and Mrozek make centrally pivots on Gödel's proof of consistency and completeness for formal axiomatic systems. There is a huge body of literature written on Godel's theorem, and there is no need for a detailed discussion of this well-traversed terrain (Nagel and Newman, 1958). As has been mentioned, Gödel proves that any formal axiomatic system will contain propositions that are indemonstrable within this system. Because our science and technology are based on formal mathematical systems and because all such systems have a problem with decidability, McMahon and Mrozek argue, there will always be problems that science and technology will not be able to solve. Therefore, there is in principle no way of proving that we will be able to produce indefinitely scientific and technological solutions that will constrain entropy in the future because of the fundamental formative nature of this law. That is why, we should seriously explore other alternatives that aim at reducing our entropy-producing capacity and limit net entropy growth due to human impact in our environment.

One can certainly agree with McMahon and Mrozek that Young has not demonstrated a possibility of constraining entropy. However, neither have they demonstrated the opposite. In fact, Gödel's proof supports a conclusion that is diametrically opposed to that drawn by McMahon and Mrozek.

Gödel's proof is very unique in the sense that it is not based on any axiom. In fact, he proves something totally different than what he sets out to prove. Also, Gödel's proof involves a very creative act. He devises a procedure for generating unique numbers in a formalized mathematical system. The procedure allows expressing customary symbolic notations familiar to every logician—such as ~ (short for 'not') or ⊂ (short for 'if … then') or V (short for 'or')—in terms of unique numbers, or so-called Gödel numbers. It essentially translates symbolic notations into arithmetical numbers. In other words, Gödel takes signs that establish relations among members of a set and expresses them in terms of this set. In a sense, he represents regulatory operations in terms of numbers they regulate.

Regulation is essential in sustaining any system. It coordinates the functions and relations among all elements of a system and provides a vital link between a system and other systems in its environment. As such, regulation must, in the combinatorial sense, possess a power greater than that of any of the parts of a system or their sum total; in other words, its level of organization is higher. The power of regulation is not magical. It is a product of the very process that constructs the system by equilibrating all of its elements (Shkliarevsky, 2007, 2013).

Obviously, one cannot use weaker levels of organization to explain more powerful ones; simply put, the former are not powerful enough. Gödel's procedure equilibrates the two levels; it translates the regulatory operations and represents them in terms of numbers. However, because these operations represent a level of organization that is more powerful than that of the members of the set they regulate, the latter cannot demonstrate the truth of their existence; it is simply not sufficiently powerful and cannot generate the procedure that Gödel's mind can generate owing to its greater combinatorial power.

By constructing a level of organization that incorporates the members of the set and the operations that regulate their relations, Gödel shows that we can always construct a level of organization that can resolve any paradox that appears at a lower level of organization. In fact, Gödel demonstrates that we can construct an infinite

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number of increasingly more powerful levels of organization (Nagel and Newman, 1958, pp. 98–102) that can solve any problem. In other words, there are no limits to our intellectual powers. Gödel also demonstrates the process by which a higher level of organization can be constructed. The operation that he used in his own construction was essentially one of equilibration. Using this operation, Gödel creates a new and more powerful system that incorporates both the numbers and the operations and demonstrates the truth of the existence of both.

The preceding discussion shows that the interpretation of Gödel's proof by McMahon and Mrozek is narrow. Its field of vision excludes the very action that Gödel has undertaken in proving his theorem. The reading of Gödel's proof offered earlier is broader and more inclusive. It includes the interpretation by McMahon and Mrozek as a particular case—one that excludes the action that Gödel performs in the course of proving his theorem. This broader and more inclusive interpretation disproves their argument against development. It also suggests that we can solve the problem of entropy production by constructing more powerful levels of organization that will make such solution possible.

Entropic processes, or dissipation, are a form of equilibration. As such, they play a very important role in the rise of new and more powerful levels and forms of organization (Shkliarevsky, 2013). Greater power is the source of disequilibrium, and disequilibrium offers the possibility for producing more entropy. Thermal equilibrium, or the so-called thermal death, does not mean that energy disappears. It simply takes a new form, with different energy flows. Black holes, for example, represent some of the most energetic states known, and temperatures below the absolute zero require much greater energy inputs than any energy states at positive temperatures (Choi, 2013).

