An (in)efficiency based measurement of economic resilience

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Abstract

The ecosystem and the economic subsystem are interlinked. In fact, it is the overconsumption of scarce resources or the overproduction of bad outputs at economic system level that causes a great part of the imbalances at the ecosystem level. Some imbalances do not originate at the economic system level, but are due to external factors. Given the possibility of external shocks, respecting static sustainability thresholds is not a guarantee for system sustainability. In a dynamic setting, the concept of resilience is therefore helpful. In this paper we show how this concept can complement the traditional efficiency approach to come to a sustainable value creating economic system.

1 - Introduction

Mondelaers et al. (2010) describe how firm technical inefficiency can be measured in the presence of higher level capacity constraints. Their method shows how sustainable development can be achieved by simultaneously meeting macro level system sustainability targets and increasing value creation, through firm level input and output inefficiency removal. In their analysis, the sustainability conditions are met when (supra firm level) 'maximum sustainable uses (MSUs)' for scarce inputs and 'maximum sustainable abuses (MSAs)' for bad outputs are guaranteed. To this end they derive in a nonparametric setting an industry level directional vector, of which the length of the input component is determined by the overall distance to the capacity constraint, while the length of the output component is function of this input component and the production frontier. A firm's distance to the frontier in the calculated direction is called its 'sustainable technical inefficiency'. The 'sustainable allocative inefficiency' on its turn is a measure for a firm's remaining distance to the sustainable profit efficient point. In the static perspective developed in the paper of Mondelaers et al. (2010), all firms are projected towards a single point on the frontier, i.e. the sustainable profit efficient point. This would work well when there are no (unforeseen) changes in the system. As there are many known and unknown unknowns, in a dynamic perspective this outcome can't be a guarantee for sustainability.

Additional to (un)systematic risk one can distinguish systemic risk, which is the risk that a whole system goes into disequilibrium. We can associate this with the concept of resilience. Brand and Jax (2007) define ecosystem resilience[1] as the amount of disturbance that a system can absorb before changing to another stable regime, which is controlled by a different set of variables and characterized by a different structure. Carpenter et al. (2001) define resilience as the magnitude of disturbance that can be tolerated before a socio-ecological system moves to a different region of state space controlled by a different set of processes[2]. Resilience is furthermore characterized by a time and space scale. Resilience in one period can be gained at the expense of the succeeding period. Likewise, resilience at one spatial extent can be subsidized from a broader scale (Carpenter et al., 2001).

Our point of departure is that to guarantee a system's resilience we need to maintain a certain degree of diversity (a portfolio). For the firms that constitute this portfolio maximum micro level sustainable efficiency should be aimed for. Some might argue that it is sufficient to maintain the firm which is under uncertain conditions the most efficient (i.e. the one that generates most value under a different set of circumstances or put differently, the firm that is the least shock sensitive). One could however also reason that, as the future is uncertain, we need to maintain different options. Whether we maintain an option or not, does not depend on its contribution to maximize value creation under uncertain conditions, but it depends on its contribution to maintaining the supersystem's resilience.

There is emerging consensus that diversity increases stability on the level of communities and ecosystems (Ptacnik et al., 2008). We can draw a parallel with studies on terrestrial plants that indicate increasing levels of primary production with increasing diversity and more diverse communities being more resistant to extreme events (Tilman et al., 2005) in

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[1] We should distinguish between descriptive and normative resilience. We can describe resilient systems that are at the same time undesirable from an anthropocentric perspective (think f.e. about a lake full of algae). Seidl and Tisdell (1999) mention that, when we talk about resilience and carrying capacity, we have to make decisions on what is the tolerable level, which is a value-judgement. By doing so, our analysis inherently switches from a positive to a normative one.

[2] In contrast, **sustainability** is an overarching goal that includes assumptions or **preferences about which system states are desirable**.

(Ptacnik et al., 2008). Some authors (Cardinale et al., 2006) have shown that this positive effect may largely be attributed to more efficient resource use in more diverse communities. Geng and Cote (2007) argue that the natural metaphor of diversity should be considered in industrial systems in order to realise sustainable development, because it provides a useful guide on how businesses in an industrial system can evolve towards greater resilience and sustainability. Similar ideas are proposed by other authors, such as Rammel and Staudinger (2002). Rammel et al. (2007) notice that in natural resource management systems, it is diversity as a fundamental system property that provides the potential to enhance adaptivity in terms of buffering and reorganising after disturbance, crisis and change. As Figge and Hahn (2004) correctly mention, a higher number of species, genes or ecosystems does not always lead to a lower risk. The key is thus to determine the critical number of options that should be sustained in order to allow adaptive capability.

