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Darwinian rational expectations

Kobi Finestone

Philosophy Department, Duke University, Durham NC, United States of America

ABSTRACT
The rational expectations hypothesis holds that agents should be modeled as not making systematic forecasting errors and has become a central model-building principle of modern economics. The hypothesis is often justified on the grounds that it coheres with the general methodological principle of economic rationality. In this article, I propose a novel Darwinian market justification for rational expectations which does not require either structural knowledge or statistical learning, as is commonly required in the economic literature. Rather, this Darwinian market account reconceives rationality as a market level phenomenon instead of as an individualistic property.

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1. Introduction

The rational expectations hypothesis holds that agents should be modeled as not making systematic forecasting errors and has become a central model-building principle of modern economics. In addition to the fact that the hypothesis often ensures consistent and tractable models, the positing of rational expectations is also commonly justified on the grounds that it coheres with the general methodological principle of economics, which requires that agents be modeled as consistent reasoners who generally exploit arbitrage opportunities. However, contrary to the general justificatory approaches deployed in the economic literature, I contend that a Darwinian justificatory strategy is capable of preserving and ensuring the rational expectations hypothesis without the need to posit either structural knowledge or statistical learning. This Darwinian account ensures rational expectations because irrational expectations are filtered out of the market environment via the bankruptcy market mechanism. Or in other words, agents with rational expectations are more likely to avoid bankruptcy and therefore, in the long-run only agents without systematic forecasting errors will remain in the market. In this respect, the market *selects* the rational expectations in the same metaphorical sense deployed in Darwinian natural selection.

In fact, this Darwinian interpretation is implicit in the earliest formulation of the rational expectations hypothesis. Although my aim in this article is not primarily historical, I contend that John Muth, who first developed the rational expectations hypothesis, can best be read as implicitly Darwinian. He states that,

> the [rational expectations] hypothesis asserts … [that] information is scarce and that the *economic system does not waste it*. [Muth, 1961, p. 316 (emphasis added)]

The personification of the economic system is more than a linguistic flourish but rather reveals an important methodological insight. For Muth, the rational expectations hypothesis is not necessarily an individual-level-property but is rather a system-level-property. To put it more bluntly, *rationality is a system-level-property*. Rationality is something that does not exist in the mind of the individual but which arises from the complex interaction of the individual and the system they inhabit and create.

CONTACT Kobi Finestone kobi.finestone@duke.edu

That being said, the Darwinian interpretation and justification of rational expectations *complements* existing justificatory strategies found in the economic literature. These include eductive processes in which agents carefully reason through future outcomes to eliminate forecasting errors, as well as learning processes in which agents incorporate new information in statistical models in order to refine their forecasts so as to converge towards the objectively correct probability distribution. Each of these different processes: eductive, learning and Darwinian, posit distinct substantive processes which are sufficient justification for the rational expectations hypothesis. And yet, this does not mean that the different processes are contradictory. This is because they can best be thought of as *perspectives*. They begin from different vantage points and see the world, so to speak, differently. But although these different perspectives differ from one another and often make different substantive claims, this does not entail that they are necessarily incompatible with one another. In fact, as I will argue throughout the remainder of the article, each of these processes complements the others in a number of ways.[1] However, before delving into these different justificatory strategies, it will be beneficial to return to the rational expectations hypothesis itself.

2. Rational expectations

Methodologically, the rational expectations hypothesis concerns how forecasts are represented within economic models. Within the context of an economic model, a forecast is a subjective probability distribution ranging over an outcome space representing the perceived relative likelihood of each possible outcome conditional on a particular information set.[2] The rational expectations hypothesis holds that agents should be modeled as not making systematic forecasting errors. It is, therefore, necessary to distinguish the methodological from the ontic. Formally, the hypothesis makes no ontological commitments concerning how flesh and blood human beings make forecasts about the future. Rather, it concerns the relationship between forecasts and objective probability distributions. In order to ensure that there are no systematic forecasting errors, Muth stipulates,

> that the expectations of firms (or, more generally, the subjective probability distributions of outcomes) tend to be distributed, for the same information set, about the prediction of the theory (or the “objective” probability distribution of outcomes). [Muth, 1961, p. 316]

More formally, the rational expectations hypothesis entails an identity relationship between forecasts and the objective probability distribution which governs the economic model. As a result, the hypothesis presumes a *convergence process* in which the forecast approaches the objective probability distribution and becomes asymptotically identical to it.

