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REGULAR ARTICLE

Scaling and discontinuities in the global economy

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Abstract

Investigation of economies as complex adaptive systems may provide a deeper understanding of their behavior and response to perturbation. We use methodologies from ecology to test whether the global economy has discontinuous size distributions, a signature of multi-scale processes in complex adaptive systems, and we contrast the theoretical assumptions underpinning our methodology with that of the economic convergence club literature. Discontinuous distributions in complex systems consist of aggregations of similarly-sized entities, separated by gaps, in a pattern of non-random departures from a continuous or power law distribution. We analysed per capita real GDP (in 2005 constant dollars) for all countries of the world, from 1970 to 2012. We tested each yearly distribution for discontinuities, and then compared the distributions over time using multivariate modelling. We find that the size distribution of the world's economies are discontinuous and that there are persistent patterns of aggregations and gaps over time. These size classes are outwardly similar to convergence clubs, but are derived from theory that presumes that economies are complex adaptive systems. We argue that the underlying mechanisms, rather than emerging from conditions of initial equivalence, evolve and operate at multiple scales that can be objectively identified and assessed. Understanding the patterns within and across scales may provide insight into the processes that structure GDP over time.

Keywords Complex adaptive systems · Cross-country analysis · Convergence clubs · Discontinuity analysis · Resilience · Scaling

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"Linearity and equilibrium have no place in living organisms and organizations, except maybe after their death" (Kurakin 2009)

1 Introduction

The application of complex systems theory to economics has been a recent endeavour relative to uptake by other fields. Most economists have not embraced a complex systems approach despite a push from within the field arguing that economies are complex adaptive systems and ought to be studied as such (Anderson et al. 1988; Arthur 1999; Foster 2005, 2006; Beinhocker 2006; Kirman 2010; Foxon et al. 2013). J. Doyne Farmer (2012) commented on the irony given that "the goal of a complex systems focus is to characterize emergent phenomena. .. and Adam Smith is widely regarded as the first to clearly articulate the concept of an emergent phenomenon". Durlauf et al. (2005) justified this slow uptake by arguing that the complex systems models often do not embody "fundamental features of financial markets", fail to produce economic insights, and do not make a sensible mechanistic connection to economic processes. These are legitimate arguments, but do not negate the need for basic research into the fundamental patterns and processes shaping economic systems as complex systems, rather than continuing to assume variations of linear, equilibrium behaviour.

A premise of complex systems science is that different types of systems can share basic principles of dynamics and behaviour (Foster 2005), which allows for the possibility of interdisciplinary cross-fertilization (Sundstrom et al. 2014). We take advantage of research and theory focused on identifying discontinuities in rank-ordered data, originating primarily in ecology, to search for patterns in global economies over time. Complex systems are multi-scaled and hierarchical, and the scales in a particular system can be objectively identified (Angeler et al. 2015). They are fundamental to the system and not arbitrarily defined levels of organization (Wiens 1989; Holling 1992). The scales present in a given system result from both system and scale-specific processes that persistently operate at limited spatial and temporal scales, creating scale domains, or 'regions where pattern does not change or changes monotonically with changes in scale' (Wiens 1989), and they provide the basic structure around which other organization develops. They also dictate interaction strengths among system elements, as elements operating at widely disparate scales are likely to have weaker interaction strengths than those operating at similar scales. Some processes, such as competition, niche market exploitation, or cognitive factors that structure short- and long-term memory and limit information processing capabilities (Ember 1963; Kosse 1990; Dunbar 2008), may operate across all scales, but may not operate in the same way across all scales, further contributing to the creation of persistent scale domains. Evidence of multi-scaled structure in economies has implications for system-level behaviour and dynamics that are of value to economics because it has direct bearing on our ability to understand the key processes structuring scale domains (analogous to size classes) in per capita Gross Domestic Product (GDP), and therefore the ability of countries to transition between scale domains.

This paper tests whether there are multiple scales in the global economy, or more precisely, whether the world's economies are discontinuously distributed. We also determine if the discontinuous distributions identified are conservative over time. As there is considerable overlap between this and the literature on convergence clubs (Barro and Sala-i-Martin 1992; Quah 1996a; Durlauf et al. 2005; Phillips and Sul 2007), we begin with a review in Section 2 of the convergence club literature, which evaluates countries or regions to determine if they share a similar rate of a particular econometric such as growth, or appear to be converging toward a similar rate. Although our research is complementary to the convergence club literature, it is grounded in different assumptions about equilibrium and other system dynamics and behavior, so in Section 3 we review the theoretical assumptions of complex systems theory and discontinuities as it applies to our analysis. In Section 4 we describe the methods used to identify discontinuities as well as the multivariate analyses we used to expand our interpretation of the results. In Section 5 we describe the results, and in Section 6 we discuss the implications of the results as they pertain to global patterns in GDP, the convergence club literature, and processes that may structure GDP over time. We conclude in Section 7 with a summary of the relevance of the analyses.

2 Economic convergence clubs

Disparities in wealth and growth between rich and poor countries has been an area of intense research, and is the focus of a vast literature on convergence clubs (see Durlauf et al. 2005 for review). Early work on convergence clubs focused on a null hypothesis of β- convergence amongst all economies in their per capita income due to differing growth rates (Barro and Sala-i-Martin 1992) and was evaluated using linear non-stochastic growth models based on Solow (1956). Convergence to a steady state could be absolute, or conditional on controlling for differences in 'conditioning' variables (Mankiw et al. 1992). Since then, research has focused on identifying convergence clubs, or subgroups of economies or regions with similar initial conditions that seem to converge to a similar growth rate, and then trying to identify univariate factors correlated with club formation, such as human capital, technology, openness, and fixed capital investment. New methods now include convergence in non-growth variables such as financial metrics (Phillips and Sul 2007; Apergis et al. 2012), as well as the consideration of multivariate analyses of factors correlated with club formation and membership (Battisti and Parmeter 2013). Despite substantial methodological developments, El-Gamal and Ryu (2013) state, "the primary conclusion of this massive literature has been rejection of the global convergence hypothesis, based on evidence of multi-modality or other measures of polarization".

Our interest in convergence clubs lies in identifying the intersections between convergence clubs and that of complex systems science and the discontinuity hypothesis, an ecological approach for objectively identifying scales in complex systems. Kurakin (2009) wrote of molecular biology, a field undergoing a similar paradigm shift to that of economics, "the transition from the old image of biological organization to a new one resembles a gestalt switch in perception, meaning that the vast majority of existing data is not challenged or discarded but rather reinterpreted and rearranged into an alternate systemic perception of reality". Although much of the convergence club literature interprets its findings primarily through variations of a neoclassical lens, we focus on the convergence research that has moved beyond expectations of equilibrium and linear dynamics to more varied, non-linear, stochastic, and non-equilibrium dynamics. In fact, the consistent finding of more than one convergence club is itself suggestive of these more complex dynamics. The evolution of the convergence literature away from the linear equilibrium dynamics of neoclassical economics has occurred in multiple ways.