We developed for inter firm comparison the same line of reasoning as Kassar and Lasserre (2004) for valuing species for biodiversity. They show that, even if there is perfect substitutability (in their case between species), diversity (or the presence of several substitutes) may generate value if there is **uncertainty** about which species will best fulfil the need under consideration in the future. Under certainty, only one resource combination (one firm, or one species) is needed at any time, because at least the same value is generated if only one production technology (species) exists as if many do. The firms (or species) best able to produce the desirable outcome may however change over time. If diversity losses are furthermore **irreversible**, than there is justification for keeping an otherwise useless resource combination (or species) alive because it may become the technology (or species) of choice in the future, despite the fact that it is currently dominated by some other technologies (species). With irreversibility we can associate the notion of **option value**, which refers to ‘potential future uses’. As Kassar and Lasserre (2004) mention, uncertainty is often approached from a static way: if we know the current state, uncertainty about diversity would be resolved. Value than comes from some notion of distance between firms. Perfect substitutability (or zero distance) than only means duplication, no value. Kazzar and Lasserre stress that, apart from knowledge about distance between species, the point of uncertain future evolution is fundamental. This nicely coincides with our call for a focus on variability, additional to the focus on efficiency.

2 - Conceptual approach

Our economic system is part of the higher level ecosystem in which it is embedded. The ecosystem and the economic subsystem are interlinked. In fact, it is the overconsumption of scarce resources or the overproduction of bad outputs at economic system level that causes a great part of the imbalances at the ecosystem level. Some imbalances do not originate at the economic system level, but are due to external factors. Mondelaers et al. (2010) address the issue of endogenous risks to system sustainability, by defining capacity constraints in a static setting.

We are interested in economic system resilience, knowing that the economic system’s continuation is intimately related to ecosystem resilience. A lower level system cannot survive when the higher level collapses (Voinov and Farley, 2007). We are currently uncertain whether the capacity constraints reflect the real sustainable resource uses. We can thus define a two stage two level game (see figure 1 below) when the ecosystem is under threat due to an external shock. The consequence of the shock is a change in the use of a resource (or the production of a bad output) at the economic system level, if not the ecosystem goes into disequilibrium. The most actual example is global warming. Not changing current resource consumption results into the undermining of the ecosystem’s resilience, which leads to a switch to a new ecosystem state. Assuming that we do not want that, as this will impact heavily on our societal system, changing resource consumption is the alternative. The question we pose ourselves now is whether our economic system is resilient to such a change in resource consumption.

Economic resilience can be defined as the degree to which an economic system is able to maintain its current level of value creation given a shock in a resource x. A system disposes of three mechanisms to rebuild this value creation after a shock: it can improve the technical efficiency of its subsystem units; it can reallocate resource x from allocative inefficient to allocative efficient firms and it can make technological progress. We will explain this in greater detail in the next sections.

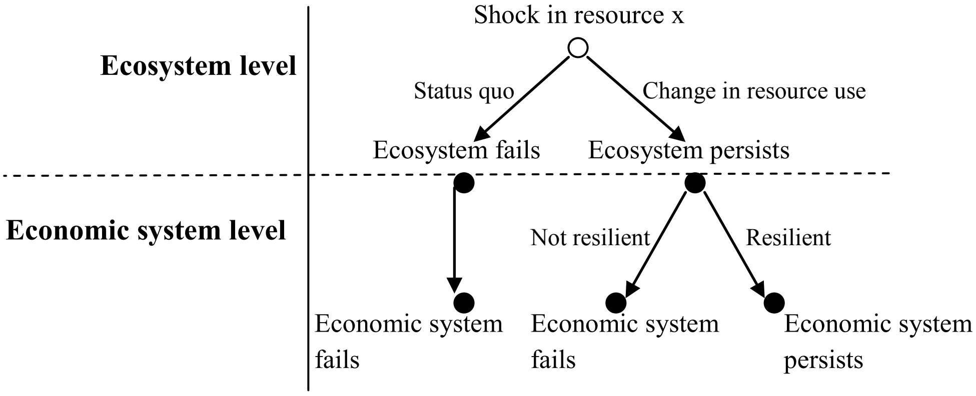

Figure 1. reaction of ecosystem and economic subsystem to an external shock

2.1 - The trade off between value creation and resilience

Similar to the direct relation between risk and return in the financial world, a relation exists between the resilience of a system and its ability to create value. When the firms in a system are all located around the same (high value) resource combination or technology, more rent is generated under steady state conditions compared to a system with a wider spread of resource combinations, but risks are however higher.