Following in the footsteps of Muth, it is beneficial to consider the rational expectations hypothesis in the context of an intertemporal model. It is worth noting that the simple ‘cobweb model’ predates both Muth and the development of rational expectations. And in fact, Muth adapted this simple model from agricultural economics in order to illustrate his more general point about rational expectations. The essential aspect of the model is that there is a *long-run* supply curve that is upwards sloping and a *short-run* supply curve that is effectively vertical. The short-run vertical supply curve follows from natural time-lags, which in the agricultural sector are associated with planting and harvesting periods. Forecasts become essential to coordinate short-run supply decisions.

To see this causal role, consider the effect of an unexpected exogenous shock that causes a decrease in supply. Diagrammatically, this will result in the short-run supply curve shifting inwards, thereby increasing the market price. However, as the increased market price is due to a transitory exogenous shock rather than a permanent structural change, any forecast predicated on the increased market price is likely going to be overly optimistic and result in eventual disappointment. Moreover, the overly optimistic forecast is itself causally efficacious and is likely to spur increased short-run production and thereby decrease the market price. However, as the decreased market price is due to a systematic forecasting error, any forecast predicated on the decreased market price is likely going to be overly pessimistic and result in eventual disappointment. This cycle of price increases and price decreases continues until the market converges towards an equilibrium because, in each time period, agents either *overreact* or *underreact* to the previous period's price, as seen in Figure 1.[3]

The intersection of the supply and demand curves represents the equilibrium state of the model in which there are no systematic unexploited arbitrage opportunities. Rational expectations preclude the kind of systematic overreactions characteristic of the cobweb model, and as a result, the introduction of rational expectations into the model ensures that the model instantaneously arrives at the equilibrium state. It is for this reason that the rational expectations hypothesis is often conceived of as an equilibrium concept that ensures that models be at the optimal outcome.

From this modeling perspective, the rational expectations hypothesis is highly sensible as it helps to ensure consistent and tractable economic models. In fact, this is largely the reason that one of the early prominent adopters and popularizers of rational expectations, Robert E. Lucas, incorporated rational expectations into his macroeconomic models. Lucas claimed that 'Muth's hypothesis of rational expectations is a *technical model-building principle*, not a distinct comprehensive macroeconomic theory' (Lucas, 1981 p. [emphasis added]). Lucas elaborated by stating that he was not directly interested in rational expectations as his 'own research [had] been concerned almost exclusively with the attempt to discover a useful theoretical explanation of business cycles' (Lucas, 1981, p. 2). For him, rational expectations were a modeling tool that he was not personally interested in justifying. Rather he sought

> to show that rational expectations can lead to workable, testable cycle models. For the argument that [the rational expectations] hypothesis is also plausible and consistent with a variety of evidence, the reader is referred to Muth. [Lucas, 1981, p. 101]

