A Brief Introduction to Dynamic Network Science

By Richard Ogle

Recognition of the key role dynamic, emergent forces play into structuring today's business, corporate, and geo-political environments led to renewed interest in systems dynamics, a discipline pioneered by C. Forrester in the 1960s, and famously celebrated as the "Fifth Discipline" in Peter Senge's 1990 bestseller of the same name. As discussed below, however, the advent of complexity science and its potent offspring, network science, has produced a far more powerful set of tools for modeling dynamic structures, situations, and events.

Enter Network Science

To begin by restating the obvious, many domains of modern life are characterized by a simple yet fundamental phenomenon: *highly dynamic, often unpredictable change*. In spite of this fact, those in business and government concerned with predicting and/or creating the future—i.e., financial, and business analysts, VCs, and not least business leaders and entrepreneurs—have largely been at a loss as to where to look for *scientifically based* guidance in modeling this phenomenon.

Fortunately, in the past decade and a half a new *science of dynamic networks* (DNS), a well defined subcomponent of complexity theory, has emerged to fill an important gap in our understanding. We'll introduce some of its key features by means of several cases chosen to illustrate some of this powerful new science's central laws and principles.[i]

Some Basics

A network (mathematically a type of graph) is simply a set of nodes and connecting links. A node can be represented as a solid circle and a link as a line. Highly interconnected nodes are typically modeled as hubs, graphically represented as hollow circles. Both nodes and hubs can be labeled, and both can be unpacked into further levels of internal structure. The links between the nodes represent the static and/or dynamic relationships between these elements.

For example, Fig. 1 shows a simplified graph of the global automobile industry, modeling some of the main players, with nodes indicating relative size and lines the degree of competition between them in the global marketplace:

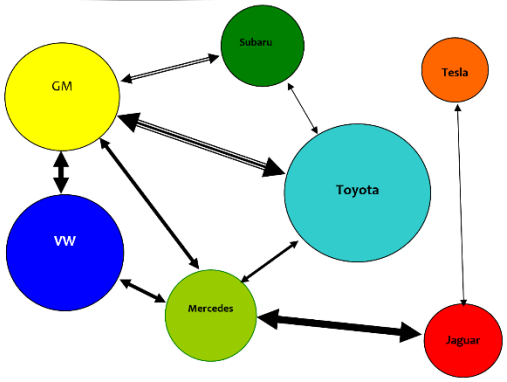

Fig. 1: The Global Automobile Industry Competitive Structure

Fig. 2 shows GM's internal structure in terms of the relative size of its brands, with lines indicating the degree of shared components:

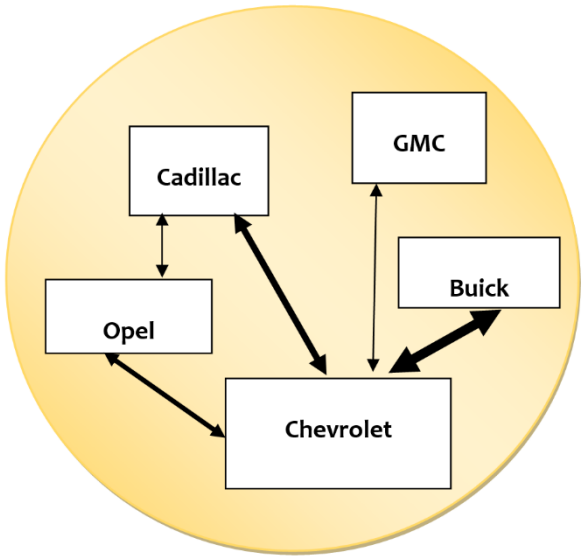

Fig. 2: GM's Brands

Figure 3 models GM's internal structure in terms of its (here unlabeled) org chart (a hierarchically organized tree diagram is a form of network with very clearly defined component/sub-component relationships):

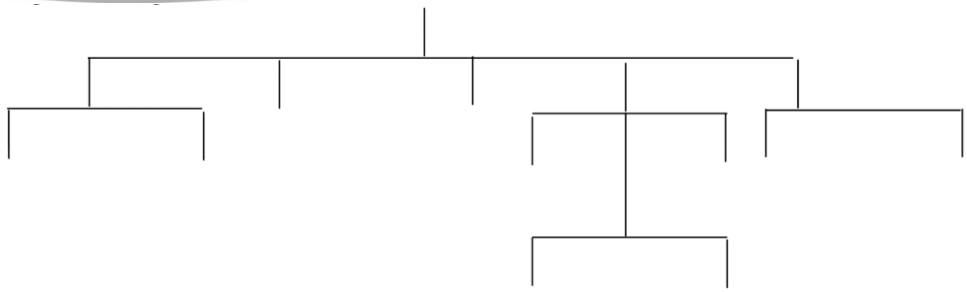

Fig. 3: GM's Organization structure

Notice that these networks are essentially *static*—snapshots in time. Fig. 1 could also be dynamically modeled, with Fig. 5 representing the speculatively predicted outcome in 10 year, when those manufacturers excelling in environmentally clean technology have surged ahead, with a corresponding decline in other brands. The market driver of clean technology is modeled with an anticipated positive (market share growth) or negative (loss) number associated with each node, as in Fig. 4 (= Fig. 1):