The perspective currently in vogue is that irreversibility is the most uniquely dominant characteristic of our universe. However, this is not the only possible way to view reality. McMahon and Mrozek, for example, admit that irreversibility is not the only organizing principle on which we base our knowledge. In fact, many of our laws of nature are actually reversible, that is, their organizing principle is diametrically opposed to the organizing principle of irreversibility (McMahon and Mrozek, 1997). Physicist Peter Corning (2002) observes that 'even as the existing "stock" of available energy in the universe is being dissipated, more is being created' (p. 66). The currently dominant view on irreversibility appears to be a result of the preference for one organizing principle of knowledge rather than another, or as physicist F. A. Hopf suggests 'an artifact of our ignorance' (Corning, 2002, p. 66). In another example, astrophysicist Manasse Mbonye does not see our universe as dominated by either irreversibility or reversibility but rather as being 'always in search of a dynamical equilibrium,' (Mbonye, 2003, pp. 1–2). Numerous critics of the dominant role of irreversibility and the Big Bang theory point to the highly speculative nature of this perspective. They argue that it is merely an extrapolation from the current conditions of our universe into the past—an operation that is always tentative and risky—and charge that it still lacks unambiguous empirical support. Sean Carroll (Carroll, ~~2010~~), for example, observes that '…scenarios of this type are extremely speculative and may very well be wrong' (p. 5). Paul Steinhard and Neil Turok (2002)—two prominent critics of the Big Bang—make a similar argument and propose their own cyclical theory of the universe that is based on reversibility as its organizing principle. On close analysis, reality is constantly in a state of flux, constantly evolving. It is a dynamic system; and as all dynamic systems, it is neither in a state of equilibrium nor in a state of disequilibrium, never random or ordered. In fact, dynamic systems are always in a state best characterized as 'the edge of chaos'—a ~~phrased~~ coined by mathematician Doyne Farmer and popularized by Stuart Kauffman.[5]

In their critique of Young, McMahon and Mrozek argue, in my view quite correctly, that one certainly cannot demonstrate the limitations of the view that emphasizes irreversibility (or entropy production) by merely appealing to reversibility. The two organizing principles are opposites, that is, mere inversions of each other. They simply exclude each

[5] See https://en.wikipedia.org/wiki/Edge_of_chaos, accessed on 28 June 2013.

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other and, as a result, there is no way anyone can argue that one is preferable to the other. The lesson of Gödel's proof is that only a more comprehensive level of organization can reveal the limitations of a reductionist perspective.

The perspective that equilibration (or entropy production) gives rise to disequilibrium, that the growth of equilibrium is always accompanied by the increase in disequilibrium, and that in reality both equilibrium (or reversibility) and disequilibrium (or irreversibility) are always in balance is broader than either the dominant view emphasizing irreversibility or its opposing view. It incorporates both organizing principles as its particular cases (Prigogine and Stengers, 1984; Vicsek, 2002; Wolfram, 2002; Carr, 2004; Shkliarevsky, 2007; Wapenaar and Snieder, 2007; Shkliarevsky, 2011, 2013).

This perspective also does not contradict the second law of thermodynamics. This laws says that in a closed system, such as our universe, entropy production cannot be less than zero. It does not prohibit a zero level of entropy production. As has been argued elsewhere, equilibration at one level of organization is always accompanied by the growth of disequilibrium at another level of organization, thus making the overall level of entropy production equal to zero (Shkliarevsky, 2013). By constantly changing and creating new levels and forms of organization, isolated systems such as our universe can continue to produce entropy and at the same time avoid 'thermal death'.

It is obvious from the earlier discussion that the solution to the problem of entropy production and consequently to the problem of sustainability lies in constructing new levels and forms of organization. Entropy, as a form of equilibration, is not an enemy to be feared and shunned—the attitude that both the proponents and the opponents of sustainable development demonstrate despite their differences in many other respects. In the perspective of this paper, entropy production is an ally we can rely on in sustaining our civilization. It is a means towards creating new and more powerful levels of organization. As the source of disequilibrium, these more powerful levels of organization will allow us to capture new sources of energy, create new energy flows, and avoid depletion. In light of this approach, entropy production will cease to be a problem but will become part of the solution. By creating new levels and form of organization, we will be able to continue producing entropy and at the same time maintain the overall level of entropy production at zero.

The argument that the creation of new levels and forms of organization (i.e. development) can ~~solves~~ the problem of entropy production (and thus ensure sustainability) does not prove that opponents of sustainable development are necessarily wrong. It says nothing about a possibility of several paths towards attaining sustainability. So, one has to test this possibility in light of the theoretical perspective that views reality in terms of equilibrium between equilibrium and disequilibrium.

A system sustains itself by conserving its functions. Conservation of functional operations requires their activation; the more they are activated, the more stable they are and the better they are conserved. Activating and coordinating systemic operations are the function of regulation. Regulatory operations trigger systemic functions and thus help conserve them. Thus, conservation and regulation play a vital role in sustaining a system.

Regulation coordinates functional operations of all the subsystems of a system and also provides a vital link between the system and other systems in its environment. It can do so because it represents a combination of all regulatory operations of all the subsystems in a system and, therefore, has a combinatorial power higher than that of any of them or their sum total. It represents a more powerful level of organization than all the subsystems of a system taken together. It is this power that makes a system more than the sum of parts. Owing to this greater power, regulatory operation can connect a system to other systems in its environment and form what Maturana and Varela called structural coupling (Maturana and Varela, 1998; Maturana, 2002), creating a new and much more powerful systemic totality.

As a functional operation, regulation also needs to be stabilized. Just like any other operation, regulation stabilizes itself through activation. The more it is activated, the more stable it is.

