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The Meaning and the Implications of Heterogeneity for Social Science Research

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Introduction

The concept of "heterogeneity" is much invoked in social science research these days. Though this has long been the case in disciplines like psychology, sociology and anthropology, it was not heard much in mainstream economics until recently.[2] Heterogeneity is now an integral part of economics in sub—disciplines like industrial organization, entrepreneurship, behavioral economics, and similar fields. What is "heterogeneity" and what are the implications for social science research?

This paper examines the fundamentals of the concept of heterogeneity – which I relate to the distinction between quantity and quality. This distinction is related also to the distinctions between simple and complex phenomena and to that between social and natural phenomena in a manner I shall explain. I offer a conceptual framework for the demarcation of situations in which quantitative methods may be expected to work well, and, by implication, situations in which they do not. I imagine the insights yielded by this framework are not new to my readers, but suggest that there is some added value and novelty to this particular formulation which helps to draw out the implications of these insights.[3]

I begin with a consideration of how to get from the observation of diverse, heterogeneous phenomena in the world to the construction of theoretical models to account for and explain what we observe. I examine the important features of complex systems and how they differ categorically from simple systems in how we observe and investigate them. Complex phenomena are emergent in a way that precludes familiar quantitative modeling. Having explained the inherent limitations of quantitative methods, I proceed to an examination of some of the merits of qualitative investigative methods, specifically that of "pattern prediction" as suggested by Friedrich Hayek (Hayek 1962) – though arguably insufficiently appreciated even by his admirers. I examine the unique characteristics of social systems (a category of complex phenomena) with special attention to entrepreneurship. I end with a brief conclusion.[4]

Heterogeneity and Complexity: Quality and Quantity in Modeling Social Structures

Fundamentally, heterogeneity is about the relationship between quantity and quality. When one breaks it down, the difference between quantitative and qualitative change becomes clear. Qualitative change involves the emergence of something new and is not amenable to measurement in quantitative terms. Quantitative and qualitative changes are categorically different. We can see this as follows.

All observation and explanation proceeds on the basis of classification (categorization). Phenomena are grouped into categories according to our perception of their essential similarity (homogeneity). The elements of any category (class) might be different in some respects, but in all respects that "matter" to us they are identical. Items within a particular category can be counted, quantified. The ability to quantify is crucially dependent on being able to count items in this manner. The number and type of categories (variables) is known and is fixed. The arrival of a new category thus cannot be accommodated within a scheme of simple quantitative variation and must be considered to be a change in *quality*. *Qualitative differences are categorical differences*.[5]

All quantitative modeling proceeds on the basis of the assumption that the individual elements of any given quantifiable variable are identical (homogeneous) and are different in some important respect from those of another variable. Variables are essentially distinguishable categories. In addition, the elements of a quantifiable category do not interact with each other—or else they could not be simply counted. Each element is an independent, identical instance of the class. (Most obvious is the case of "identical randomly distributed variables"). This does not preclude the elements themselves being composed of interactive sub-elements—being the result of lower-level interactions, like identical molecules or biological cells, which are complex[6] phenomena in their own right.

But when we consider social structures, quantitative modeling comes up short. *Structure* implies connections/interactions between elements across categories. A structure is composed of heterogeneous items that are more than simply a list of those items. If a heterogeneous mix of items is structured, they work together to "produce" something that is qualitatively different from the sum of its parts. A physical capital-structure, for example, is a complex structure made up of heterogeneous elements that more literally "produces" outputs. When those heterogeneous elements interact—when, say, the electronics of computer hardware and satellite technology interact with software instructions—new categories that make up the capital structure, such as navigation systems, emerge. The emergence of these new systems, in turn, fundamentally changes the capital structure.[7]