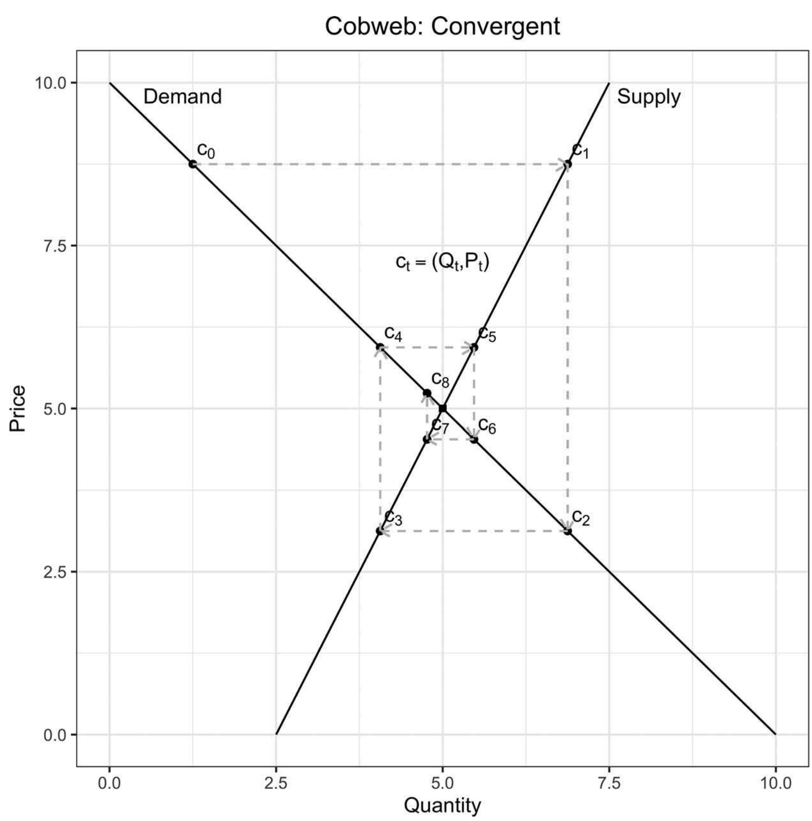

Figure 1. Cobweb model.

It seems clear that Lucas was less interested in justifying his use of rational expectations than in incorporating them into interesting macroeconomic models in such a way as would ensure testable equilibrium models. Doubtless, for many economists, this is precisely the methodological attitude they have adopted towards the rational expectations hypothesis. It is a tool to be used in modeling, but not one to be justified or critically examined.[4]

However, for some economists, the rational expectations hypothesis is of intrinsic interest and is something in need of its own independent justification. For example, Muth's interest in rational expectations goes beyond the hypothesis's instrumental value. His focus seems to have been largely centered on the nature of rationality itself as well as on how to create workable testable economic models. Moreover, it is noteworthy that he developed the hypothesis while working closely with Herbert Simon and others at the Carnegie Institute of Technology (Holt et al., 1960). In fact, the rational expectations hypothesis can be understood as a *reversal* and *reaction to* Simon and behavioral economics, as Muth wrote.

> [I]t is sometimes argued that the assumption of rationality in economics leads to theories inconsistent with, or inadequate to explain, observed phenomena, especially changes over time (e.g. Simon [**29**]). Our hypothesis is based on exactly the opposite point of view: that dynamic economic models do not assume enough rationality. [Muth, 1961, p. 316]

That being said, there is a legitimate worry that Muth may have moved too far in the opposite direction away from behavioral economics and that the rational expectations hypothesis is too far divorced from human behavior and is therefore in need of some kind of justification. As I stated above, the rational expectations hypothesis ought to be understood as a methodological statement about the representation of agents within models rather than the psychology of flesh and blood human beings, and yet there does seem to be something off if a representation bears no resemblance to its punitive target. To allay these concerns, a number of justificatory strategies have been developed in the economic literature, notably eductive processes and learning processes. While the primary focus of the article will be on Darwinian market processes, it will be beneficial to consider these two other processes briefly.

3. Eductive processes

In economics, eductive processes involve individual agents carefully reasoning through each strategic interaction. Such reasoning processes can ensure that the economic system reaches the rational expectations equilibrium; however, in order for such processes to successfully operate the agents need to already possess *structural knowledge* (Guesnerie, 1992, pp. 1268–1273, 2002). To see this, consider games of skill such as chess or go. In such games, players deploy eductive reasoning to determine the optimal outcome by reasoning through potential choices through the process of backwards induction. However, the chain of reasoning is predicated on one already knowing the rules of the game *and* knowing that one's opponent knows the rules of the game. Without these conditions being met, one could not react appropriately or be assured that one's opponent would react appropriately. This generalizes to form the foundation for the two most important necessary conditions for eductive processes: (i) all agents must possess structural knowledge and (ii) all agents must know that all other agents possess structural knowledge (Guesnerie, 1992, p. 1257). These two structural knowledge conditions are very restrictive once one moves beyond the scope of game-theory.

Historically though, eductive processes were pioneered by game theorists and are most naturally at home in the neat and tidy world of games. In fact, it was the game-theorist Binmore who first distinguished eductive processes from learning processes.[5] It was Guesnerie who then transplanted eductive process from game-theory to more general economic settings in order to justify the rational expectations hypothesis. This was done by explicitly replacing games with economic models, including the cobweb model (Guesnerie, 1992, p. 1256). In the cobweb model, eductive reasoning can best be understood in relation to the persistent *overreactions* and *underreactions* characteristic of the model. Recall that agents consistently overreact to the price in the previous period; however, if agents were to react appropriately, then there would be no instances in which they oversupply the market or undersupply the market. By stipulating that all of the agents possess structural knowledge and the capacity to reason through the strategic implications, it is possible for each and every agent to determine the optimal supply level in the next time period. The result is the elimination of the kind of systematic forecasting errors which dogged the cobweb model and consequently the achievement of the optimal outcome.