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Stabilization involves structural coupling with other systems. The new systemic whole also acquires its own regulation, which is a combination of regulatory operations of its components. This new and more comprehensive regulatory operation marks the emergence of a new and still more powerful level of organization.

Thus, one can see the vital connection between the dynamic nature of systems and their conservation. A system conserves itself by fully engaging in the creation of new and more powerful levels of organization. It is the main condition of the survival of any system, particularly one as complex as human civilization. If a system does not evolve, if it does not constantly activate its regulatory operation and does not create new levels of organization, the stability of its regulatory mechanism diminishes. If the functioning of this mechanism is unstable, it does not coordinate the functioning of subsystems properly. With a lack of coordination, the system begins to disintegrate as its subsystems begin to operate increasingly on their own. However, this process of disintegration does not stop there. Subsystems are also systems in their own right. As such, they have their own regulatory operations that need to be stabilized through connections and activation. It is this stabilization that originally led to the creation of the system that incorporated them prior to its disintegration. The decomposition of a system necessarily leads to the undoing of its subsystems. This process eventually and inevitably leads to the collapse of all the underlying levels and forms of organization.

As the preceding discussion demonstrates, the survival of any system, particularly such complex systems as our civilization, is impossible without development. Neither steady state nor de-growth can achieve sustainability. They can only lead to the disintegration of our civilization. In other words, there is no sustainability without development.

TOWARDS A SUSTAINABLE FUTURE

Development has been the principal strategy of the global quest for sustainability since at least the mid-1980s and the Bruntland Report. Yet the results have been mixed, if not disappointing. As has been mentioned earlier, the widespread dissatisfaction with the current approach ~~on~~ sustainability has generated a great deal of criticism. The criticism of this approach does not come exclusively from the proponents of limits to development or de-growth who regard it as unbalanced and overly anthropocentric (Robinson, 2004; López *et al.*, 2007; Martínez-Alier *et al.*, 2010). Much criticism actually comes from within the camp of sustainable development. Some developmentalists charge that the current strategy is poorly defined, that its foundational documents, such as the Brundtland Report, are overly general, vague, and contradictory to serve any useful purpose. John Robinson (2004), for example, points out:

> The term 'sustainable development' has been seen by some as amounting essentially to a contradiction in terms, between the opposing imperatives of growth and development, on the one hand, and ecological (and perhaps social and economic) sustainability on the other. These critics might indeed be said to believe that trying to achieve sustainable development amounts to trying to square the circle, in the sense of trying to achieve the impossible (pp. 369–70).

There are also charges that the current policy of sustainable development is merely a façade for neoliberal economics, special interests, and business as usual, that it is too narrow, too market-driven, and overly favourable to corporate elites. According to Michael Gunder (2006):

> …the discourse of sustainable development often is deployed simply to further the interests of the entrepreneurial supportive state and its institutions. These are pro-market interpretations of sustainable development that water down the concept of sustainability to literally that of business as usual (p. 209).

These criticisms point to the need for fundamental revisions of the current policies and the formulation of a new approach.

Jeffrey Young, the target of the article by McMahon and Mrozek, is in many ways a typical representative of the dominant paradigm of sustainable development. Young's approach is

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essentially reductionist. He fully subscribes to economic and technological determinism. For him, the problem of sustainability is primarily an economic and technological problem. Consequently, the solution lies in the market mechanism and technological innovation.

Young is not particularly concerned with energy because, in his view, the earth is an open system that imports solar energy. His major, if not only, preoccupation is scarcity of material resources. He deems that the market mechanism and technology with the assistance of recovery and recycling are totally sufficient for resolving any problem arising from resource scarcity (Young, 1994). The market mechanism is capable of sensing shortages and triggering (mostly through resource pricing and taxation) technological response. In his own words, '[i]n principle economic models of resource prices which signal relative ~~recourse~~ scarcities are sufficient [to resolve the problem of sustainability]' (Young, 1994, p. 213).

Although Young, as other developmentalists, differ in many ways from the opponents of sustainable development, the two share a common view of entropy. He regards entropy production as an enemy that should and can be constrained. Such a view of entropy production significantly narrows the field of vision of policy planners, limits their options, and precludes them from considering and choosing the most productive directions. For example, the developmentalists provide no answer as to what we should ultimately do about entropy. Some, like Young, simply dismiss the problem; others suggest, as Kaberger and Mansson (2001) do, that entropy can be exported but make no indication as to where it could be exported. Because of this view of entropy, developmentalists tend to look for solutions in limiting entropy production, which often results in constraining rather than enhancing economic development. In other words, their choices tend to work against development rather than for it.

It is no exaggeration to characterize the developmentalist perspective as reductionist. Like Young, most of them subscribe to economic and technological determinism. Even though documents such as the Bruntland Report refer to areas other than economy and technology, they offer few specific proposals for changes in these areas. Spheres such as social, cultural, and even political receive little attention and only to the degree that they facilitate economic and technological solutions. Neither does the developmentalist perspective envision any need for systemic changes in the economy and its institutions, economic management, or the process of making economic decisions.