Figure 2 below shows a technical production frontier (full line) and the isocost line (black dotted line) that allows to determine the allocative inefficiency, when two resources x_1 and x_2 are used to produce a fixed output y. A, B and C are three companies with the same technology frontier. All three can become more technically efficient, as the black arrows show. Company B’ is economically efficient (both technical and allocative). To guarantee the system’s adaptive capability, diversity in resource combinations should be optimized. So, although economic efficiency seems to push us towards B’, it is from a resilience point of view also interesting to ‘maintain’ the combinations A’ and C’. These options allow us to easily shift, if, for some reason, one resource becomes more constrained, to the other resource. Due to the ‘option value’ of the maintained combination, adjustment costs will be lower. So, allocative efficiency suggests that B’ is optimal from a firm’s perspective, while from a societal perspective, (f.e. due to the mismatch between price and ecosystem resilience), point C’ (or A’) might be(come) most efficient. To go one step further, the distance from the technical efficiency line to the allocative efficiency line can be considered as a measure for the ‘resilience contribution’ of a specific firm, or the ‘***cost of resilience***’.

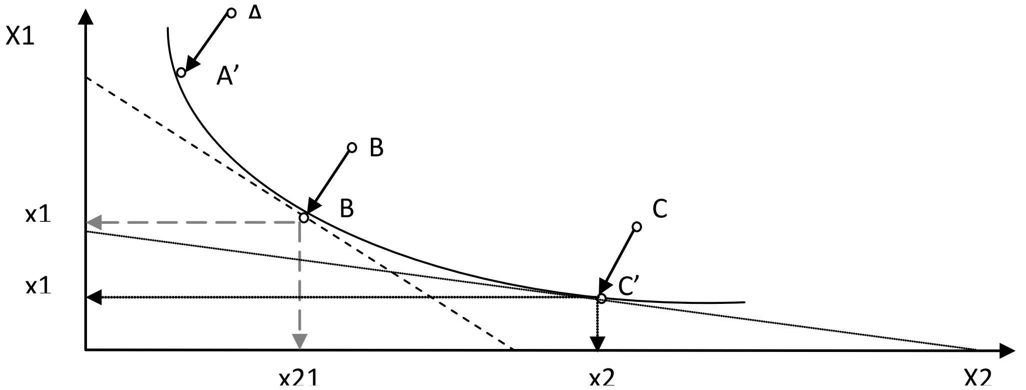

Figure 2. Relation between sustainable efficiency and resilience

In the following step, now that we have the technical efficiency frontier, the 'sustainable allocative efficiency frontier' and a distribution of firms along the technical efficiency frontier, we can calculate the economic system's resilience and an individual firm's contribution to this resilience.

2.2 - The link between inefficiency and resilience

In Mondelaers et al. (2010) a procedure is explained how sustainability targets at the higher level and output increase at the firm level can be achieved jointly by simultaneously removing technical inefficiency at the input and output side. They also show how profit can be maximized by applying the sustainable allocative efficient combination. Technical efficiency relates to the production function, the efficient conversion of physical inputs into outputs. Sustainable allocative efficiency occurs when the production function is applied that generates maximum profit, given prices corrected for sustainable input use and output generation. Remarkably, firms (radial) technically inefficiency score is independent from a system shock t_1, while the allocative inefficiency score is shock-dependent. An allocative efficient firm in t_0 can become allocative inefficient after shock t_1 and vice versa. A technical inefficient firm remains as inefficient after the shock.

It is not because the technical inefficiency is shock independent that it does not impact on a system's resilience. By becoming technical efficient an inefficient firm can set free some units of resource x to help absorb the shock. Thus, the more inefficient firms in the system, the more adaptive capability a system has to external shocks, ceteris paribus. However, the more technical inefficiency the less value is created in the system, ceteris paribus.

To objectively measure a system's resilience, i.e. its adaptive capability to shocks, we have to focus on the allocative inefficiency in the system. As explained above, the allocative inefficiency is shock-dependent, because a system shock in one resource changes the relative amounts of resources and therefore also the relative prices. There exists a direct relation between allocative inefficiency and an economic system's value creation potential under uncertain conditions. The more allocative inefficiency present in t_0, the more value can still be produced in the short run after a shock t_1[3]. When there is no allocative inefficiency in t_0, i.e. only the optimal production technology for regime t_0 is in use, a sizeable shock may imbalance the whole system. Accordingly, switching costs to a new system configuration are high, as the desired technology is not yet in use. When different production technologies are in use, some allocative inefficient firms in t_0 become allocative efficient in t_1. The switching costs for the system will be considerably lower. Even more, in the short run some system

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[3] under the assumption that the shocks are random and allocative inefficiency is not unidirectional

elements will still be able to generate positive value. There is thus a tradeoff between present value creation and the potential to create value under uncertain conditions.