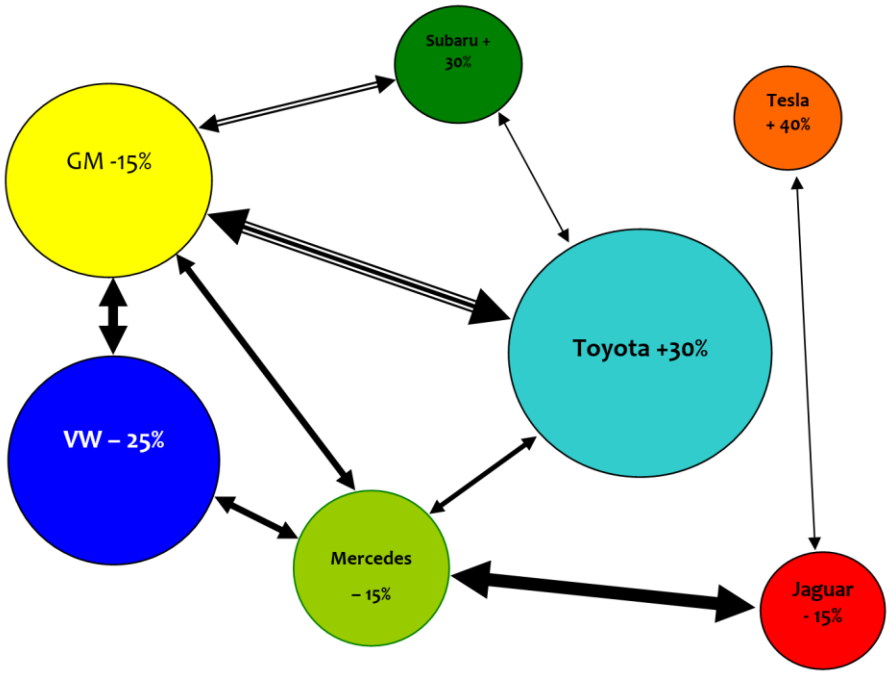

Fig.4: Original Competitive Structure, with Clean Technology Driver

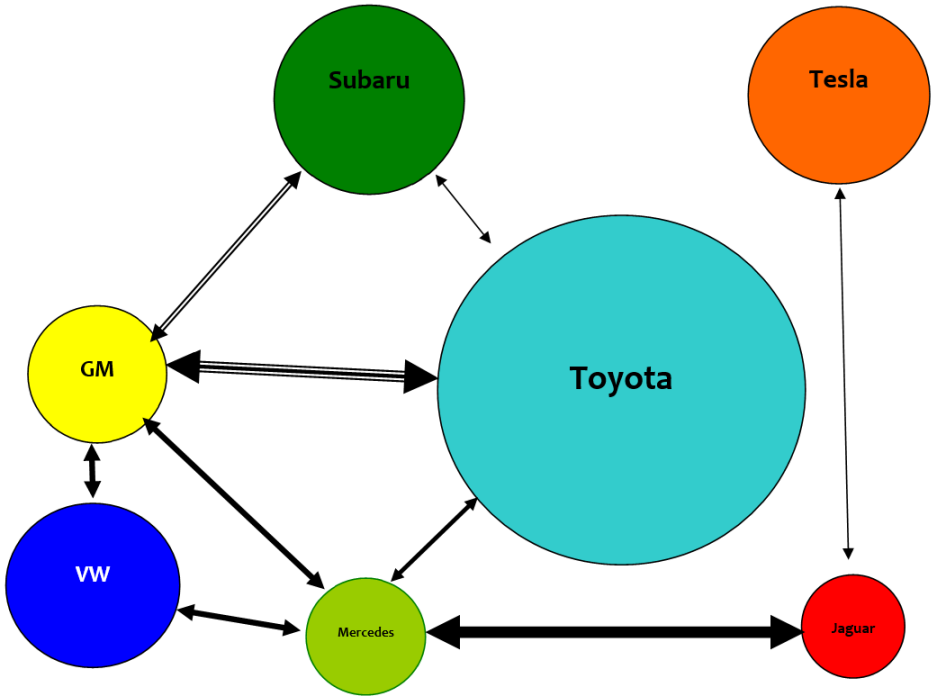

Fig. 5: Anticipated Outcome of Clean Technology on Sales 10 Years Later

Some Laws of Dynamic Networks

So far, we've shown that labeled, graph-based networks can be used to model both static and dynamic factors. While this kind of representation can be used for a wide range of types of phenomena, from simple org charts to quantitative marketing and sales predictions, *it's of no great interest in itself*. There already exist plenty of perfectly good graphical means of doing this, associated with the appropriate quantitative analytical theory.

The real power of dynamic network theory becomes apparent when we consider cases where what matters, from the point of view of insight, are the *structural properties of the network as a whole*—in other words when we focus primarily on dynamic relationships rather than purely quantitative factors.

Let's consider an interesting current development in branding, the apparent fragmentation of taste on a global basis. Globalization has of course driven (and in turn been driven by) the growth of global brands, whether in automobiles (Toyota, GM), tobacco (Marlboro), soft drinks (Coke, Pepsi), alcoholic beverages (Johnny Walker Black Label), fashion (Prada, Dolce e Gabbana), or any number of other product categories. This has been very good for business. At the same time, as savvy marketers are well aware, a disturbing new trend is emerging in some of these industries: the *progressive fragmentation* of consumer

taste. This is the very opposite of the vector of consolidation of taste spawned by globalization, and is considerably complicating the task facing marketers.

The liquor industry is a good example.

The advent of the so-called craft micro-brew industry in the 1970s, driven in part by the Anchor Steam brand in the U.S. and the Real Ale movement in the UK, was the first serious challenge to global beer brands such as Heineken and Bud Light. The Dutch brew, now the best-selling brand of beer in the world, is unlikely to be seriously challenged for a while. But the highly desirable 20-35 yr. old market segment has been progressively turning its attention to something different: locally made beers using highest quality ingredients, each with its distinctive individual characteristics, such as hoppiness, dryness, and alcohol content.