A structure is an "order" in the sense that Friedrich Hayek (1973) described when he discussed the ways in which rules and cognitive tools (such as money prices), rather than human design, lead to intelligible results. As Hayek explains, an "order" refers to a situation in which it is possible to know something about the whole by observing the *types* and the ways in which elements are *related*, without having to observe a totality of the elements. Returning to the capital structure example, we can understand how navigation technology is related to business activity and can reasonably predict how innovations in navigation systems may reduce the costs of interstate commerce. Similarly, we understand the structure ("order") of language by knowing the categories involved and how they relate to one another to produce meaning, without having to know every instance, or even a significant proportion of instances. The same is true for the structure of legal systems. The primary feature of structures is that they are *relational.* Elements are defined not only by their individual characteristics but also by the manner in which they relate to elements in other categories. These interactions are, in effect, additional variables.[8]

Quantitative modeling works well in helping us understand reality only when both the independent and dependent variables are meaningful, identifiable, quantifiable categories that can be causally related.[9] The model "works" then in the sense of providing quantitative predictions, in for example, predicting weather patterns with reasonable accuracy. The inputs and outputs can be described and connected in quantitative terms. However*, when the outcome of the process described by the model is a new (novel) category of things, such as a novel response to radically changed circumstances, no such quantitative prediction is possible.* Ambiguity in the type and number of categories in any system destroys the ability to meaningfully describe that system exclusively in terms of quantities.

We have a sense then of the effects of heterogeneity and may adopt the following terminology (see Table 1). *Variation* applies to quantitative range. *Heterogeneity* (variety) applies to qualitative (categorical) range. *Diversity* incorporates both, but they are significantly different. Complex systems (discussed below) are likely to result from substantial heterogeneity, *especially* *where heterogeneity is open-ended, in the sense that the set of all possible categories of things is unknown and unknowable.*

Table 1: A Typology of Diversity

Type of Range	Type of Diversity
Quantitative	Variation
Qualitative (Categorical)	Variety (Heterogeneity)

Consider a simple, but general, formalization:

y = f(x)

y=[$y_{1,} y_{1}, \ldots y_{m}$] and **x**=[$x_{1,} x_{1}, \ldots x_{n}$]

where **y** and **x** are vectors of dependent and independent variables (categories) respectively. For this to work, the components of **y** and **x** must be known and fixed, and the functional form of the m y-equations must be tractable and "realistic" depictions of the reality being investigated. In this case, one is able to derive implications ("predictions") of the form $\frac{\partial y_j}{\partial x_i} = \beta_{i,j}$. However, if the components of **x** or **y** are unknown, or open-ended (un-listable), this kind of model does not invariably provide reliable knowledge. If, for example, some previously unknown (or unconsidered) variable, x_{n+1} or y_{m+1}, were to emerge, the equation system would be mis-specified, and would not yield accurate predictions. Instead, a statistical estimation would yield an *historical* instance of the associations between the variables. This may conform to an intuitive, and expected pattern of associations between the variables, but it would not, in essence, be a quantitatively accurate reflection of reality – it reveals no *universal*, stable laws of association.[10,11]

The reader may recognize this as another way of illustrating the "Lucas critique" (Lucas 1976) of econometric practice. The parameters we estimate are most often "reduced form" rather than true structural parameters. And without knowing all the necessary variables and their interactions, there is no way to know (or to estimate) the "true structure" of the world. Indeed, as I shall emphasize, interactions are important. In complex systems there are likely to be multiple interactions. If the vector **x** is large, the number of possible interactions may be a large multiple of that number—interactions may occur between any possible combination. In the extreme the number of interactions may be so large as to be greater than the size of the data base, with obvious implications.[12] Quite restrictive structural limitations are thus necessary in order to obtain fruitful results from strictly quantitative investigation. This is particularly apparent where some of the components of **x** are unknown or unknowable.

