The Critical Rationalist

ISSN 1393-3809

Volume 01 **Number 02**

26-Nov-1996

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The Metaphysics of Scarcity: Popper's World 3 and the Theory of Finite Resources

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Keywords: Scarcity, Metaphysics, Invention, Information-Content, World-3, Diminishing-Returns, Increasing-Returns, Theories, Means-End-Scheme.

Abstract

Natural resources are infinite. This is possible because humans can create theories whose potential goes beyond the limited imaginative capacity of the inventor. For instance, no number of people can work out all the economic potential of quantum theory. Economic Resources are created by an interaction of Karl Popper's Worlds 1, 2 & 3, the worlds of physics, psychology and the abstract products of the human mind, such as scientific theories. Knowledge such as scientific theories has unfathomable information content, is universally applicable, and infinitely copyable. The point can be made with technological knowledge such as that embodied in the wheel. The theory of the wheel has unbounded potential to be embodied in unforeseeable new technologies, is useful on the Moon as on Earth, and can be infinitely copied. Unlike a piece of land (using fixed factors), such knowledge shows increasing returns. This helps to explain Julian Simon's observation that "natural" resources are now less scarce than they used to be and why an increasing population can increase resources in the long-run. It was Simon's breakthrough to elaborate on the abstract character of "natural" resources. I further explore this abstract character and thereby explain why natural resources are infinitely expandable.

Economic growth and the creation of natural resources depends on the rate of invention. F. Machlup's suggestion (Machlup 1962) that the opportunity for new inventions increases geometrically with the number of inventions at hand is acknowledged for its suggestiveness, but criticised for its conservative position. Frank Tipler's fascinating argument for indefinite economic growth (Tipler 1994), is reinforced by my argument by making a distinction between information in the engineer's sense and the infinite potential "information" in our scientific knowledge based on Popper's notion of information content.

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1 Introduction

(1) How is it possible for a resource to be both scarce and infinite?

Most philosophical treatments begin their discussions of global problems by taking the finite-resource view for granted. I contend that economic raw material resources are in an important sense infinite in the long-run. With the invention of the rocket and nuclear power, we may have already created the theoretical knowledge that will make economic resources infinitely expandable.[1] Like all theoretical knowledge, these inventions have unfathomable economic potential and instead of showing diminishing returns (like a piece of land), show increasing returns. Just think how more more useful a transistor is now than it was 50 years ago when first invented. How much more useful are the natural numbers now than they were when first invented simply for counting? But this marvelous quality of abstract knowledge needs a philosophical explanation. A combination of Julian Simon's analysis of the concept of a natural resource (Simon 1981) plus Popper's Worlds 1, 2 and 3 (Popper 1993), helps us to understand the nature of a resource and, as a bonus, helps to explain how natural resources might be both scarce and infinitely expandable.

(2) I argue, along with Simon, that the conventional notion of a natural resource is profoundly misleading. It implies that resources are simply portions of matter/energy just waiting to be discovered. On the contrary, even "natural" resources are created by an interaction between the human mind, theories and the physical world. In a sense, all resources are created, artificial. Seen from this angle, the issue of the finite/infinite extent of resources solicits a very different sort of answer. But we may consider that even Simon's notion of a resource needs to be extended to more accurately describe the multifaceted nature of a resource, taking into account its physical, psychological and logical (or abstract) character.

(3) The growth of knowledge or World 3 in general impacts on economic growth and the scarcity of resources through the affect it has on the rate of invention. F. Machlup's suggestion (Machlup 1962) that the opportunity for new inventions increases geometrically with the number of inventions at hand is criticised for its conservative position. Frank Tipler's fascinating argument for indefinite economic growth (Tipler 1994), is reinforced by my argument by making a distinction between information in the engineer's sense and the infinite potential "information" in our scientific knowledge.

(4) My thesis is that at any given time, raw material resources are scarce

[1] See (Tipler 1994). Tipler would add computing theory to nuclear power and rocketry as the sufficient conditions for permanent economic growth.

in that humans have more uses for them than they are able to satisfy (for the most in-depth criticism of the possibility of eliminating scarcity in this traditional economic sense, see Steele 1992). However, the flow of services from raw material resources is in principle infinitely expandable over time without diminishing returns. This is made possible by the infinite potential of our theoretical understanding of a resource. A piece of copper may be used over and over again indefinitely without diminishing its quantity. But this does not capture its full potential as a useful item. To capture this you need to examine the theories we use in our use of the copper.

(5) Popper divides all that exists into three domains: World 1 (the world of physics, chemistry and biology), World 2 (the world of psychological states, dispositions and processes), and World 3 (the sum total of the objective abstract products of the human mind). The purpose of the theory of World 3 was to account for the objectivity of scientific criticism, creativity and the relationship between the mind and the body. Both Popper and Eccles see World 3 as containing such things as theories, numbers, and even tools and institutions considered as abstractions (Popper & Eccles 1977). They are our products, but once created they have autonomous existence, properties and relations that go beyond our expectations and intentions, indeed beyond any psychological states. The natural numbers were created by us but we then discovered, as an unforeseeable and irrevocable consequence, that this sequence has odd and even numbers. Through a sort of plastic control, world 3 is able to affect and constrain our thought and, only through our thought, influence World 1. The invention of numbers, for example, enabled us to develop counting and calculating methods such as calendars, balances and computers that in turn greatly changed the physical world.

(6) I argue that inventions and, less obviously, natural resources have three ontological aspects: a World 1 aspect, a World 2 aspect and a World 3 aspect.

1. Economic theory was first worked out as it applies to humans, but at least some economic theorems apply to all organisms. Economics is as old as life itself and like other aspects of life, it has an evolutionary history. Thus there were relatively crude economic resources even before the advent of consciousness. But with consciousness and especially the emergence of human time-binding and the ability to create and visualize new independent, distant goals and means for reaching them, more interesting economic actions became possible.