This same fragmentation of the mass (now global) market is now beginning to invade the hard liquor market as well. The shift to higher end, more expensive brands is entirely predictable as a function of growing world prosperity. But tastes in whiskies, for example, have shifted not just to internationally known single malts like The Macallan and Laphroig, but to the products of small-batch distilleries that previously served an almost exclusively local clientele. The same thing is happening in craft-made Ryes and Bourbons. It's no longer fantasizing to assume one could walk into the foreign correspondents favorite watering hole in Saigon and order a shot of Bulleit Rye, as it certainly would have been even ten years ago.

The market for craft-made liquors (they make rum in Thomaston, ME, vodka in Camden, NJ) is small but growing fast, especially among 20-something crowd. It's disrupting the growth and acquisition plans of the big liquor manufacturers, who must now make important investment and strategic marketing decisions under conditions of considerable uncertainty.

The first task in addressing this strategic challenge is to be able to model this highly dynamic situation, which is precisely where the power of dynamic network theory can be forcefully and insightfully applied. The process of building a model will serve nicely to illustrate several network laws and principles, including the laws of the Rich Get Richer (RGR), The Fit Get Rich (FGR), and the Fit Get Fitter (FGF). Additionally, the model will reveal the importance of using Hiedegger's concept of *recurrence* in world-spaces, together with certain so-called semantic redundancy rules, as a way of imparting forms of internal structure to worlds in ways that allow dynamic network laws to operate on them.

It is just this theoretical and methodological advance that constitutes the real power of DNS.

Liquor and the Laws of Dynamic Networks

A. The Law of the Rich Get Richer

The basic driver of global brands such as Glen Livet, Johnny Walker, and Jack Daniel's, especially in Asia, has been their comparative prestige in the west. A rising, increasingly prosperous middle class has sought status through consumption of prized western brands. The bigger and more prestigious the brand, the more status it was regarded as conferring. The natural driver of growth was thus the well-known business

(and commonsense!) law of the Rich Get Richer. Fig. 6 maps isomorphically into Fig. 7, with time and gross sales as the main parameter of change:

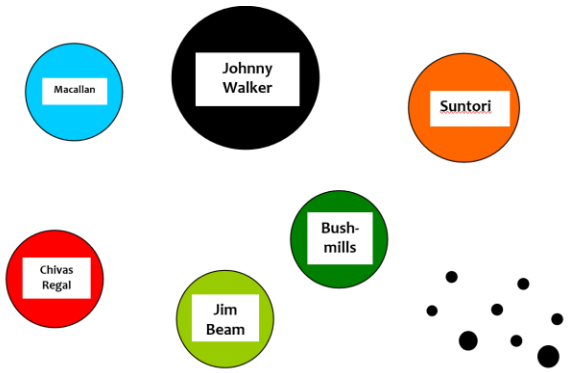

Fig. 6: Asian Market for Scotch, Irish Whisky, Japanese Whiskey, and Bourbon, 2000 (the small black nodes represent local craft liquors)

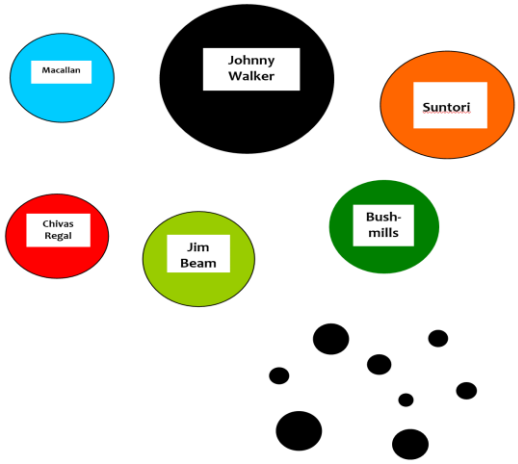

Fig. 7: Asian Market for Scotch, Irish Whisky, Japanese Whiskey, and Bourbon, 2014. (the small black nodes represent local craft liquors)

Under the driving force of rapidly increasing globalization and concomitant prosperity, all the main global brands have grown. This is the Law of RGR. Note that the relative size (and hence market share) of the brands has remained more or less constant, as RGR would predict. This law underlies the phenomenon of first-to-market advantage. Other things being equal, the first mover will retain much of its original lead over rivals.

Albert-László Barabási, one of the founders of modern network science, has reformulated the first-mover advantage as what he terms the law of *preferential attachment*, which states that we tend to connect "at a higher rate to those nodes that are already heavily linked." This induces "*a rich-get-richer phenomenon* that helps the more connected nodes [such as those of a first-mover] grab a disproportionately large number of links at the expense of the latecomers."[ii] This is illustrated in Fig. 8:

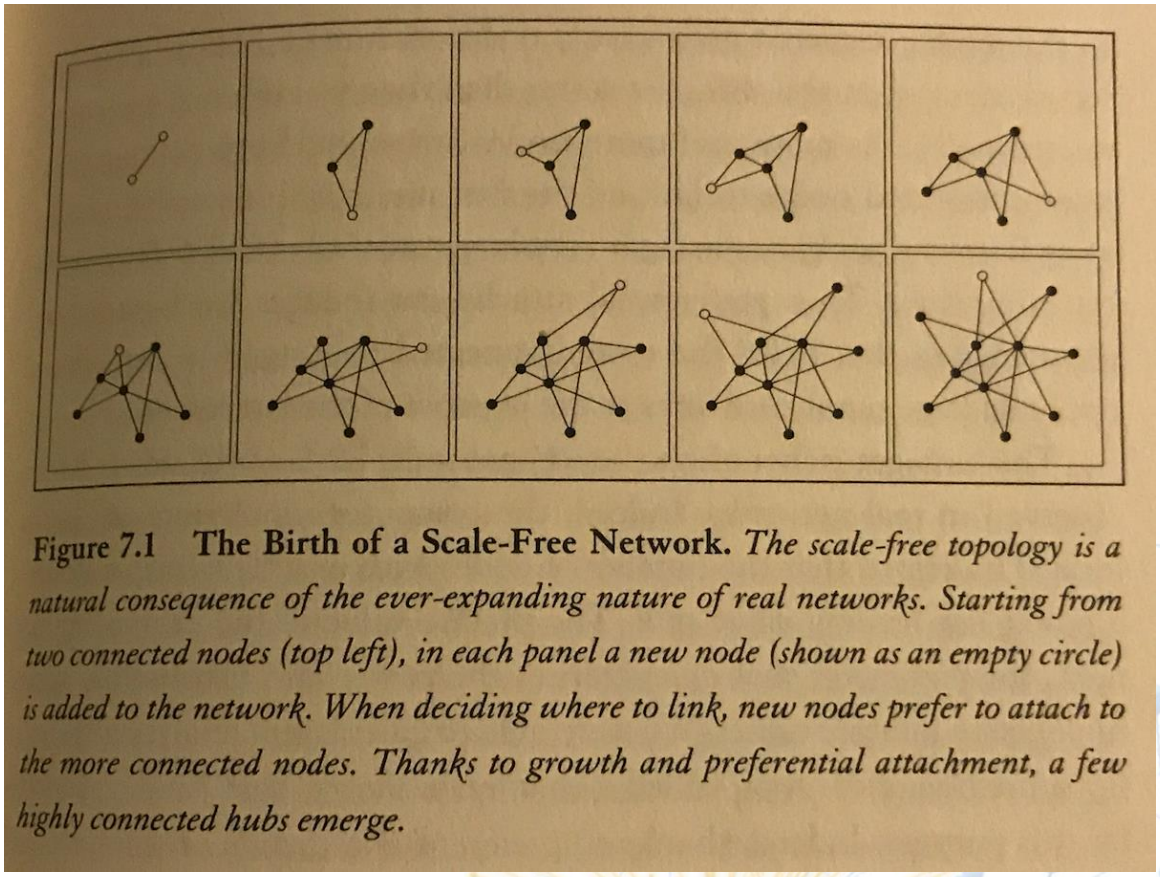

Figure 7.1 The Birth of a Scale-Free Network. *The scale-free topology is a natural consequence of the ever-expanding nature of real networks. Starting from two connected nodes (top left), in each panel a new node (shown as an empty circle) is added to the network. When deciding where to link, new nodes prefer to attach to the more connected nodes. Thanks to growth and preferential attachment, a few highly connected hubs emerge.*

Fig. 8: The Law of Preferential Attachment, or the Rich Get Richer (RGR) (Barabási)

It should be self-evident how this applies to Figs. 6 and 7 above to ensure that relative market share among global brands remains more or less stable.

The growth of the small craft liquor companies tells a different story, however. Their growth has been explosive (over 300% in some cases), relative to that of the global brands, and now threatens to start taking away a serious slice of their market share. Since these brands were largely latecomers to the global market, the question is, what is driving their exponential growth—since RGR can't be operating here?

B. The Law of the Fit Get Rich

The answer is a different law: *The Fit Get Rich* (FGR), which overrides RGR. For example, while Intuit's *Quicken* was the forty-third personal finance software package to market, it swiftly rose to a dominant position. Why? Because it fit the prevailing but unaddressed needs of the current market far better than its competitors. Much simpler to use than existing programs (which mimicked complex professional accounting software) and 70 percent cheaper, Quicken not only became the market leader, it expanded the personal finance software market a hundredfold. In reality, Quicken produced a tipping point in the personal finance software industry, completely changing the criteria for what constituted a successful product.[iii]

Similarly, when Google launched in 1998, it came late to a crowded search-engine market led by AltaVista, Lycos, and Ask Jeeves, but quickly vanquished its competitors through its vastly superior search technology. In both cases the programs qualitatively and quantitatively transformed the way people use the type of software application in question—in other words, the world-spaces of personal accounting and Internet searching "tipped" as a result of their appearance.

The essentially Darwinian principle of fitness comes into play when a company is able to offer consumers a product with truly significant advantages over the competition. Fitness, in other words, represents a product's capacity to satisfy core customer concerns. Intuit offered customers a far more user-friendly product at a significantly lower price. Similarly, Google vastly increased the accuracy of searches.

We can state this network principle as follows:

THE LAW OF THE FIT GET RICH

In an open, dynamic, scale-free network, the fit get rich. (For present purposes, a scale-free network is one with large hubs.)

Preferential attachment is in this case driven by increased fitness. The probability that a given node will link to another is expressed by the formula $\kappa\eta/\sum\kappa^i\eta^i$, where κ is the number of links and η the relative fitness.

Barabási explains this as follows:

Each new node decides where to link by comparing the fitness connectivity product of all available nodes and linking with a higher probability to those that have a higher product and are therefore more attractive. Between two nodes with the same number of links, the fitter one acquires links more quickly.[iv]

Fitness, he goes on, "is a quantitative measure of a node's ability to stay in front of the competition." In formal network terms, fitness measures a node's ability to compete for links: nodes with higher fitness are linked to more frequently. In this case, preferential attachment is driven not by richness alone but by the product of a node's fitness and the number of links it has. In plain English, what all this says is that—using the example of search engines—a user is more likely to choose Google (i.e., link to the Google hub) if it has more links and/or its links are more fit than competing search services.

You may be wondering at this point if we really need all this theoretical machinery. Why not simply say that the best product quite naturally rises to the top? The trouble with that idea is that it leaves unexplained why some products produce tipping points—qualitative transformations accompanied by explosive growth—while others don't. We need to understand how increasing fitness triggers tipping points, and what light network theory can throw on this. Let's return to our analysis of the global liquor industry. This will lead us to two more laws of network science, The Fit Get Fitter (FGF) and the Law of Tipping Points (TP).