The economic theory that underlies sustainable development is also quite narrow and is often aptly characterized as neoclassical. Young's thinking, for example, lies entirely within the current market doctrine that he accepts as the final word; he relies exclusively on the market mechanism (mostly resource pricing and taxation). Such exclusive reliance on the market prevents seeing the full range of choices and may lead to overestimation of the capacity of the market mechanism to address the needs of sustainability. As beneficial as the market mechanism is, it is not a panacea. For example, as many have pointed out, it may be difficult to develop adequate ways of assessing the levels at which entropy production may be priced and taxed. Also, as any innovation, technological innovation is a complex process that requires many inputs, not just signalling from the market. Although technological innovation may indeed be one response to scarcity, it is not the only response possible. The market can also react to scarcity by increasing prices for products, which may lead to curtailment of production. In other words, the market mechanism may also work against development—the professed goal of developmentalists—rather than for it.

Finally, proponents of sustainable development often display infinite faith in the capacity of science and technology to generate solutions in a sustainability crisis. They seem to be blissfully oblivious to ideological and institutional factors that may have detrimental and deadening effects on scientific and technological creativity. As Hans Weiler (2009) points out,

> Specifically, the debate on knowledge and development reveals particularly well how profoundly the notion of knowledge and the practice of its creation and its use is [sic!] affected by political forces. In this respect, the

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> discourse on development is similar to the discourses on gender roles and on democracy which also, in their own way, testify to the political nature of knowledge (p. 485).

Interestingly, Weiler specifically emphasizes that the influence of politics in knowledge production is particularly evident in the role of the World Bank. As he observes, the role of the World Bank is

> …by no means confined to exercising influence on economic activity and policy. Less well-known, but extremely effective is the influence the World Bank wields by imposing an orthodoxy of knowledge to which all countries and institutions that wish to enter into negotiations on financial support with the World Bank must subscribe (Weiler, 2009, p. 489).

If sustainability requires increased scientific and technological innovation, we need to think about changes in organization and institutional practices in areas relevant to the development of science and technology.

As the earlier discussion shows, there are serious shortcomings in the current approach to sustainable development. The most important one concerns its failure to appreciate the close relationship between growth of entropy and new levels of organization. As a result, it tends to treat symptoms of the entropy production problem rather than its cause. Secondly, it has a very narrow view of the problem of sustainability. It largely regards the complex problem of sustainability of our entire civilization, or what I would call 'human system', as a function of its few select areas, with other important subsystems playing essentially a subordinate role. Moreover, these selected areas are accepted basically in their current form with no significant modifications and changes deemed necessary. The narrowness of this approach may be one reason why sustainable development in its current formulation has not successfully dealt with criticisms and failed to create a broad consensus in the sustainability debates that is essential for moving forward. In a word, the current approach to sustainable development is badly in need of fundamental rethinking.

There are several important points that follow from the theoretical perspective outlined in this paper and that may prove to be beneficial for such rethinking. As has been argued earlier, sustainability of any system vitally depends on new levels and forms of organization. Therefore, sustaining the process of construction of new levels and forms of organization should be the principal goal and the main product of our human system and all its subsystems without exception. Sustainability depends on our creativity in all spheres, rather than just in the select few.

The currently dominant approach to sustainable development views economy and technology as the primary areas where one should search for solutions of the sustainability problem. As has been mentioned earlier, systems, particularly as complex as the human system, have many dimensions and subsystems that are intricately entangled with each other. Systemic evolution is comprehensive and involves all the aspects of a system and all of its subsystems. Because of entanglement, it is hard to identify some subsystems as more important than others.[6] Therefore, the approach to the problem of sustainability of the human system should also be comprehensive. All the subsystems of the human system, not just economy or technology as in the current approach, should be involved in the process of constructing new levels and forms of organization in their respective areas. It must involve fundamental changes in all spheres of our civilization: the political system, the system of economic management and decision making, and the system of education, healthcare, and others. They all require changes that would make them more open, more inclusive, and more democratic.

The human mind represents the most powerful level of organization of reality. As has been argued elsewhere, 'organization of reality that involves symbolic thought has no limitations; it is in fact infinite' (Shkliarevsky, 2013, pp. 47–48). This capacity makes our mind the most important resource in creating new levels and forms of organization. And yet, it is precisely this resource—that is, the creative capacity of the

[6] Kenneth Rogoff, for example, suggests an interesting connection between a lack of innovation and the financial crisis of 2008 (35).

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human mind—that remains systematically underutilized in our human system in general, and in our economy in particular.

Underutilization of resources results in lower productivity and efficiency. The underutilization and wastage of the creative capacities of the human mind deprive our economy of its most valuable resource. It diminishes our capacity to create new levels of organization that would allow us to capture new energy flows, identify new physical resources, and maintain the overall entropy production at the zero level. As a result, we have to rely on the existing energy flows and resources, which leads to their depletion. A more efficient, systematic, and sustained creation of new levels and forms of organization will create conditions that will work against depletion of resources and energy available to us.