   Previously useless physical substances become resources, created by our valuations, intentions and imagination with respect to their physical properties. Copper became a new economic resource when people placed various portions of it within new means-end schemes. There was a time when humans had no use for copper, but now it can be used in copper wiring in TV sets etc. At this level of analysis, a resource is a World 2 object.

2. A resource can also be captured in an objective abstract theory or cluster of theories. The metal in a computer becomes very useful only because of the enormous amounts of abstract mathematics, logic and other technological theory embodied in it. Thus a resource is a World 3 object.

3. Along with the inventions that make natural resources useful and expand them, their infinite long-term serviceability without diminishing returns is made possible partly by their World 3 characteristics: namely, the objective logical properties of the theories that partly constitute them.

(7) That a natural resource such as copper is a World 1 object might seem obvious. But every resource is not simply a portion of matter or energy, but becomes a resource on account of being interpreted (correctly) as part of a theoretical means-end relationship. (This means-end scheme may be a rather complex cluster of technical and social hypotheses). For it is the services we can obtain from a natural resource that we are interested in when we speak of a natural resource.

(8) A similar point has been made about other "objects" of social science: money, for example, is not money until it is interpreted and valued as money[2] (cf. Searle 1984). Such thinking can, I think, be traced back to the marginalist revolution in economics, inaugurated by Menger (1871), Walrus (1874) and Jevons (1871). This placed a general theoretical emphasis on the importance of subjective factors in social science. To reinforce the point made by Searle and others, it might be said that these interpretive theories may only become conscious when something goes wrong and they are refuted. For example, during a hyperinflation money ceases to be money because people no longer see it as money, i.e., each person no longer entertains the theory that most other people think that it is valuable to most other people. My point is that just as there is no chemical or physical analysis alone that will determine what makes money money, so there is no chemical or physical analysis alone that will determine what makes a resource a resource.

(9) On the other hand, I want to say that because of the, in many ways laudable, emphasis on subjective factors instigated by the marginalist school of economics, there may be a tendency to overlook the part played by the

[2] Of course, certain sorts of objects will be objectively more suited to perform the function of money.

objective content of our theories and other abstract products of our minds. This is easily done without the distinction between Worlds 1, 2 and 3. Theories, considered as objective knowledge, have a special economic status that makes them quite different to, say, a piece of land. Economic knowledge may be divided into the unspecifiable personal knowledge of circumstances and skills (such as the ability to ride a bicycle or use a tool or machine) stressed by Hayek (1945) and Polanyi (1958) and the specifiable objective knowledge (such as scientific theories) stressed by Popper (1972)[3]. Popper argues that objective knowledge, the kind we find represented in books, tapes, computer memory, has an autonomous existence from the psychological or physical states that produced it and in which it may be represented.[4] I would like to suggest that focusing on the World 2 psychological aspects of economic knowledge obscures the interesting ramifications that flow from the infinite content of the theories that interpret sections of World 1 to make resources. Therefore, some economic knowledge has a special metaphysical status. The special autonomous properties of this domain of economic knowledge has interesting implications and ramifications for the nature of scarcity and the power of the inventions we use to reduce scarcity.

2 Respectable Metaphysics Versus Partial Operationalism

(10) In dealing with the issue of the infinite versus finite nature of resources, we are dealing with a metaphysical issue. Expressed colloquially, metaphysics provides a view of the world as a whole. An example of such a view was Faraday's conception of the universe as a network of fields of forces.

(11) Methodologically, I think it useful to interpret metaphysical issues in terms of theories and their logical relationships with one another. Provisionally, we may say that a metaphysical theory is one that taken alone is empirically untestable by confrontation with basic statements. A basic statement is one that describes an observable event of definite space-time coordinates.

[3]The most recent strong argument for the non-specifiable nature of personal skills and even the ability to discover mathematical proofs is presented by Roger Penrose in *Shadows of the Mind* (Penrose 1994).

[4]One might say that the division into personal versus objective knowledge obscures the fact that some intentional states (e.g., dispositional expectations) shade over into propositional intentional states, i.e., World 3 status. Peoples' "constitutive" attitude to money is a good example, for it may only be a shock like a hyperinflation that jolts people into making their unconscious expectations explicit and placed in linguistic form. But we do need the distinction between Worlds 2 and 3 to talk about the transition from one state to the other.

"There is red ball of at least 8 cm diameter within one meter of the entrance to Bolton's central library" is a basic statement. An example of a metaphysical statement would be "There is a red ball which will give everlasting life to the person who touches it". To emphasise the fact that this distinction is one of logic and not between the everyday and the mystical, this last example can be changed to "There is an incompressible red ball". Another example would be "There is an inexhaustible barrel of oil". This definition of metaphysical conforms with the traditional sense in which metaphysics transcends experience, but conformity with tradition is not crucial. More importantly, it allows us to talk about interesting logical relationships between statements of quite differing character.

(12) All economic theories, even if they are scientific in being empirically falsifiable, contain explicit or implicit metaphysical assumptions or presuppositions. In this they are in good company as all the great scientific theories were not only inspired by, but also contained, metaphysics. In some cases the metaphysical elements are simply weak logical implications of the empirical theory. In some cases the metaphysical elements are more like adjuncts that can be dispensed with without diminishing the empirical content of the theory. In many cases, however, they play an important role not only in augmenting empirical content, but in guiding research. cf. (Watkins 1958). Also (Watkins 1975). See also (Agassi 1964). More recently (Zahar 1989).

(13) I have said that metaphysical statements are untestable by direct confrontation with basic statements, but things are not so simple. Popper has even shown that combining what are individually untestable metaphysical statements can sometimes yield a testable theory (Popper 1982*b*, Chapter III). This clearly shows that a statement may be only relatively metaphysical. This perhaps should not be so surprising as even scientific statements of the law-like variety only become fully testable in the presence of initial conditions and other theories, though some crude testable implications are derivable from the law-statement alone.[5] In any case, it is clear that in the analysis of metaphysics we have moved a long way from the cavalier attitude of the Vienna circle, and that metaphysical elements in science require serious and discerning treatment. In assessing the empirical value of a statement that is metaphysical when taken alone, one has to investigate its role within a larger system of hypotheses, how it contributes to the empirical consequences of

[5]For example, from the law-like statement "At atmospheric pressure silver melts at 960 degrees centigrade." one cannot derive a statement predicting a melting of silver at some definite spatio-temporal coordinates, or indeed even a purely existential statement to the effect "that some silver at some place and time has melted at 960 degrees centigrade at atmospheric pressure". But one can derive negative predictions, such as the statement "One will not observe the melting of silver below 960 degrees centigrade at spatio-temporal coordinates w, x, y, z at atmospheric pressure".

the system. The point here is that even though the assumption that resources are infinite may itself be untestable, the explanatory theory in which it occurs may be the more powerful (and more testable) for its presence.

(14) Examples of metaphysical doctrines are atomism, determinism, the irreversibility of time, and recently the idea of locality in physics.[6]

(15) Let us become acquainted with the feel of metaphysical statements. I was struck recently by how common unacknowledged metaphysical assumptions are in every day conversations. One I encountered recently might be called failure-metaphysics: there are some people who have fallen into circumstances of poverty and misery from which it is impossible to escape. If any putative confirming candidate subsequently becomes rich and happy, then the advocate of failure-metaphysics can always say that he misidentified the example. Of course, the contrary (success-metaphysics), that there is always a way of escaping from any circumstances of poverty providing one uses the correct methods is also untestable by itself. Such metaphysical assumptions are more to do with self-help methods than economic theory as such. An example from economics might be the following:

> A person is willing to sacrifice some bit of any desired thing if he can obtain a sufficient increase in the amount of some other desired goods. (Alchian & Allen 1964, p. 21)

(16) This is not empirically testable as it stands, for no limit is placed on what might be a "sufficient" increase in other goods: does it stop short of owning the Earth, the Solar system, the Universe? Nor does it specify a limit on the smallest "bit" of sacrifice allowed: does it include the sacrifice of one 1/1000th of a cup of coffee per year? However, I do suspect that this "postulate" does contribute to a theoretical system that is empirically testable when taken as a whole. The situation is analogous to Einstein's use of Lobachevskian geometry in his theory. By itself, Lobachevskian geometry

[6] The logical form of metaphysical doctrines may be of the all-Some variety. For example, determinism may be stated thus: for every event there is a cause. Or more informatively, for every event x there exist a y and a z such that y is a lawful relationship describable by some true universal law u, and z is an event (set of initial conditions) preceding x, and x is predictable (deducible) from z in the presence of y (or of u) (cf. Popper 1982a, p. 196). This is clearly untestable by confrontation with a basic statement, for suppose someone presents the determinist with a putatively uncaused event. The determinist always has two defensive options. No matter how far you have searched for the cause of some unexplained event and failed, the determinist can say either that you failed to look hard enough for the initial conditions or that you have insufficient imagination to formulate the correct lawful relationship connecting the two events (the initial conditions and the event to be explained). He can say this because you cannot logically exclude the possibility that the very next search will identify the cause.

cannot be empirically refuted, but it can contribute to the refutable empirical content of a theory. Assuming the economic postulate to be true, it does lead one on to interesting speculations about values and the structure of the world. For example, most people will not sacrifice any amount, however small, of their moral values such as "Thou shalt not kill". Is this a refutation of the postulate or could it be that the world is such that the "pay-off" just could not be arranged, perhaps because of the constraints of physical laws etc. Perhaps some might murder if the reward were everlasting life for them and their family—the Vampire option. But the world is such that everlasting life is impossible.

(17) Although the assumption of infinite resources and its contrary are metaphysical they play an important part in the empirical theories to which they belong. The assumption of infinite resources can be stated as follows: for every increase in resource-scarcity, there is at least one resource-augmenting invention or discovery that will more than compensate for this increased scarcity. The assumption of finite resources can be stated thus: at some point in the future the amount of resource-scarcity will increase irretrievably. Taken alone each of these statements is obviously metaphysical in the narrow sense of being unfalsifiable by confrontation with basic statements. The first places no limit on the delay between an increase in scarcity and its correction and it is not clear whether the compensatory correction takes account of time-preference. The resource finitist can sustain their gloom no matter how long humans live in abundance and luxury.

(18) The resource-finitists do try to include testable assumptions. The standard approach to estimating global resource quantity is first to estimate the presently-known physical quantity of the resource, secondly estimate the current rate of use, and finally predict a diminution of the first estimate over successive periods of time until the first estimate is exhausted. This approach, as Simon points out, is based on a confusion of the micro and macro contexts (Simon 1982). It is based on Hotelling's theory of the optimum rate of use of a spatially definite mine or well. The resource finitist's error can be put this way. The world's resources are seen as a large store-house which will be emptied in a finite period even if our technology improves the speed with which we empty it. But the world is not a store-house with pre-defined finite contents, since it is interpreted by our creative minds and theories.

(19) Prima facie, one might think (as Julian Simon does) that there are two ways of challenging the assumption of finite resources in the long run in a macroeconomic context. One is to point to empirical statistics, such as trends in resource prices and invention creation, and project from past data, a method pioneered by Barnet & Morse (1963). For example, price data for minerals over the past 200 years was adduced by Barnet and Morse (and more recently by Julian Simon) to show that the scarcity of minerals has actually been declining over the centuries, contrary to popular imagination. The argument is that if a resource were becoming more scarce, its price would be bid up by speculators, so reflecting its greater future level of scarcity. To reinforce this, statistics on the increasing rate of creation of inventions (some of which increase resources) is also adduced. When one projects this data into the future, the picture looks quite rosy. The supposed alternative is take a more theoretical approach.

(20) But such a division into empirical versus theoretical approaches is unsound. One can do theory without empirical research, for one can test a theory for internal inconsistency, simplicity, axiomatizablity and consistency with other background theories; but one cannot do empirical research without some, perhaps implicit, theory, as even singular statements describing definite events or objects contain universal terms that have dispositional (and counterfactual) implications that transcend any immediate (or indeed any finite set of) experiences or observations (Popper 1980). Even the seemingly trivial and untheoretical statement "There is petroleum oil in that barrel" is highly theoretical in that its implications go far beyond any experience. The statement implies that the liquid in the barrel can be refined into petrol and other useful organic substances.

(21) Simon thinks that the reason why economists have been slow to adopt the Barnet and Morse approach is that it is merely empirical or rule of thumb, without a theoretical justification. The resource finitist is interpreting the data in the light of a metaphysical theory. The resource finitist sees the world as a finite store-house. Humans may be getting the goods out faster and faster with improvements in the machines they use, but this will only empty the store-house sooner.

(22) To provide a theoretical interpretation of the data Simon introduces the idea of partial operationalism. Simon stops short of a wholesale operationalism, but insists that in order for any economic theory of finite resources to be testable, one has to construct an operational definition of the word "finite" in order that it may be measurable. The attempt to make any theory more testable is admirable. However, this aspect of Simon's approach is unsuccessful. Testability and measurability are, though related, quite different concepts. Strictly, introducing measurement-orientated concepts may increase the empirical information content of our theories, and as such is to be valued, but a theory may lack measurable concepts and still be testable. Moreover, a theory may be replete with measurable concepts and still be metaphysical, for example: "there exists a cylindrical iridium rod of precisely 1 centimetre in diameter and 1 metre long." One may consistently maintain such a theory no matter how much of space-time is surveyed. Even if some plausible candidate were found, the testability of the statement is confined to ranges of measurement outside the physical limits of measurement because of the qualification "precisely".

2.1 Explaining versus Justifying Predictions of Scarcity

(23) I think that there is another more profound problem with the assessment of past price data. I think that the relevance of past price data is to be understood through a separation of the notions of justification and explanation. I would suggest that all the really interesting so-called "justifications" of a scientific theory (those that are obtained by trying to test the theory) should be looked at as cases of explanation. It is, after all, the intellectual revelation and economic usefulness of an explanation that we want, and not its justification. One can act no better than in the light of the truth, so adding justification is both intellectually and economically superfluous. This puts past price-data in another light. It is not something that completely determines the theory (and projections), but something that can only test alternative theories (along with their projections).

(24) Those who wish to argue that raw material resources are infinite should aim for the best empirically testable theory that both explains past data and how resources might be indefinitely expanded in the future. One need not "justify" future predictions on the basis of past data. On the contrary, the question should be: how do we explain both the past price data and explain the hypothetical projection? Ever since Hume undermined both simple and probabilistic induction, we have known that an infinite number of future projections are logically compatible with any series of past data taken alone.[7] (For a recent refutation of inductivist thinking see Miller 1994) In order to exclude at least some projections one needs a universal theory. Notice I am talking about explaining declining scarcity, not justifying such a prediction. Ideally, in a scientific prediction one needs a universal theory plus initial conditions to logically derive (but note, not demonstrate) a definite testable description of some future state of affairs. But short of this, one can settle for a more or less schematic explanation, which is often the case in the so-

[7] Popper deals with the methodological problem of picking the best curve through some given graphical points in sections 32 & 38 of *Logic of Scientific Discovery* (Popper 1980). Popper argues that given that one wants the most informative, and therefore most falsifiable, theory one should opt for the (theory) curve that has the lower degree of dimensionality, i.e., the one whose statement requires the smaller number of parameters. Theories with higher dimensionality require a greater number of basic statements to falsify them. For example, to refute the theory that all planetary orbits are circles requires only 4 singular statements, whereas to refute the theory that all planetary orbits are ellipses would require six singular statements.

cial sciences. An extreme example is our everyday schematic explanations of human actions: even though we do not scientifically predict in detail a piece of behaviour we can understand it afterwards in the context of the person's knowledge, aims and problems.[8] If someone shivers on a cold day, this alone will be insufficient to allow us to scientifically predict that he will put his coat on; but if he does put his coat on, we have no hesitation in explaining this as his attempt to get warm, because we have a general theory that sees humans as goal-directed, rational agents etc.

(25) The sort of thing that can be done is for the resource-finitist and resource-infinitist to put some time limit on the predictions:

1. Resource-finitist: measured in real prices over 20 year periods, resources will consistently become more scarce;
2. Resource-infinitist: Any diminution of resources, measured in real prices over 20 year periods, will be more than compensated for within a 20 year period.

(26) Are there any general theoretical ways of explaining why resources and resource-augmenting inventions do not simply dry up? I do not think it possible to develop a theory from which one can scientifically derive the prediction of continued growth in economically useful inventions. I do not think that this is possible because, as Popper has argued, technical developments are strongly influenced by the emergence of new ideas, but there are logical reasons why one cannot predict (scientifically) any radically new idea (Popper 1982*a*). The argument is involved, but briefly and crudely put it is that if one succeeded in predicting now the emergence in the future of some new idea, this would be paradoxical since how can an idea that is only new in the future be predicted now. The idea would, after all, have to be stated now as part of the prediction, but it's newness would evaporate as soon it was stated. This argument leaves open shrewd conjectures about future technical development that are not strictly derived from theory plus initial conditions, and also the possibility of predicting types of new ideas rather than definite descriptions of future inventions. It also allows for carefully stated conditional predictions. One must also bear in mind that a single new unpredictable idea may lead to the destruction of society as such.

(27) Nevertheless, I do believe it possible to offer a very general argument

[8] With the spread of psychological knowledge, this is a little unfair to "everyday" explanations. The knowledge of visual illusions, for example, is quite wide spread, and with this knowledge one can make quite precise predictions about another person's subjective experience and possible introspective reports.

that suggests the sort of considerations that are necessary (though not sufficient) to explain schematically:

1. The emergence of an invention or new application of an old invention in response to a problem. This may only be possible in retrospect.
2. Why indefinitely continued invention is possible. One might think that resources will be finite in the long run because one will eventually "use up" the old inventions. My argument shows that possible inventions are not finite in the long run.

(28) Natural resources are infinite because of the following two fundamental facts:

1. A theory (such as the theory of boolean logic gates used in computers) can be applied an infinite number of times and in an infinite number of different useful projects because of its universal reference to all space and time and because of its infinitely varied logical and (in the case of scientific theories) information content.
2. Any two theories of technological use can be usefully combined not in just one way, but in an infinite number of ways. Not necessarily alone: a hair-dryer and a computer, for example, may not be easily combined directly, but they may be combined in a larger means-end scheme.

3 A Summary of Simon's Argument for the Infinite Extent of Resources

(29) The most powerful general theoretical argument against the claim that natural resources are finite comes from the pen of Julian Simon. Simon places the issue of natural resources in the context of the debate on the impact of population growth on the world's resources. Simon's basic point is that the concept of a natural resource can be defined for economic theory only relative to a service that we obtain from it. In this approach, Simon is systematically applying Alfred Marshall's conception of an economic good. Simon thus focuses on the World 2 aspect of a resource. Before a use for oil was invented it was not a resource (in fact, it was a nuisance to farmers). Similarly, petrol was at first regarded as a dangerous by-product of the extraction of paraffin. I guess there is at least ten million tons of copper in the core of the star Alpha Centauri, but it is not a resource (at present) because no one can possibly use it for any service. (This is not to say that it may not become a resource in the future. It is an extreme example to show that the concept of a resource includes the notion of service.) Things become less clear in some respects and clearer in others when one considers such things as beautiful views of sunsets over the Amazon forest. Views, or at least ones that can be appreciated as resources, only come into existence with the emergence of self conscious minds that can frame them and regard them as a product of, but also as independent of, the self. A beautiful view is less clearly part of a means-end scheme than a piece of copper, but E. Gombrich has argued that they are constituted by a theoretical framing of the visual world (Gombrich 1960). Moreover, if people are willing to pay for a view then we can more easily see that they are part of a means-end scheme.

(30) On this analysis of natural resource, the implication of the claim that our natural resources are finite is that the amount (or even types) of services that we can obtain from the world are limited. You can see that we are already moving away from the idea that a resource is identifiable with a lump of matter/energy alone and that we must bring in a psychological interpretation (World 2) that links any given resource material to a goal in such a way that the agent regards the material as a means to the goal. As I have already hinted in the introduction, this psychological element already involves a theoretical component that enables the subject to grasp the goal and the means and their relationship to one another and to the self. Popper argues in *Objective Knowledge* that all understanding involves the grasping of a World 3 object or relationship (Popper 1972). We can extend this to the understanding that is involved in a subjects' economic behaviour. Understanding a means-end relationship often involves understanding that there are alternative means and alternative goals to choose from. It is impossible to construct this understanding except in terms of the subject's use of theoretical interpretations—that is, World 3 objects.

(31) The involvement of World 3 in the question of scarcity becomes clearer once we review the ways in which the scarcity of a resource (i.e., its services) can be reduced:

1. Discoveries of further deposits.
2. Invention of substitute products.
3. Invention of more efficient ways of surveying, mining, processing and transporting the resource.

(32) All these ways of augmenting resources involve not only psychological (intentional) states (World 2), but the use of linguistically formulated theories (world 3). The discovery and invention of new resources and products can be an extremely theoretical task. The discovery of further deposits of a mineral, for example, often involves the use of astrophysical theories and the theoretical interpretation of satellite and seismic data.

(33) Simon argues that as population growth puts a pressure on the demand for services from resources, the real cost and prices of these resources may increase. But this very pressure creates the incentive for further inventions which not only compensate for the increased demand but increase production to lower costs and prices below their pre-shortage values. (This is the best explanation for the results of extensive historical research. cf. Boserup 1981)

(34) So the argument moves from whether there is a fixed amount of copper in a mine or the Earth etc., to whether there are diminishing returns in the long run given (a) the growth of our total imaginative capacity (World 2) and (b) the growth of our inventions and in general our World 3 objective knowledge. Both of these increase with increases in population, since the more people there are, the more minds there are to work on problems of scarcity and add to our objective knowledge.

(35) We have shown that it is the volume of services we obtain from a resource that is the most meaningful index of the quantity of a resource. Having established this, it becomes possible to envision the uninterrupted physical depletion of a non-renewable resource in a never ending process in which the total volume of services obtainable per unit of physical resource increases practically forever. (The only limit might be the atomic nature of matter. But what might be more important than physical quantity is accessibility for use. The last remaining atoms of the resource may just become less frequently available for use in any given project.)

(36) This is how Simon (1986, p. 55) sums up his position with respect to his predecessors:

> It is important to notice that there need not be diminishing returns over time to additional people, because the stock of technology with which people may combine their creative talents grows with time. Kuznets makes an argument for increasing returns on two grounds: (a) the stimulative effect of a dense environment, and (b) “interdependence of knowledge of the various parts of the world in which we human beings operate” (Kuznets 1960, p. 328); for example, discoveries in physics stimulate discoveries in biology, and vice versa. Kuznets discounts the possibility of diminishing returns because “the universe is far too vast relative to the size of our planet and what we know about it” (Kuznets 1960, p. 329). Machlup suggests that every new invention furnishes a

> new idea for potential combination with vast numbers of existing ideas "... [and] the number of possible combinations increases geometrically with the number of elements at hand" (Machlup 1960, p. 156). It is this latter idea of an increasing number of possible permutations of the available elements of technology as the stock increases, when combined with the idea of a reduced likelihood of duplicate discoveries as the number of possibilities increases faster than the number of potential technology producers, that seems most compelling to me.

(37) The implication is that the number (or amounts) of resources also can increase geometrically in parallel with the inventions. (It is important to bear in mind that Simon's complete theory is fairly elaborate and I can only hint at its full structure here.) Simon's theory does actually explain the price trends of (non-monopolistic) mineral resources. However, it must be granted that the form of the explanation is schematic, for it cannot predict or explain price data precisely (say, the price of gold 2 months from now) by deducing them from the model plus initial conditions, but it is, nevertheless, a valuable and testable alternative theory. Indeed, this is typical of economic theories and constitutes no demerit. It shares its schematic character with its rival, the hypothesis of finite resources. However, unlike its rival, the elaborate theory in to which the assumption of infinite resources is placed has a high level of testability. (To be completely fair, some resource-finitist models have made definite predictions, but often it is not clear how the prediction is logically derived from the theory, assumed initial conditions and other background knowledge. Indeed, it is not even clear what the background knowledge is. Cf. Meadows et al. 1974)

(38) Let us return to the more general question. A sceptic might ask why he should accept the idea that the number of possible combinations of inventions grows geometrically with the number of elements. He might suggest that a geometric combinatorial increase might still be finite. Inventions, he could say, are like melodies: one can easily get the impression that the class of possible melodies is infinite, but though large it is far from infinite in size.[9] I believe that the best way of answering him is to explore the theoretical content of inventions, that is, their World 3 aspect. This will show how it is possible for an invention to be applied in a literally infinite number of different ways in production, not only with other inventions but alone. It will become apparent that it is misleading to say that the number of possible combinations of inventions increases geometrically with increases in the number of elements

[9] I am talking about melodies that can be appreciated by humans. Thus I am talking about discernible note lengths and pitches, which will obviously be finite in number, and melodies of finite length.

at hand. Even keeping the number of basic inventions constant, the number of ways in which inventions might be combined is infinite. This fact is obscured by looking at inventions as simply physical objects that one adds together in different groups or permutations of order. This sees inventions as simply World 1 objects. Popper's notion of an autonomous and causally active world of abstract entities, World 3, is, I think, the only way to understand how the potential of our inventions and hence our resources is infinite.

4 World 3 and the Unfathomable Content of our Knowledge

(39) To recapitulate, World 3 is the realm of abstract, objective products of the human mind: theories, logical relationships, numbers, symphonies. Its content includes a diverse mixture from the humble Acheulian axe to the magnificent constructions of modern mathematics such as Godel's proof of the incompleteness of arithmetic. The point I wish to stress here is that World 3 is a factor of economic production that cannot be reduced to Worlds 1 or 2, and whose contribution is quite distinct.

(40) Suppose I make the following inference on paper: If it is cloudy, it will rain; it is cloudy, therefore it will rain. On Popper's model there are three aspects to this inference. There are the marks on the paper, which constitute the physical embodiment of the logical relationship between the premises and the conclusion; there is the psychological process of inference that I make (or go through) in grasping the logical relationship together with the ability to make the inference again; and there is the actual logical relationship as such.

(41) It is important to stress that World 3 makes a difference to our thought and therefore economic production. For example, the existence of logical standards makes a difference to our thought. Even a fallibilist can allow that we sometimes get things right, and not only that, but also that we get things right because they are right. You believe that you are reading an article in English (at least partly) because you are. Many people will accept the validity of the above argument (at least partly) because it is valid; they will also reject other arguments as invalid (at least partly) because they are invalid. You may include training in logic etc. as other contributing factors in our discrimination between valid and invalid inferences, but this does not make validity and invalidity causally impotent, because validity cannot be defined in terms of training or dispositions to discriminate.[10] The logical contradiction between

[10] To deny the influence of logical relationships would be to imply something very strange indeed: that the way things are never has the slightest influence on what we think or are

say, Newton's theory and Einstein's theory of gravitation, made a difference to the way scientists think.

(42) World 3 has the following properties:

1. It is an abstract product of the human mind.
2. It is partially autonomous in four senses:
   (a) it has a partly unfathomable content;
   (b) it has an unintended and irrevocable structure and consequences;
   (c) it has properties and relations that we discover but cannot alter;
   (d) it is irreducible to psychological or physical states of affairs or laws.
3. It is causally active on World 1 via World 2.

(43) One of Popper's arguments for the reality of World 3 is that our grasp of a World 3 object (such as the natural numbers) can affect our interaction with the physical world and that it is common sense that only real things can affect a physical object. (However, it is wrong to see the affect on physical objects as "constituting" the reality of World 3 objects.) An architect's understanding of mathematics makes a difference to the buildings that he can construct or would even consider constructing, but such an understanding would hardly exist if the mathematics had not first been invented. Hence World 3 makes a difference to economic production. But how much of a difference can it make? To answer this you need to look closely at its infinite content.

(44) Part of the content of World 3 will always remain in principle unfathomable. World 3 has been likened to a library of human knowledge, but although this is a good metaphor as far as it goes it is misleading. When a theory is created it is written down in a book and some of its implications may even be worked out and also written down. This is the part of the theory that becomes represented in a physical form. Think of all the future worked-out implications of the theory. This is still only a part of the theory's content, the rest is the part that never gets represented in physical form. There is always a residual because the content is infinite. There are two ways of bringing

prepared to maintain. Correctly identifying errors in reasoning is on this view a purely accidental affair. But if the set of hypotheses we maintain in science is controlled even slightly by the process of trial and error elimination, in which the false hypotheses are cast from the body of science because they contradict true observation reports, then the maintainance of some hypotheses after each period of elimination is partly explained by their being true and the rejection of false ones is partly explained by the fact that they are false.

out the infinite content of a theory: by talking of the information content and the logical content. The logical content of a theory is the class of all the (nontautological) consequences that can be logically derived from the theory (it may be identified with Tarski's "consequence class").

(45) The argument for the infinite logical content of a theory t can be put thus. Suppose an infinite list of statements that are pair-wise contradictory and which individually do not entail t: $a, b, c\ldots$ Then the statement "t or a or both" follows from t. The same holds for each and every one of the statements in the infinite list. Since the statements in the list are pair-wise contradictory one can infer that none of the statements "t or a or both", "t or b or both" etc., is interderivable. Thus the logical content of t must be infinite.

(46) This in itself is not so important, but when combined with the idea of information content, the two notions produce some very interesting ramifications. In the *Logic of Scientific Discovery* (Popper 1980), Popper put forward the idea that a statement says more the more it forbids. Carnap, accepting Popper's suggestion, defined the assertive power of a sentence as the class of possible cases it excludes (Carnap 1942, p. 151). Later Popper reformulated the intuitive idea in terms of theories, of both high and low universality (Popper 1974, see esp. note 15). The information content is the class of all those statements that are logically incompatible with the given theory. Thus since Einstein's theory contradicts Newton's theory, Einstein' theory is part of the information content of Newton's theory. Newton could hardly have known this, and so it could not have been part of his psychology.

(47) Most philosophers resist this analysis because of their adherence to psychologism and conceptual analysis. But Popper's analysis reveals that much of interest is to be discovered in the analysis of theories as such, considered as objective entities, and their logical relationships with one another.

(48) As Popper shows, when we combine this result with the idea of logical content we obtain a parallel result, for if E is part of the information content of N then Non E is part of N's logical content. Thus both the logical and information content of theories consist of an infinite number of non-trivial consequences. As Popper says, it follows that the task of understanding a theory is infinite. Furthermore, there are an infinite number of unknown theories that form part of the information content and logical content of Newton's theory, and indeed of any empirical theory. Since the concept of knowledge is often quite restrictively defined, it might be better to speak in more general terms of "representations", and say more generally that Newton's mind obviously did not have a representation of Einstein's theory or its negation, let alone most of the other theories that are part of its information or logical content.

(49) Of course, one can also mention the work of Gödel in this connection as pointing to the unfathomable content of our theories, and therefore of our inventions and resources. It can be shown that the complete system of all true propositions in the arithmetic of numbers is not axiomatizable and is undecidable. This means that there will always be an infinite number of unsolved problems in arithmetic. I wanted to focus on the ideas of logical and information content because these are rarely discussed or applied to new interesting areas. The exception has been the late Professor Bartley, who has applied these ideas in a fascinating way to art criticism and the Marxian idea of alienation (Bartley III 1990).

5 The Special Economic Status of Objective Knowledge: Resources and Inventions as World 3 Objects

(50) The above has some interesting implications for an economic analysis of resources and the issue of long-run diminishing returns.

(51) Just as a resource needs to be interpreted, so an invention cannot be reduced to its chemical and physical properties and relations, but must be placed in a means-end relationship. All inventions are means/ends relationships; they are invented and adopted for a purpose. This shows their World 2 aspect. But a means/end relationship is partly constituted by its theoretical interpretation, and thus all inventions are theory impregnated. Inventions, therefore, have a world 3 aspect also.

(52) I must make clear at this point that I do not subscribe to the popular view that every technological decision and action (including inventions) is prescribed by one or more scientific theories; in fact none are. This would overlook the fact that scientific laws are universal and therefore can only proscribe; alone, they can tell us only what cannot happen, not what will happen, and therefore alone cannot tell us what we should do to achieve a given end. Building a bridge, car, space-ship and tube of toothpaste is a matter of engineers discovering sets of constructible initial conditions that typically lead efficiently to the desired result. This is a conjecture and refutation affair. Universal theories of science help the engineer insofar as they can be used to eliminate some of the hopeful candidates of efficient sets of initial conditions, namely the ones whose description contradicts the accepted scientific theories.

(53) In talking of the theories that help to constitute and identify a given invention or resource, I include these low level theories. But I also want to make it clear that even these theories plus our psychological dispositions toward the invention or resource do not exhaust the useful possibilities inherent in a type or particular invention or type or particular portion of a resource. It is sufficient for my argument that at least part of the range of its useful possibilities is encompassed by these low level theories.

(54) Now theories as World 3 objects have three relevant properties:

1. They are universal, applying to all space and time.
2. They have infinitely varied logical/information content.
3. They are infinitely copyable.

(55) Now, on the basis of these facts it becomes clear how it is possible for a) an invention to be applied in a literally infinite number of significantly different possible ways and b) combined in a literally infinite number of significantly different possible ways with other inventions. But an exactly analogous argument applies to resources, for resources are also interpreted as a means/end relationship.

(56) Any particular wheel or lever or computer will wear out, but due to the universality of the theory that helps to constitute the invention, the invention type may be applied a potentially infinite number of times without diminished effect. Due to the infinitely varied logical/information content of the invention-theory, the invention may be applied in an infinite number of significantly varied ways. No one person, therefore, can work out all the useful content of a theory of a resource. If one employs more and more people on a given piece of land, one will get diminishing returns; after all, there is only so much room on a piece of land. But one may not get this when employing more and more people on a given theory, say the theory of levers or the quantum computer. Due to its infinite content, it has an infinitely varied terrain to work on, as it where. This is most clearly the case with something like the theory of arithmetic, where in the light of the work of Gödel and Tarski, there will always be an infinite number of problems to work on. Unlike a piece of land, an indefinite number of copies can be made of a theory. At any time, any number of people can be working out useful ramifications and implications of the theory and applying them.

(57) Let us return to Machlup's suggestion that the number of possible combinations of inventions increases geometrically with the number of elements at hand. From our analysis it is clear that any two inventions will each have a cluster of theories that explains, partly constitutes and identifies it. It is the logical and information content of these theories that allows us to combine them to make further inventions. But because of the infinite content of the theories they can be combined in a potentially infinite number of ways. To explain the emergence of any given combination one will look to see what the inventor's problem situation was, how the inventor searched through different combinations of different portions of logical and information content, and finally, how the two or more invention-theories were combined. On this analysis, it becomes clearer that a "fusion of two inventions" may consist of the following possible combinations:

(a) Proper subsets of the theoretical contents of the two inventions.

(b) A proper subset of one with the whole of the other.

(c) A newly discovered subset of the content of one with a familiar subset of another.

(d) Whole or part contents brought together via a bonding theory.

(58) In fact, since the aim of the fusion of two inventions is a new invention, the two invention-theories will form part of a larger action schema, and so it will always be through some third theory that the two inventions are combined.

(59) I suggest that this logical analysis is a more subtle and powerful way of revealing the way in which the number of possible combinations of inventions increases much more rapidly with the number of elements at hand, than saying with Machlup that they increase "geometrically". This is reinforced when one considers that in combining two theories one sometimes obtains interesting implications and ramifications not contained in the content of either theory considered alone. Watkins has fruitfully explored this possibility in his book *Science and Scepticism* (Watkins 1984). It is often said that an invention that simply combines previous inventions is not really a new invention, but a logical analysis of inventions in terms of content allows us to see that such invention-combinations can bring radically new useful consequences, emergent properties, into existence.

6 The Possibility of Infinitely New Information Processing: Why Tipler Needs World 3

(60) Before I conclude this paper, I must discuss the relevance of Frank Tipler's fascinating argument for indefinite economic growth to my own argument.

(61) Tipler argues that life and hence economic growth can continue forever (Tipler & Barrow 1986, Tipler 1994). Carbon based life-forms like ourselves are doomed eventually in the extremely high temperatures to be encountered at the approach to the final singularity in a closed universe. However, our successors—highly sophisticated, self-reproducing computers—will colonize the whole of space and will effectively undergo an infinite amount of economic growth and experience before the singularity.

(62) Tipler accepts that growth rates within the present epoch are limited by physics, but thinks that most predictions of physical limits have ignored economics and thus grossly underestimated the potential for economic growth. Following Simon, Tipler assumes that economic production is equivalent to the production of services, but Tipler adds that each of these units of service are in turn equivalent to the production and transfer of amounts of information. Thus the limits of economic growth are the limits of the growth of knowledge: the amount of information that can be read, stored and processed.

(63) Tipler says: "Information processing is constrained by the first and second laws of thermodynamics. These laws imply that the amount of information that can be processed at a given temperature T is $I = E/(kT \ln 2)$ where E is the energy available for processing, $(\ln 2)$ is the natural logarithm of 2, and k is Boltzmann's constant. Now any temperature T that we can use is greater than the background radiation, which is 3 degrees on the Kelvin scale, and if we limit ourselves to operations on the Earth, the greatest available energy is $E = Mc^2$, where M is the mass of the Earth." (Tipler 1988, pp. 4–5) Thus even life based on steady state economies is doomed, if it remains confined to the Earth. But life need not be confined to the Earth, since there is the possibility of expanding into and beyond the solar system using von Neumann probes. In any case, Tipler points out, this relationship between energy and information processing allows for a one hundred-billion-fold increase in economic wealth before we reach the physical limits of the Earth. This estimate is based on the assumption that we can increase economic wealth at the same rate as we increase the speed of our computers.

(64) Tipler argues that what is important to future self-conscious intelligent life will be subjective time, measured in terms of the number of thoughts experienced, not what physicists call proper time, that measured by atomic clocks. Tipler identifies thought with information processing of high speed computers. Tipler argues that indefinite economic growth is possible in a closed universe only if an infinite amount of information can be processed before the end of time. This is possible if the rate of information processing increases to infinity before the big crunch. This, Tipler argues, is possible. The required energy for the information processing is obtained from the differential speeds at which different regions of the universe will collapse, a phenomenon known as sheer.

(65) However, there is an important qualification. If this information processing is done on a finite state machine, then eventually it will start to repeat itself: no new thought would be possible. This information processing must be conducted on an infinite state machine. To supply this machine, Tipler conjectures that life, taken as a whole, can be regarded as an infinite state machine; but Tipler fails to explain how. I conjecture that the body of scientific knowledge provides the basis for an infinite state machine. The unfathomable information content of theories provides the "infinite tape" for the Turing machine. Stated more generally, the possibility of thinking an infinite number of new thoughts is made possible by World 3. It must be born in mind that there are two senses of "information" here. Tipler's "information" is the engineer's conception of actually encoded information (Shannon and Weaver), existing as realized distinct states of matter/energy, such as on-off electrical states in a computer. The "Logical content" and "information content" of say, scientific theories, are mostly unencoded, existing as only *potential* information in the engineer's sense. In some places Tipler explicitly identifies knowledge and information. But the above analysis of the unfathomable content of scientific theories makes it important to distinguish between knowledge and information. Tipler's bold and fascinating argument is thereby reinforced.

7 Conclusion

(66) One might think that there is a lacuna in my argument. The fact that an invention can be applied in an infinite number of significantly different ways does not show that those ways are all economic or even useful. But this misunderstands my case. I am not expounding an a priori argument that concludes that resources are necessarily infinite. I am making a conjecture that resources are infinite in the long-term and the trying to explain how this is possible by looking at the interaction of Worlds 1, 2 and 3.

(67) I think that my argument points to the World 3 abstract structure of our resources and inventions that acts as both a "scaffolding of thought" for the inventor and as a means whereby the human mind can endlessly expand the usefulness of the world. Whether this be for good or ill, is another question.

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