2.1 Initial conditions

The importance of initial conditions, history, and path dependence has been explicitly incorporated into models to varying degrees, and its importance to long-run economic behaviour is generally acknowledged (Nunn 2009), but often has simply manifested in confining groupings of countries to those with similar initial conditions in accordance with the definition of convergence clubs by Durlauf and Johnson (1995) (as in Baumol 1986, but see Owen et al. 2009). This becomes problematic when researchers consider clubs to be interchangeable with multiple steady states, multiple equilibria, and basins of attraction. The literature appears to have adopted terminology but not content from dynamical systems research, as there are no such definitional restrictions regarding the dynamics of attractors and basins of attraction. A fixed point attractor can pull in systems from widely varying initial positions, a strange attractor can push apart two systems that begin close together, and a single steady state system has no basin of attraction because all points begin and end at the same place (Kauffman 1993). It is unclear why researchers have constrained their modelling assumptions in such a way when the type of attractors operating in economic systems is largely unknown. Likewise, acknowledging that initial conditions are relevant to the current state of economies, but then assuming that the arbitrary start year of their data set contains the necessary initial condition, casts doubt on the fundamental (non-observer defined) nature of the clubs thus identified. Finally, path dependence via history are important to dynamics over time for reasons beyond initial conditions, and these are rarely if ever incorporated into growth models (Beinhocker 2006) (though see Nunn 2009).

2.2 Constraints on results resulting from theoretical and methodological assumptions

More studies are allowing for the possibility of multiple clubs, and some are allowing the number of convergence clubs to emerge from the data, rather than being *a priori* selected (Desdoigts 1999; Huang 2005; Owen et al. 2009; Di Vaio and Enflo 2011). However, the number of countries included in the analyses varies widely and ranges from the teens to close to the full complement of countries, so both the ability to detect clubs and the number of clubs found varies widely, making generalized conclusions difficult (Alfo et al. 2008). Despite the finding of multiple clubs, most methods cannot distinguish between multiple equilibria that are transient states reflecting different initial starting positions along a singular trajectory towards one long-run equilibrium, or actual alternative states (Durlauf et al. 2009; Owen et al. 2009; Galor 2010). It is not uncommon for researchers to describe these multiple equilibria as being stationary (Azariadis and Drazen 1990), which suggests an expectation for long-term growth behaviour akin to a fixed point attractor and single point equilibrium dynamics (though see El-Gamal and Ryu 2013). Although there has also been a partial shift within economics from expectations of non-stochastic equilibrium to alternative ideas of stochasticity, deterministic chaos, non-linearity, and non-equilibrium dynamics, it has been sporadic. For example, in Phillips and Sul (2009), neoclassical expectations of homogenous technology and global convergence are relaxed to allow for heterogeneous technological progress and the possibility of global convergence to a steady state (among other possibilities), but the definition of global convergence is one in which ‘all countries are growing’, which is a rather different proposition than one which requires that all countries converge on a similar growth rate. In a review of the literature, Apergis et al. (2012) write, “The actual data confront researchers with the fact that real income per capita diverges across all countries. What remains unclear is what factors prevent incomes from converging”, which assumes that there is one underlying fixed-point attractor. We suggest that multiple convergence clubs may be an inherent and fundamental feature of complex adaptive systems (CAS’s). Some researchers have moved away from testing convergence clubs per se, and are asking more fundamental questions about the existence of multiple regimes in economies (Di Vaio and Enflo 2011; Cao et al. 2014). This is a promising development as it denotes basic theory building about fundamental assumptions.

2.3 Treatment of growth

Growth is increasingly treated as heterogeneous in both rate and time to convergence (Maddala and Wu 2000), and is largely treated as endogenously generated rather than the result of exogenous technical progress. Some modelling techniques can capture heterogeneities in control variables, and not just the growth term (Di Vaio and Enflo 2011). We suggest that the separation of endogenous and exogenous drivers is a matter of observer scale and the boundary of the system in question rather than a true distinction between external and internal drivers. As economist John Sterman wrote, “(Almost) nothing is exogenous” (2002). The consequences from the perspective of theory, modelling, and implications of results is far from a matter of semantics, because Solowian growth models which view growth as exogenously driven are constrained in how far they can be adapted to internalize what were once considered externalities (Beinhocker 2006). Endogenous growth models allow growth to be generated from processes of self-organization and internal system features, thus are more appropriate for modelling CAS’s. Whether or not shared growth rates are a key process forming the multiple equilibria/basins of attraction/scale domains of the global system is a highly non-trivial question.

2.4 Assumptions around modality and basins of attraction

Where researchers allow for multiple modes, they are finding more than bimodality for a wide variety of econometrics (Durlauf and Johnson 1995; Apergis et al. 2012), including relatively stable and persistent clusters of rich and poor countries but also an intermediate group of countries which are less stable and more dynamic (Battisti and Parmeter 2013; El-Gamal and Ryu 2013). If the clusters identified represent basins of attraction as is often assumed in the convergence literature, then dynamical systems theory suggests that basins in the messy middle range are not of equal size or stability relative to those in the tails. Basins can be transient and/or shallow, blipping in and out of existence as the terrain of the state space changes shape (Kauffman 1993). This is not recognized by the convergence club literature, however, which tends to assume that a basin must be static to qualify as a basin (Galor 2010; Pittau et al. 2010). A system can move from one basin of attraction to another due to a small disturbance given the right conditions, and does not necessarily require large shocks as many researchers suppose (Nunn 2009; Pittau et al. 2010) (though see Bloom et al. 2003). Galor (2010), like others, presumes that large exogenous shocks are required to overcome thresholds in poor convergence clubs and therefore discounts the very notion of thresholds because it does not account for how once poor countries that are now rich overcame the threshold in the absence of a large shock. This is a strawman argument, as endogenous dynamics can move a system near to a threshold, reducing the size of shock necessary to surmount it. Likewise, the height of the threshold between basins is dynamic in response to drivers that can change both the state space within which the basin is embedded, or the dimensions of the basin itself. This is not to say that movement directly from any one attractor to any other is possible; movement is thought to be limited to a few neighbouring attractors, from which further perturbations can push the system to yet others (Kauffman 1995). But presuming that movement between basins requires a large exogenous shock is not supported by theory or data from systems research (Scheffer et al. 2001). In a particularly egregious miscomprehension of CAS dynamics, Nunn (2009) argues against the presence of multiple equilibria in economic systems because of examples such as cities that experience severe disturbances such as the bombings of WWII, but quickly return to their pre-bombing populations, when it is system resilience, or the size of the basin of attraction, that denotes the size of shock necessary or capable of moving a system into another basin (Holling 1973; Scheffer and Carpenter 2003; Fletcher and Hilbert 2007). Finally, assuming that economies fall into only two or three clubs defined by immobility closes the door to the implications of the dynamism inherent to a state space and basins of attraction.

2.5 Univariate versus multivariate explanatory models

Correlates of growth are beginning to be evaluated using multivariate models which more closely resemble economic reality than do univariate models (Desdoigts 1999; Alfo et al. 2008; Battisti and Parmeter 2013). Multivariate models allow the possibility of assessing the role of multiple variables and their interactions on club formation and membership. It is likely that there are a few key variables for each convergence club that are crucial (Pittau et al. 2010). Battisti and Parmeter (2013) argue, “Given the multivariate nature of the clusters these results suggest something more complex than solely income divergence. The key implication is that the clusters are diverging across their entire constitution: output, human capital accumulation, physical capital accumulation, and total factor productivity”.

2.6 Growth rate and threshold behavior

More researchers are considering the possibility of threshold behaviour, which is a characteristic of non-linear dynamics and alternative regimes. Researchers have found that thresholds in human capital accumulation, technology, initial per capita GDP, and literacy, among others, are correlated to multiple equilibria in growth rates (Azariadis and Drazen 1990; Hansen 2000; Huang 2005). For many of the reasons already articulated (widely varying methods, definitions, and data sets) generalizations of results are difficult, beyond the basic conclusion that countries are not all following the same growth path, and there appear to be thresholds in the correlative relationship between various econometrics and growth regime. These studies assume that growth is an appropriate process by which to define convergence clubs, and that may be so, given the goals of the convergence club research. However, if one asks a more fundamental question regarding the presence of multiple basins of attraction and the key processes governing them, growth may or may not be a defining characteristic of any or all basins, and a threshold response does not necessarily denote an alternative basin of attraction as a system can respond sharply to a varying factor without having alternative basins (or multiple equilibria) (Scheffer 2009). Adjustable rates of processes are a primary mechanism by which complex adaptive systems self-organize to remain in the same basin and adapt to the dynamism inherent in any CAS (Kurakin 2009). For example, businesses do not manufacture their products at one fixed rate, but must adjust to accommodate the changing landscape of the economy they operate within. Convergence in growth concurrently with globalization is a fairly recent phenomenon and seems to be restricted to industrialized countries, whereas poorer countries have witnessed divergence in growth (Epstein et al. 2003; Huang 2005; Di Vaio and Enflo 2011), which suggests, at a minimum, that different basins of attraction are governed by different key processes (Cao et al. 2014).

3 Complex adaptive systems

There is no singular definition of a complex system, nor should there be. There are, however, working definitions that are sufficiently general to apply to most types of complex systems, as well as sufficiently detailed to be useful. Foster (2005) defines a complex economic system in two layers, which serves our purposes and does not fundamentally differ from the definitions proposed by Foxon et al. (2013) or Beinhocker (2006). In their most basic sense, complex systems are “dissipative structures that import free energy and export entropy in a way that enables them to self-organize their structural content and configuration, subject to boundary limits. At the same time, they are open systems irrevocably connected to an environment that contains other systems” (Foster 2005). Foster (2005) defines complex adaptive systems (CAS) in terms of human agency and learning, arguing that an economic CAS would have the following four properties: 1. It contains dissipative structures that transform energy into work and converts information into knowledge; 2. Each CAS is a whole unto itself, as well as a part of some systems and oppositional to others, allowing the emergence of organized complexity at multiple scales; 3. It has a degree of structural irreversibility owing to the inherent hierarchical structure which results in inflexibility and maladaptiveness; and 4. Evolution is temporal, therefore history matters. Phases of emergence, growth, stationarity, and transition result in the generation of variety, innovation, selection, and maintenance.

Complex systems are by definition hierarchical and modular, but there have been few tools available for the objective identification of the fundamental scales of structure. Typically researchers define arbitrary levels of observation based on observer bias. In this paper, we borrow from ecological theory to understand how scaling impacts the structural features of complex systems. These ideas are formally grounded in complex systems theory, which postulates that system structure consists of multi-scaled hierarchies emerging from processes of self-organization which emerge to dissipate energy gradients (Schneider and Kay 1994; Beinhocker 2006). Other critical assumptions besides emergent phenomena are that economies, as CAS's, operate far from equilibrium; history and initial conditions matter; there are multiple alternative regimes that an economy can reside in and membership in a particular regime is not immutable; many, if not all processes and patterns are defined by non-linearities; and whether or not a process is viewed as endogenous or exogenous largely depends on the scale of observation. These assumptions stand in contrast to that of much of economic theory and literature, including the bulk of the research conducted on convergence clubs.

3.1 The ecological perspective

Scaling issues have long been a thorny issue in ecology, yet they remain an area of central importance (Levin 1992). It has been tackled by some of ecology's most eminent researchers for more than a century, yet one such researcher lamented relatively recently that, "we need non-arbitrary, operational ways of defining and detecting scales. .. how may we recognize scales in a way that avoids arbitrary imposition of preconceived scales or hierarchical levels?" (Wiens 1989). Aggregate behaviour at one level of organization, such as that of an individual, does not typically explain behaviour at a higher level of organization. The non-linearities in complex system dynamics is both a fundamental challenge of understanding scaling in complex systems, and a gift, because it is not always necessary to understand the behaviour of individuals in exquisite detail in order to model the behaviour of the system. System-level behaviour *emerges* from individual interactions and is more than the aggregate of those interactions, yet it is constrained by biophysical limits; it will never be fully knowable or predictable over long time spans, but the probable behaviour can be modelled based on an understanding of the scales at which key interactions, processes, and non-linearities occur.

Scaling is of central importance to the understanding of any complex system. The processes that structure any given system do not operate equally across all spatial and temporal scales, and the entities that operate within the system do not interact with each other, structure, or processes equally. For example, small-scale produce farmers who sell their crops at local farmers markets are unlikely to directly interact with food conglomerates that do billions of dollars annually. The local farmer operates at spatial and temporal scales that are magnitudes of order smaller than that of the conglomerate. Explicitly recognizing that scales are inherent to complex systems, that behaviour witnessed at one scale may be less relevant at another, and that patterns observed at one scale domain may disappear when viewed from smaller or larger scales, is critical. Unfortunately, the identification of relevant scales tends to be observer-biased, selected *a priori*, and confounded with levels of organization or aggregation. We recognize the necessity of constraining the scope and scale of any study, as no singular study can encompass all spatial and temporal scales. However, if the choice of scales is arbitrary, then researchers should recognize that any observed patterns may be random or a function of the scale selection, rather than reflecting actual system patterns and behaviour.

In recent decades, seminal work (O'Neill et al. 1986; Allen and Starr 1988; Wiens 1989) has demonstrated that many ecological processes occur over a limited range of spatial and temporal scales (termed a scale domain) and that even within smooth gradients of process there can be tipping points or non-linearities in the response of structure to thresholds in process (Diez and Pulliam 2007; Yarrow and Salthe 2008). Holling (1992) proposed that if key processes operate over discrete ranges of scale with sufficient persistence over time, then ecological structure should reflect those scalar patterns. Structure that occurs at limited but persistent ranges of spatial and temporal scales should comprise spatial and temporal domains of opportunity for the species that interact with that structure, and be reflected in animal physiology and behavior (Peters 1983; Wiens 1989; Holling 1992). In short, processes that persistently operate at discrete ranges of spatial and temporal scales generate basins of attraction that shape both ecological structure (e.g. vegetation) and animal species. In other words, there are size classes in both ecological structure and animal physiology because key processes that structure ecosystems are not scale invariant (Krummel et al. 1987; Holling 1992; Allen et al. 2006; Nash et al. 2013, 2014a). There are ranges of body mass over which animal species are present, and gaps that reflect the non-linear transition to the next scale domain of pattern and process. This aggregation/gap structure is discontinuous. Within the gaps, structuring processes are so variable as to not generate any pattern; therefore having a body mass that operates at those scales would not be evolutionarily advantageous. Thus the structure of a complex adaptive system can be understood in large part as an interaction with pattern and process at discrete spatial and temporal scales.

The discontinuity hypothesis has been formally extended to other complex systems, such as cities and firms. Regional city size distributions and firm size distributions were found to be discontinuous, consisting of aggregations of similarly sized cities and firms, separated by gaps (Garmestani et al. 2005, 2006, 2008). The pattern of clusters and gaps for city sizes was conservative across 100 years of data, and growth rates varied by size class (Garmestani et al. 2007), confounding expectations of power law behavior in growth rates (Gibrat 1957; Gabaix 2009). Although this is compelling evidence in favour of the theory of multi-scaled hierarchies of structure in complex systems, there is also a body of evidence demonstrating that city size, firm size, growth rates, and animal size distributions fit a power law distribution (Zipf 1949; Brown and Nicoletto 1991; Stanley et al. 1996, 2000; Canning et al. 1998; Axtell 2001; Marquet et al. 2005; Luttmer 2007; Batty 2008; Castaldi and Dosi 2009; Podobnik et al. 2010). Scale invariance is a hallmark of self-organized complexity (Kurakin 2009). However, evidence for scaling laws that represent a process that operates the same way across a wide range of scales and for which the mechanism is well understood is small. There is often a poor fit in the tails of the data (Stanley et al. 2000; Durlauf 2005; Luttmer 2007; Batty 2008; Gabaix 2009), and this suggests that different processes are at work in the tails. One of the best known scaling laws is Zipf's law, which predicts that city size distributions will be continuous and fit a linear power law because growth rates are independent of size and vary randomly (Zipf 1949; Gibrat 1957). Garmestani et al.

(2008) showed that the power-law fit masks ranges of scale over which different power laws fit—in other words, the data is discontinuous, and power laws fit over a cluster of similarly-sized cities, as opposed to over the entire distribution. Similarly, Cao et al. (2014) show breaks in the power law fit for the GDP of 181 countries indicating two distinct sets of structuring processes.

Claims of a power law fit are often made for data that only represent a limited range of scales, whereas scale invariance presumes that processes are invariant across a wide range of scales (Avnir et al. 1998; Cristelli et al. 2012). There is often no link to a mechanism or even plausible reasons as to why a power law fit makes sense. Durlauf et al. (2005) makes this argument for many of the power laws found in socio-economic variables, and Castaldi and Dosi (2009) also argue for the importance of an economic interpretation of underlying processes driving invariance in statistical properties of economic distributions. It is likely that many of the power laws detected in economic and other data types are artifactual rather than reflecting a meaningful process, because power laws can be generated from purely stochastic processes, as well as dimensional relationships between variables (Avnir et al. 1998; Brock 1999; LeBaron 2001; Lux 2001; Brown et al. 2002; Stumpf and Porter 2012). As Brock (1999) writes, "scaling laws [in economies] are of limited use unless accompanied by a persuasive interpretive framework". He presciently anticipates both the departures from Gibrat's and Zipfs's discussed earlier (Garmestani et al. 2007, 2008), and the potential to apply discontinuity analysis to economic data (Brock 1999). Avnir et al. (1998) argues that researchers still derive benefits from framing the research in terms of a power law, because it "allows one to correlate in a simple way properties and performances of a system to its structure and to the dynamics of its formation". This is precisely what we would argue for the method we present here: identifying the fundamental scales of structure in a system will allow us to analyse the processes pertinent to their formation, and how emergent phenomena of interest can arise from that structure. In our experience, it is where data deviates from scaling laws, or where a power-law fit masks underlying discontinuities, that the interesting dynamics occur (Avnir et al. 1998; Bettencourt et al. 2007, 2010; Garmestani et al. 2008).

The question therefore becomes, are economies discontinuous with regard to their size, as represented by GDP? If economies fall into discontinuous size classes, and furthermore, if those size classes are robust over time, then it suggests that 1. the processes that structure GDP vary across spatial and temporal scales (i.e. are not scale invariant); and 2. the perspective offered by the discontinuity hypothesis on scaling in the global economy could drive novel insights into disparities between poor and wealthy countries. Discontinuity analysis as methodological choice has benefits, including that the methods are not sensitive to either measurement error or missing data (Nash et al. 2014a), unlike the convergence literature where measurement error can have a significant impact on results (Durlauf et al. 2009). Nor are there issues of initial position, whereby the selection of the year used as the initial baseline for calculation of convergence can change results, all common issues in the convergence literature (Bloom et al. 2003; Canova 2004). Because we used a metric (GDP) available for all countries, data limitations do not constrain or bias pattern expression or restrict the implications of our results. The method does not require averaging or aggregating data across years, an approach which risks losing interesting deviations as it can only represent average behaviour (Quah 1996b). Nor does data require binning, which can blur the number of aggregations that can be detected (as in Bianchi 1997; Paap and Van Dijk 1998). There is no need to manipulate the data extensively, as is common to convergence analyses such as Barseghyan and DiCecio (2011), where to express output per worker they must go through many steps.

Furthermore, discontinuity analysis has no *a priori* subjective constraint on the number of possible groups or the membership within groups based on assumptions of shared initial conditions. There are no assumptions regarding the identity of the processes structuring the scale domains (analogous to clubs), so there is no risk that the choice of metric misses the mark entirely or is a stand-in for something else. Our approach makes no assumptions about the identity of the countries in each aggregation from year-to-year, so makes no assumptions about behaviour over time—it is concerned with whether or not there are aggregations and gaps in similar locations over time, which is indicative of scale domains independent of the identity of the countries within those aggregations. This means there are also no assumptions about mobility, as Pittau et al. (2010) and others make. We make no assumptions about equilibrium or any other dynamics. Perhaps most importantly, our method is embedded within a well-developed theoretical framework. This theory includes multi-scaled hierarchical system architecture, multiple alternative regimes governed by different structuring processes, and thresholds that control movement between regimes, so provides a robust framework within which to discuss the results (Dakos et al. 2011; Lenton et al. 2012; Nash et al. 2014a; Allen et al. 2014).

4 Methods

We used real GDP (GDP in 2005 constant dollars) and country population data from the United Nations Statistics Division (United Nations Statistics Division 2012) to calculate a constant GDP per capita for all the countries of the world, for each year from 1970 to 2012; this was the maximum temporal extent of data availability for all countries. The number of countries changed as countries were formed or dissolved, so both the sample size and the identity of the countries from year-to-year is dynamic. All data were log-transformed, and each rank-ordered distribution was analysed for discontinuities using two methods, Monte-Carlo simulations using a unimodal null (e.g., Restrepo et al. 1997), and Bayesian classification and regression trees (BCART) (Chipman et al. 1998), as is recommended (Stow et al. 2007). Our Monte Carlo approach compares the observed size distribution with a continuous unimodal null distribution generated by smoothing the observed data with a kernel density estimator (Silverman 1981). The null distribution is sampled 4000 times and the probability that the observed discontinuities in the size distribution occur by chance is calculated as a Gap Rarity Index (GRI) statistic and tested for significance (Online Resource 1). The BCART is a Bayesian implementation of a classification and regression tree (Breiman et al. 1984) which performs a stochastic search over the space of all possible trees, using prior probabilities of a split occurring at any given node. The log integrated likelihood is used to select the best tree. Previous experiments with the sensitivity of the BCART to selection of prior probability determined that the number of iterations was more important, so standard procedure is to use a fixed prior of 0.5 and run 1 million iterations, 25 times. The results of the Monte Carlo approach were confirmed with the

BCART results. Countries that bounded the distribution were permitted to be a group of one if they met the simulation significance threshold, while groups elsewhere in the data needed a minimum of two countries to be classed as a group.

Once we identified the groups and discontinuities, if present, we generated a dissimilarity matrix for the purpose of comparing the dissimilarity of the distributions using non-metric multidimensional scaling (nMDS), a non-parametric ordination technique (Clarke 1993). The nMDS uses only rank information and makes no assumptions about linearity or non-linearity (Zuur et al. 2007; Oksanen 2013). We were primarily concerned with capturing broad changes in distribution structure over time, so created the nMDS matrix to represent that group/gap structure. The rows of the matrix spanned the range of GDP values in the entire data set from smallest to largest, but were expanded to three decimals (GDP was rounded to two decimals) in order to account for the discontinuities, or gaps. Columns represented each year of data. The matrix cells were filled in with 1's and 0's, whereby a 1 indicated the presence of a country at that particular GDP value in that year, and a 0 represented an absence of a country for that particular GDP in that year. The entire aggregation from smallest to largest GDP was coded as a continuous 1, or presence, and the discontinuities between aggregations were coded as 0's, or absences. The nMDS uses this matrix to calculate all pairwise distances among samples, or each year of data. Once the number of dimensions was selected, the distance between each sample is plotted in ordination space, a two-dimensional graph such that years which have a similar structure are closer together and dissimilar years are farther apart. If the location of the discontinuities and the extent and location of each aggregation was completely random, then this would be apparent in the distance and placement of each year's distribution to the others in ordination space.

The nMDS was conducted using metaMDS in package vegan in R 3.1.2 (R Development Core Team 2018). The dissimilarity matrix was created using Euclidean distance for binary data (Nash et al. 2014b). The number of dimensions to be used in the nMDS was determined with a scree plot, which shows the decrease in ordination stress with the increase in the number of ordination dimensions. A stress of <0.2 is widely accepted as adequate (Clarke 1993). A cluster analysis using function agnes from package cluster and method = average was performed to detect groupings of years with similar structure. The cluster dendrogram was arbitrarily pruned to show 6 clusters. This was considered a reasonable compromise between the two extremes of all years in 1 cluster, and all years in individual clusters. As the number of clusters increases from three, which consists of one outlier and two large groups, the two large clusters break into increasingly smaller sub-groupings without ever mixing in years from the other large cluster. There is no data to suggest how many clusters is 'best'. The nMDS was overlaid with the cluster results, in order to show groupings in ordination space.

An ANOSIM (Analysis Of Similarities) compared two timespans of the data. Group 1 encompassed 1970–1989, and Group 2 encompassed 1991–2012. These groupings captured the substantial increase in countries that occurred between 1989 and 1991, mainly due to the dissolution of the USSR, in order to assess whether the change in number of countries was partially responsible for the large distance that occurred between 1989 and 1991 in multivariate space. We removed 1990 from the ANOSIM as it is not possible to have a group of 1 country. The number of countries increased from 186 in 1989, to 197 in 1990, and to 208 in 1991. We ran 999 permutations. The ANOSIM generates an R statistic and a significance value for that statistic and denotes the degree to which differences in aggregation/gap structure is higher among the years in Group 1 and Group 2, or is higher between the two groups.

The axis scores from the nMDS were used in a spearman rank correlation analysis to see if the differences in structure between the distributions of countries in multivariate space explained movement along one or both of the axes in the nMDS. The structure of each distribution was assessed using 6 metrics: the total logGDP difference in wealth between the richest and poorest country; the number of countries; the number of aggregations; the average size of the gaps in logGDP; the average number of countries within each aggregation; and the average span of each aggregation in logGDP. These metrics describe the basic discontinuous structure of each distribution.

5 Results

The number of countries ranges from 186 in 1970 to 210 in 2012. We found that in all years the distributions of per capita constant GDP are discontinuous, with groups of similarly sized economies separated by discontinuities, or gaps (Fig. 1 and Online .csv file). Furthermore, many of the gaps are conservative and persist across the 43 years of data, particularly in the bottom and top thirds of the distributions. The middle of the distribution tends to be more variable, with gaps persisting in the same location for fewer than half of the years. The overall picture is one of conservative discontinuous structure, with some variability in the persistence and location of gaps between years, and more variability in the middle of the distributions. If the discontinuities are artifactual, then we expect more randomness and variability in the tails of the data, rather than the centers. However, even in the center of the distributions there are gaps that are present in 25–50% of the years.

In general, the total difference in wealth between the poorest and richest country narrowed over the span of the data. Similarly, the number of aggregations declined over time, as did the average size of the gap between aggregations. The average number of countries per aggregation increased, as did the average span of an aggregation (Online Resource 2–6). The number of aggregations varied from 3 to 10, but more than 50% of the years had either 4, 5, or 6 aggregations (Table 1 in Online Resource).

The result of the nMDS on the per capita constant GDP shows that in general, the distribution for each year is more similar in structure to the years that come before and after it than to years from which it is temporally separated, implying a conservativeness to the group/gap structure over time (Fig. 2). However, the cluster analysis overlaid on the nMDS reveals that there are groupings of years that are more similar to each other than to other clusters (Fig. 2). Interestingly, the two largest clusters capture broad movement along the y-axis, which correlates with unknown factors (see spearman rank correlation analysis below). Two dimensions were sufficient to capture the complexity of the data with an acceptable stress value (0.1937). The ANOSIM results, which compared two groupings of years (1970:1989 and 1991:2012) were significant ($R = 0.54$; $p < 0.001$), suggesting that the difference between the two groups is greater than the differences in multivariate structure within each group (Fig. 3). This confirms our expectations that the abrupt change in the number of countries which occurred in 1990

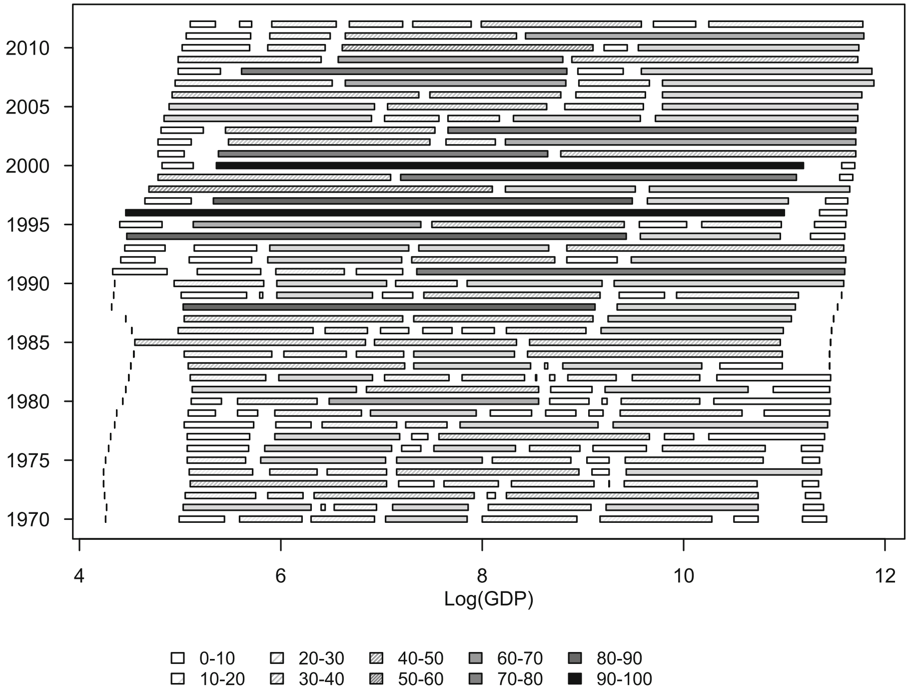

Fig. 1 Yearly discontinuous distribution of log-transformed per capita real GDP (constant 2005 dollars) for 43 years. Shading represents the proportion of countries falling in each cluster

and 1991 played a role in the large distance in ordination space between 1989 and 1991.

The spearman rank correlation analysis, which evaluated the degree of correlation between the nMDS axis scores and the metrics capturing the structure of each distribution shows that the spread of the years along the x-axis (axis 1) is highly correlated

Table 1 Spearman rank correlation coefficients *r* plus associated *p*-values between the two ordination axes, and 6 variables describing the structure of each year's distribution of GDP. Wealth Spread is the total spread of GDP; No. of Countries is total number of countries that year; No. of Aggregations is total number of aggregations that year; Avg Gap Size is the average size of a discontinuity or gap in logGDP; Avg # of Countries/Aggregation is the average number of countries per aggregation; and Avg Aggregation Spread is the average logGDP distance between the smallest and largest country

	NMDS Axis 1		NMDS Axis 2	
	r	*p*	*r*	*p*
Wealth Spread	−0.55	0.001	0.38	0.01
No. of Countries	0.88	0.001	−0.05	0.75
No. of Aggregations	−0.72	0.001	−0.10	0.52
Avg Gap Size	−0.65	0.001	−0.01	0.96
Avg # Countries/Aggregation	0.77	0.001	0.06	0.71
Avg Aggregation Spread	0.74	0.001	0.14	0.38

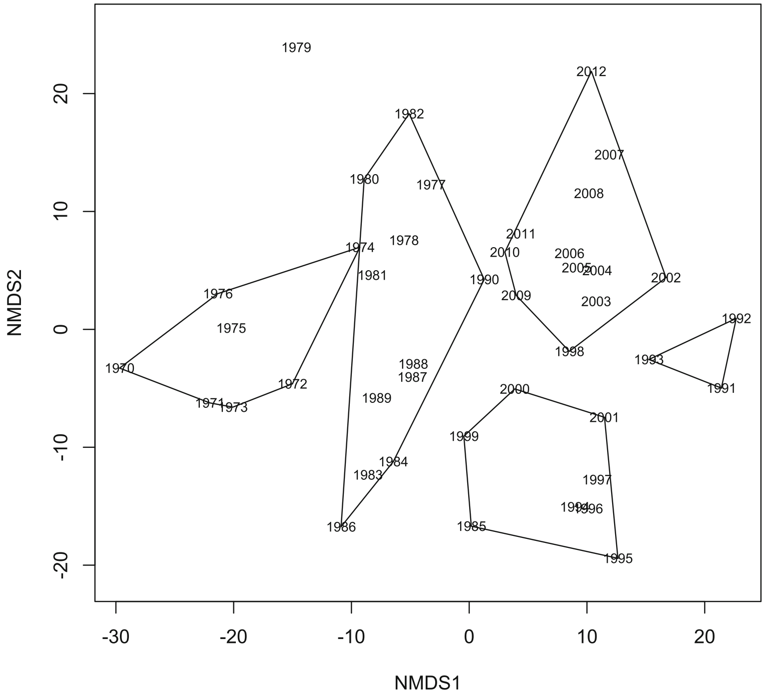

Fig. 2 Ordination results for the two-dimensional non-metric multidimensional scaling (nMDS), showing the dissimilarity between years in terms of their structure of aggregations and gaps. The clusters represent years which are most similar to each other

with the structure of the distributions (Table 1), as all of the metrics are strongly correlated to the axis 1 scores. That is, the movement of years along axis 1 was explained by a decrease in the overall span of wealth (range in logGDP from poorest country to richest country), an increase in the number of countries, a decrease in the number of aggregations (Fig. 4), a decrease in the average gap size, an increase in the number of countries per aggregation, and an increase in the average logGDP span of an aggregation. The location of the distributions along the y-axis (axis 2) are not correlated to these structural metrics, with the exception of a moderate positive relationship with total span of wealth encompassed by the distribution (Spearman's $rho = 0.38$, $p = 0.01$). This means that these metrics only partly explain the relationship of these distributions to each other in ordination space, as they are strongly correlated to only axis 1.

6 Discussion

We analysed 43 years of GDP data representing all countries of the world, and found that the rank-ordered size distribution for each year had a discontinuous pattern of aggregations and gaps, where aggregations of similarly-sized economies were separated by discontinuities, or gaps in the distribution. These discontinuous distributions suggest that as with ecosystems, city sizes, and firm sizes, there are scale-specific structuring processes that create persistent scale domains (Garmestani et al. 2005; Allen

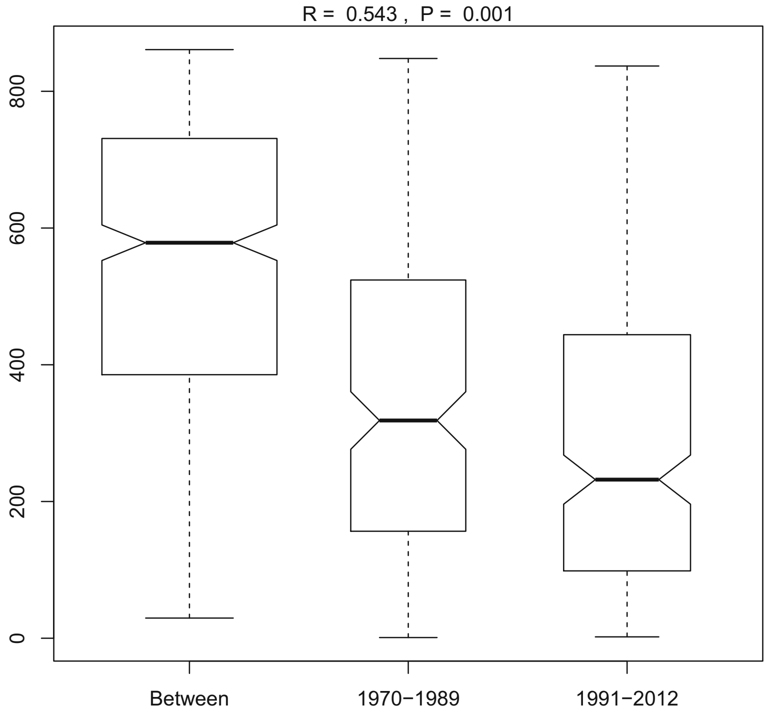

Fig. 3 An ANOSIM (Analysis Of Similarities) comparing within group and among group differences in aggregation/gap structure for 2 groups: 1970–1989 and 1991–2012, to test whether the change in number of countries between 1989 ($n = 186$) and 1991 ($n = 208$) was responsible for the large distance between these two years in the nMDS

and Holling 2008; Nash et al. 2014a), as the pattern of the aggregations and gaps is largely conservative over time. That economies fall into distinct GDP size classes which are conservative over time has fundamental implications for understanding the processes that shape a country's GDP, and could help resolve some of the inconsistencies in results found in the convergence club literature, where a process highly relevant to one convergence club or one analysis is less so in another. The theory behind discontinuity analysis expects different processes to be relevant over different spatial and temporal scales. This analysis provides a foundational first step in understanding the multi-scaled structure of the global economic system, and the economies of which it is comprised.

The persistence of the pattern of aggregations and gaps was particularly strong in the lower and upper thirds of the distributions, and aligns with the most consistent results from the convergence club literature, namely, that the poorest and wealthiest nations belong to distinct convergence clubs (Quah 1996a; Bloom et al. 2003; Apergis et al. 2012). The muddying of the pattern of aggregations and gaps in the mid-ranges of the data is also supported by the convergence club literature, as analyses which allowed for more than two clubs found a strong pattern of poor and rich clubs, with transient clubs in the middle that have been proposed as regions that facilitate movement from the poor to wealthy end of the spectrum (Battisti and Parmeter 2013; El-Gamal and Ryu 2013).

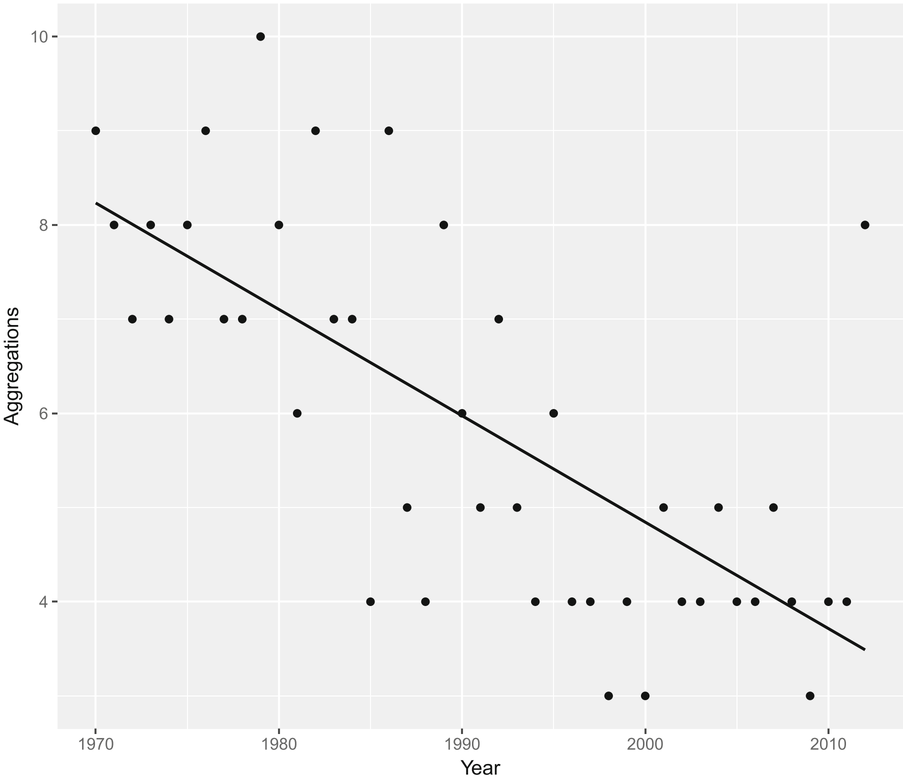

Fig. 4 Change in number of aggregations over time from 1970 to 2012

The multivariate analysis highlighted that the persistence of pattern over the years was not random. The nMDS treats each year as a 'community', and measures the pairwise distance of each community in terms of dissimilarity in structure (location of aggregations and gaps on a continuum of logGDP). We represented structure via the pattern of aggregations and gaps, so the nMDS compares how similar the aggregation/gap structure is between years and then plots it in ordination space—in this case, in two dimensions. This visual representation reveals that as we move through the years the pattern of structure is largely retained, but also changes over time. So 1970 is furthest from 2012, but also distant from 1991 to 1993. If we traced a line through the years in chronological order, it would zigzag. This suggests that the number of aggregations and the location of gaps is patterned but not static, nor does it change smoothly from one year to the next. This is what we would expect in a highly dynamic state space governed by non-linear or rapidly changing processes. The spearman correlation analysis showed that the location of each distribution along axis 1 (the x-axis) is highly correlated to the structure of each distribution. However, movement along axis 2 was not related to the structural metrics, indicating that there are other factors driving the differences between distributions. Further research should test if axis 2 is correlated to econometrics such as those commonly assessed in the convergence club literature for their relationship to club formation, or to major disturbance events, such as wars or recessions.

We also performed a discontinuities analysis on constant GDP without adjusting for population size, and the pattern of aggregations and gaps was similar to that of per capita GDP, but the gaps were more consistently present over time (Online Resource 7). Economies are constrained in their size by factors such as geography and the material resources present within the system, as well as history and the events which have played a role in their structuring. Adjusting for population size accounts for some of these inherent differences between countries, which may be why the aggregation and gap structure was clearer in the real GDP data than in the real per capita data. Using real GDP may also conflate two things (size of population and size of economy) which interact, but are structured by different process. Regardless, using real GDP masks critical qualitative differences between economies in the same size aggregation, as some of the countries may be in a poverty trap, whereas others may be quite wealthy for their size. Having both kinds of countries in the same basin of attraction is not sensible, as they are clearly being structured by different processes. Adjusting for population size accounts for this difference, making it more likely that the aggregations reflect countries in the same basin of attraction.

Finally, we recognize that the convergence literature often uses a balanced panel of countries in their studies. It is useful to note that our aim was markedly different than the convergence literature. We were not seeking to group countries into aggregations with a shared attribute, such as growth rate, but to test whether there are persistent basins of attraction in the global economy that generate size classes in the global economy. The identity of the countries that fall into a given size class are peripheral to this question. Furthermore, if key structuring processes operating at limited ranges of scale generate an attractor and basin of attraction, the basin should exist regardless of the composition of countries operating on that attractor. Using an unbalanced panel of countries is therefore the most conservative test of the hypothesis. However, we also conducted a discontinuity analysis on a balanced panel of countries, which consisted of 177 countries present in all years from 1970 to 2012 (Online Resource 8). The discontinuities were present in the same location (at the same value of log GDP) as in the unbalanced panel, and were unsurprisingly more robust in that they were present in more years. The mid-ranges of the data tended to be slightly more patterned, and the trend in declining aggregations over time was largely the same.

6.1 Basins of attraction and resilience

If economies operate in a state space such that they will dynamically move towards one or more attractors, then there are repercussions of such dynamics and behaviour that impinge on other assumptions with regard to the short- and long-term structure, behaviour, and dynamics of economies, and these have not been effectively dealt with in the economics literature. Similar to the convergence literature, our approach cannot analytically demonstrate that the scale domains identified are actual basins of attraction. Our analyses support a conceptualization of economies as complex adaptive systems, operating within a global economic state space. Basins of attraction are the regions within a state space for which a set of initial conditions will converge towards the same attractor. A state space can have more than one basin of attraction, and both the state space and the basins are dynamic over time and space (Mumby et al. 2014; Bozec and Mumby 2015). Basins can change shape as a result of endogenous and exogenous forcing, and they can be temporally transient, as the state space can be altered to either allow or disallow the development of new attractors (Scheffer 2009).

If the set of national economies are the entities operating in the global economic state space, then our results suggest that there are deep basins of attraction operating in the upper and lower portions of the distribution, while the middle ranges of the distribution are a more dynamic region with shallower and more transient basins winking in and out of existence (Fig. 5). Future research could model the dynamics of these basins of attraction, and the properties associated with the movement of countries within and across the basins.

6.2 Implications of aggregation/gap structure for economics

The finding of discontinuous structure in economies suggests that economists can utilize the extensive literature pioneered in other fields to contribute to an understanding of dynamics in complex economic systems. A discontinuity analysis has the advantage that the number of aggregations detected emerge from the data unconstrained by methodological choices, as there are no assumptions of shared initial conditions or equilibrium dynamics, and the method does not require binning, averaging, aggregating, or other data manipulations that can blur inference and pattern (as in Paap and Van Dijk 1998). Identifying discontinuous structure is the first step; one cannot infer from the discontinuous structure what creates it, but detecting said structure without observer bias is the foundation for subsequent analyses. Future research could identify the key processes responsible for structuring the scale domains, and determine the extent to which they are coincident with the processes already found to be critical in the economics literature (e.g. Alfonso-Gil et al. 2014). Doing so in the context of the aggregation/gap structure identified in this study explicitly incorporates scaling, which is considered beneficial, and may help resolve the often inconsistent results found in the economics literature, where a process highly relevant to one convergence club or one analysis is less so in another. Although there are processes such as competition and market niche exploitation which are scale-invariant, we would expect that many processes operate over a limited range of scales, or operate differently at different scales.

Future research may find that the key processes structuring the scale domains we identified may well be the same processes already widely analysed by economists for

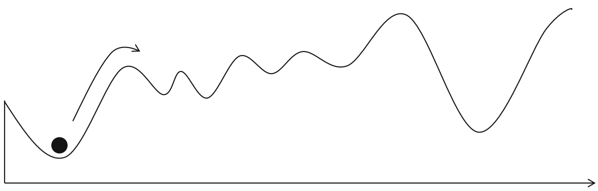

Fig. 5 The ball and cup heuristic represents a simplified state space with multiple basins of attraction. The x-axis is the discontinuous distribution of GDP. Each valley is a basin of attraction, analogous to an aggregation of similarly-sized countries, as identified in the discontinuity analysis. The threshold which must be surmounted for a country (represented by the ball) to move into a wealthier basin tends to increase along the x-axis. The lower and upper thirds of the distribution have larger and deeper basins, while the central basins are shallow, close together, and easier to move between

their role in wealth creation, or be related to more recent advances such as metrics of diversity in product space (Hidalgo et al. 2007; Hidalgo and Hausmann 2009; Hausmann and Hidalgo 2017), thermodynamic orientors focused on maximizing energy and matter throughput at different stages of system development (Fath et al. 2004), or may be more fundamental to the biology of humankind, such as competition, neurological hard-wiring that structures population sizes (Kosse 1990; Dunbar 2008), the tension between self-interest and the 'we' (Lynne 2006), or the tension between diversity/redundancy that appears to characterize all complex adaptive systems (Zipf 1949; Lee et al. 1998; Page 2010). Our method does not constrain the space of what might matter in the way convergence research does with its a priori assumptions, and it explicitly incorporates scales, something missing from most convergence research. Intriguing work in macroeconomics has uncoupled geographic attributes from national boundaries, allowing for a far more nuanced examination of the role of spatial geography in economic activity (Nordhaus 2006). The relationship between the location of countries within an aggregation and their mobility between aggregations, or size classes, is also ripe for further exploration. Brock (1999) argues that work on evolutionary theories of firm dynamics and turbulence closely parallels discontinuity research showing that species located near the edge of an aggregation by virtue of their body size are more vulnerable to invasion and extinction risk, as well as variability in abundance (Dosi et al. 1995; Forys and Allen 1999; Wardwell and Allen 2009). This is likely to be a fruitful avenue for future research, as a country's variability in GDP or other econometrics of interest may be related to its location within an aggregation.

6.3 Reduction in number of aggregations

There was a steady reduction in the number of aggregations over the years, with a sharp reduction beginning in 1996 and persisting through 2011. This suggests that there are fewer scale domains and fewer key processes structuring the size of economies. These findings are consistent with graphs in Pittau et al. (2010), which show a reduction in the number of modes over similar timeframes using a kernel density approach, and other convergence work showing increasing distance between the wealthy and the poor (Quah 1996a; Pittau et al. 2010). The non-random trend over time suggests fewer critical processes that structure economies. This may seem counterintuitive, as CAS's tend to grow in their complexity in order to capture and dissipate more energy and retain more material within the system (Schneider and Kay 1994; Beinhocker 2006; Hidalgo and Hausmann 2009). The complexity of a system derives from a multiplicity of features, including the heterogeneity of its parts, the number of them, the degree of connectivity between them, and the diversity and number of hierarchical levels, among others. Had we data from previous centuries, we would expect to see an increasing number of aggregations over time as economies and the world have increased in complexity across all these features (Schneider and Kay 1994; Ulanowicz and Abarca-Arenas 1997; Beinhocker 2006). A reduction in the number of aggregations suggests a particular kind of simplification, in which fewer processes are responsible for generating basins of attraction. This is not contradictory to the ongoing increase in economic complexity with regard to the increase in output diversity and complexity in production (Klimek et al. 2012).

The reduction we observed may reflect the following, which are not mutually exclusive: a) a world with increasing connectedness between national economies and therefore a reduction in the number of key processes structuring the relative wealth of countries; b) a partial collapse of complexity, where resilience to disturbance is reduced and the ability of economies to capture and dissipate energy is diminished (Schneider and Kay 1994; Hidalgo and Hausmann 2009); c) the network of economies is over-connected, rendering the global network vulnerable to cascading disturbances (Gunderson and Holling 2002; Pascual and Dunne 2005; Havlin et al. 2012); d) a reduction in resilience, as quantified by the contraction in the number of scale domains and thus a loss of heterogeneity. Future research could test these various hypotheses, and better historical data could test whether the drivers of complexity in terms of the number of aggregations change over time, as would be expected.

7 Conclusion

The relevance of both our work and that of convergence clubs lies in uncovering groupings of countries that may represent fundamental structuring processes in economic systems. The difference between the two approaches is that our method does not violate assumptions of complex systems theory, can objectively identify system scales, and makes few assumptions about the data. In fact, we stripped away virtually all the assumptions that are the starting point of convergence club research, and began with only one—that the size of an economy matters and is related to other important features. Then we asked whether size classes of GDP are robust over time, regardless of the composition of the countries in each size class. The robust pattern of groups and discontinuities at particular ranges of GDP over 40+ years strongly supports the hypothesis that processes that occur at discrete ranges of spatial and temporal scales are creating basins of attraction that host clusters of similarly sized countries, in terms of per capita GDP. If there are powerful structuring processes at work in economies, as there are in other complex adaptive systems, then this provides a new way of thinking about why some countries have a large GDP and others do not that is less about differences between countries and more about the importance of scale-specific processes that structure size classes/basins of attraction.

These results warrant future research with regard to specific processes which may structure the identified scale domains. An understanding of the key processes governing each scale domain might improve our ability to manage those processes to achieve two fundamentally distinct things: facilitate the movement of an economy from a smaller scale domain to a larger by moving the economy towards the threshold defining the basin of attraction so as to facilitate a shift to another scale domain (synonymous with basin of attraction); or work to maintain the resilience (shape of the basin of attraction) of a desirable basin so as to more readily stay within a particular GDP aggregation. Both ecology and economics have much to offer on these goals. There is a burgeoning literature in ecology on basins of attraction, regime shifts, and thresholds, while economics has much to offer on understanding the processes that drive growth and wealth creation.

The movement away from linear equilibrium models in economics is marked, but has not manifested in a rigorous uptake of complex systems theory. In many cases, neoclassical ideas of global convergence have merely been expanded to include multiple such equilibriums without altering fundamental assumptions about long-term dynamics and behaviour. When an attempt to incorporate pieces of alternative theories has occurred, few researchers incorporate all of these changed assumptions and dynamics into their models at the same time, nor have they defined their new terms and assumptions in a robust manner. If the base model is still equilibrium in nature, than only one or two assumptions can be relaxed at a time (Beinhocker 2006), and even if the model is not predicated on equilibrium, it can be challenging to incorporate all the assumptions of complex systems dynamics due to methodological or data limitations. The implications of a bimodal world bifurcated between rich and poor is a simpler and more tractable model than that of a multi-modal, multi-scalar world with different processes driving the creation and maintenance of each mode or basin. As Ricardo Hausman (2012) wrote, "In trying to understand the nature of economic reality we have been much less willing to let the world tell us what it is made of and more willing to believe our theoretical contraptions".

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Data availability The dataset analysed during the current study is available from the United Nations National Accounts Section of the Statistics Division, https://unstats.un.org/unsd/nationalaccount/data.asp

Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

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