As Fig. 7 shows, even while the overall Asian market for liquors continued to expand linearly, the market for small batch, craft-made liquors grew exponentially during the past decade. In order to explain this, we need to take a closer look at how market "fitness" acted as a driver. Put simply, the small liquor brands both fit and helped drive an emerging trend among Asian consumers, especially those under 35, for *acquiring status* through the brand of liquor they choose.[v] Initially, status focused on drinking prestigious western mainstream brands. But as in the beer industry, this began to change as a result of **three dominant driving forces: the search for authenticity, the spread of social media, and the desire for high quality, natural ingredients**. These acted not only as active individual vectors in driving the market in the direction it is now taking. *They interacted, each reinforcing the others in non-linear ways*. This is where the network dynamics of fitness comes to the fore.

It's long been observed that the desire for authenticity, in fashion, food, beverages, and other forms of consumption, has been a strong driver of buying habits among the younger (post-boomer) generation. One's taste in everything from T-shirts to shoes to food and drink is consciously regarded as a marker and measure of one's identity. The more special and unique the choice, the higher one's status—"coolness"—among knowledgeable peers. Buying products one's parents bought no longer cut it. This meant knowledge of the market was at a premium.

Because of this, the drive for authenticity quite naturally received a major boost from another emerging trend of the early 2000s, the rise of social media. Google search, Facebook, YouTube, and Twitter, along with conventional websites, all made it possible for small brands—just like small bands in music—to achieve international presence almost overnight. In the case of alcoholic beverages, status accrued to those who could prove they were knowledgeable about the newer brands of single malt scotch, for example. This in turn drove the rise of social-media based marketing, which correspondingly further deepened and expanded the knowledge and purchasing habits of consumers of specialty liquors.

The ensuing market shift coincided with a third emergent trend, the growing interest in natural, healthy ingredients of high quality. This initially manifested in the food industry, starting back in the 1980s with Alice Waters' promotion of local organic produce through her Berkeley, CA, restaurant *Chez Panisse* and her various books, and becoming mainstream through writers like Michael Pollan, Mark Bitman of the *New York Times*, and multiple others. In the case of liquors, the impact was a focus on the ingredients used, their source, and the processes used to produce the beverage in question. As should be obvious, this fit quite naturally with the drive for authenticity and was in turn boosted by specialty knowledge circulated by means of social media.

In short, no less than three independent social trends of the past 10-20 years together drove the Asian (and indeed western) market for craft-made liquors. The fitness of these brands with the market as a whole was a function of the non-linear interaction of these trends, as indicated in Fig. 9.

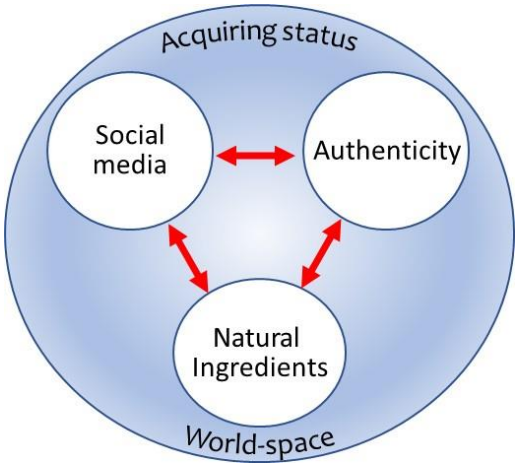

Fig. 9 Dominant forces shaping *acquiring status* world-space

The fitness formula, $\kappa\eta/\sum\kappa^i\eta^i$, that drives the law FGR gave rise to the exponential growth of the small, independent liquor brands. Dynamic interaction among the three driving nodes increased η, the fitness index itself. This in turn drove κ, the number of links, as new start-up brands entered the market.

Notice that the relatively linear growth of the conventional global brands was a function of their lacking all three of these fitness drivers. They relied on standard means of advertising—print and television—much more than on social media for brand promotion; by virtue of being mainstream they lacked authenticity; and for the most part they did not use (or did not stress) the naturalness of their ingredients or (another booster of authenticity) their artisanal methods of production.

A couple of observations are in order. First, although each of the three drivers—authenticity, social media, and natural ingredients—arose independently, they came to cohere in a closely interactive, self-reinforcing web in the world-space of young adults in both the west and Asia. This mutually reinforcing network property is the *primary reason why growth was non-linear*.