We therefore argue that a good measure for an economic system's resilience is the amount of value that can be created under uncertain conditions. As we explained, there is a strong relation with the amount of allocative inefficiency present in the system.

Figure 3 shows the distribution of firms according to their consumption of a resource x_1. In Figure 3, a shock to the left will make firms on the right more allocatively inefficient, even though these firms might have been allocative efficient in t_0. Similar to Hicks' induced innovation hypothesis (1932), the system will first react to the shock by making its subunits more efficient, both technically and allocatively.

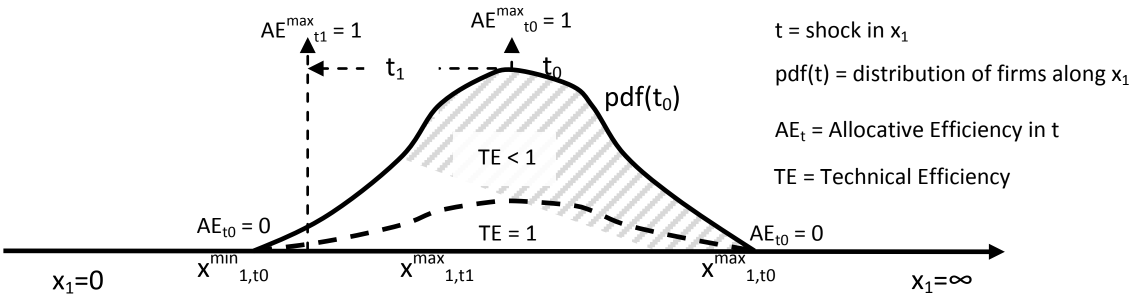

Figure 3. Distribution of firms along the resource x_1 axis. With each x_1 value another production technology is associated. The dotted line separates the technical efficient from the technical inefficient firms. AE^{max}_{t0} shows the allocative efficient point in t_0, while AE^{max}_{t1} is the same point in t_1. The raster area shows the firms that generate negative profits after a shock t_1 in resource x_1, while the remainder firms are considered still profitable. A shock in x_1 will first hit the most inefficient firms and proceed until the new equilibrium is met.

3 - Methodological approach

As a measure for resilience we would like to compare the amount of value that a heterogeneous system *He* is able to produce under uncertainty, with the value that a homogeneous system *Ho* can produce. We will term the system in which different technologies[4] are in use, the heterogeneous system (*He*), as opposed to the homogeneous system (*Ho*) in which only 1 technology is used, namely the one that maximizes profit under regime t_0. We are indifferent between both systems when they create equal value. When the homogenous system creates more value, it is not worth diversifying. The optimal level of diversification is the amount of diversification for which value creation under uncertainty is maximal.

We only consider a shock in a resource for which no substitute is available. We also assume that no technical inefficiency is present in the system, only allocative inefficiency. A such, our firms follow a distribution along the production frontier. Both assumptions can be relaxed, introducing some additional complexity to the developed model. Due to space limitations we will not consider these extensions here.

3.1 - A single shock *t* in x_1

For the case of a single resource x different technologies are in use that allow production of the same output y. One of these technologies, the allocative efficient one under regime t_0, creates currently most value V_0. Probably most firms focus on this technology, i.e. this is the technology with highest density in the probability function. Some firms still use a technology that consumes a lot of x (the so called 'laggards' according to Rogers' innovation

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[4] or resource combinations

theory, 1983), while some other firms who anticipate a shock already adopt a (more costly) technology that consumes less x to produce y (the ‘innovators’).

In figure 4, the pdf(t_0) reflects the distribution of technologies f(x) across the firms in a system around $f(x^{opt}_{,t0})$, which is the technology that creates most value in regime t_0. From efficiency theory, we know that several technologies can generate the same output, but that in a steady state only one maximizes profit, i.e. the allocative efficient combination. A change in the stock of the resource at ecosystem level creates a new most valuable point $x^{opt}_{,t1}$, i.e. the new allocative efficient point. We can calculate how much value is destroyed in the short run due to the shock t_1, how much value remains, how much value can be regenerated in the longer run by reallocating x across firms with existing technologies and how much of the initial value can only be restored after new technologies are introduced. The distribution of technologies in system 2 in figure 4 is characterized by a much wider spread compared to system 1. As a consequence, less value is created in system 2 under regime t_0. On the other hand, given a shock t_1, less of its original value is destroyed. System 2 is thus more resilient to shocks compared to system 1.

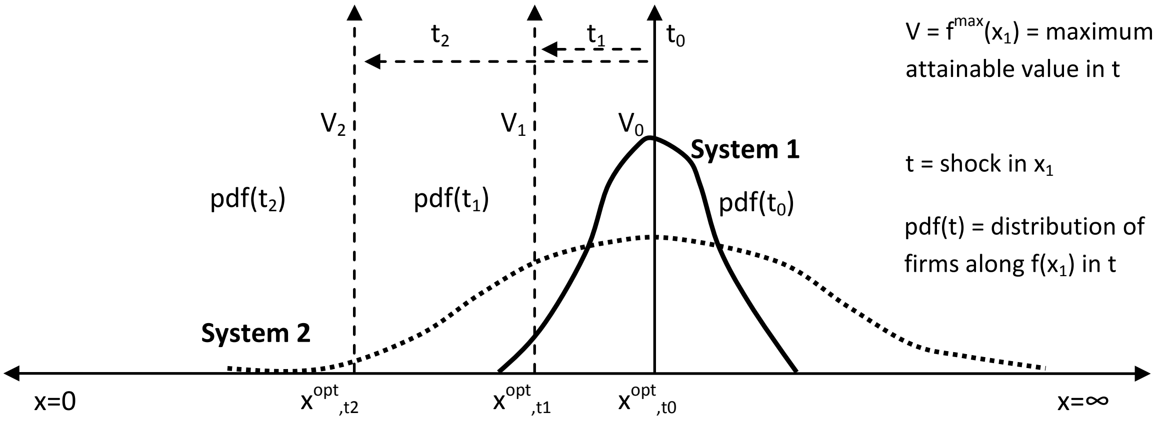

Figure 4. Distribution of firms in 2 systems around the value maximizing technology. When a shock in one of the resources occurs, only part (or none) of the technologies are still usable to rebuild the system. Some combinations are redundant while other have become more important to restore value creation. A shock of size t_2 brings system 1 in total disequilibrium, while system 2 can still partly use existing technologies to rebuild its value creation and resilience.

The initial value created in the system under regime t_0 (area under pdf(t_0) in figure 5):

$$V_{t0,tot}^{He} = \int_{x_{t0}^{min}}^{x_{t0}^{max}} pdf_{t0}(x)\, f_{t_0}(x)dx$$

$pdf_{t0}(x)$=probability density function of combination (x) under regime t_0
f(x)=value created with combination (x) under regime t_0

The *pdf* indicates for every *x* how many firms use the associated production function *p(x)* and profit function *f(x).*

For this latter system (Ho), we can calculate what the maximum value $V_{0,tot}^{Ho}$ is that can be generated in the system under regime t_0, when all firms are allocatively (and technically) efficient:

$$V_{t0,tot}^{Ho} = \max_{n} n f_{t_0}^{Ho}(x)$$

$$\text{s.t. } \sum_1^n x_{t_0} \leq \sum_1^{n_0} x_{t_0}$$

n=number of firms in the industry under application of best technology
n_0=actual number of firms in the industry

The maximization and the restriction are introduced to ascertain that strong sustainability in t_0 is guaranteed, i.e. that not more of x is consumed than what is currently available in regime t_0.

The ratio between $V_{t0,tot}^{He}$ and $V_{t0,tot}^{Ho}$ indicates how much present value the economic system is prepared to forego to maintain some resilience to shocks.

Consider now a random shock t_1 in resource x. As outlined in Mondelaers et al. (2010), we can determine the new profit maximizing point and the associated shadow price of using x_1 and thus the new profit function f, given that the technology $p(x)$ is known a priori. With this new equilibrium input price, we can calculate which technologies are now more profitable under t_1.

The point x_{t1}^{max} reflects the technology where private profit generation drops to zero[5]. The positive value that can still be produced in the heterogeneous system in the short run (SR) after shock t_1 (shaded area in figure 5):

$$V_{t1,tot}^{He,SR} = \int_{x_{t0}^{min}}^{x_{t1}^{max}} pdf_{t0}(x)\, f_{t_1}(x)dx$$

$V_{t1,tot}^{He,SR} - V_{t0,tot}^{He}$ reflects the value that is destroyed or created due to the shock. As outlined below, this value can be further increased by rearranging resource combinations under the new regime. The ratio between $V_{t1,tot}^{He,SR}$ and $V_{t0,tot}^{He}$ gives a relative indication of the value that is still available in the system in the short run after shock t_1:

$$res(t_1) = {V_{t1,tot}^{He,SR}}\Big/{V_{t0,tot}^{He}}$$

When $res(t_1)=1$, no value is destroyed due to the shock. When $res(t_2)=0$, all value is destroyed, i.e. no resource combination is able to create value under the new regime. This measure gives us already an indication of the adaptive capability of the system. In a system with a wide spread of technologies, more technologies will remain feasible compared to a system with low variance in technologies.

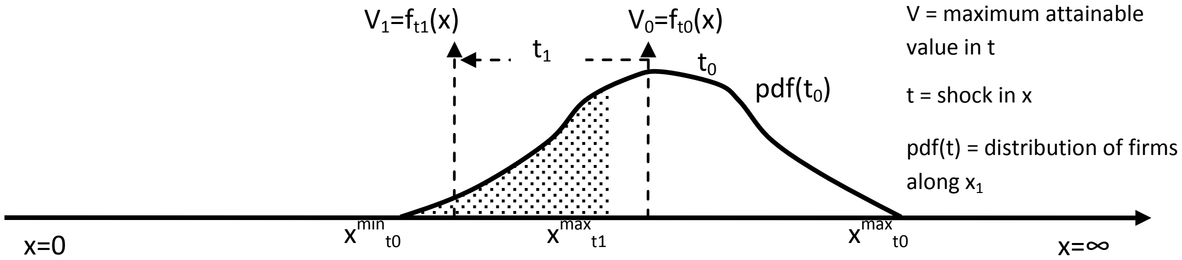

Figure 5. Distribution of firm technologies along resource x. Technology $f_{t0}(x)$ generates highest profit V_0 under regime t_0, while $f_{t1}(x)$ the highest profit V_1 under the resource x restricting regime t_1. Only the combinations using less than x_{t1}^{max} are viable in regime t_1.

In the long run after shock t_1 a particular technology $p(x)$ will have a different probability of occurrence compared to t_0. Some technologies are outlived, as they generate negative profits and therefore have a probability zero of occurrence in the new system configuration. In the spirit of Schumpeter (1942), these combinations should be destructed to set free material for the more viable combinations, which are the ones that occur under both regimes (or the ones that still have to be invented). The value that can be created by upscaling[6] technologies already existing in the system (dotted area in figure 5):

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[5] Under assumption that market effects such as changes in output prices are absent. The model can be extended to accommodate changes therein.

[6] Upscaling = increasing the probability of occurence

$$V_{t1,tot}^{LR} = \int_{x_{t0}^{min}}^{x_{t1}^{max}} pdf_{t1}(x)\, f_{t1}(x)dx$$

The technology *p(x)* is known, as well as the associated profit function *f(x)*. The point $x_{1,t1}^{max}$ still reflects the point where private profit generation drops to zero. The difficulty is however to define $pdf_{t1}(x)$. As outlined in Mondelaers et al. (2010), we can determine the new profit maximizing point and the associated shadow cost of using *x*. With this new equilibrium price, we can calculate which technologies *p(x)* are still profitable under t_1. Profit function $f_{t1}(x)$ differs from $f_{t0}(x)$ due to the change in price, as outlined before. The associated resources of unprofitable firms can be reallocated over the remaining firm technologies, with profit maximization of the whole system as behavioral rule. As such we obtain the *potential* value that can still be produced in the system:

$$V_{t1,tot}^{LR} = \max \sum_{x_{t0}^{min}}^{x_{t1}^{max}} f(x)$$

As explained before, the production function *p* of the value maximizing technology $f_{t0}^{best_{t0}}(x)$ is assumed constant, only the profit function *f* changes (as the relative prices change). The amount of value that a homogenous system applying only technology $f_{t_1}^{best_{t0}}(x)$ can generate in the short run after shock t_1, is:

$$V_{t1,tot}^{SR,best_{t0}} = n f_{t_1}^{best_{t0}}(x)$$

Between the firms in the homogenous industry (Ho), resources can be reallocated to allow that the change in resource x, due to the shock, still generates highest firm level value. As a consequence the number of firms will change. The number of firms n_1 can be determined for which *f'* generates maximum value in t_1, still assuming away technological progress:

$$V_{t1,tot}^{LR,best_{t0}} = n_1 f_{t_1}^{best_{t0}}(x)$$

Now, given this we can calculate the difference in potential value creation between the homogenous and the heterogenous system in t1, both in the short and in the long run.

$\Delta V_{t1}^{SR} = V_{t1,tot}^{SR} - V_{t1,tot}^{SR,best_{t0}}$ and $\Delta V_{t1}^{LR} = V_{t1,tot}^{LR} - V_{t1,tot}^{LR,best_{t0}}$

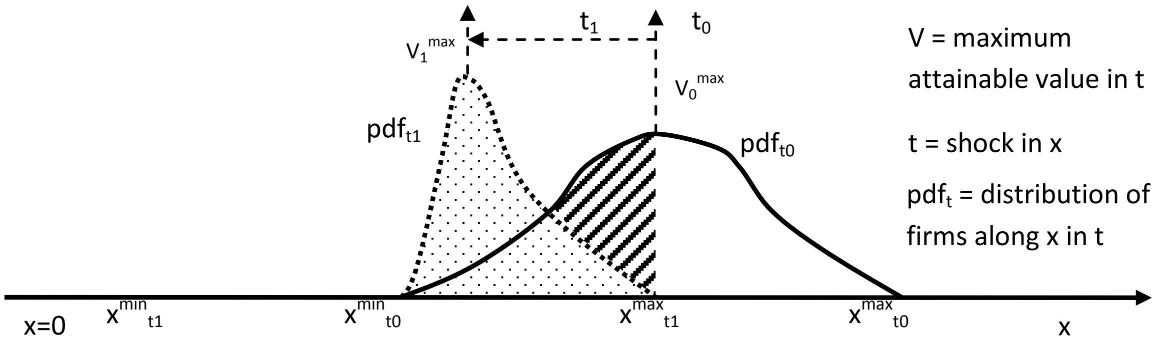

Figure 6. Long run reaction of a system (without technological progress) when a shock in its resource x occurs. After the shock only part (or none) of the technologies are still usable to rebuild the system. Some combinations are redundant (the white area) while other have become more important to restore value creation (the dotted area).

3.2 - Introducing a probability for shock occurrence in x_1

Shock t_1 will not occur with absolute certainty. It is reasonable to assume that small changes (small shocks) have a higher probability of occurrence than big shocks. We can introduce a probability function for the occurrence of shock t, which will allow us to calculate the expected difference in value creation between the heterogeneous and homogeneous system under uncertainty in x_1:

$$\Delta V_{tot}^{SR} = \int_{t=0}^{t=\infty} P(t)\, \Delta V_t^{SR} dt$$

$$\Delta V_{tot}^{LR} = \int_{t=0}^{t=\infty} P(t)\, \Delta V_t^{LR} dt$$

When this ΔV_{tot}^{LR} is positive, the heterogeneous system creates more value under uncertain conditions compared to the homogeneous system. In that case it is worthwhile diversifying. The resilience to a small shock is high while the resilience to a big shock is low. Systems with a higher spread (more variance) will have a higher resilience score, i.e. a higher capability to create value in uncertain conditions.

Similarly, the variance in the difference in value creation can be calculated as:

$$Var(\Delta V_{tot}^{SR}) = \int_{t=0}^{t=\infty} P(t)[\Delta V_t^{SR} - \Delta V_{tot}^{SR}]^2\, dt$$

This variance indicates how sensitive the economic system's value creation is to shocks in x_1.A high ΔV_{tot}^{SR} value indicates that a lot of value remains in the system given random shocks in x_1. A high $Var(\Delta V_{tot}^{SR})$ value indicates that the system's resilience is shock sensitive. This basic model can be extended for (simultaneous) shocks in multiple resources.

The index $res_{tot}^{x_1}$ shows relatively how much value can be created under uncertain conditions compared to the value that can be created under t_0 when all firms would be technically and allocatively efficient.

3.3 - Adjustment costs and option value

It is important to note that even the combinations which consume a lot of x_1, the so called 'laggards' contribute to resilience, as the shock can go in either direction. Electric power generation can serve as an example. In the sixties, nuclear energy production was considered to be the new cutting edge technology, outperforming classic hydraulic power plants. Now we have more insight in the bad outputs generated by nuclear power plants, making hydraulic power plants a valuable alternative again.

The value forgone by maintaining an allocative suboptimal production technology (the so-called 'cost of resilience') should be set against the adjustment costs to switch to this production technology when a shock occurs favoring this technology. The adjustment costs are considerably lower when a production technology is maintained compared to when it is abandoned. In the former case only upscaling costs are required, while in the latter also development costs have to be borne. It is clear that this will foremost impact on the adaptive capability in the short run. The optimal point is where the cost of resilience meets the difference in switching costs when the option is maintained or abandoned (corrected for probability of occurrence of the shock). When the cost of resilience of an option exceeds the difference in switching costs the option can be abandoned.

$$f_{t_0}(x) - f_{t0}^{max}(x) = \Delta CP(t)$$

With $f_{t_0}(x)$ the ideal technology when shock t occurs in x; ΔC= difference in switching cost from f_{t0}^{max} to f_{t0} when f_{t0} is maintained or not and P(t)=probability that t occurs

3.4 - *Technological progress*

It is clear that without technological progress, the economic system's resilience decreases, as the number of technologies in use either remains the same (when the shock is in favour of the economic system) or decreases (when some units are outlived) after a shock. Mathematically, this is reflected by the reduction in variance of the new population.

It is not possible to assess ex ante whether technological progress will always find an answer to system shocks. What can be calculated is the value that should come from technological progress in order to restore the value that is currently created in the system. This can be done by taking the difference between the current total value creation and the remaining value creation after a shock t in x_1. Likewise, it can be calculated how much technological progress should be made to maintain the same level of resilience in the system.

Assuming that the industry evolves to the same level of resilience as prior to the shock, i.e. assuming the initial distribution in the population, the value that should come from technological progress (rastered area in the figure) is:

$$V_{new} = \int_{x_{t1}^{min}}^{x_{t0}^{min}} pdf_{t0}(x)\, f(x)dx$$

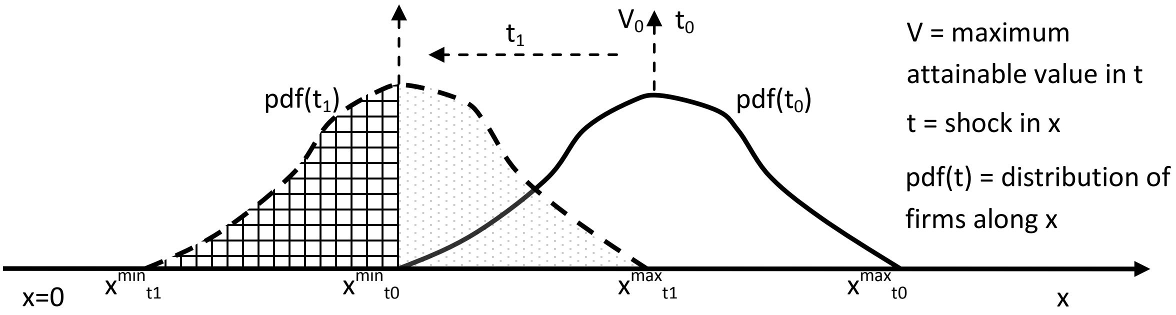

Figure 7. Reaction of a system when a shock in its resource x occurs. After the shock only part (or none) of the technologies are still usable to rebuild the system. Some combinations are redundant while other have become more important to restore value creation.

4 - Discussion and conclusion

Different extensions can be made to make the conceptual and methodological framework better suited for empirical use. A first potential extension relates to the substitution which could take place between resources. This can be accommodated by incorporating the joint probability functions and by introducing the interdependency between resources in the production functions underlying the profit functions. Second, sequences of shocks could be modelled, introducing a more dynamic perspective. Scenarios could be based on a prioir knowledge or simple random walks. A third change relates to changes in output prices. To incorporate these, the model should be extended with demand functions. Additional information is then needed concerning the relationship between supply and demand changes. A fourth extension could relate to the potential improvement through reducing technical efficiency, which has now been ignored.

In this paper we offer a conceptual and methodological approach for the incorporation of uncertainty into sustainability analysis. By expanding on the interrelation between efficiency and resilience, we show that maintaining a certain degree of inefficiency in the system is key to maintaining adaptive capability in a system. This is especially true because short run switching costs are considerably lower when a technological option is maintained. As such the 'liquidity' of the system is higher, enabling it to more easily to become solvent again in the future, mainly by upscaling now (allocative) efficient technologies and by developing new technologies.

The debate on the relevancy of public subsidies can be also related to this. Policy makers compensate private actors for bearing the 'cost of resilience'. The policy relevant question is thus of course to what extend we can let the market self define its optimal level of resilience or when public interference is required.

5 - References

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