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DISCUSSION

On the problem of scale: a general theory of morphogenesis and normative policy signals for economic evolution

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Abstract The paper analyzes evolution to the end of furnishing a general theory of economic change. This analysis is applicable to both organisms and organizations. The general theory presented here is based on four analytical constructs: symmetry, scale, complexity, and collapse. Complexity is modeled as a force, similar to gravitation. Evolution is understood as a condition exhibiting an increase in morphological complexity. In the final analysis, economic change is linked to the structure of the political state. Pathologies of economic change, including morphostasis (in other words reaching a stage where growth and development are anemic due to the system's form and structure becoming static), necessitate a rethinking of political organization. Polycentricity and the principle of subsidiarity [see generally Aligica and Tarko (Governance 25:237, 2012); Føllesdal (J Polit Philos 6(2):190, 1998)], with a praxis inspired by sovereign cities [see for example Gussen (J Philoso Econ 7(1), 2013a)], are imperative for the continuous evolution of societies, and hence economies. In this future, nation states become subsidiary. Sovereign cities replace nation states on the 'international' stage.

Keywords City · Complexity · Emergence · Evolution · Morphology · Nation state · Scale · Subsidiarity · Technology

JEL Classification A12 · B52 · C00 · H11 · H77 · K10 · R10 · Z18

> I rank our growing preference for automated sameness over a personal touch as one of the greatest ills of our age (Gould 2009, p 2).

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1 Introduction

The proposition in this paper is that an evolutionary understanding of economics would produce specific normative signals as to the structure of the political state. More precisely, the evolution of economies requires a political structure around sovereign cities that interact freely with each other (on a global scale). This proposition flows from an analogy between organisms and organizations, and an understanding of the evolutionary process through the theory of complexity.

This paper follows in the footsteps of Adam Smith, Alfred Marshall, W Brian Arthur and other prominent economists in modeling economic change through biological metaphors (Callejas 2007). In particular, constructs from evolutionary biology provide policy signals apt for the complexity inherent in economic processes and economic change, especially when the latter is embedded in their wider social context. While other economists have frowned upon the use of metaphors, notably Joseph Schumpeter, metaphors are in line with the breakdown of the reductionist paradigm and the rise of complexity in its place (Hodgson 1999, 60 and 67). Given the general theory of morphogenesis presented in this paper, where evolution is understood as a process leading to greater complexity, it would be apposite to rely on metaphors if only to help explain the workings of this model.[1]

There are more similarities than differences between social organizations and organisms to justify considering the former as analogous to a biological organism (Waldrop 1992, 179). Both organizations and organisms are behavior systems (Boulding 1981, 169). Both biological and human systems self-organize towards higher complexity (Saviotti and Pyka 2008; Carroll 2001). This complexity is reflected in the richness of self-organizing interactions between independent (and hence heterogeneous) agents. These behavior systems are not only complex and self-organizing but also adaptive: they try to turn events around them into their own advantage. This process of adaptation is the trademark of evolution. However, like every analogy, ours has its limitations (Knudsen 2002, 446; Hayek 1990, 291). In particular, human systems, unlike biological ones, are capable of mutating at negligible time spans (Gould 2007). Human evolution shifts to attributes that are easier and faster to adapt. Humans evolve along a pathway that maximizes the options of behavior for the least cost to adapt (see below).[2] Options are related to rules. Rules could be defined as the enforced prescriptions concerning what actions are required, prohibited, or permitted (Commons 1924; Ostrom 1980).[3] Options

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[1] For other theories of evolution see for example Prigogine et al. (1972a, b).

[2] The model presented in this paper is neo-Lamarckian. It attempts to explain evolution without "random variation" and "natural selection".

[3] Note that institutions in economics are understood as the "basic rules of the game". See North (1990). In this paper, we expand the definition to include options (of rules) rather than enforced rules only.

instead are enforceable rather than enforced prescriptions (Ross 1976).[4] Note that this objective of maximizing options is analogous to biological evolution in that it induces larger variety (I elaborate on this point later). Take for example the local varieties of beak designs that Darwin recorded in finches on the Galapagos Islands. Human behavior attempts to provide similar variety in designs that are suited to their local environments. An example of this variety is studied in Sect. 2 in the context of the history of the Australian electric power grid. Notwithstanding these differences, both behavior systems could be understood through the process of exchange (Boulding 1984; Archer 2013).[5] The analogy is strengthened when we study life and evolution looking for macro trends that exist in both organisms and organizations. To be precise, our analogy entails understating organizations as possessing the quality of life, and changing through the process of evolution. A common denominator is seen in a trend towards larger, more varied and more complex structures. These points are delineated in the following sections.

The paper is structured as follows: Sect. 2 expounds the meaning of evolution as it applies to the Australian electric power grid. Section 3 introduces a general theory of morphogenesis that explains evolution in terms of symmetry, scale, and complexity. Section 4 continues the analysis from Sect. 3 by examining the problems flowing from the current architecture of economic organization under the nation state. The paper ends with some concluding remarks.

2 A history of the electric grid in Australia

To motivate our discussion of evolution, I introduce a brief history of the electric power grid in Australia. This history is no different from that in most other countries, except for the vast areas which the grid covers and the relatively low-density population covered by the grid. The analysis that follows is hence general in nature and applies in other contexts pertaining to organisms and organizations. The 'evolution' of the grid can be seen in Fig. 1 which provides a comparison between the high voltage transmission systems over a span of seventy years (from 1927 to 1997).[6] In this narrative, focus is on the change in the structure of the grid and the geographic distribution of technologies used to generate electricity. This example will motivate the discussion in Sect. 3 on the nature of evolution.

Since the creation of the Australian Commonwealth in 1901, the federal constitution was silent on the subject of electricity supply. This allowed each of the

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[4] Both rules and options can be seen as part of institutions. This paper emphasizes the complex causational chain between the structure of such institutions and the localization of economic activities. On this point see also Martin (1999); Philo and Parr (2000); Martin and Sunley (2001); Wood and Valler (2001). Emphasis is on Original Institutional Economics (à la Veblen) were an institution is "a process of changing structure" rather than a "structure of changing process" as under New Institutional Economics (Potts 2007, 343).

[5] Boulding 1984, xix, xxix, and xxxi. This, therefore, provides a link to constitutional economics through the extension of this exchange regime to politics.

[6] Adopted from Brady (1996), Fig. 1. The 1927 map is based on data from Gibson (1927), while the 1997 map is based on data from the Electricity Supply Association of Australia (ESAA) (1996).

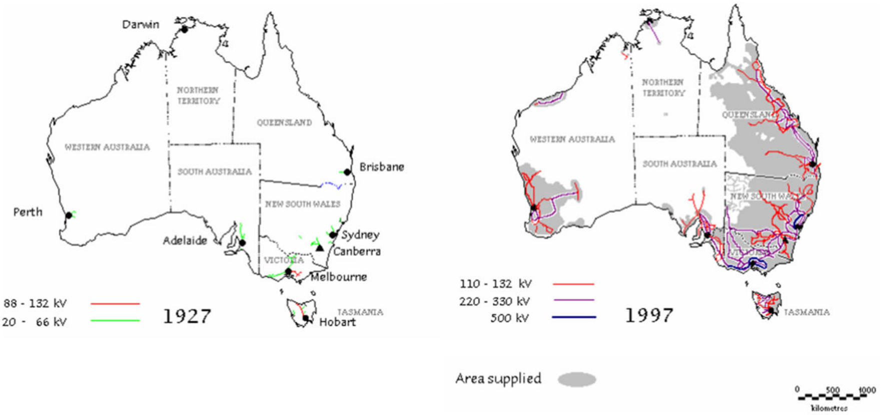

Fig. 1 The growth of the Australian electric grid throughout the twentieth century. Source: Brady (1996)

six states making the Commonwealth to legislate independently for its own grid (Brady 1996). In New South Wales, Queensland and Western Australia ownership was vested in local authorities. But there was also competition from private utilities, resulting in piecemeal allocation of franchise areas. In the other states (Victoria, Tasmania and South Australia) ownership was more in the hands of the private sector.

From the beginning there were indigenous varieties in the favored fuel for electricity generation. Figure 2 shows this geographic distribution of large generators in Australia by technology.[7] Notice the clustering of similar types of generators in certain geographic areas. In Victoria, around Melbourne, we see a clustering of coal fired generation where there are vast (brown) coal deposits at the Latrobe Valley. In Tasmania, we see a clustering of hydroelectric generators where they avail themselves from the capacity of the Great Lake and other hydro resources. In South and Western Australia, emphasis is more on the vast oil and gas fields (not shown in Fig. 2).

Today the generation mix has become more diverse.[8] In Queensland, the maximum installed capacity of coal power stations is around 8500 MW. But there is now a capacity of 3500 MW from gas turbine stations, 190 MW from reciprocating engines, 670 MW from hydroelectric stations, 12 MW from wind farms, and 345 MW from biomass. This is not to mention an increasing uptake of photovoltaic cells. Note that the oldest of these technologies uses fossil fuels, among the most recent are wind farms and biomass. A similar picture can be seen in the other states. In Tasmania for example, we see 240 MW from gas-fired steam turbines, 315 MW from gas turbines, 4 MW from reciprocating engines, and 2275 MW from hydroelectric stations. In Western Australia, steam turbines fired by coal account for 2300 MW, while 65 MW comes from gas turbines. Steam turbines powered by gas account for 410 MW. Reciprocating gas stations account for 108 MW. Only

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[7] Australian Energy Regulator (AER) (2014), Fig. 1.4.

[8] Data from the Australian Electricity Market Operator (AEMO).

Fig. 2 Large electricity generators in the national electricity market [sources: the Australian Energy Market Operator (AEMO), the Australian Energy Regulator (AER)]

32 MW comes from hydroelectric, and wind farms provide 400 MW. Biofuel provides only 6 MW, while solar photovoltaic stations provide 10 MW.

The same picture of ‘increase in variety’ can be seen moving forward. Current projections for electricity generation, in Gigawatt-Year (GWYr), are shown in Fig. 3.[9] Note how over time new technologies are expected to join the mix. For

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[9] Adopted from Hayward and Graham (2012), Fig. 6.

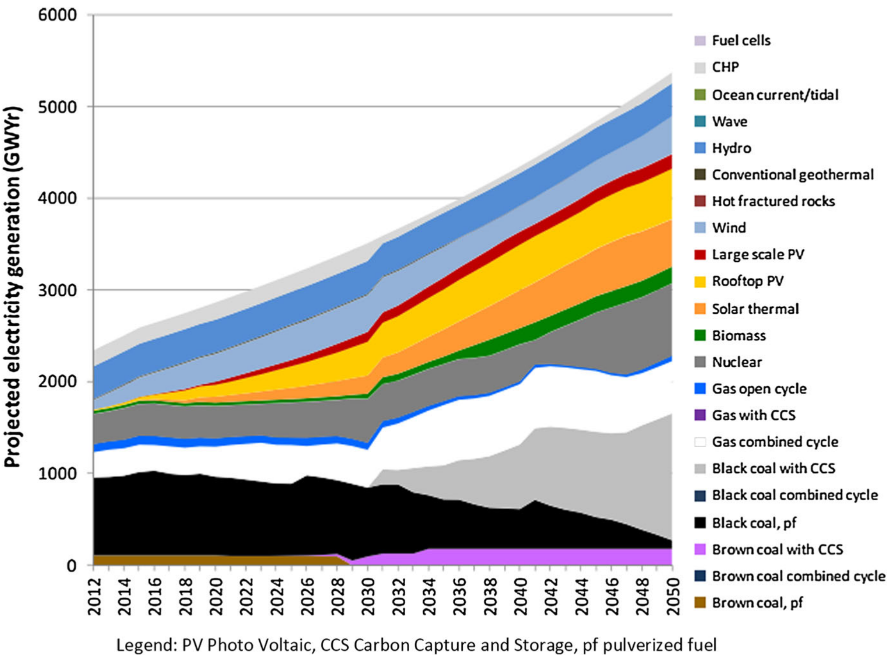

Fig. 3 Projected electricity generation in Australia by technology (source: Hayward and Graham 2012)

example, solar thermal is expected to gain momentum in the next few years and has a considerable share by 2050. On the other hand, we can also see a potential for extinction. For example, black coal is expected to shrink its share considerably by 2050.

This mix of varied technologies is expected to be produced by diverse generators. These generators participate in the Australian National Electricity Market (NEM), a wholesale market that helps deliver electricity to almost 10 million homes and businesses. The NEM covers all Australian states except Western Australia. Over ten billion Australian dollars are traded annually in this market. The market is divided into three sections: generation, transmission, and distribution. A key feature of this market is the fact that what is being sold, namely electricity, cannot be stored efficiently, and hence needs to be sold in real time (as it is generated). Efficiency in this market requires the coordination of generation and distribution over the transmission network. Competition in the upstream (generation) and the downstream (distribution) is intended to deliver efficient outcomes. However, given the highly integrated nature of the power market, sometimes, these efficient outcomes would be delivered by cooperation between the upstream and downstream operations rather than through competition. The role of the Australian Electricity Market Operator (AEMO), the Electricity Suppliers Association of Australia (ESAA), and the Australian Electricity Regulator (AER) is to ensure the cooperation between upstream and downstream organizations leading to the envisaged efficiencies.

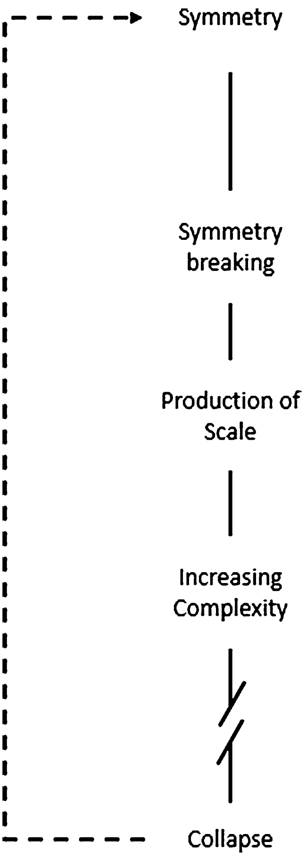

Fig. 4 The five stages of evolution

This brief introduction into the history of the Australian electric grid will be revisited in the following sections to elaborate on the meaning of evolution.

3 A general theory of morphogenesis

Our analysis so far leads to the evolutionary process shown in Fig. 4.[10] The process is built on four core concepts: symmetry, scale, complexity, and collapse. Evolution suggests a difference in temporal rhythm and temporal clock from institution to institution and from organism to organism (Hayden 1988). We find symmetry breaking leading to anagenesis (i.e. change within species), but also to speciation (new species). A break is shown in the line leading to collapse (or extinction) to indicate that this eventuality occurs at time scales making it too remote to be analytically treated with the four preceding stages. Each concept has a technical

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[10] See Gussen (2013b) for the background of this model.

meaning. Their treatment here is not extensive—only their essential features are summarized.

3.1 Definitions

3.1.1 Symmetry (σ)

Symmetry exists where change leaves some aspects of a system unchanged. Symmetry is immunity to a possible change.[11] Symmetry generally implies that certain degrees of freedom are absent to enable a state of equilibrium (de Wit and Smith 1986). In this sense, symmetry is analogous to entropy (S) (see below). In particular, we think of homogeneity as symmetry. Symmetry is broken due to instabilities in the local surroundings. More precisely, symmetry is broken when undifferentiated (identical) degrees of freedom become differentiated.

Symmetry breaking does not mean that all symmetry is lost. There would be still a new symmetry but different from the one before. The process of symmetry breaking is represented by the change of symmetry with respect to degrees of freedom (τ):

Symmetry breaking: $\frac{d\sigma}{d\tau} \neq 0$ (1)

where τ represents a tensor of the degrees of freedom in the system (i.e. the organism or organization), including time.[12]

3.1.2 Entropy (S)

Entropy is taken to be analogous to symmetry. More precisely, it is a condition that maximizes symmetry:[13]

$$S\colon \frac{d\sigma}{d\tau} \to 0 \tag{2}$$

It follows that negentropy (J) is a condition on symmetry such that:

$$J\colon \frac{d^2\sigma}{d\tau^2} \to 0 \tag{3}$$

By entropy we mean the disorder registered by a given system. This disorder is proportional to the degrees of freedom the system has (Brissaud 2005). The more the freedom, the more is the entropy. For an isolated system (i.e. a system subject only to its own gravity), this means that entropy is maximized as the system is isolated from environmental forces (that contribute to complexity) and hence maximizes its symmetry. Note that this also means that entropy is proportional to the symmetry inherent in the system. As symmetry is broken, entropy is reduced, or

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[11] For a general introduction to symmetry, see Rosen (2008) and Brading and Castellani (2003).

[12] Tensors include scalars and vectors but could also have higher dimensionality.

[13] Entropy attempts to achieve absolute symmetry where there is a total lack of differentiation.

to put it differently, negative entropy (or negentropy) is increased. Negentropy is increased due to symmetry breaking.

3.1.3 Scale (μ)

Scale is the set of relationships between constituent parts and their change over degrees of freedom (and time). Symmetry is an ontological concept (related to existence) while scale is predominantly an epistemological one (related to our knowledge of symmetry). Scale relates to the proportionality (relationship) of parts (to themselves and to their environment) as perceived by an observer. Scale is said to be produced as a result of symmetry breaking (i.e. negative entropy). In order to produce scale, first asymmetry needs to be introduced. By breaking symmetry, we are compensating for the loss of symmetry by increased interaction between the resulting different agent types.

Given that symmetry relates to a generalized concept of distance, scale can be defined as a generalized momentum:

$$\mu \triangleq \kappa \frac{d\sigma_{\kappa}}{d\tau} + d\kappa \frac{d\sigma_{d\kappa}}{d\tau} \tag{4}$$

where κ refers to the quantum of matter in the system (e.g. the number of agents).[14] Quantum (κ) can be thought of as a form of generalized mass. There are two symmetries in the definition. The first σ_{κ} is in relation to the symmetry of the existing quantum. The second symmetry is $\sigma_{d\kappa}$ and refers to the symmetry in the change of the existing quantum, which allows for growth in the population of existing matter in the system.

To see why scale is defined as a generalized momentum we only need to consider the nature of the relationship between symmetry and distance. A generalized concept of distance is a metric for a set of states of a system. A null distance represents equivalence between two states, and hence symmetry (Rosen 2008). For example, think of the bilateral symmetry of the human body. We are able to recognize this symmetry due to the similar distance points on the human body have from the plane that cuts the body into two identical halves.

One form of producing scale is where strong links between elements (or subsystems) emerge. This is a form of 'impatient' production of scale that results in $\frac{d^2\mu}{d\tau^2} \rightarrow \infty$. Such tight 'coupling' in dynamical systems results in chaotic behavior. This is the kind of coupling emphasized in evolutionary economics today, where options are reduced through competition. Instead of allowing for local variety between different attractors (which are points in phase space towards which the system evolves), a tight coupling would destroy these attractors but one. On the other hand, if systems are neither too tightly nor too loosely coupled, that is to say there is symmetry in the production of scale (or in other words there is no acceleration in the production of scale), they will have complex attractors. These

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[14] I use quantum in its physical sense, as the physical entity involved in the interactions defining a given system.

attractors have local characteristics that differ from one another as they have limited access to one another (Marion 1999, 155).

3.1.4 Morphology

Morphology is defined as the study of forms and structures that give rise to scale. In this paper it is used interchangeably with scale. We therefore also attribute to morphology the study of relationships between entities constituting the quantum in the system. Note that morphogenesis is the process that leads to a particular scale (form and structure) in a given organism or organization. Morphological analysis is a technique that identifies the dimensions of complexity over a number of constructs and analyzes the resulting structures from a variation in each dimension.[15]

3.1.5 Complexity (π)

Complexity is simply the operational ramification of scale production. Complexity, and the produced scale on which it operates, using energy throughput compensates for lost symmetry. Complexity is the change of the relational field we call scale over time and space. Complexity to scale is what force is to momentum. Complexity is the force required to bring an organism (or organization) up to a certain operational level, given its scale. In other words, by breaking symmetry, or freezing some degrees of freedom, a system gains structure. As the dialectic between symmetry and symmetry breaking continues, the system becomes fractal: it evolves a structure at every scale. This structure manifests itself in spatial and temporal complexity. Because of the need for energy throughput, the notion of complexity would be more meaningful when describing living forms.[16]

Complexity is defined as follows:

$$\pi \triangleq \frac{d\mu}{d\tau} = \kappa \frac{d^2\sigma_\kappa}{d\tau^2} + \left(\frac{d\sigma_\kappa}{d\tau} - \frac{d\sigma_{d\kappa}}{d\tau} \right) \frac{d\kappa}{d\tau} \tag{5}$$

Note that complexity exists even if there is no change in quantum (κ). The level of complexity depends not only on the quantum in the system (e.g. number of constituent parts), but also on the rates at which symmetry and quantum are changing. Where quantum is constant (no growth), complexity is proportional to the curvature of symmetry. A key feature of complex systems is decentralized structures as opposed to the centralized and hierarchical structures found in simple systems (Hanusch and Pyka 2007, 278). Morphological complexity, which is the key product of evolution (see below), exhibits itself in a variety of structures and forms that share a common origin. Complexity is closer to a Lamarckian explanation of evolution (as a natural selection process) than a Darwinian one. In Darwinian selection, the replicator set cannot be changed, while in a Lamarckian selection, the set is modified by environmental stimuli (from interactors) (Knudsen 2002, 449). In

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[15] See for example Zwicky 1969).

[16] But this does not mean that these living forms have to be carbon-based. See the discussion on the signs of life in Sect. 3.

(emergent) complexity, the macrostructure affects the local scale and vice versa (Allen 2001, 313).[17]

3.2 Propositions

Proposition 1: *Evolution is a process of change that leads to increased morphological complexity. Evolution is a process of change where*:[18]

$$\frac{d\pi}{d\tau} = \frac{d^2\mu}{d\tau^2} > 0 \qquad (6)$$

This condition accounts for an increase in morphological complexity.[19]

In order for us to understand evolution we need to understand development, and to understand development we need to understand the trail left by development, namely morphology. Morphology is focused on the analysis of form and structure. Form is an envelope that describes spatial qualities such as size. Structure is about scale: the relationships between entities which define physiology or functionality.[20] A form could be the product of many structures, but a structure is more likely to have only one form. Form could linger even after structure has changed. Emphasis on form as a proxy for functionality risks assuming stability of forms when there is none. Morphology on the other hand puts emphasis on scale.

In economics, evolution has been defined in a number of ways. Boulding defines evolution in relation to ecosystems as "ongoing ecological interaction, of populations of species of all kinds which affect each other, under conditions of constantly changing parameters" (Boulding 1981, 23). Witt defines evolution as the "self-transformation over time of a system under investigation" (Witt 1993, 91). Dopfer and Potts define evolution as "the (ongoing endogenous) process of (emergent novelty, re-coordination and change) in (the knowledge base of the economic order) through the origination of new ideas" (Dopfer and Potts 2014, ix). The objective is to understand the dynamic process behind the spread of observed change, rather than the origin of this change (which is simply explained by chance). The classical formulation of this dynamic process is where economic agents are faced with two alternative modes of behavior (two options) (Matthews 1984, 91; Arthur 1989, 117): A and B. The issue under investigation is the process that may cause A to become generally adopted. If the economic agent is rational and fully informed, she would use the process of optimization to maximize utility: she would adopt A because of her rational foresight (or learning) that enables her to discern the relative merits of A over B *ex ante*. If, however, rationality is bounded or there is no full information, agents would maximize survival through competitive selection (or survivor selection) where some choose A and some choose B. Over time, those who selected option B would be eliminated in the ensuing competition. The optimization

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[17] We can think of this along the lines of the first law of thermodynamics.

[18] This means that evolution progresses through 'jerks' rather than gradually as proposed by Darwin.

[19] Hyperjerk systems are not excluded by this formulation.

[20] Structure is taken to mean relationships rather than rules, and hence maintaining the ontological divide between structure and agency. See Porpora (2013, 26).

under competitive selection is indirect. This second approach has developed into an analogy with biology that informs the process of economic "natural selection".

Looking back at our electric grid example it seems that there is more to evolution than mere competitive selection. Figure 3 projects if anything an increased variety of options for generating electricity. Change is not governed by a choice between two existing options, but by adding new options to an existing set. Evolution seems to correspond to the following operation: $\{A, B\} \overset{\text{time}}{\rightarrow} \{A, B, C\}$, while there is also the possibility of extinction as we saw with black coal (in Fig. 3), which also suggests the inverse operation: $\{A, B, C\} \overset{\text{time}}{\rightarrow} \{A, B\}$. It is this last operation that economic literature is mostly interested in. On the balance, however, we could see from our power grid example that the general trend is for more options to be added to already existing ones. The combined representation would be as follows: $\{A, B, C\} \overset{\text{time}}{\rightarrow} \{A, B, D, E\}$. Hence while some options become extinct, other options become operational. The resultant being net increase in options.

In order for us to better understand evolution we need first to look at what life actually is. If we are to describe the economy as a living organism, this would suggest that economies exhibit the following signs of life (Whitfield 1998, 48–50):

- Reproduction: where living organisms make copies of themselves.
- Growth: where organisms produce new living cells.
- Nutrition: where organisms convert raw material into their own substances.
- Respiration: where energy from the environment operates the process of nutrition.
- Excretion: where living organisms remove waste that cannot be processed any further.
- Senses: where organisms gather information to obtain nutrients.

To illustrate, we will use the electricity industry as an example. In this industry, organisms are represented by electricity generators. They make copies of themselves through new entrants to the market. This can be seen in Fig. 2 above where generators using the same type of technology cluster in a small geographical region. This asexual production is driven by the learning process that occurs over time and allows new generators to enter the industry. These companies produce new cells in the form of new added capacity (turbines), new power plants, and new connections to the transmission grid. They convert raw materials to the substances they would use in their products (for example coal, gas, or wind is converted into electricity), obtain energy to enable the conversion process (for example using coal to run steam turbines which are then used to produce electricity), and produce waste in the form of greenhouse gases. As to senses (and locomotion), companies pick up information about the state of their environment throughout the planning process, from short-term to long-term planning.

When we look at evolution we can detect a gradient where unicellular organisms (less than one millimeter in diameter) evolve to the rich variety of life forms we have today. Evolution resulted in a stunning diversity of life, with over nine million living species (Camilo et al. 2011). The change can be discerned as one of production of scale where organisms became larger, more complex,[21] and more diverse (Bonner 1988; Gould 1996; McShea 1994). The increase in size creates the potential for different cell types, which in turn leads to morphological complexity (Carroll 2001), something we can also discern in Fig. 1 (above) in the context of the Australia electric grid. The variety we see today in the design of a power plant, the fuel type, the nameplate capacity, and so on, resembles the diversity in living species (both in adaptation and speciation). For example, the structural variation in the beaks of the Galapagos finches (studied by Darwin). It is the increase over time in the (structural) variety that suggests the occurrence of evolution. This variety is linked to adaptation to local conditions (i.e. environment). In the Australian power grid, new technologies were adapted to existing fuel types in different geographic locations. Going back to the Galapagos finches, we see different beak designs adapted to obtaining the type of food available on each island. Finches who feed on the flowers of cactus trees have long and pointed beaks more fitted for picking seeds out of cactus fruit, while finches who feed on seeds found on the ground have shorter and stouter beaks. This suggests that evolution is about tweaking structures to meet local needs. In the evolutionary process, the environment puts certain demands on species to change. Put differently, evolution is about the creation of options that serve to meet indigenous needs.

Evolution is about the creation of options, or as Niklas Luhmann puts it, evolution is about "normalizing the improbable". Evolution "involves increasing the rate of movement, interdependencies, lack of time of varying degrees and risks which are conditioned by and increased reciprocally with the remedies which relate to them" (Luhmann 1979, 162).

The analogy between evolutionary economics and evolutionary biology requires an analytical regime grounded in complexity theory.[22] The tendency to increase options explains the dynamics inherent in social (and economic) change through the construct of emergence, which leads directly to complexity theory. Complexity theory, through emergence, explains the mechanisms leading to order and disorder (which through entropy leads eventually to symmetry).[23] Emergence leads to higher scales which have arisen from, but are not predictable at, lower scales (Lawson 1997, 176). Complexity enables order for a low cost and a short time span. Complexity will not eliminate the possibility of extinction, but will increase the rates of adaptability to support a given level of scale. Evolution is the path that organisms take towards the increased complexity of more elaborately structured organisms. During emergence, an interaction of biological and cultural evolution leads to higher levels of self-organization where organisms coevolve: they adapt to each other. Free markets are a prime example of where structures emerge. The ability of buyers and sellers to interact freely changes the structure of a given market in ways that were not intended or envisaged in the first place (Kirman and Vriend

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[21] A formal definition of scale and complexity is furnished in the next section.

[22] On the application of complexity in economics see Holt et al (2011).

[23] Through Evolutionary Institutional Economics we can interpret the emergence of structure as institutionalization. See Elsner (2010, 450).

2001). In the context of the Australian electric grid, the structure of transmission networks, and the production of more generation capacity were coevolving with public purposes. For example, in Queensland, the first generation of electricity was in the capital and largest city, Brisbane to provide a lighting system in the city center (Dunn 1985). The gird coevolved with the social and economic structures in the same locale.

While the evolutionary approach in economics suggests that it seeks to account for the development of the structure of economies (Metcalfe 2008, 24), the understanding of evolution under this approach seems to be purely statistical. In economics evolution is understood as a general (uncoordinated) selection theory, largely based on Darwinian natural selection and modeled using biological constructs such as genotypes (replicators) and phenotypes (interactors) (Dawkins 1976). Evolutionary economics is largely based on the Darwinian model of struggle resulting in the survival of the fittest. For Darwin nature is savage. Each creature is locked in a struggle for survival that leads inevitably to (violent) death. Survivors were the best adapted to their environment. On the hands of Adam Smith, this became the idea of perfection through competition. To be precise, it was the ideas first formulated by Adam Smith and Thomas Robert Malthus that had a lasting impact on Charles Darwin (Claeys 2000; Coase 1998; Gordon 1989). The Darwinist analogy in evolutionary economics limits evolution to combinatorial novelty that reduces the process of evolution to statistical probabilities within a closed system, hardly able to exhibit any signs of life. Evolution results from novel connections between existing predefined and fixed agents. This is a short-term view of evolution. On the long run, under Lamarckian progressive evolution of complexity, new agents are added to the mix (Boden 1990; Wilkins 2001).

The analogy propounded in this paper is therefore a critique of the orthodox view of evolution, which emphasizes competition over cooperation. Given the huge species variety we have today, evolution cannot be based on keen competition alone. All habitats contain a community of species living and evolving side by side. The individuals of these species interact with one another by competing for resources. It is in this context that a change in one species may stimulate an alteration in another. Such interlocked evolution can be seen in parasitism or in symbiosis. In the former the parasite damages the host while in the latter survival chances are improved for both partner species. Coevolution is based on this dialectic of competition and cooperation.[24] There is no need to assume that humans cooperate to gain a mutual benefit. Humans could be selfish and still choose to cooperate. Power imbalances are one reason why a weaker social group chooses to cooperate with a stronger one. Stronger groups also have a selfish motive to cooperate: they force the weaker group to adapt and hence externalize the cost of change, while still reaping the benefits of that change (Kropotkin 1904; Axelrod 1984; Goodwin 1994; Waldrop 1992; Bookchin 1982).

While Darwinian evolution (through natural selection and adaptation) suggests that all states of a dynamical system are potential equilibria, morphological fields

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[24] One of the prime examples of the interaction of competition and cooperation in economics is the Prisoners' Dilemma.

have attractors to which the system settles.[25] These attractors are structures that are intrinsically robust. According to Darwin, evolution is a gradual historical process where the logical unity of biological forms comes from historical continuity and diversity comes from functional necessity. This meant that any form is possible and the only principle is survival through adaptation. Darwinian evolution is not helpful when it comes to morphological analysis. In contrast, complexity theory explains evolution as an increase in morphological complexity, where evolution is abrupt, analogous to a jerk (the derivative of force with time or the change in acceleration).

In addition, complexity brings into the analysis the idea of self-organization.[26] Self-organization provides dynamism not evident under Darwinian evolution. In other words, complexity leads to a non-equilibrium understanding of evolution where emphasis is on transformation and change. This emphasis can be seen in the work of Brian Arthur and the emphasis on positive feedback loops that lead away from equilibrium. These positive feedback loops are associated with cooperation, while negative ones are associated with competition. In the Australia electric grid example we see this in Fig. 2 showing the clustering of power generators using the same technology. A model of economic change based on self-organization would mean that there would be no externalities since all would be part of the system, and structures would be constantly changing. Complexity theory would also open the door for modeling the economy as an ecosystem where resilience, hierarchy theory and the theory of dissipative structures help explain economic change. Ordinary complexity involves structure and self-organization (implying some teleology) where behavior can be explained by mechanistic models with functional growth and survival. In such ordinary complexity, competition and cooperation are complementary. In emergent complexity, there is oscillation between completion and cooperation. This leads to a level of consciousness and morality that cannot be explained mechanistically and functionally. In emergent complexity, mechanical models are only temporary representations of structure. The focus of the analysis should instead be on the evolution of the structure of such systems, i.e. on morphogenesis. Morphology (structure and form) and physiology (functionality) are interrelated; the question is one of emphasis. Machines, given their static structure, are however more about functionality while organisms of emergent complexity are more about morphology (Lewin 1992; Goodwin 1994; Inayatullah 1994; Helling 1994; Arthur 1994; Funtowicz and Ravetz 1994; Allen 1994).

Proposition 2: *The change of energy (W) in the system could be represented as*

$$\delta W = \pi d\sigma \tag{7}$$

where δ emphasizes that the energy is path dependent and hence can only be differentiated inexactly. This suggests that an organism can do work only if complexity is non-zero and symmetry is changing.

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[25] Compare to the discussion of structural attractors in Allen (2005).

[26] For the role of self-organization as a principle of economic evolution see Geisendorf (2009). Friedrich Hayek was one of the main economists to stress the role of self-organization. See also Heylighen (2009).

The idea that economies are ‘alive’ leads to another proposition. The structure of any organism, including economies, is the culmination of its evolutionary history, a history of speciation (emergence of new species or technologies), adaptation (change within the same species), and extinction. Enter the concepts of negative entropy and energy.

Energy and negative entropy (or potential) are necessary for the evolutionary process, both in organizations and organisms (Boulding 1981). In the words of Erwin Schrodinger “evolution is the segregation of entropy” (Schrodinger 1967, 79). Evolution is about the creation of “extraordinary little islands of order” in the organism at the cost of disorder elsewhere (Boulding 1981, 151). The second law of thermodynamics could be stated in terms of potential (negative entropy) as follows: evolution occurs because there is potential for it to occur. In other words, evolution occurs due to a process of symmetry breaking (which as discussed in the following section would inevitably lead to the production of scale and higher levels of complexity). This also suggests that evolution occurs only in open systems where there is a throughput of energy. The process of reproduction moving from a genotype (e.g. a fertilized egg) to the phenotype (the organism) requires an energy throughput that leads to this growth process. But the law of entropy is one of diminishing return. Evolution cannot continue indefinitely (at any scale), unless potential (negative entropy) is continuously replenished, for example through new technology and new resources. Eventually, however, it is not unlikely that the diminishing potential would lead to a global death (extinction), both in organizations and organisms (see below).

In summary, evolution requires energy potential and leads to emergence which is registered through an increase in the behavioral options (variety) available at any given analytical scale. For example, an evolved economy would be able to avail itself of a number of technological revolutions simultaneously: the agricultural revolution, the industrial revolution, and the information revolution (albeit at different intensities). It follows that evolution is not about (natural) selection. It is about progress towards higher levels of scale (and hence complexity).[27] We have already seen this trend in Fig. 1 above where the Australian electric grid, just like a living organism, spread over a larger area, exhibiting more technological variety in generating electricity and as a consequence more complexity in the operation of the National Electricity Market (NEM).

Proposition 3: *Collapse is a process that results from sustaining the following condition:*

$$\delta W = \pi d\sigma = 0 \tag{8}$$

As to collapse, important insights can be gleaned from the reliability theory of aging and longevity. In terms of this theory redundancy is at the center of evading collapse, both for machines and organisms (Gavrilov and Gavrilova 2004). From another angle, collapse can be seen as relief from the complexity condition. A system with a high level of complexity will usually have more than one (complex) attractor. The interaction (coupling) of these attractors leads to a restoration of the

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[27] See Sect. 3. See also Gussen (2013b).

symmetry that was originally ‘lost’. Hence, after several stages of symmetry breaking, the symmetry is “resurrected” by a series of symmetry creating collisions of chaotic attractors. This symmetry creation destroys the (spatial and/or temporal) structure gained earlier through symmetry breaking.

Complex attractors are especially useful for understanding how collapse can be mitigated, as these attractors are largely immune to cascading damage (Marion 1999). Collapse in complex systems is therefore a function of the level of coupling between the subsystems or elements of any given system. The higher the coupling between the elements, the wider will be the effect of any sudden changes on the system as a whole (hence collapse is globalized). With no coupling between the elements, there will be no system of course. But in between these extremes there is a region where a low level of coupling will localize the effects of collapse and provide a more robust system.[28]

4 Histopathology of economic change

While morphology looks at the form and structure of organisms in general, histogenesis looks at the formation of tissues from undifferentiated cells. For an organism, tissues constitute a mesoscale between individual cells and organs (i.e. subsystems that perform a specific function). In contrast physiogenesis looks at the function of such organs. To understand the problems facing economic change, we need to look at a histopathology that seeks to understand organizations at a meso level (the city), and a cytopathology, which studies diseases on the cellular (individual) level. This paper focuses exclusively on histogenesis, taking the city to be the characteristic level for our analysis.

When economic change is analyzed as morphogenesis, emphasis is placed on structure (Schumacher 1977, 1999). One of the most dominant structures is that of the political state, with political boarders being one of the key structural elements of the state. The bigger the country, the greater is the need for internal structure to support its size (Mumford 1967; Schumacher 1999). An emphasis on structure leads in turn to an emphasis on scale, and to a lesser extent on its manifestation as form. Scale “is extremely crucial today, in political, social, and economic affairs just as in almost everything else” (Schumacher 1999, 49). Just like language, scale (qua space and time) conditions action. In the medieval period, it signified importance. Between the 14th and 17th centuries, with the development of capitalism and the discovery of the laws of perspective, the scalar hierarchy of values was replaced by a system of magnitude. Through a long sequence of abstractions, scale was transformed from a signifier of importance to a proxy for relationships. Unfortunately, this abstraction progressed to a stage where it threatened the life of real organisms. These scalar changes brought about the ‘human machine’, which required a ‘priesthood’ for the reliable organization of knowledge (natural and supra-natural), and a ‘bureaucracy’ for an elaborate structure for giving and carrying

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[28] The work by Mark Granovetter is useful here to explain further the nature of coupling. See Granovetter (1973), Granovetter (1983), and Granovetter (1985).

out orders. There was now an almost universally institutionalized concern with punctuality and regularity (Mumford 1972).

An understanding of evolution as competition and cooperation leads to a critique of the necessity of a strong central government, particularly as advocated by Thomas Hobbes. Hobbes starts his analysis from two contradictory positions: while he sees men as virtual machines, he also sees them in constant conflict until they surrender to an external sovereign. Surrender is analogous to the behavior of automata, which are machines. For Hobbes, life is a power struggle. This understanding later resulted in the Malthus–Darwin struggle for existence, which emphasizes competition to the point of extermination. Hobbes' Leviathan turns men into machines, hence removing to a sovereign all decision making powers. Leviathan reveals the ultimate tendency of despotic governments, namely automatism. This automatism signaled the rise of the machine. For the greatest part of human history, tools were simply an extension of the human organism. They did not exist independently. However, through their semiautomatic functioning they came to be regarded as having an independent existence. Hobbes' emphasis on power translated into the need for a centralized state to establish law and order. The goal of this power system is progress measured in quantitative units, leading to a perpetual effort to increase size, but not necessarily structure. Technology made every part of this system undergo rapid change, but the system as a whole became rigid (with low variety). Under this Hobbesian existence, the purpose of life is quantitative increase to insure domination (Hobbes 2011; Kropotkin 1904; Gould 2007; Mumford 1934, 1970). This Hobbesian model lacks any ethical content. It has no anthropological concerns. It is limited to biological needs. Only through limiting mankind existence to biological needs would totalitarian states be possible (Bookchin 1982; Schumacher 1977). The triumph of order over freedom is exhibited in the idea of 'mechanomorphism', or the scientific approach, where a mechanistic explanation of organic behavior is seen as sufficient. The problem with economics is that it imitates science in being 'mechanomorphic'. Hobbes' 'zoömorphism', where animal attributes are passed to human beings, led to distortion greater than the 'anthropomorphism' it reacted against. The character of systems changes not only because of scale production but also because they reach morphostasis. In essence, the production of scale leads to a distortion of the structural proportionality that defines the system. While technological change extends the size limits for social organizations, for example improved communication or transportation systems, such mechanical aids are not enough. There is also a need to change the internal structure to push the envelope of change. This is achieved by new methods of specialization (the division of labor). Increasing form (size) would be an evolutionary stable strategy only if accompanied by an increasing complexity of structure (Boulding 1971; Mumford 1970; Boulding 1984).[29]

The etiquette of history is scalar change. A vivid example of this etiquette can be seen in the transformation from medieval to baroque institutions, a shift from

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[29] Also refer to Boulding's five principles of morphology (structural organization) that illustrate how growth creates form and how form limits growth (Boulding 1968, 81).

localism to centralism, from the absolutism of God to the absolutism of the temporal sovereign and the nation state.

The nation state is anti-evolutionary. It prevents any evolutionary praxis. Through its uniform jurisdictional footprint (qua contiguous territory), it limits all available options. The worship of national history (à la Fichte) is a perversion driven by a mechanistic model of human relationships which is intended to exclude and dominate. The same mechanism can be traced throughout the nineteenth century in a Malthusian gradient that saw an imperialist struggle between nation states occult class struggle, and by doing so preserving the status quo of economic and power distribution. The nation state was the harbinger of a very specific pathology: the 'ancien régime' syndrome. Internal contradictions, the birthmark of civilization, were suppressed rather than resolved. Novelty and diversity now suffocate by the nation state. The homogenization of society suppressed social problems to ensure the creation of a state that favored the expansion of a market economy. In the process, the modality of capitalism adopted by the nation state ensured destroying governance structures at the local level. The rise of the nation state leads to the death of the city, though a transformation through history that is recorded as a change in scale (Mumford 1934, 1944, 1961; Funtowicz and Ravetz 1994; Kropotkin 1975; Boulding 1971; Bookchin 1982, 1987).

Before the nation state, governance was based on sovereign cities rather provinces and nations. The nation state replaced the polis and its politics (a grass-root organization embedded in localism) with statecraft to the end of highly centralized structures. The centralization brought about by the nation state can be traced back to the French Revolution of 1794. City-based governance before the revolution can be seen in Italian city–states, or communa. However, these communes did not last long, as they created economic and political differentiation, setting popologrosso versus popolomagro. The rich merchants hence favored the rise of the nation state to lessen local resistance to free trade. As a result, city sovereignty was lost and their role was reduced to one of slavery to the nation state. Cities are a viable alternative to the nation state. The city is an emergent complex system, the hub for economic activity (Yanguang 2003), and hence a natural candidate for designation as an attractor. Historically, the city was the state itself. It was sovereign. But it was not a centralized state. It was organized as a federation of villages with common interests and aimed to achieve peace. The origin of the city arises from villages attaining a critical mass. The rise of cities is a product of 'cultic practices' rather than technological discoveries. The self-jurisdiction of the city developed out of the jurisdiction in the marketplace. The earliest cities were ideological creations of highly mutualistic communities.

Tinkering with ancient morphogenetic principles such as structural proportions led to the histopathology we see today. The demise of the sovereign city was not only due to limiting cooperation to a small association that distinguished between immigrants and earlier settlers, but more importantly to neglecting agriculture in favor of industry and trade. It was Roman law that eventually brought down the medieval city with the idea that salvation must be sought in a strongly centralized state. The state proceeded to weed out internal structure (of subsidiarity), in favor of narrow minded individualism (as a cytopathology). The state brought about standardization, mass production and the factory system. The same role of the state can be seen in legislation passed in England in 1809 marking the end of small-scale manufacturing. Such laws not only emphasized qualitative growth but denied a just distribution system. There is now tension between current economic theories and localism. The former are never submitted to the test of experiment. Now, monotechnics created for economic expansion and military superiority has taken the place of a polytechnics, based on the needs of living organisms (i.e. their ecologies) (Goodwin 1994; Kropotkin 1904; Mumford 1970).

Schumacher links the size of the jurisdictional footprint (qua territory) with the theory of ‘economies of scale’ and modern technologies. He looks back at his native Germany and compares its economic fortunes under the Bismarck Reich with those of German-speaking Swiss and Austrian citizens, finding that the latter were no worse economically. He goes on to give a hypothetical where Denmark was annexed by Bismarck, and then queries whether Copenhagen would be under that scenario anything more than a provincial city (Schumacher 1999, 46–47, 53).

Over time, the power over other men that flowed from mechanomorphism resulted in a reversal where the organic began to dominate the machine. There was now a qualitative change towards social interests, due to a tendency to attain ‘smallness within bigness’ once the size of organizations (including polities) reaches a ‘great size’. During the 19th century, there was a significant increase in self-governance. Regional entities suppressed by mechanomorphic technics are resurrected on every continent, both culturally and politically. The Scottish and Catalan separatist movements evidence this gradient. The most effective form of organization is where society is ‘polylithic’ rather than ‘monolithic’, with many centers of power and an overall organization with limited power to underwrite the system. The ideal of capitalism is based on a ‘polylithic’ society, as opposed to a ‘monolithic’ society which editomizes communism (although not necessarily Marxism). In ‘small-scale’ organizations, private ownership is natural. Conversely, in ‘medium-scale’ organizations, ‘private ownership is unnecessary’, as ‘voluntary surrender of privilege’ is not likely to occur where there is a large number of anonymous members. In ‘large-scale’ organizations, private ownership is irrational. Nationalism is a response to the irrationality of private ownership in large-scale organizations, which accentuates the danger of over-centralization. Capitalism is about small scale. When wedded to large-scale organization, capitalism faces the same fate of communism (à la Soviet Union). Large-scale organizations suffer a breakdown of communication before reaching the size of the Soviet Union. Russia, China, India, and the USA, inter alia, are destined to face a similar collapse albeit under different time scales (Mumford 1934, 1970; Schumacher 1999; Boulding 1971, 1984). In particular, the rise of large organizations does not destroy small ones, due to the Principle of Interstices: holes can be occupied by organizations of smaller sizes. Small-scale organizations are resilient. Even under a system of keen competition, the middle-size farm can compete with the large (Mumford 1938, 1967; Bookchin 1987; Boulding 1971; Kropotkin 1901, 1904).

The solution lies in municipal freedom, which is the basis for political freedom. Free cities act as ‘peripheral niches’ which become ‘supernovas’ of evolutionary change. Today ‘regionalism’ (the development of regions within a country) is the most pressing issue for countries with large jurisdictional (territorial) footprints (like Australia for example). For such regionalism to be successful, emphasis should shift to 'intermediate technology' geared towards local production and local use. Economic development is the process of transition from one type of organization of society to another at a higher level of complexity. Economic regionalism leads to a balanced economy, where technic is spread not by transport (as it was in the nineteenth century), but by local development. The greatest benefit of economic regionalism is that different development practices could be experimented with and compared. Emphasis would be on quantitative riches rather than qualitative abundance, which would bring an economy of 'plentitude'. The best examples of plentitude exist in quite primitive communities (Bookchin 1987; Gould 2007; Schumacher 1999; Boulding 1971; Mumford 1934, 1970).

5 Concluding remarks

This paper furnishes a general theory of morphology that explains evolution in terms of complexity. Evolution leads to increased diversity and variety. In relation to the nation state this suggests the need for polycentricity. Our analysis suggests a problematisation of scale, where the rise of the nation state portends a structural collapse. Evading such collapse would require restructuring inter-communal relations away from the epistemological privilege attached to the nation state. Moving from large to small polities does not necessarily mean secession. Instead, the decision making process needs to be embedded in the affected localities. This could be achieved by borrowing from one of the pages of the middle ages, by resurrecting the idea of charter cities.[30] While I do not go into any detail as to what would be the best locality to carry out the burden of autonomy, nor do I delineate the legal architecture that would lead to propelling such localities into taking over much of the role currently played by nation states, I anticipate future research would be dedicated to carrying out these tasks.

It is hoped that the ideas presented here would provide a stimulus for future development of economic and legal doctrines that embody the drive towards smaller polities. This jurisprudence would then need to find a political voice through a new breed of political parties that emphasize constitutional limits on jurisdictional footprints (territories).

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[30] See also Amabile et al. (2010) for a discussion of Paul Romer's idea of charter cities.

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