Second, we can characterize the relationship between the component recurrent features of the various hubs in terms of semantic redundancy rules. Thus in the world-space of hip (i.e., knowledgeable, cool, with it) young adults, natural ingredients and artisanal production methods strongly associate with authenticity:

<<nat. ingredients>> + <<artisanal>> → <<authenticity>>

Similarly, authenticity implies special or expert knowledge, which in turn implies skilled use of social media:

<<authenticity>> → <<special knowledge>> → <<skilled use of social media>>

The specific indices of strength associated with these redundancy rules control the degree of dynamic interaction between the three main hubs in Fig. 9.

Fig. 9 represents a purely quantitative approach to growth. But this was accompanied by *qualitative* change as well: the fit don't just get rich, *they get fitter*. The new law, the Fit Get Fitter, or FGF, was first postulated in *Smart World*, Chapter Five: Darwinian Networks, or Why the Fit Get Fitter, and may underlie neurological phenomena uncovered by Gerald M. Edelman, a neuroscientist and Nobel laureate. Edelman's concern, from the mid-1970s on, was focused on how the brain gives rise to the mind. His research led him to postulate a theory of the brain called neuronal group selection, which came to be known as "neural Darwinism." Edelman believed that when something happened in the world — something encountered by one of our senses — some neuronal groups responded and were strengthened by a series of biological processes. Those groups, he concluded, became more likely to respond to the same or a similar stimulus the next time, and thus did the brain learn from its own experience and shape itself over the course of a life.[vi]

In similar fashion, in a scale-free network with large hubs such as the one depicted in Fig. 9, a dynamic can emerge in which each hub begins to reshape the other(s). In Fig. 10, for example, the arrows drive change according to the numbered redundancy rules given below:

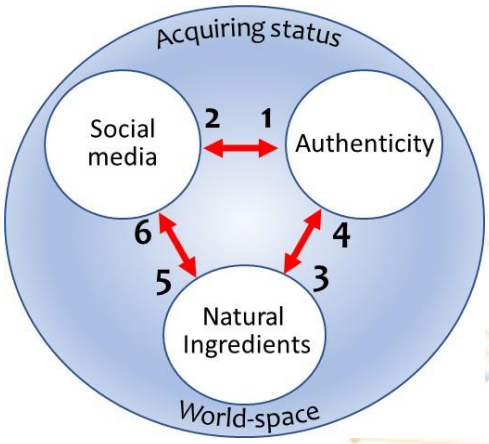

Fig. 10 Redundancy rules governing dynamic interaction

Redundancy Rules dictate six possible ways in which these hubs can interrelate:

[1] Social media → authenticity

[2] Authenticity → social media

[3] Authenticity → natural ingredients

[4] Natural ingredients → authenticity

[5] Social media → natural ingredients

[6] Natural ingredients → social media

However, all are not equivalent in terms of actively shaping fitness in this specific case. The obvious dynamic ones are:

[1] Social media → authenticity

The growth of social media tools, services, and platforms such as Facebook, Twitter, Google, etc., has fed the focus on authenticity by making it much easier for small groups of aficionados to make their enthusiasms known on a global basis through web pages and other digital means that provided a wealth of information and informed taste expertise to novice enthusiasts of craft-made beers and liquors. This not only drove their growth, but also shaped the very nature of the authenticity of these brands, which could remain small and true to their production ideals while reaching a global audience. The linking up of these hubs/world-spaces thus led to a *qualitative* as well as a quantitative shift.

[3] Authenticity → natural ingredients

Emerging consumer focus on the importance of authenticity as an identity marker partly expressed itself as an interest in the use of natural ingredients, which are regarded as inherently authentic, particularly in contrast to the synthetic nature of many of the varieties of food and beverage products currently available to global consumers. The emergence of authenticity as a marketing factor increased, in purely quantitative terms, the sheer amount of natural ingredients used in consumer products, not least alcoholic beverages. But again, as in the case of the effect of social media on authenticity, it qualitatively shifted the production and consumption of such ingredients, as consumer expertise in this area increasingly fed back into production methods and ingredient choices. This was very apparent in the transformation of the craft beer brewing industry over the past three decades, for example in producer claims about the local sourcing, and uniqueness, of their hops, barley, water, etc.

[4] Natural ingredients → authenticity

Over the past two decades, a multiplicity of factors—demographics, environmental and health concerns, increased desire for longevity, etc.—has driven a global shift, especially in the industrialized countries, towards consumption and use of natural ingredients in food, beverages, and consumer products. Craft-produced beverages such as single malt whiskies have, by pure tradition, and more recently for marketing reasons, typically made use of the purest natural ingredients, primarily for the sake of quality, uniqueness, and not least, taste. The emergence of consumer interest in natural ingredients once again has had the effect of not only increasing authenticity quantitatively (i.e., in terms of intensity, variety, etc.) as a growth factor in the beverage industry, but also shaped its inherent nature for consumers, who had previously tended to think of authenticity primarily in terms of brand uniqueness.

[5] Social media → natural ingredients

Just as the rise of society media both drove and transformed the focus on and nature of authenticity for

consumers, so it also changed, quantitatively and qualitatively, the interest in natural ingredients. As awareness spread of the benefits of consuming such ingredients, it simultaneously began to transform the growing, choice, and use of such ingredients, especially on the part of producers. The more kudos accrued to products containing high quality natural ingredients through marketing and sales, especially via digital channels, the more incentive producers had to use such ingredients, and even to engage in research and experimentation focused on their selection and growth.

The remaining two links are clearly less prominent:

[2] Authenticity → social media

[6] Natural ingredients → social media

The obvious reason for this is size and degree of activity. The emergent focus on authenticity in consumer habits was hardly strong enough to significantly affect the rise and nature of social media. Correspondingly, increased interest in, and use/consumption of, natural ingredients was a minor phenomenon in the emergence of social media and its role in marketing.

These various binary relationships between hubs—which, recall, are actually world-spaces—eventually form a complex series of three-way feedback loops, with any change in one hub/world-space affecting the other two in an ongoing process. This is a classic illustration of a fundamental phenomenon of dynamic world networks: a space that drives its own transformation. *Understanding this phenomenon is absolutely vital for understanding the dynamic of the future as it unfolds*.

We can state the Law of the Fit Get Fitter (FGF) as follows:

THE LAW OF THE FIT GET FITTER

In an open, dynamic, scale-free network with positive feedback loops between hubs, the fit get fitter.

Conclusion

Let's review what can be learned from the DNS theory we've set out above:

1. Even the best strategic thinkers are often blindsided by the eruption of unforeseen events. As Rumsfeld was at pains to point out, such events may arise from that dark domain of blindness—what you don't know you don't know.
2. Strategic-level decision-making is often distorted by the parameters of the world in which it occurs.
3. Competitive advantage in conflict/competition goes to those who best see/understand the nature of the "game."
4. Linear development and return-to-equilibrium/stability, including in economics, is no longer the main characteristic of change in an hyper-connected world.
5. Rather, what we see now is emergent, non-linear, non-equilibrium dynamics, best characterized by new laws and principles of network science.

Seeing the future before it arrives, or *solving Noah's problem*, is more urgent than ever before, but also harder, given the sheer complicatedness, complexity, and velocity of change, of the world we now live in, with its multiple drivers of rapid geo-political upheaval, game-changing technology, and amply funded disruptive innovation.

Competing explanatory frameworks such as game theory and Big Data analytics, while grasping part of the problem, do not have the breadth or depth of explanatory power possessed by the DNS framework. DNS theory, as demonstrated, represents an entirely new level of analysis, with multiple modes of practical application in multiple domains. On a practical level, it holds forth the real possibility of getting a handle on the future through grasping the hidden parameters, in the form of emergent world-spaces, their structural characteristics, and the network laws and principles driving them, of the global game being played.

Rumsfeld was too pessimistic. *You can get a grasp of what you don't know you don't know*, if you rigorously apply the principles and parameters of the DNS framework. You can come to perceive and understand the principal dimensions of the game being played, ahead of the competition. And by extension, you can see the future well before it arrives. Solving Noah's problem no long

[i] See Ogle 2007 and SWIFT Network Science Tutorial (10-1-13) for a detailed history and exposition of network science.

[ii] See *Linked: The New Science of Networks*, by Albert-László Barabási, Cambridge, MA: Perseus, 2002, pp. 86ff. and Ogle 2007, Ch. 5 for details.

[iii] See Albert-László Barabási, *Linked* (2002), and Richard Ogle, *Smart World: Breakthrough Creativity and the New Science of Ideas* (Harvard Business School Press, 2007). Ch. 5.

[iv] Barabási 2002, p. 96.

[v] "Status in the New Asia," by Roger Cohen, NYT MAY 12, 2014, http://www.nytimes.com/2014/05/13/opinion/cohen-status-in-the-new-asia.html?hp&rref=opinion

[vi] See "Gerald M. Edelman, Nobel Laureate and 'Neural Darwinist,' Dies at 84," By BRUCE WEBER, NYT MAY 22, 2014, http://www.nytimes.com/2014/05/13/opinion/cohen-status-in-the-new-asia.html?hp&rref=opinion, from which I am paraphrasing/quoting here.