In studying the production of a given product, it may be possible to articulate some of the inputs into the production process, but many processes cannot be easily duplicated. Consider, for example, the production of wine. We have an idea of the categories of things that go into it – the quality of the soil, the climate, the type of grape, etc. But we also know that much of it cannot easily be explained, that there is a "culture" of growing wine, a great deal of tacit knowledge, possessed by those who do it well, that cannot be articulated or easily duplicated. There are just "too many variables."[13]

The traditional neo-classical model involving well-behaved cost curves, derived from a well-behaved firm production functions, omits the main elements of real-world competition, namely, product differentiation and improvements in production technology. A simple (well-behaved, twice differentiable, homothetic, etc.) production function of the form $Q = f(K,L)$, yields the necessary AC and MC curves and the perfectly competitive condition $MC = P$ as the optimal long-run equilibrium of a competitive process. Though logically complete and helpful for a particular range of situations, this analysis fails to capture the essence of competition in current economic processes. The latter are not about the optimal price and quantity of a standardized product in a market characterized by a fixed, unchanging production technology. Rather, economic competition is about the inexorable pressure to innovate by producing products differentiated from those of your rival that will add value in the eyes of the consumers in your market; and about ensuring that your methods of production are "cutting-edge" in a world of rapidly changing technology. It is a world of "innovate or die."

Forced into the formal language of neoclassical economics, the firm is moving rapidly from a situation like $Q = f(K,L)$ to a new situation $Q' = f'(K',L')$ where the presence of a ' on a variable indicates a qualitative change. A model based on $Q = f(K,L)$ will fail to capture a reality characterized by $Q' = f'(K',L')$. And, given that this type change is ubiquitous, rapid and continuous in many product markets, the relevance of the traditional model becomes extremely doubtful in any general discussion of competition (for a fuller discussion see Holcombe 2013, chapters 5 and 6).

These considerations apply with even more force at the aggregate level where the $Q = f(K,L)$ is applied to macroeconomic growth accounting. The aggregates in this equation contain huge numbers of disparate and changing items – changes that are qualitative as much as they are quantitative in nature. Clearly, though measures of economic growth are not without meaning and relevance, there is no doubt that they fail to capture the detail of the processes that underlie this growth – what we normally think of in terms of development or progress (Holcombe 2013, chapter 7; Baetjer, 2000; Foss, 1998)

Another example is macro-economic policy. The only thing we can say for sure about macro-economic policy predictions is that they are always wrong in a fundamental sense (Colander 2010). They deal in aggregates composed of fundamentally heterogeneous items, whose precise magnitudes can never be accurately predicted. Historical associations among reified macro-aggregates, like output, employment and price indexes, play a large and almost mythical role in the social-network of macro-forecasting and analysis. But there appears to be very little real learning going on – very little to suggest that experience is bringing us closer to a consensus understanding of an invariable underlying structure approximated by the models of these aggregates. Again, there are just "too many variables."[14]

Interestingly, and perhaps ironically, the limitations imposed upon the usefulness of econometrics by heterogeneity of social data were highlighted both by Hayek and also by Keynes. Keynes wrote in his review of Jan Tinbergen's early work on econometrics: "If we were dealing with the action of numerically measurable, independent forces, adequately analyzed so that we were dealing with independent atomic factors and between them completely comprehensive, acting with fluctuating relative strength on material constant and homogenous through time, we might be able to use the method of multiple correlation with some confidence for disentangling the laws of their action." The problem, however, is that "every one of these conditions is far from being satisfied by the economic material under investigation". (see Lawson, 1996: 99.[15]

Sometimes, as in the investigation of incentives for and outcomes of entrepreneurial action in diverse cultural environments, both the **y** and the **x** are very imperfectly known. Investigators may be unsure what they are looking for as indicators of entrepreneurship and what the appropriate criteria (categories) spurring or deterring such action are. Indeed, entrepreneurship may consist in the creation of new categories of outputs and inputs. Qualitative research, like detailed field interviews, may reveal important aspects of the underlying structure. Sometimes investigators need to get "closer" to their subjects than grand surveys allow (Chamlee-Wright 2010).