However, it is worth noting once again that eductive reasoning is predicated on the possession of structural knowledge and that the cobweb model is a structurally simple model. It is perhaps plausible to posit that agents embedded in the cobweb model possess such structural knowledge just as the chess player knows the rules of chess. However, in many contexts, it is implausible to posit that agents possess detailed structural knowledge of complex economic systems. Not all the world is as orderly as a game of chess. And in that disorderly world, it is unclear from the perspective of eductive processes how agents can come to *learn* about the world. But this is not a deficiency of eductive processes but rather a natural consequence of their focus. This is a perspective designed for the tidy world of games and one which works well within that context where structural knowledge is relatively easily available. In other economic contexts where structural knowledge is easily available, eductive reasoning is similarly well suited. But, as eductive processes simultaneously require structural knowledge and provide no mechanism by which such knowledge can be attained, eductive processes necessitate some kind of *complementary* learning process. It is in this respect in which eductive processes can be thought of as a perspective that is necessarily incomplete in some sense and complemented by other perspectives.

4. Learning processes

There are many different ways to represent learning, but generally, economists have chosen to do so in terms of formal statistical and econometric modeling techniques. On this general approach, learning is understood to involve the accumulation of data which is then fed into a statistical, econometric model in a consistent algorithmic manner akin to the inferential practices of practicing econometricians. The resultant forecast is then meant to provide evidence for the kind of structural knowledge required for eductive reasoning. It is in this way that learning processes can be thought of as a complementary perspective to eductive processes. They provide the means by which structural knowledge is gained. From the learning perspective, agents in the cobweb model do not know the structure of the model, but with each time period, they accumulate additional data, which allows them to determine not only that they are overreacting to the previous period's price but the magnitude of their overreaction. Over time, as more data is accumulated, the learning agent will eventually cease overreacting and will eventually supply the optimal amount, thereby ensuring the model as a whole reaches its equilibrium state.

There are, of course, complications that can preclude an economic system from reaching an optimal outcome. In the learning literature, forecasts are traditionally decomposed into information sets and econometric models. The information set is the input that agents use to learn about an economic system; however, there is no consensus over what kind of data ought to be included in the information set.[6] The major categories include (i) historical data, (ii) the beliefs of other agents and (iii) allegedly 'frivolous' variables (Bullard, 1991, p. 55–57). A similar issue arises for the econometric model, which can intuitively be thought of as the proprietary model of the agent. In the learning literature, there are a number of econometric models, each of which have different applicability conditions (Evans & Honkapohja, 2001; Marcet & Sargent, 1988; Marcet & Sargent, 1989a, 1989b).

The resultant pluralism naturally complicates learning processes as there is no deterministic decision-procedure that can identify the optimal forecast for a particular learning exercise. However, this complexity should be considered a feature of learning processes rather than a bug as economic systems themselves exhibit structural complexity. That being said, the complexity of learning processes does pose a problem. Learning processes rely upon two complex tasks: (i) data collection and (ii) statistical inference. Neither of these tasks is known innately. In this respect, both data collection and statistical inference are similar to structural knowledge in that they must be *learned*. Or in other words, agents must learn how to learn. Therefore, just as eductive processes require a complementary perspective in order to operate and thereby justify the rational expectations hypothesis, learning processes seem to require a complementary perspective in order to operate and thereby justify the rational expectations hypothesis. That is, at least if learning is understood in an explicitly statistical sense.

One plausible response is to recast learning processes in terms of heuristic rather than in terms of explicit statistical analysis.[7] On this understanding, agents would learn not by data collection and statistical inference but rather by reliance on readily available heuristics, which roughly correspond to those statistical techniques pioneered by econometricians. This proposal effectively eliminates the challenges posed by statistical learning while simultaneously doing justice to the underlying rationale of learning processes that conceptualize agents in broadly Bayesian terms. However, while I think this heuristic proposal is inherently interesting, it is a poor characterization of the learning literature, which takes the statistical nature of learning seriously (Evans & Honkapohja, 2001). This is not to say that flesh and blood human beings do not rely on heuristics nor that economists should not research the role of heuristics in learning. Rather, my claim is that there is specific literature in economics which is commonly referred to by the moniker 'learning', which is *not* characterized by heuristics but *is* characterized by statistical analysis.