The wastage of human resources and the resulting inefficiency have other negative effects in our economy. Wastage of resources and inefficiencies of any kind make production wasteful and inefficient. As a result, our competitiveness drives the economic growth that is fundamentally inefficient and wasteful. The more we experience this kind of growth, the more inefficiency and wastage we produce.

Inefficiency and wastefulness increase the cost of production that drives up prices. High prices make products inaccessible to some potential consumers. The inability of a growing number of people to consume the product has detrimental effects on the economy as a whole, even under conditions of its relative growth. In a recent interview given to *The New York Times*, President Obama, for example, remarked: 'If we don't do anything [about disparity of incomes], then growth will be slower than it should be. Unemployment will not go down as fast as it should. Income inequality will continue to rise' (Calmes and Shear, 2013). First, it leads to increasing concentration of wealth and the emergence of the underclass that has little if any buying power. A growing potential for social instability is the most obvious effect of such a concentration of wealth and the resulting division in society into haves and have-nots. However, it is certainly not the only one. Concentration of wealth also creates serious distortions in economy. Because the product has to be consumed, the economy has to cater increasingly to the consumers who have high buying power, which leads to distortions in consumption patterns. The high-end clientele requires products that satisfy its increasingly saturated market. Its consumption becomes conspicuous. Members of this group tend to buy products that symbolically represent their economic power and social prestige. A growing market for such conspicuous consumption can seriously distort economic production by encouraging trends that essentially do not generate more beneficial patterns of consumption—for example, consumption of knowledge.

Under the current conditions of the welfare state, an increase in poverty also puts additional strain on the economy and society. The Western model of the welfare state is committed to providing support for underprivileged groups. Growing poverty increases government expenditures. As the percentage of the poor increases, so do government expenses on their support. At the same time, overall economic inefficiency reduces government revenues. This combination of increased spending and declining government revenues creates budget deficits that put additional strain on the economy as they undermine the government's credibility that is essential for maintaining the health of our economic and financial institutions.

Catering to an increasingly exclusive group of consumers depresses economic growth. The declining growth forces producers to cut their expenses in order to stay competitive in the marketplace that is increasingly shrinking. As a result, they are forced to reduce their production expenses and concentrate their financial resources on essentials. The pressure is to reduce expenditures on externalities—for example, environmental sinks—that are largely regarded as inessential for production. The result is the increased depletion of natural resources and the growth of entropy level in the environment that further reduces the flow of energy and resources from environment into economy. Thus, environmental problems—in terms of both resources and sinks—are closely related to the underutilization of the human resources and the resulting inefficiencies in production. Indeed, these problems are

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symptoms of a serious defect in the way our human system is organized. Treating symptoms does not solve the problem. A policy that addresses merely the effects of inadequacies in our human system, as we currently do, can at best temporarily slow down the process of degradation, but it will not stop it.

Because mind and knowledge play such an important role in the construction of new levels and forms of organization, sustaining this process and making it more efficient require changes in ways we view knowledge and approach knowledge production (Brown, 2011). Knowledge production vitally depends on institutional practices in allocating resources. The constantly growing demand for knowledge requires an efficient system of assessing knowledge and identifying the most promising directions in its development. The emerging global system of knowledge production and its national subsystems—research institutions, universities, colleges, and other educational and research institutions—certainly do not meet these needs. Its institutions have a high degree of inertia and are thoroughly politicized. As Thomas Kuhn, among others, has pointed out, our scientific establishment, for example, has a high degree of resistance to change (Kuhn, 2012). Despite some successes, the current system of knowledge production tends to stifle creativity and obstruct innovation (Brown, 1998; Charlton, 2009; Weiler, 2009; Shkliarevsky, 2013). For example, there have been no major theoretical breakthroughs in physics since the formulation of quantum mechanics in the early part of last century. The current methods of assessing and validating knowledge are woefully outdated. Power plays a disproportionate role in determining allocation of resources; the system rewards conformity (Burbidge, 1997). Lamenting the current state of knowledge in cosmology, for example, physicist Martin Lopez-Corredoira writes:

> A small number of scientists cannot compete with the huge mass of cosmologists dedicated to polishing and refining the standard theory. The present-day methodology of research in Cosmology does not favour the exploration of new ideas. The standard theory in Cosmology became dominant because it could explain more phenomena than the alternative ideas, but it is possible that partial successes have propitiated the compromise with a general view which is misguided and does not let other ideas advance that might be closer to a correcter [sic!] description of the Universe (Lopez-Corredoira, 2008, p. 3).