In sum, heterogeneity matters for the way we do research. Quantitative modeling and accurate quantitative prediction is only possible when the number of categories (variables) is fixed and known and where interactions are manageable. Multiple interactions might imply too many variables; unknown interactions would render the quantification invalid; and unknown multiple interactions is a frequent property of complex systems, especially social systems, the investigation of which using standard closed-end quantitative modeling is extremely unlikely to yield meaningful results. We investigate this further in the next section.

The Nature of the Research Environment – simple and complex phenomena

As argued above, different types of diversity lead to the quantity-quality (variation-variety) distinction. In turn, as a matter of types of *subject matter*, the crucial distinctions are between simple and complex phenomena, and natural and social sciences (see Table 2). We have a bi-part division between types of systems according to whether they are natural or social, or simple or complex. Notably, all social systems are complex and involve both variety and variation.

Table 2: Types of Research Environment

	Simple (involves variation)	**Complex** (involves variety and variation)
Natural Sciences	Astronomy, Physics	Biology, Complexity Studies, Ecology
Social Sciences	Formal (equilibrium-based) Economic Theory	Applied Economics, Anthropology, Management Studies

Complex systems are systems (networks, structures) with many elements that relate to one another in limited, but complicated and often numerous, multi-level (to be explained below) ways, that lead to outcomes that are essentially unpredictable (in their details, though the possible "patterns" that can result may be known). Complex *adaptive* systems (CAS's) are complex systems whose multiple interactions lead to outcomes that are in some significant sense "ordered" or "functional" (Hayek 1974: 26; also 1955 and 1964). In these systems, complex interaction leads adaptively to outcomes that are coherent and useful according to some scheme of action and evaluation. For example, evolution in nature is a CAS that works through some selection-replication process (constrained by the physical environment) to produce outcomes that are better adapted to the environment (Hayek 1964). The evolution framework is highly generalizable and has been applied in multiple contexts, including, of course, to human societies (in which connection it was first conceived; see also Hodgson, 2004).[16]

Though it is the subject of an increasing body of research effort, and though it has a clearly common-sense meaning, there is no readily agreed-upon definition of the concept of "complexity" (Page 2011: 24-32; Mitchell 2009: 94-111). One way to approach complexity is to see it in essence as a matter of "too many variables."[17] It is not a question *merely* of too many variables. The difference in conceptual structures to which Hayek is referring is of a magnitude that fundamentally changes the investigative challenge.[18] It is in the first instance a practical matter, but it is most likely also more fundamental and elusive in that in order to successfully model essentially complex structures we would have to engage in a degree of complex classification that is *intrinsically* beyond the capacity of the human brain to accomplish.[19] In addition there are some systems that are *intrinsically* non-computable/decidable – like the classic Holmes-Moriarty game, which closely mimics many entrepreneurial situations (see Koppl 2010) which I discuss briefly below.

I spoke earlier of multi-level interaction. Our description of complex phenomena implies the phenomenon of *emergence*. Complex adaptive systems are (most) often hierarchical in nature, exhibiting "lower" and "higher" levels. Elements existing at the lower level interact in ways that result in the "emergence" of *qualitatively different* (as explained above) elements at a higher level. But interaction is not limited to any level. Elements at a lower level may be affected (in a "downward" direction) by the emergent elements at a higher level – as when individual action is influenced by social structures (like institutions and standards) that are, themselves, the result of *prior* individual actions; hence multi-level interaction. The observation that the changes are "qualitative" in nature is basically a recognition that they cannot be fully "accounted for" by changes in the elements at the lower level. The new characteristics appear to "emerge" in a not fully explicable way from the interactions that occur at a lower level. This is a discernible aspect of the "too many variables" problem, commonly found with complex phenomena.

Pattern Predictions and Refutations

The implications of complexity in a system (structure, network) are typically that, though intelligible, the outcomes that result from their operation do not provide us with precise value (quantitative) predictions. Instead, they are intelligible in that we are able to understand (comprehend the *meaning* of) the *types* of outcomes that are possible and are observed. Thus, as suggested above, *patterns* rather than values are what can be predicted. Crucially, this does not preclude the possibility of an important type of (Popperian) falsification or refutation (a criterion taken by many scientists as the hallmark of acceptable "scientific" investigation, see Table 3 below).