Therefore, learning processes are fundamentally statistical processes that can under the right conditions justify the rational expectations hypothesis but which require that agents be capable of data collection and statistical inference. In this respect, learning processes can be thought of as a perspective akin to eductive processes in so far as it is simultaneously incomplete and complemented by other processes. In order for learning processes to operate successfully and justify the rational expectations hypothesis, there needs to be some explanation for how agents are capable of engaging in data collection and statistical inference. Of course, in certain contexts, it is perfectly acceptable to stipulate these conditions, just as it is perfectly acceptable to stipulate that agents possess structural knowledge during a chess game. However, in other contexts, it is less reasonable to presume that agents are well versed in data collection or statistical inference and in these cases, learning processes are less suited to justify the rational expectations hypothesis. For these less well-ordered cases in which learning processes are not appropriate, Darwinian *market processes* can serve as a complementary perspective.

5. Market processes

The economic literature has primarily concerned itself with the two justificatory strategies considered in detail above. However, as I have argued, while these strategies are capable of ensuring the rational expectations hypothesis under the right conditions, they both face serious limitations. Eductive processes require that agents possess structural knowledge, which while plausible under certain conditions such as in simple games or models, may be less plausible in much of the disorderly economic world. Similarly, learning processes require that agents be capable of data collection and statistical inference. These tasks, while certainly possible under the right conditions, are by no means always possible for all agents under all circumstances. The result is that while both eductive processes and learning processes are justificatory strategies for the rational expectations hypothesis, they may not be the most apt justificatory strategies in all contexts and under all circumstances. In light of this, I propose that *market processes* can complement the existing literature.

In order to apprehend where market processes differ from the more traditional justificatory strategies, it will be beneficial to consider the relationship between rational expectations and behavioral economics again. Recall that the rational expectations hypothesis is commonly justified on the grounds that it coheres with the general methodological principle of economics, which requires that agents be modeled as consistent reasoners who generally exploit arbitrage opportunities. More succinctly, this principle could be thought of as the requirement to model agents as economically rational. However, behavioral economists from Herbert Simon onwards have consistently demonstrated in experimental settings that human subjects fail to live up to the dictates of economic rationality. And yet, despite these findings, economists en masse have not abandoned the methodological principle of rationality. The reason for this reluctance is that in many cases, economic systems operate *as if* agents behave rationally. Or in other words, the methodological principle of rationality ought to be understood *metaphorically*.

Metaphors in science have a noteworthy pedigree, and an important example can be found in Darwin. Given the complexity and seeming functionality of natural systems, traditional biological and theological systems had often invoked teleological elements to explain the fit between observable and measurable phenotypic traits and the environment. The Darwinian image of nature does away with teleology but maintains the close fit between phenotypes and the environment by invoking *natural selection*. However, the entire notion of natural selection, while commonplace to modern ears, is entirely metaphorical. Darwin, in fact, defended the metaphor against

> [those who] have objected [that the term] selection implies conscious choice in animals which become modified; and it had even been urged that, as plants have no volition, natural selection is not applicable to them! In the literal sense of the word, no doubt, natural selection is a false term … but who objects to an author speaking of the attraction of gravity as ruling the movements of the planets? Every one knows what is meant and is implied by such metaphorical expressions; and they are almost necessary for brevity. So again it is difficult to avoid personifying the word Nature. [Darwin (1859/1963), p. 64–65]

For Darwin, the metaphor of natural selection bleeds seamlessly into the personification of nature. I contend something similar occurs for Muth when he states that

> the [rational expectations] hypothesis asserts … [that] information is scarce and that the *economic system does not waste it*. [Muth, 1961, p. 316 (emphasis added)]

Here the economic system is personified in much the same way as Darwin personifies nature. For Muth, the economic system, not the individual, is the locus of rationality. This may be only a metaphor, but it is an important metaphor that shapes his entire way of thinking in much the same way as the metaphor of natural selection shapes the entirety of Darwinian thought.

Moreover, the market process implicit in Muth is analogous to the Darwinian system.[8] In its simplest formulation, the Darwinian system can be thought of as a convergence process in which a diverse set of phenotypes are filtered out of a selective environment until a phenotypic equilibrium is reached. Naturally, this presentation of evolutionary science is drastically over simplified as it omits novel mutations, genetic drift, levels of selection and a whole other range of issues relevant to the biological sciences.[9] However, for the purpose of the analogy, it is beneficial to focus exclusively on the role of natural selection in evolutionary biology. In order for natural selection to operate, there are three necessary and mostly sufficient conditions: (i) variation, (ii) inheritance and (iii) differential reproductive success (Brandon, 1995, p. 7). Variation entails that there exist a diverse set of phenotypes without which there can be no selection. In other words, if all objects are identical along a particular dimension, then it is impossible to choose amongst them along that dimension. Inheritance entails that phenotypes persist, often probabilistically, across generations. This ensures that selective pressures can build up over generational time, which is necessary for the convergence process to occur. Finally, differential reproductive success is the pressure that selects. Uniform survival or uniform death leaves no room for selection. Selection requires the nuance which exists between those two extremes. Given the presence of variation, inheritance, and differential reproductive success, the best adapted organisms are *most likely* to survive and reproduce, and the end result is intergenerational phenotypic convergence towards a phenotypic equilibrium.[10]

My contention is that the market operates in an analogous manner to selective environments and can metaphorically select the best adapted forecast, which in this case is the rational expectation.[11]

The end result being that the market can justify the rational expectations hypothesis. While it would be ideal to posit and present a formal economic model at this time, it will suffice to draw out the analogy with the Darwinian system as there exist plausible market analogs for the evolutionary conditions described above. However, the first analogy involves forecasts themselves. In evolutionary biology, there is a distinction between *phenotypes* and *genotypes*. Phenotypes are observable and measurable traits that are realized in organisms and importantly, it is phenotypes that are selected on by the environments. However, phenotypes are not directly inheritable. Genotypes are the genetic traits that are not directly observable but which give rise to those phenotypes selected on. Moreover, it is the genotypes that are inherited across generations. In the market context, the *forecast* is analogous to the phenotypic trait in that it is observable and measurable. Furthermore, because the forecast is causally efficacious, it is what is directly selected by the market. However, forecasts do not persist over time. This is because forecasts are not projectable. Rather, it is the underlying *generating procedure* by which the forecast is generated which persists overtime. This generating procedure can either be explicitly statistical, as conceptualized in the learning literature or as a heuristic. Regardless, both kinds of generating procedures are analogous to genotypes in that they persist over time and give rise to causally efficacious point forecasts.

Drawing on the distinction between forecast and generating procedure, it is possible to explicate the market analogs for the evolutionary conditions. Biological variation has a straightforward market analog. In order for the market to select the best adapted forecast or rational expectation, there must exist a diverse set of forecasts in the market. Or in other words, there must exist *forecasting variation*. Biological inheritance similarly has an analog in the market context, in this case being *generating procedure persistence*.[12] In order for the market to select the best adapted forecast, generating procedures need a degree of stability with respect to time. Without such stability, there would not be the necessary continuity across time for the convergence process to operate. Note that market processes are therefore necessarily temporally extended. Time is a necessary ingredient and cannot be abstracted away from market processes. And finally, the selective pressure of the market is *bankruptcy*.[13] It filters certain agents out of the market, thereby removing their forecasts from the market environment.[14] In this respect, it is analogous to differential reproductive success. Given the presence of these market conditions, the market is likely to *select* the best adapted forecast, thereby achieving the rational expectations equilibrium.

Market processes, it is worth noting, are fundamentally probabilistic in much the same way as Darwinian biological systems. The market selects forecasts on the basis of accuracy given the plausible assumption that accuracy probabilistically tracks market success and therefore forestalls bankruptcy. The best adapted forecast will consequently be the most accurate forecast, which just is the rational expectation. Therefore, in the long-run, those agents with the rational expectations will be *most likely* to survive and thrive in the market. For example, consider the cobweb model without positing that agents engage in eductive reasoning or statistical learning. All that is required in order to achieve equilibrium is that there be some negative probabilistic connection between forecasting accuracy and bankruptcy as well as an initial distribution of forecasts. Over time, those agents with the most inaccurate forecasts will be more likely to become insolvent, leaving those agents with the more accurate forecasts in the market. In the limit, only those agents with rational expectations will remain in the market, thereby achieving the rational expectations equilibrium. Such a model could be constructed and tested using simulation studies.

All that being said, my proposal does draw heavily on a historical precedent. Armen Alchian developed a similar evolutionary model of the economy. The rationale behind his account was that it would be capable of explaining observed economic behavior without the need to posit firm profit maximization. In essence, his

> approach embodie[d] the principles of biological evolution and natural selection by interpreting the economic system as an adoptive mechanism which chooses among exploratory actions generated by the adaptive pursuit of "success" or "profits". [Alchian, 1950, p. 211]

The market fulfills a similar selective function for Alchian and me. Moreover, our motivations are similar. The assumption of profit maximization which bedeviled Alchian follows naturally from the very same general methodological principle of economics, which requires that agents be modeled as consistent reasoners who generally exploit arbitrage opportunities. The difference lies only in the specific domain to which that general principle is applied. For him, it arises as profit maximization, and for me, it arises as rational expectations. Finally, and perhaps most importantly, Alchian is sensitive to the fact that his evolutionary model must *complement* more traditional economic models. He insists that his

> model was designed to present in the extreme form only one element of the suggested approach. It is not argued that there is no purposive, foresighted behavior present in reality. In adding this realistic element – adaptation by individuals with some foresight and purposive motivation – we are expanding the preceding [evolutionary] model. We are not abandoning it or futilely trying to merge it with the opposite extreme. [Alchian, 1950, p. 217]

Similarly, market processes are but one perspective that can and, in fact, must complement the existing economic literature. There is room for purposive foresight, whether it be eductive reasoning or statistical learning, to augment market processes and thereby achieve the rational expectations equilibrium. But the power of the market is that it does not require individualistic rationality. The market has its own rationality, which is complemented by the rationality of agents but does not depend on it. In this respect, market rationality *emerges*.

Notes

1. In the philosophical literature, there are a range of views broadly known as Perspectivism or Perspectivalism. Although there are important differences which can be found within this tradition, the unifying idea is that scientific knowledge is perspectival, in that it is situated from a vantage point. Importantly, different vantage points are compatible with different vantage points, therefore seemingly incompatible theories can be understood as compatible perspectives. For more see on this literature see (Chang, 2019; Giere, 2006; Hoover, 2012; Teller, 2019).
2. The term 'forecast' is not universally adopted across economic sub-literatures. It is not uncommon to find the same entity referred to as 'expectation' or 'prediction' depending on which sub-literature one is examining. For the sake of clarity, I have opted to consistently use 'forecast' throughout the article.
3. There are other theoretical results possible for the cobweb model. It is possible for the model to continue in the price cycle indefinitely or to diverge outwards away from the equilibrium state. The particular result which holds depends on the relative elasticities of supply and demand.
4. The methodological attitude of Lucas towards the rational expectations hypothesis is *not* straightforwardly instrumentalist, although rational expectations are a tool which he uses to build workable and testable business cycle models. By drawing on the recent Lucas scholarship, it is possible to apprehend that Lucas has a far more subtle methodological position than either naïve realism or straightforward instrumentalism, especially with regards to rational expectations. Galbács notes, in reference to Lucas, that

   > [e]ven an extremely strong abstraction is realist as long as the relevant casually active properties are maintained. And as the narrowest set of active properties is to be preserved whilst everything else can be ignored this strategy makes it clear how descriptively ill-performing models can still satisfying perform in empirical terms and how they can support causal understanding. The modeler highlights the analyzed mechanisms from reality by preserving the relevant properties of the object under scrutiny. [Galbács, 2020, pp. 294–295]

   In this case, the rational expectations hypothesis is an extremely strong abstraction which preserves the relevant properties of the economic system in such a way which allows the model to perform well empirically, or at least to be testable. In this respect, rational expectations are more than just a tool and Lucas is not an instrumentalist. However, Lucas is equally uninterested in justifying the rational expectations hypothesis as his focus is on business cycle models.
5. It is worth noting that the terms originally used by Binmore (1987) differ from those used throughout this article. As a game-theorist, Binmore was primarily concerned with eductive processes and distinguished them from what he referred to as 'evolutive' processes which were dynamic learning processes. In order to avoid confusion, I have opted to use the term 'learning' process consistently throughout the article.

6. The rational expectations hypothesis is always relativized to the *same information set*. Therefore, if the information sets differ between two agents or between an agent and the objective data generating process, then it is possible for probability distributions to differ without violating the rational expectations hypothesis. This is an important caveat to the rational expectations hypothesis which arises under conditions of asymmetric information.
7. Heuristics can be understood as 'efficient cognitive processes that ignore information' (Gigerenzer et al., 2011, p. 1) and have long played an important role in psychological studies and in behavioral economics (Simon, 1957). Although such heuristics are often considered to be inferior to statistical learning process, there is considerable psychological evidence which indicates the efficacy of heuristics in a number of different learning contexts. I am indebted to an anonymous reviewer for suggesting that they may be relevant for understanding learning processes in this domain of economics.
8. The role of analogical reasoning in the sciences has a long track-record but has often been overlooked in philosophical analysis. A notable exception to this can be found in Hesse who develops a *tripartite* account of analogical reasoning (Hesse, 1966). On this account, any two objects can be similar to one another along an infinite number of dimensions, thereby creating an infinite number of *positive analogies* and *negative analogies*. However, there is an important third category of *neutral analogies* which are epistemically relativized. These neutral analogies can become either positive analogies or negative analogies through scientific investigation but at the outset of research remain unknown to the scientist. Hesse contends that it is through neutral analogies that scientists learn about the world.
9. For a more comprehensive and philosophically rigorous account of biological evolution which accounts for the nuances and complexities raised in population genetics, see (Brandon, 1978, 1995).
10. The nature of fitness is a highly philosophically controversial concept in the philosophy of biology. Within the literature, there are two broad camps. The *Statisticalist Thesis* holds that natural selection is the change in population-level statistics (Walsh et al., 2002). On this account, fitness plays no causal selective role. The *Propensity Thesis* holds that fitness is a causally efficacious propensity which explains those population-level statistics (Pence & Ramsey, 2013).
11. The analogy between markets and selective environment can be traced back (at least) to the behavioral economics of Herbert A. Simon. In particular, he conceived of satisficing heuristics in the contexts of environmental 'life space[s]' which would shape the behavior of bounded rational beings (Simon, 1957, p. 262).
12. The primary difference between biological inheritance and generating procedure persistence is the role of generational change in biological systems. Unlike in economic systems, biological systems rely upon reproduction in order to operate and therefore, biological persistence conditions must be explicitly intergenerational. Inheritance is nothing more than intergenerational persistence. Because economic systems do not necessarily require intergenerational persistence, the market analog to inheritance can be more general than the biological analog.
13. It is worth noting that as an institutional and legal arrangement, 'bankruptcy' is a cluster concept which admits of a great degree of variation. With that in mind, many forms of bankruptcy do not involve the total liquidation of an agents asset and subsequent exit from the marketplace. This is an historical contingency and does not necessarily bear on the underlying rationale of the account. Given that there exist some version of bankruptcy in which an agent must liquidate all assets and exit the marketplace, then *that* version of bankruptcy can be considered analogous to differential reproductive success. However, given the diverse kinds of legal arrangements known as 'bankruptcy' it is beneficial to clarify the precise parameters of the concept at play here. I am indebted to Kevin D. Hoover for drawing my attention to this issue.
14. In line with the general defense for complementary perspectives, it is worth noting that the Darwinian system complements a Lamarckian evolutionary system in in which organisms inherit acquired traits. Both evolutionary processes can operate simultaneously in a single environment. Similarly, in the market context, Lamarckian processes could very well be at work. These could involve internal reorganizations or more run of the mill learning exercises in which agents reassess their generating procedures. Importantly, the presence of Lamarckian processes does not undermine the possibility of Darwinian processes. Moreover, the prevalence of Lamarckian processes remains fundamentally an empirical question. I am indebted to Kevin D. Hoover for drawing my attention to this issue.

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Notes on contributor

Kobi Finestone is a doctoral candidate in philosophy at Duke University whose research lies at the intersection of philosophy and economics. His research is primarily centered on the epistemic capacities of scientific models and the role of expectation formation and uncertainty in economic thought. He also incorporates insights from economics into interdisciplinary normative projects concerning the obligations and rights of business leaders and regulators.

ORCID

Kobi Finestone http://orcid.org/0000-0002-5925-1424

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