An efficient system of knowledge production should be based on a better understanding of what constitutes knowledge and how it is produced. We can no longer afford a system of validation that depends on conformity and access to power. A more efficient system requires the institutionalization of more open, inclusive, democratic, and, ultimately, more rational practices in validating knowledge and allocating resources. As has been stated earlier, the more inclusive a knowledge system is and the more extensive is its combinatorial capacity, the more powerful it is. Inclusiveness and power (in Gödel's sense), not conformity to dominant trends, should be the most important criteria in assessing knowledge.

Critical awareness and introspection should be another important criterion. We often pay lip service to critical judgment and just as often forget that critical judgment concerns, first and foremost, our capacity to examine critically our own premises and self-evident truths. We should exercise a conscious and deliberate control over our own 'truths' and unconscious biases rather than allow old and tired ideas that hinder knowledge production. Critical awareness is essential for the efficiency of knowledge production.[7]

As this paper suggests, the solution to the problem of sustainability lies in the most efficient utilization of human resources. This level of efficiency will require the use of the creative capacities of all members of human civilization in constructing ~~every~~ new level and form of organization. Much needs to be ~~carried out~~ in order for our society to maintain consistently ~~this~~ level of efficiency.

It is certainly beyond the scope of this paper to engage in a systematic analysis of this issue, particularly in the conclusions of the paper. Let me just provide an outline of what achieving this level of efficiency will require. First of all, it will require

[7] A fuller discussion of knowledge production is in 'Science and Its Discontents' (Shkliarevsky, 2013).

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ubiquity of open democratic political systems on national and international levels that would allow access ~~to~~ broad segments of the population to political power. A profound democratization of our economy, again on the national and international levels, will be another important requirement. We will need to reform our modes of economic management in a way that would allow the processes of self-organization and creative interaction among producers at all levels, instead of our currently prevalent and hopelessly outdated vertical system of command and control. Attaining efficiency in creating new levels and forms of organization will involve fundamental changes in the philosophy and practice of our system of education—the subject of my current research. Construction of knowledge and acquisition of skills and habits required in ~~such a~~ construction should be the centrepiece of our education. The reorganizations of economic and political systems should pursue also a profound transformation of our society that would seek to eliminate profound and destabilizing social divisions. It should also enable and empower every individual by providing access to social services that would enhance his or her creative capacities and help him or her become productive ~~members~~ of our society.

Attaining the level of full utilization of human creative capacities is not a utopian goal. There is no final state of social organization that would correspond to this goal. On the contrary, this level of efficiency will require constant renewal and reinvention at all levels and in all dimensions of our civilization; it will require constant transcendence of the existing levels of organization and the construction of new ones.

Our civilization is essentially a dissipative system that constantly generates entropy. As soon as this system ceases to create new levels and forms of organization, it begins to deplete available resources. The only way it can sustain itself indefinitely is by constantly redefining itself in ways that allow us to capture new energy flows and material resources; and where there are new energy flows and new material resources, work can be performed. It is our destiny to play this catch-up game, and the only way we can play it indefinitely is by constantly creating new levels and forms of organization so as to maintain the overall entropy level at zero. There is no return for our civilization to less powerful levels of organization of social existence. Limits to growth or de-growth are not ultimately realistic possibilities. Our civilization can only move forward. If we decide to limit this movement, we will embark on the path that leads only to the eventual decomposition of our civilization and its disappearance —an option that even limits to growth or ~~even~~ de-growth entertain.

There are no fundamental obstacles to infinite sustainability other than those that we have erected ourselves. Human mind is our most valuable and important resource in the quest for sustainability; indeed, it is the only resource that can help us attain this goal. In order to achieve infinite sustainability, we should strive for a maximal utilization of this resource. The minds of all members of our civilization, not just a select few, should be engaged in the creative enterprise of constructing new levels and forms of organization. The capacity to be creative is not limited to some exceptional individuals or groups. All human beings are in possession of this enormous creative power. We all accomplish one very important creative act in comparison with which all other human creations, no matter how important, pale. We all become conscious beings. The acquisition of consciousness is a creative act of enormous proportion and significance. If we master the mechanism that we use in constructing our consciousness, if we establish control over our creative capacity, we will harness an awesome power. This creative power has sustained our civilization in the past, and it will undoubtedly help us sustain our civilization into an indefinite future.

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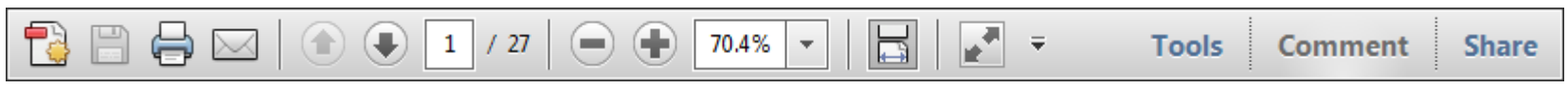
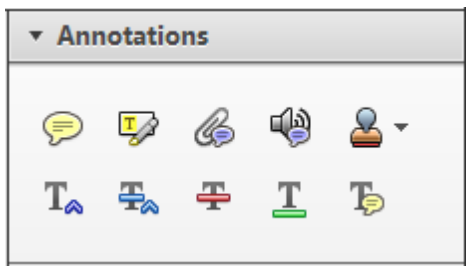
Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:



This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We've picked out some of these tools below:

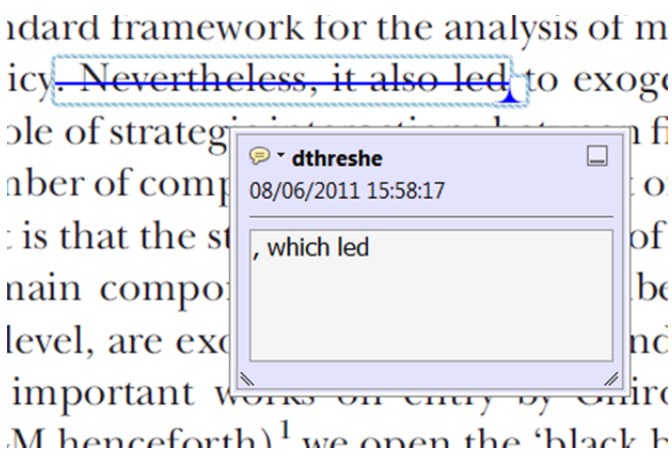


1. Replace (Ins) Tool – for replacing text.

Strikes a line through text and opens up a text box where replacement text can be entered.

How to use it

- Highlight a word or sentence.
- Click on the Replace (Ins) icon in the Annotations section.
- Type the replacement text into the blue box that appears.

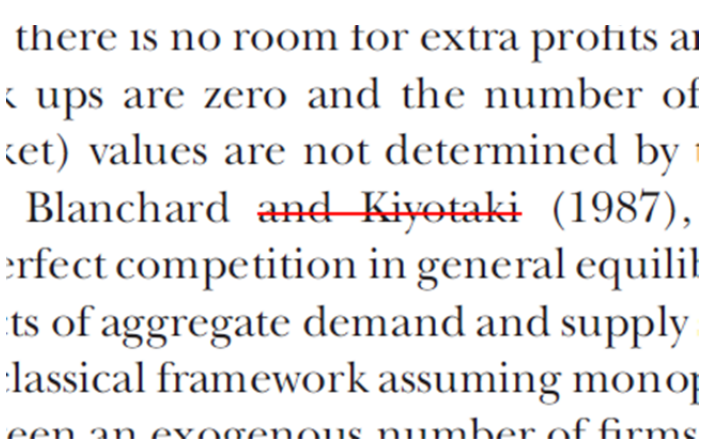


2. Strikethrough (Del) Tool – for deleting text.

Strikes a red line through text that is to be deleted.

How to use it

- Highlight a word or sentence.
- Click on the Strikethrough (Del) icon in the Annotations section.

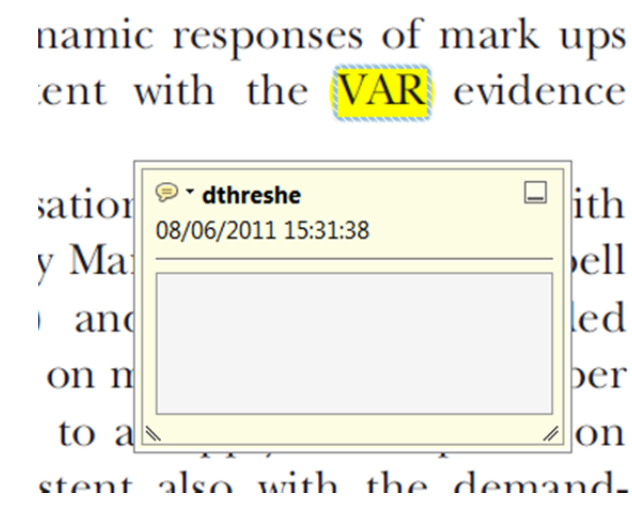


3. Add note to text Tool – for highlighting a section to be changed to bold or italic.

Highlights text in yellow and opens up a text box where comments can be entered.

How to use it

- Highlight the relevant section of text.
- Click on the Add note to text icon in the Annotations section.
- Type instruction on what should be changed regarding the text into the yellow box that appears.

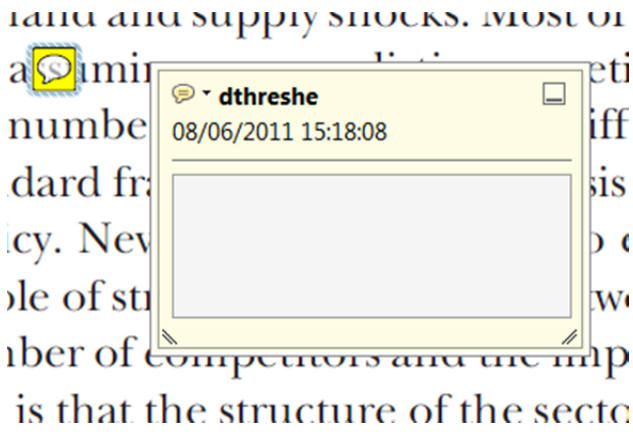


4. Add sticky note Tool – for making notes at specific points in the text.

Marks a point in the proof where a comment needs to be highlighted.