Certain resulting patterns *could be* ruled out by this type of investigation. And the range of possibilities thus ruled out is a measure of the power of the theory informing the investigation. The observation of a pattern of results not within the range predicted by a model of complex phenomena would refute the model (Hayek 1964: 32-33; 1974: 30-32).

Table 3: Popperian Growth of Knowledge Through Pattern Prediction and Refutation

Framework	Result	Examples				
		Biological evolution	**Inheritance of traits**	**Price-controls**	**Hyperinflation**	**Entrepreneurship**
H_0: null hypothesis	pattern A – the hypothesis is maintained.	Lamarkian adaptation cannot explain biological evolution	A recessive trait cannot be inherited unless both parents have it	Setting an enforceable price above the market price always causes a shortage	Need not be preceded by a large increase in the supply of money	Successful market entrepreneurship cannot exist in the absence of secure property rights
H_1: alternative hypothesis is sought.	Not pattern A, pattern A is refuted.	Observation of traits inherited by Lamarkian adaptation => it is possible.	Observation of a recessive trait inherited when only one parent has it	Observation of an enforceable price set above the market price with no resultant shortage	Observation of hyperinflation without a prior large increase in the money supply.	Observation of successful entrepreneurship without secure property rights

Pattern predictions concern the instance not of quantitative magnitudes, but of configurations of categories of instances. Pattern prediction, in a sense, operates at a higher level of abstraction than quantitative prediction. Examples from the biological sciences come to mind. Confirmed observations of inherited traits acquired in a Lamarckian manner would refute the Darwinian version of evolution. Similarly, by contrast, refuting Lamarckian adaptation leaves open the viability of Darwinian evolution (until *it* is refuted). As another example, the confirmed observation of the inheritance of a recessive gene-characteristic not present in both parents would refute the Mendelian version of inheritance. In social contexts such refutations are less common – the demarcation and observation of familiar categories is more difficult, and the pitfalls of spurious aggregation abound. So, for example, the observation of the phenomenon of "stagflation" – the simultaneous occurrence of inflation and unemployment increases would ideally refute the theory that suggests that they are trade-offs. Such refutations are, as expected, often shielded from refutation by the difficulty of operationalizing the notion of "simultaneous occurrence," difficulties of measuring inflation and so on. Yet, such an historical episode (strongly evidencing the concurrence of price inflation and unemployment) was indeed pivotal in producing widely shared doubt about the efficacy of Keynesian economics policies in the 1970s and 1980s. In fact, these broad pattern observations are what drive the subsequent attempts to "further refine" the relationships involved in structural equation models. But, though econometrics may appear to be about precise quantitative prediction it is more accurately a type of quantitative history of pattern occurrences. As discussed above, the values of the parameters are realistically at best a measure of an historically contextual effect, not an instance of a universal law.

Other examples of potential refutations from economics might be the failure of a shortage to follow the imposition of a maximum price below the unconstrained price; the occurrence of hyperinflation without a prior sizeable, sustained increases in the money supply; the failure of migrant patterns to flow toward higher opportunity environments; and so on. One may likewise think of similar pattern predictions and refutations in the fields of sociology (for example, concerning weak and strong network ties), political science (for example, concerning expenditure and constituency patterns), social linguistics (for example, concerning grammatical patterns), and so on.

Social Phenomena are Complex but Different – the Case of the Entrepreneur

Examining the cells of Table 2 above we see that complex phenomena may be social or natural. Complex phenomena share certain characteristics, as explained above, but they are also different in crucial respects. A brief examination of the characteristics of social systems and of entrepreneurial action within them will conclude our examination.

All human action in society is embedded in *networks* of shared, but (by definition) subjective meanings that propel and arise from the interaction between individuals – in short, all human action in society is human *inter*action. The "data" that inform human decisions are not given "objectively" in the sense that data on the physical world are, but rather, include prominently the expected actions of others upon whom the success of our actions depend. For planned actions to succeed there needs to be some process of coordination at work. As social scientists, in our search for understanding and policy-leverage, we are concerned with the motives and purposes of our subjects, something that is absent from the natural sciences (Hayek 1937). This means we are unavoidably engaged in the *interpretation* of actions, expressions and gestures – we are concerned with the *shared meaning* of things to us and to our subjects. We are in the realm of the *inter-subjective* (Schutz, 1967; Storr 2010).

This is particularly true of the field of entrepreneurship. The entrepreneur is someone who "discovers"[20] an opportunity to create value, and, in the commercial for-profit sector, to earn a profit in the process. The successful entrepreneur is an *innovator*, someone who sees things that others do not. In a sense she transcends the conventional means-ends framework by imagining a new product, a new use for a product, a new way of organizing things, a new method of production (combining and organizing productive resources), and so on. The entrepreneur thus introduces something that is *qualitatively* different. It is no coincidence that successful new products are sometimes referred to as "category killers" by those in the trade. The details of entrepreneurial action are clearly unpredictable, though intelligible. If entrepreneurial action is predictable in any way, then it is as a *category* of actions. For a variety of reasons we are clearly interested in the conditions that militate in favor or against the *likelihood* of successful entrepreneurship. The entrepreneur is the driving force of the economy, the key to economic growth and development, so this is a matter of some importance.

Yet, insofar as entrepreneurship is, itself, a complex process, embedded within an environment of on-going complex processes, it is a phenomenon that is not amenable to standard quantitative methods of investigation. The predictive categories themselves are social phenomena that the researcher must struggle to understand and interpret. To be more specific, entrepreneurial action, like all human action, takes place within an institutional framework – a framework of formal rules and regulations, informal rules, practices, norms, habits, customs, traditions, etc. The natural environment is only one, sometimes a minor, part of the equation. It is the social environment that is the key predictor of entrepreneurial action and success, yet it is something that is not amenable to simple observation or the tally of instances of familiar categories. It requires that the researcher get "closer" in an intersubjective sense to the nuances of this framework in order to understand and calibrate in some way their influences (Chamlee-Wright 2011).[21]

Conclusion

The social researcher has much in common with the entrepreneur. The entrepreneur is defined by the "production" of novelty – the introduction of new categories of things, as well as simply new instances of old categories. Economic progress is about innovation, not merely accumulation. Thus, entrepreneurship research and research into social science in particular, must deal with this phenomenon of category change and emergence.

Social systems are composed of essentially heterogeneous elements that are related in complex ways. Because social systems are complex there is category dynamism and ambiguity. Received quantitative methods, deriving from probabilistic frames, will not work in investigating much of the social world. This is more true the more dynamic and innovative that social world is. Thus, to understand this world, the researcher must try to see it as the entrepreneurs who made it and are making it see it. There is an essential connection between researcher and subject matter that is absent in the case of the natural world. This paper reaffirms this well-known phenomenon.

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Notes

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[2] In Austrian Economics, and other heterodox economics, heterogeneity has always played a role – most explicitly in the work of Ludwig Lachmann (in connection with capital theory) and Friedrich Hayek (in connection with complex phenomena more generally, of which capital theory is an instance) (see Lewin 2013).

[3] Those who are familiar with qualitative research may see in this framework a little different and complementary perspective. Those who ply their trade by constructing complex structural equation econometric models (often with latent variables) may consider this framework a challenge to the robustness and relevance of those models.

[4] My inspiration comes mainly from the work of Friedrich Hayek on research methods in social science and from the work of Ludwig Lachmann on capital theory in economics. A paucity of references to the philosophy of science literature generally reflects that this paper arises mainly (perhaps solely) from thinking about these two literature streams (Hayekian philosophy of science and Lachmannian capital theory). Some recent work using essentially the same Hayekian and Lachmannian (and related) ideas in a comprehensive examination of the implications for social investigation is Richard Wagner's, 2010, 2011, 2012. I will leave it to others to make wider connections.

[5] Reiss (2001) distinguishes formally between "natural and fictitious" quantities. Intuitively, the former are simply countable in the manner described in the text, while the latter are not, being the (sometimes complex) result (for example aggregate) of multiple natural quantities. The discussion in the text is consistent with this idea

[6] I explain complexity as a technical consideration in the next section.

[7]Though the elements of a quantifiable category may be unstructured, these elements may be *composed* of structured sub-elements. This is the basis of the phenomenon of *modularity*. Self-contained (possibly complex) modules may be quantified. This dramatically simplifies the organization of complex phenomena (to be examined below), as has been noted in a fast growing literature on the subject. Modularity is a ubiquitous phenomenon in both nature and social organizations. It is an indispensable principle of hierarchically structured complex systems. The benefits of modularity in social settings include the facilitation of adjustment to change, and of product design, and the reaping of large economies in the use and management of knowledge (see for example Baldwin and Clark 2000, Langlois 2002, 2012).

[8]Emergent outcomes may be designed or spontaneous (organic, unintended). Hayek distinguished between organizations and orders – the former are designed, the latter, though "the result of human action are not the result of human design." (See Lewis 2011: 177, quoting Hayek, quoting Adam Ferguson). Similarly, Menger distinguished pragmatic from organic institutions (Menger, 1883). Within social-systems it is manifestly true that multiple sub-orders/organizations exist that are complex amalgams of design and spontaneous order. The capital structure is a graphic case in point. Local capital combinations are carefully designed to produce certain preconceived outcomes, but the capital structure of the industry, or of the economy, as a whole, is a complex lattice-work of intricate, interrelated connections that no-one can comprehend in in its entirety. As we shall see later, complex systems are emergent, and may contain within them both designed and organic components.

[9] This is true even for so-called qualitative probability models like probit or tobit models, where the zero-one codings are performed on categories that are composed of identifiable elements of a particular type. And this applies regardless of the particular concept of causation one uses.

[10] Hayek has a more detailed account: "[We are addressing situations] where *the number of significantly interdependent variables is very large* and only some of them can in practice be individually observed. The position will here frequently be that if *we already know* the relevant laws, we could predict that if several hundred specified factors had the values $x_1, x_2, x_3, \ldots, x_n$, then there would always occur $y_1, y_2, y_3,$

… , y_n. But in fact all that our observation suggests may be that if $x_1, x_2, x_3, \ldots, x_n$, then there will occur [some recognizable subset of $y_1, y_2, y_3, \ldots, y_n$ and there may be a large unknown number of subsets; or that perhaps some type of configuration of the variables, P, *or* equally a different type, Q, could result from a $x_1, \ldots, x_m$ or similar input]. There may be no possibility of getting beyond this by means of observation, because it may in practice be impossible to test all the possible combinations of the factors $x_1, x_2, x_3, \ldots, x_n$. If in the face of the variety and complexity of such a situation our imagination cannot suggest more precise rules than those indicated, no systematic testing will help us over this difficulty." (Hayek 1955: 8, first set of italics added; see also van den Hauwe 2011).

[11] A side effect of this is to produce an incentive to investigate only those problems for which reliable quantitative inferences can be made, and to consider all other situations, falling outside of this closed-form **x-y** world, to be beyond the purview of "real science." Such is the effect that may be produced from the well-known, debunked but still quite common, presumption that, unless one can quantitatively measure a phenomenon, one cannot have scientific knowledge of it, and, conversely, that the measuring of something quantitatively, in itself, yields scientific knowledge.

[12] A simple way to try to capture any interaction is to construct the new variable x_ix_j ($i \neq j$) for any i and j. Call this new variable z_i. We could then construct the new variables z_iz_j or x_iz_j ($i \neq j$) for any i and j, and so on. The number of possible combinations is large.

[13] The "too many variable" problem is both a metaphorical and, within a formal conceptual framework, a literal way of describing an aspect of complex phenomena. I take this up in more detail in the next section.

[14] Macroeconomic aggregates like GDP, the capital stock, the rate of unemployment, etc., are, it seems to me, "artificial" quantities in the sense of Reiss 2001 (though he is more agnostic on this). Their key components are incommensurable elements – which have to be reduced to homogeneity in order to arrive at the aggregate. For example, the diverse, heterogeneous items that make up GDP or the capital stock are rendered countable by using the momentary prices of their components as a measure of their "value." Clearly, there are many problems with this approach. Perhaps the most obvious is the total eclipse of consumer surplus in the case of GDP, or the well-known difficulties of obtaining values for current durable capital items. My case can be supported by considering that, for any given value of GDP, there are an infinitely large number of arrangements of its essential components (real goods and services of various types) which in no reasonable sense can be said to be economically equivalent.

[15] I thank an anonymous referee for this observation and reference.

[16] The brain itself is a complex adaptive system (Hayek 1952).

[17]"[S]ocial sciences, like much of biology, but unlike most fields of the physical sciences, have to deal with structures of *essential* complexity, i.e. with structures whose characteristic properties can be exhibited only by models made up of *relatively large numbers of variables*" (Hayek 1974: 26, italics added). It is illuminating to again view this problem in the context of statistical modeling and the well-known difficulty of inferring from the estimated reduced-form parameters the fundamental structural parameters of the model. The model is supposedly an "accurate" depiction of reality. As mentioned earlier in the text, this is the "Lucas critique" leveled at econometric practice (Lucas 1976). The response has been to try to find better (more easily identifiable) models. But, in the context of the discussion in the text, it may be seriously doubted that such a strategy is ever likely to be viable. The structural parameters of real-world complex processes are the result of multi-level interaction an order of magnitude far beyond the capacity of any statistical modeler to specify.

[18] Hayek (1964: 25n references removed) quotes John von Neumann, 1951 "we are dealing here with parts of logic with which we have practically no experience. The order of complexity is out of all proportion to anything we have ever known." Hayek continues: "It may be useful to give here a few illustrations of the orders of magnitude with which biology and neurology have to deal. While the total number of electrons in the Universe has been estimated at 10^{79} and the number of electrons and protons at 10^{100}, there are in chromosomes with 1,000 locations [genes] with 10 allelomorphs 10^{1000} possible combinations; and the number of possible proteins is estimated at 10^{2700}. C. Judson Herrick suggests that "during a few minutes of intense cortical activity the number of interneuronic connections actually made (counting also those that are actuated more than once in different associational patterns) may well be as great as the total number of atoms in the solar system" (i.e. 10^{56}); and Ralph W. Gerard has estimated that in the course of seventy years a man may accumulate 15 x 10^{12} units of information ("bits"), which is more than 1,000 times larger than the number of nerve cells. The further complications which social relations superimpose upon this are, of course, relatively insignificant. But the point is that if we wanted to "reduce" social phenomena to physical events, they would constitute an additional complication, superimposed upon that of the physiological processes determining mental events."

[19] As Hayek observed in his 1952 work on cognitive psychology, the brain itself is a classifying mechanism of lower complexity than the observed structures.

[20] I leave aside the question of exactly what entrepreneurial opportunity discovery means. This is the subject of a large and still growing literature (for example Klein 2008; McMullen et. al. 2010; McCaffrey 2013). For a recent review see Koppl & Minniti, 2010 and the Dialogue in the AMR January 2013: 154-166).

[21] A recent article (Venkataraman et. al. 2013) broaches the question of entrepreneurship as an empirical science in the sense of the discovery of universal elements that can be useful for policy or entrepreneurial action itself. How are some individuals better able to perceive opportunities for value-creation? The discussion above suggests the strong conclusion that this question cannot be answered. It goes to the heart of the working of the market process – a complex-adaptive system that defies description in mechanical terms.

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