How to use it

- Click on the Add sticky note icon in the Annotations section.
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.



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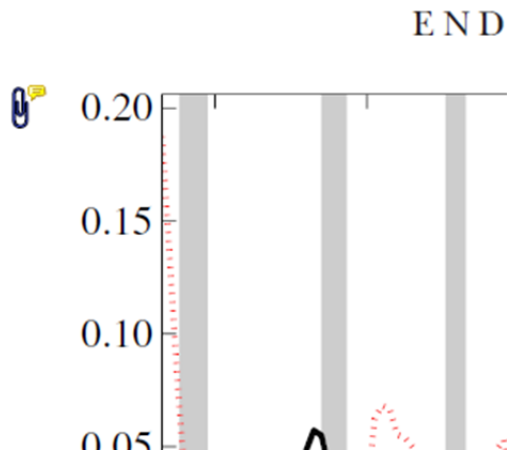
USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

5. Attach File Tool – for inserting large amounts of text or replacement figures.

Inserts an icon linking to the attached file in the appropriate pace in the text.

How to use it

- Click on the Attach File icon in the Annotations section.
- Click on the proof to where you'd like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.

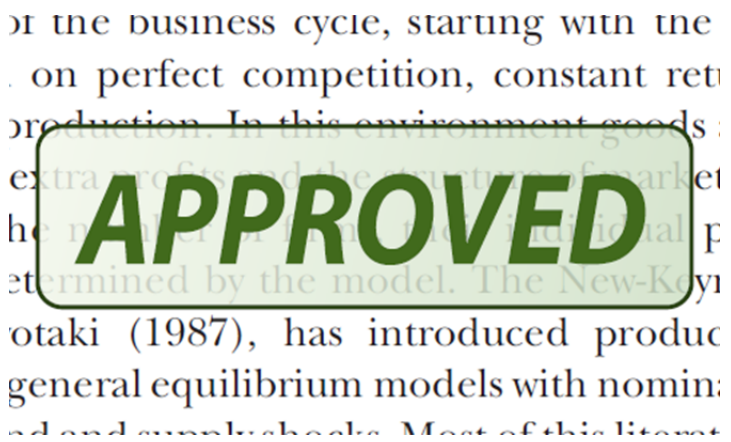


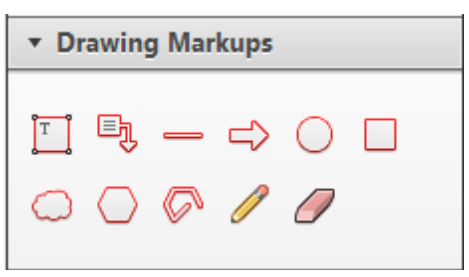
6. Add stamp Tool – for approving a proof if no corrections are required.

Inserts a selected stamp onto an appropriate place in the proof.

How to use it

- Click on the Add stamp icon in the Annotations section.
- Select the stamp you want to use. (The Approved stamp is usually available directly in the menu that appears).
- Click on the proof where you'd like the stamp to appear. (Where a proof is to be approved as it is, this would normally be on the first page).



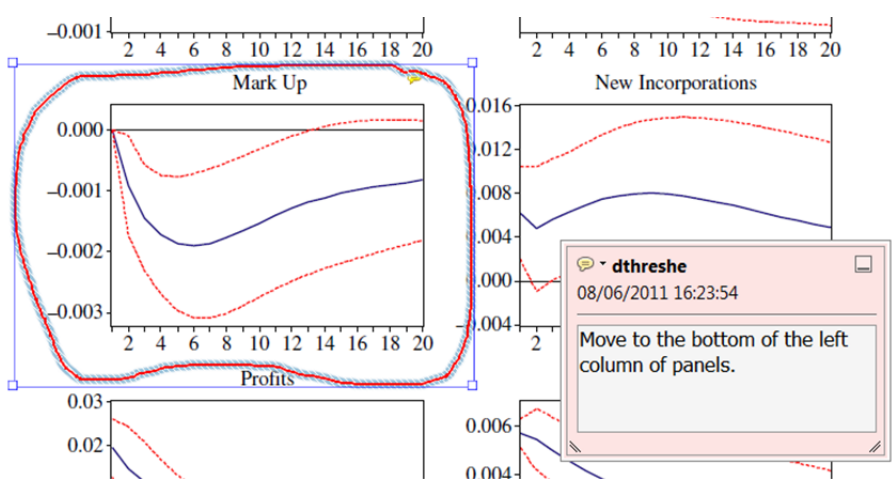


7. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks..

How to use it

- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.



For further information on how to annotate proofs, click on the Help menu to reveal a list of further options: